THE NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM

SUPPLEMENT TO THE PRESIDENT'S BUDGET

FY2018

October 2017

About This Document

This document is a supplement to the President's 2018 Budget Request to Congress. It describes the activities planned for FY2018 by the Federal agencies participating in the Networking and Information Technology Research and Development (NITRD) Program, primarily from a programmatic and budgetary perspective. It reports actual investments for FY2016, enacted investments for FY2017, and requested funding levels for FY2018 by Program Component Area (PCA). For the FY2018 budget request of each PCA, this Supplement identifies the expected societal benefits, strategic priorities, key programs, and planning and coordination activities.

About the National Science and Technology Council

The NITRD Program is managed by the NITRD Subcommittee of the National Science and Technology Council (NSTC) Committee on Technology. The NSTC is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development (R&D) enterprise. A primary objective of the NSTC is establishing clear national goals for Federal science and technology investments. The NSTC prepares R&D strategies that are coordinated across Federal agencies to form investment packages aimed at accomplishing multiple national goals. The work of the NSTC is organized under committees that oversee subcommittees and working groups that focus on different aspects of science and technology. More information is available at https://www.whitehouse.gov/ostp/nstc.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976 to provide the President and others within the Executive Office of the President with advice on the scientific, engineering, and technological aspects of the economy, national security, homeland security, health, foreign relations, the environment, and the technological recovery and use of resources, among other topics. OSTP leads interagency science and technology policy coordination efforts, assists the Office of Management and Budget with an annual review and analysis of Federal research and development in budgets, and serves as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the Federal Government. The Director of OSTP also manages the NSTC. More information is available at https://www.whitehouse.gov/ostp.

About the NITRD Program

The Networking and Information Technology Research and Development Program is the Nation's primary source of federally funded work on advanced information technologies (IT) in computing, networking, and software. The multiagency NITRD Program seeks to provide the R&D foundations for assuring continued U.S. technological leadership and meeting the needs of the Federal Government for advanced IT. It also seeks to accelerate development and deployment of advanced information technologies in order to maintain world leadership in science and engineering, enhance national defense and homeland security, improve U.S. productivity and economic competitiveness, protect the environment, and improve the health, education, and quality of life of all Americans. Now in its 26th year, the NITRD Program is one of the oldest and largest of the formal Federal programs that engage multiple agencies in coordination activities. It was established by the High-Performance Computing Act of 1991 (P.L. 102-194) and reauthorized by Congress in the American Innovation and Competitiveness Act of 2017 (P.L. 114-329). The NITRD Program provides a framework and mechanisms for coordination among the Federal agencies that support advanced IT R&D and report IT research budgets in the NITRD crosscut. Many other agencies with IT interests also participate in NITRD activities. More information is available at https://www.nitrd.gov.

About the NITRD National Coordination Office

The National Coordination Office (NCO) supports the NITRD Subcommittee and the Interagency Working Groups (IWGs) that report to the Subcommittee by providing technical expertise, planning, and coordination, and by serving as the Program's central point of contact. The NCO continuously seeks to enhance its ability to be a catalyst for collaboration, exchange of information, and outreach to foster knowledge, methods, R&D, technology transfer, and innovation for U.S. global leadership in networking and information technology and its applications. In cooperation with the NITRD agencies and IWGs, the NCO is also responsible for preparing the annual Supplement to the President's Budget for planned Federal expenditures related to networking and information technology research and development. More information is available at https://www.nitrd.gov/About/about_nco.aspx.

Acknowledgments

This Supplement to the President's Budget was developed through the contributions of the NITRD Federal agency representatives and members, the NCO staff, and other Federal agencies participating in the NITRD Program. Sincere thanks and appreciation go out to all who have contributed.

Published in the United States of America, 2017.

SUPPLEMENT TO THE PRESIDENT'S BUDGET FOR FISCAL YEAR 2018

The Networking and Information Technology Research and Development Program

A Report by the

Subcommittee on Networking and Information Technology Research and Development

Committee on Technology

National Science and Technology Council

October 2017

NITRD Supplement to the President's FY2018 Budget prepared by

National Science and Technology Council Committee on Technology

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Executive Secretary, OSTP

Subcommittee on Networking and Information Technology Research and Development (NITRD)

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EXECUTIVE OFFICE OF THE PRESIDENT

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

WASHINGTON, D.C. 20502

October 27, 2017

Dear Members of Congress:

I am pleased to transmit the Networking and Information Technology Research and Development (NITRD) Program's FY2018 Annual Supplement to the President's Budget. The NITRD Program coordinates Federal research and development (R&D) activities to ensure U.S. leadership in pioneering digital technologies and the associated infrastructure needed for the security, prosperity, and health of all Americans.

This document describes the activities planned for FY2018 by the Federal agencies participating in the NITRD Program. As required by the High-Performance Computing Act of 1991 (P.L. 102-194) and reauthorized by Congress in the American Innovation and Competitiveness Act of 2017 (P.L. 114-329), this Supplement reports actual investments for FY2016, enacted investments for FY2017, and requested funding levels for FY2018 by NITRD Program Component Area (PCA). The President's 2018 Budget Request for the NITRD Program is $4.46 billion.

Thank you for your shared support of this important Federal program.

Sincerely,

Ted M. Wackler, Acting Director
Office of Science and Technology Policy

NITRD DEPARTMENTS AND AGENCIES

Member Departments and Agencies

These Federal departments and agencies conduct or support R&D in advanced networking and information technologies, report IT research budgets in the NITRD budget crosscut, and provide support for NITRD 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)
  - Office of the Secretary of Defense (OSD)
  - Service Research Organizations (Air Force, Army, Navy)
- Department of Energy (DOE)
  - National Nuclear Security Administration (DOE/NNSA)
  - Office of Electricity Delivery and Energy Reliability (DOE/OE)
  - Office of Science (DOE/SC)
- Department of Health and Human Services (HHS)
  - Agency for Healthcare Research and Quality (AHRQ)
- Department of Health and Human Services (HHS) (cont.)
  - National Institutes of Health (NIH)
  - Office of the National Coordinator for Health Information Technology (ONC)
- Department of Homeland Security (DHS)
  - Science and Technology Directorate (S&T)
- Department of Justice (DOJ)
  - National Institute of Justice (NIJ)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Archives and Records Administration (NARA)
- National Reconnaissance Office (NRO)
- National Science Foundation (NSF)

Participating Departments and Agencies

These Federal departments and agencies participate in NITRD activities and have mission interests in advanced networking and IT R&D and applications; they support NITRD Program coordination but do not report IT investments in the NITRD budget crosscut:

- Appalachian Regional Commission (ARC)
- Department of Commerce (DOC)
  - National Telecommunications and Information Administration (NTIA)
  - United States Census Bureau (Census)
- Department of Defense (DoD)
  - Defense Research and Engineering Network (DREN)
  - DoD Intelligence Information Systems (DoDIIS)
  - National Geospatial-Intelligence Agency (NGA)
- Department of Education (ED)
- Department of Energy (DOE)
  - Idaho National Laboratory (INL)
  - National Nuclear Security Administration (NNSA)
  - Office of Environmental Management (DOE/EM)
- Department of Health and Human Services (HHS)
  - Centers for Disease Control and Prevention (CDC)
  - Food and Drug Administration (FDA)
  - Health Resources and Services Administration (HRSA)
  - National Institute for Occupational Safety and Health (NIOSH)
- Department of Homeland Security (DHS)
  - Customs and Border Protection (CBP)
  - Federal Protective Service (FPS)
  - Transportation Security Administration (TSA)
- Department of Housing and Urban Development (HUD)
- Department of Justice (DOJ)
  - Federal Bureau of Investigation (FBI)
- Department of Labor (DOL)
- Bureau of Labor Statistics (BLS)
- Department of State (DOS)
- Department of the Interior (Interior)
  - National Park Service (NPS)
  - U.S. Geological Survey (USGS)
- Department of the Treasury (Treasury)
  - Office of Financial Research (OFR)
- Department of Transportation (DOT)
  - Federal Aviation Administration (FAA)
  - Federal Highway Administration (FHWA)
- Department of Veterans Affairs (VA)
- Domestic Policy Council (DCP)
- Federal Communications Commission (FCC)
- Federal Deposit Insurance Corporation (FDIC)
- Federal Trade Commission (FTC)
- General Services Administration (GSA)
- Institute of Museum and Library Services (IMLS)
- National Economic Council (NEC)
- Nuclear Regulatory Commission (NRC)
- Office of the Director of National Intelligence (ODNI)
  - Intelligence Advanced Research Projects Activity (IARPA)
  - National Counterintelligence and Security Center (NCSC)
  - National Counterterrorism Center (NCTC)
- U.S. Agency for International Development (USAID)
- U.S. Department of Agriculture (USDA)
  - Agricultural Research Service (ARS)
  - National Institute of Food and Agriculture (NIFA)

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EXECUTIVE SUMMARY

Advanced digital information and communications technologies today impact practically all aspects and products of government, the economy, and society, driving innovations that powerfully boost national security, economic growth, and job creation. The U.S. Networking and Information Technology Research and Development (NITRD) Program coordinates Federal research and development (R&D) activities to ensure constructive U.S. leadership in pioneering digital technologies and infrastructure that support our Nation's entire innovation ecosystem. The Program provides R&D leadership in two complementary spheres as no private sector program can. First, it promotes R&D coordination across Federal agencies to meet the Nation's *strategic needs* in computing and networking, to advance an unrivaled, secure, and innovative IT infrastructure that allows U.S. agencies to consistently fulfill their evolving missions. Second, it promotes R&D coordination across economic sectors to meet the Nation's *societal needs* in computing and networking, to advance a reliable, resilient, accessible, economical, and safe IT infrastructure that allows American individuals, businesses, and communities to grow and thrive.

As required by The High-Performance Computing Act of 1991 and follow-on legislation in 1998, 2007, and 2017, this NITRD Supplement to the President's fiscal year (FY) 2018 Budget details the NITRD Program's FY2018 requested budgets by participating agency and Program Component Area (PCA) to meet Program goals. It describes the priorities of NITRD PCAs and Interagency Working Groups, and it highlights the benefits to society of Program investments. The following examples, distilled from this NITRD Supplement, illustrate how the combined R&D investments and activities of NITRD Federal agencies and their nongovernmental partners provide broad benefits to the Nation and society:

- **Economic prosperity:** NITRD-supported R&D for advanced IT and standards broadens access to distributed education, collaboration, and commerce; promotes "smart" technologies and services for communities; and boosts industrial productivity, business revenues, and job growth.
- **Education and training:** NITRD-supported R&D advances remote course delivery mechanisms, improved STEM education for all population groups, and integrated IT research and education programs to close talent gaps and expand citizen and workforce cyber capabilities.
- **Energy and environment:** NITRD-supported R&D in energy-efficient information technologies enables efficient and safe energy infrastructures, comprehensive environmental and agricultural monitoring, accurate weather and climate prediction, and environmentally benign energy systems.
- **Health and healthcare:** NITRD-supported R&D in health IT fosters efficient, secure use of patient and population health data, precision medical diagnosis and treatment, remote and mobile health solutions, better understanding of the human brain, and effective robotic surgery and in-home care.
- **National security and defense:** NITRD-supported R&D produces secure cyber infrastructures, low-vulnerability defense software, IT systems to identify adversarial activity, and high-capability computing for simulation of armor protection materials and nuclear stockpile stewardship.
- **Open and transparent government:** NITRD-supported R&D in affordable, high-confidence IT systems improves remote interactions of the public with government, including for emergency planning and response, public communications, and access to government data and services.
- **Quality of life:** NITRD-supported R&D in accessible, trustworthy IT systems broadens people's ability to balance work–life interests, while improvements in Big Data, communications, and computing support distributed commerce, healthcare delivery, personal security, and emergency response.
- **Science and technology leadership:** NITRD-supported foundational, long-term, interdisciplinary IT R&D positions the Nation to lead the world in emerging frontiers—like automation and artificial intelligence, smart cities, and precision health—to advance other societal benefits in the future.

The President's 2018 Budget Request for the NITRD Program is $4.46 billion, a decrease of $0.33 billion or 6.90 percent, compared to the $4.79 billion enacted in 2017. The overall decrease is due to decreases of $234.7 million at NIH, $121.3 million at NSF, and smaller increases and decreases at other agencies.

Five departments and agencies (NSF, DoD, NIH, DOE, and DARPA) each invest over $500 million per year in NITRD Program activities, with nine other departments and agencies demonstrating broad Federal commitment to the NITRD Program. Agencies collectively invest over $500 million in each of four NITRD PCAs—HCIA (supercomputing infrastructure), CSIA (cybersecurity and privacy), CHuman (co-evolution of society and IT), and LSDMA (big data)—with more modest investments in the other six PCAs. Although the total NITRD investment declined slightly in the FY2018 Budget Request, it has grown three-fold since FY2000, demonstrating the tremendous mission value that agencies see in NITRD investments.

As noted above, NITRD agencies request and make R&D investments within ten NITRD Program Component Areas. The paragraphs below briefly define these PCAs and describe their key strategic and societal priorities.

Computing-Enabled Human Interaction, Communication, and Augmentation (CHuman) R&D advances information-enabled systems that enhance the ability of individuals, teams, and communities to interact both with the systems and with each other to realize personal and shared goals. CHuman R&D investments provide Americans new tools and opportunities in such diverse aspects of their lives as distance education, decision making, healthcare, financial services, social media, citizen science, vehicle and traffic safety, and use of personalized software.

Computing-Enabled Networked Physical Systems (CNPS) R&D centers on systems that integrate the cyber/information, physical, and human worlds, including R&D of cyber-physical systems (CPS), the Internet of Things (IoT), and related complex, networked computing systems. The expanding capability and dependability of these systems will transform individual standards of living and improve cities and communities through applications as diverse as smart grids, smart manufacturing, aerospace, autonomous vehicles, transportation systems, electronic records security, and emergency services.

Cyber Security and Information Assurance (CSIA) R&D pursues dramatic advancements in the resistance and resilience of information systems and networks to cyber threats, such as system penetration, information theft, identity theft, and risks to personal privacy. CSIA advancements protect every sector of the economy—including critical infrastructures such as power grids, financial systems, and air-traffic-control networks—as well as strengthen Federal missions such as national defense and homeland security and provide support for cybersecurity education and workforce development.

Education and Workforce (EdW) R&D aims to advance and apply IT in novel ways to markedly enhance the quality, accessibility, and personalization of education and training methods, generally, and for IT disciplines specifically. EdW advances will improve and broaden U.S. education across disciplines, age groups, and communities and build the Nation's much-needed cyber-capable citizenry and high-tech workforce of the future.

Enabling R&D for High-Capability Computing Systems (EHCS) R&D pursues advancements in high performance computing (HPC)—also known as supercomputing—as well as revolutionary computing paradigms such as quantum, superconducting, and cognitive computing. This R&D ensures and advances U.S leadership in HPC in support of such priorities as national security, aerospace and defense technology, advanced manufacturing, medical advances in treatment and diagnosis, and materials science for technology innovation.

High-Capability Computing Infrastructure and Applications (HCIA) investments provide high-capability computing systems, cyberinfrastructure, applications, and expertise that support national initiatives and advanced research to bolster the Nation's security, economic competitiveness, and innovation ecosystem. HCIA investments make possible U.S. scientific advancements in such highly complex areas as cybersecurity, understanding of the human brain, Big Data, astrophysics, meteorology, nanotechnology, advanced materials, and precision medicine.

Intelligent Robotics and Autonomous Systems (IRAS) R&D improves the capabilities of intelligent collaborative robots and other autonomous systems while improving safety and trust in human interactions with these systems. Increasingly sophisticated autonomous systems are beginning to assist people in learning and decision-making, conducting research, doing such challenging or dangerous work as complex surgery or disaster site cleanup, providing routine personal care, and automating some repetitive manual tasks.

Large Scale Data Management and Analysis (LSDMA) R&D advances the capacity of the United States to manage and use its rapidly expanding wealth of Big Data. This allows the Nation to fully exploit the transformational opportunities of Big Data for priorities that include cyber threat detection, scientific breakthroughs, organizational efficiency and innovation, customs enforcement, improving first responder insight, and control of water-food-energy production.

Large Scale Networking (LSN) R&D provides the advanced infrastructure and superior performance needed for the U.S. networks that underpin digital interactions across commerce, defense, security, social networking, education, and science research. LSN advancements enable critical wireless and fixed communications for new and evolving multibillion-dollar IT industries, broad societal participation, cutting-edge science, global battlefield superiority, remote and mobile medicine, and informed emergency response.

Software Design and Productivity (SDP) R&D pursues rapid development of quality software that will improve the cost and effectiveness of applications ranging from smart cities to space exploration. This R&D will drive advancements in aerospace and defense, supercomputing, data and energy grid management, autonomous vehicle function, the emerging Internet of Things, networking operations, and countless other digital activities throughout the Nation.

This Supplement describes examples of how the NITRD Program is pioneering the next big innovations in IT, as the Federal Government did with the Internet, GPS, supercomputers, and numerous other IT-dependent breakthroughs. NITRD-coordinated advances will power the next stage of U.S. leadership in remarkable—and soon indispensable—technologies that support national security, economic strength and resilience, and improved quality of life, among many other benefits.

1. Introduction and Overview

Information technology (IT) is perhaps the most broadly transformative technology ever invented. Innovation in IT continually enables pivotal new applications that advance U.S. national priorities and Federal agency missions. For 26 years, the Networking and Information Technology Research and Development (NITRD) Program has helped Federal agencies coordinate information technology research and development (R&D) to optimize Federal investments that support agency missions and provide societal benefits.

The NITRD Program was established by the High-Performance Computing Act of 1991 (P.L. 102-194) and reauthorized three times, most recently in 2017 by the American Innovation and Competitiveness Act (P.L. 114-329).[1] The NITRD Program provides a framework and mechanisms for coordination among the many Federal agencies that support R&D in advanced information technologies and report IT research budgets in this NITRD Supplement. The Program is the Nation's primary source of federally funded work on R&D in computing, networking, and software. It is managed by the NITRD Subcommittee of the National Science and Technology Council (NSTC) Committee on Technology and supported by the NITRD National Coordination Office (NCO).

The NITRD Program is tasked with providing the R&D foundations for assuring continued U.S. technological leadership in IT and for supporting the needs of the Federal Government for advanced information technologies. In addition to the approximately 20 agencies that are formal NITRD members, some 40 other agencies with IT interests also participate in NITRD strategic planning, information sharing, and collaborative activities as a means to contribute to and take advantage of the important technological advances arising from Federal networking and information technology R&D efforts.[2]

The NITRD Program also is tasked with accelerating development and deployment of advanced information technologies as a means to achieve high-level societal benefits on behalf of the American people in the areas of economic prosperity, education and training, energy and environment, health and healthcare, national security and defense, open and transparent government, and quality of life. These national and societal benefit areas are described in the 2012 NITRD Strategic Plan,[3] with the addition of "science and technology leadership" to enable future U.S.-led breakthroughs in revolutionary applications that are perhaps not yet imagined.

Recent highlights of the NITRD Program can be found at https://www.nitrd.gov/about/about_nitrd.aspx.

The NITRD Budget Reporting Structure

The NITRD budget reporting structure is organized by Program Component Area (PCA) and by agency to facilitate budgetary and programmatic comparisons from year to year. The PCAs are the major subject areas under which the projects and activities coordinated through the NITRD Program are grouped. There are ten NITRD PCAs. Section 2 of this document provides the agency and PCA budgets and budget requests for fiscal years (FYs) 2016–2018; Section 3 provides full descriptions of the FY2018 PCAs and associated R&D priorities and coordination activities.

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[1] Sec. 105 of Public Law 114-329 is the "Networking and Information Technology Research and Development Modernization Act of 2016"; https://congress.gov/bill/114th-congress/senate-bill/3084/text#toc-idB56FB943F79348E9AEE03036E5C90675.

[2] Page iv lists member and nonmembers agencies and departments that participate in NITRD program activities.

[3] *The Networking and Information Technology Research and Development (NITRD) Program 2012 Strategic Plan* (Washington, DC: EOP, NSTC, July 2012), pp. 1, 3; https://nitrd.gov/pubs/strategic_plans/2012_NITRD_Strategic_Plan.pdf.

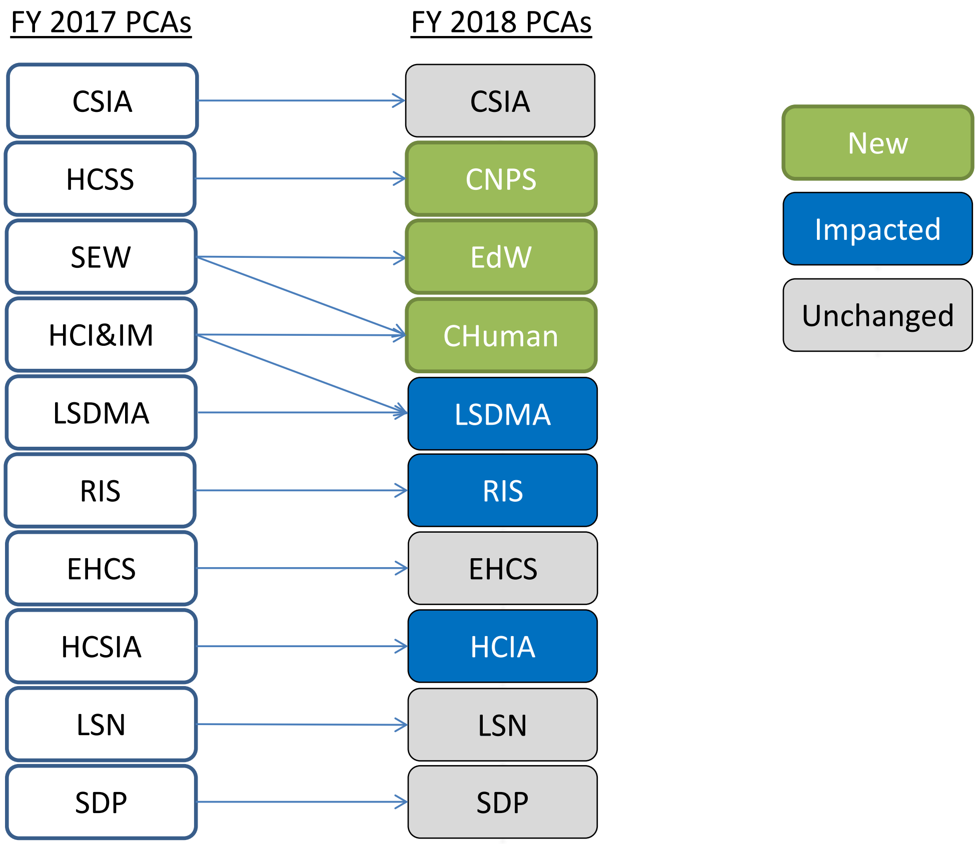
Changes to the NITRD PCAs

FY2018 NITRD PCAs differ somewhat from the FY2017 PCAs. In January 2016, the NITRD Subcommittee established a Fast-Track Action Committee (FTAC) to review the NITRD PCA definitions and to adopt changes, as deemed necessary, beginning with the FY2017 budget cycle. The changes reflect the rapidly evolving IT R&D environment and the societal benefits and focus areas on which the NITRD Program's future direction is set. Following consultations with the NITRD Subcommittee and NITRD member agencies, the FTAC defined three new PCAs, revised and updated the definitions of three PCAs, and left the definitions unchanged for four PCAs. Table 1 below provides a summary list of the NITRD PCAs used for FY2017 and their relationships to the new set of PCAs used for FY2018.

Table 1. Relationships between the NITRD PCAs in FYs 2017 and 2018

FY2017 PCAs
• Cyber Security and Information Assurance (CSIA) • High Confidence Software and Systems (HCSS) • Social, Economic, and Workforce Implications of IT and IT Workforce Development (SEW) • Human Computer Interaction and Information Management (HCI&IM) • Large-Scale Data Management and Analysis (LSDMA) • Robotics and Intelligent Systems (RIS) • Enabling-R&D for High-Capability Computing Systems (EHCS) • High-Capability Computing Systems Infrastructure and Applications (HCSIA) • Large Scale Networking (LSN) • Software Design and Productivity (SDP)
FY2018 PCAs
• [UNCHANGED] Cyber Security and Information Assurance (CSIA) • [NEW] Computing-Enabled Networked Physical Systems (CNPS) • [NEW] Education and Workforce (EdW) • [NEW] Computing-Enabled Human Interaction, Communications, and Augmentation (CHuman) • [REVISED] Large-Scale Data Management and Analysis (LSDMA) • [REVISED] Robotics and Intelligent Systems (RIS) • [UNCHANGED] Enabling-R&D for High-Capability Computing Systems (EHCS) • [REVISED] High-Capability Computing Infrastructure and Applications (HCIA) • [UNCHANGED] Large Scale Networking (LSN) • [UNCHANGED] Software Design and Productivity (SDP)

The following diagram illustrates the relationships between the FY2017 PCAs and the FY2018 PCAs.



The NITRD Interagency Working Groups

Federal agencies whose missions require ongoing R&D in specific topics coordinate that work through one or more of NITRD's Interagency Working Groups (IWGs) to achieve the most productive results from their R&D investments in the PCAs. With legislative guidance and with support from the NITRD NCO, the IWGs work in the following ways to harmonize their R&D investments, promote open flows of information, broaden R&D impact, and build community consensus and engagement:

- Coordinate robust, synergetic interagency R&D planning, goal-setting, and investments and activities to effectively advance agency missions and national priorities, including creating, updating, and abiding by carefully crafted strategic R&D plans, and sharing best practices across agencies and groups.
- Promote support for foundational, large-scale, long-term, multidisciplinary R&D.
- Collaboratively identify and advance mission-driven R&D grand challenges.
- Exchange information and engage with State and local governments, academia, industry, and international research organizations in crosscutting IT and networking pursuits, and include the general public at multiple stages in goal-setting and communications processes.
- Leverage research to accelerate translation of U.S.-led discovery and innovation in science and technology into practice and into new products and applications.
- Promote education and workforce development to grow the country's cyber capabilities.

Structure of this Supplement

Section 2 of this Supplement to the President's FY2018 Budget provides budget data for the R&D investments made in FY2016, underway in FY2017, and requested in the President's FY2018 Budget in the ten NITRD PCAs, along with analyses that highlight key aspects of the NITRD investments. Section 3 describes the NITRD PCAs and the societal benefits that result from Federal R&D investments in these PCAs, and planned FY2018 Federal R&D activities associated with the funding presented in Section 2, as coordinated by one or more NITRD Interagency Working Groups. Section 4 briefly reviews several NITRD interagency coordination activities that do not currently fall under one of the PCAs. Appendix A presents the Federal Cybersecurity Strategic Plan Implementation Roadmap (introduced in the CSIA PCA descriptions in Section 3); Appendix B provides highlights of FY2016 accomplishments of the National Strategic Computing Initiative (NSCI), which the NITRD NCO helps to support; Appendix C provides the definitions of all the FY2018 NITRD PCAs; and Appendix D defines the abbreviations used in this document.

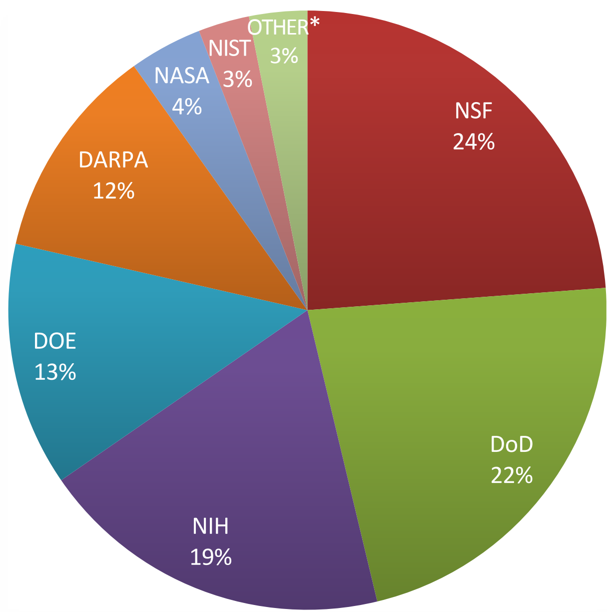
2. NITRD Budgets by Agency and Program, FYs 2016–2018

This section provides details of the NITRD agency budget requests by means of the following:

- Charts 1–2 that show relative NITRD budget requests by agency and by PCA for FY2018.
- Charts 3–4 that show NITRD budget trends by agency and by PCA for FYs 2000–2018.
- Table 2. Agency NITRD Budgets by PCA, FYs 2016–2018, that shows NITRD program budgets and budget totals organized by agency and by Program Component Area. For ready comparison of recent trends, the budget table includes actual expenditures for FY2016, enacted budgets for FY2017, and requested funding for FY2018.
- High-level analyses of significant changes between NITRD agencies' FY2017 enacted budgets and the FY2018 Budget Request, including overall allocations of resources by PCA and by agency.

Additional information on NITRD-related R&D expenditures from FY2000 to FY2018 may be found at the NITRD dashboard website, http://itdashboard.nitrd.gov/.

NITRD Budget Charts and Table



* "Other" (*light green slice*) includes AHRQ, DHS, EPA, NARA, NIJ, NNSA, and NOAA

Chart 1. FY2018 Budget Request, as percentages of the total NITRD request, by agency.

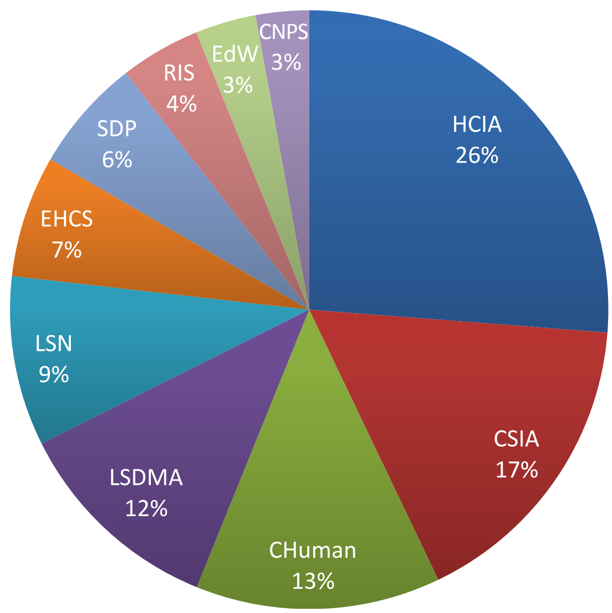
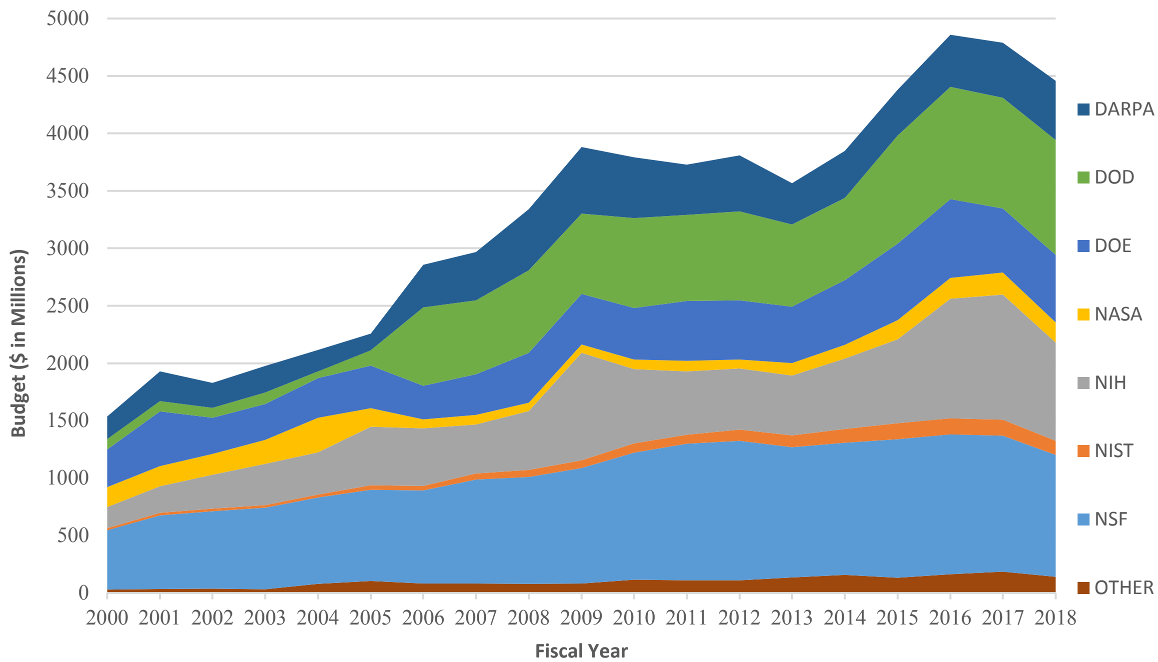
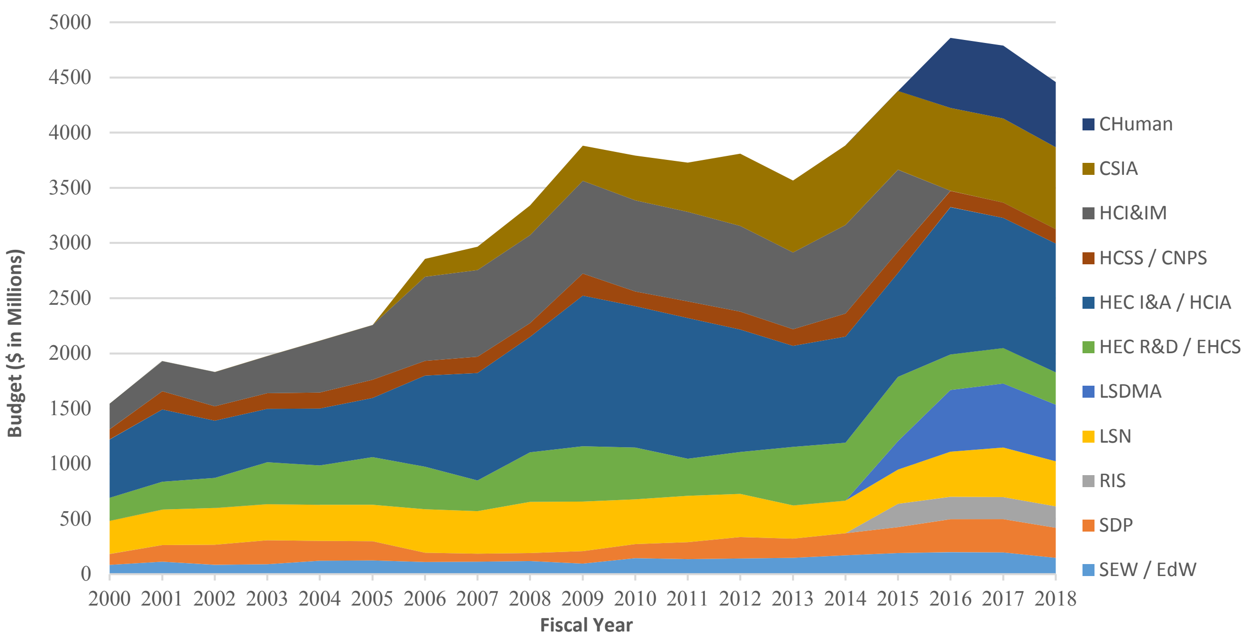


Chart 2. FY2018 Budget Request, as percentages of the total NITRD request, by PCA.



DOD includes OSD and DoD Service research organizations. DOE includes DOE/NNSA, DOE/OE, and DOE/SC. OTHER includes AHRQ, DHS, EPA, NARA, NIJ, and NOAA.

Chart 3. NITRD budget trends FYs 2000–2018, by agency.



For three pairs of PCAs (HCSS and CNPS, HEC Infrastructure and Applications [I&A] and HCIA, and HEC R&D and EHCS), the names of these PCAs changed starting with the FY2017 Supplement, but their scope and agency reporting were essentially unchanged, so each pair is plotted as a single PCA.

Chart 4. NITRD budget trends FYs 2000–2018, by PCA.

Table 2. Agency NITRD Budgets by PCA, FYs 2016–2018

FY2016 Budget Actuals, FY2017 Budget Enacted, and FY2018 Budget Request (Dollars in Millions)

Agencies are listed in order by FY2018 Budget Request, highest to lowest. The notes key is on the next page.

Agency	Budget Year	NITRD Program Component Areas										Total [a]
		CHuman	CNPS	CSIA	EdW	EHCS	HCIA	LSDMA	LSN	RIS	SDP	
NSF	FY2016 Actual	90.2	85.9	111.7	76.4	133.0	197.9	248.9	138.9	48.9	86.7	1,218.6
	FY2017 Enacted	91.8	76.1	111.0	78.4	139.0	176.9	237.7	137.7	48.3	86.2	1,183.1
	FY2018 Request	79.6	75.3	98.5	68.9	116.1	178.7	198.8	128.2	41.3	76.4	1,061.8
DoD [b]	FY2016 Actual	139.5	17.2	178.6	3.2	43.1	311.0	51.7	106.4	106.1	19.7	976.6
	FY2017 Enacted	127.9	17.4	179.9	2.9	43.2	276.4	61.4	137.9	97.6	17.8	962.6
	FY2018 Request	133.2	14.5	206.2	3.0	38.9	283.8	56.3	119.6	99.8	45.1	1,000.4
NIH	FY2016 Actual	353.7	25.9	4.7	68.6	34.9	210.4	148.2	9.1	4.4	179.8	1,039.7
	FY2017 Enacted	376.1	27.3	4.8	71.9	36.1	219.1	154.4	9.4	4.6	184.6	1,088.3
	FY2018 Request	295.4	21.7	3.6	57.0	29.7	172.9	122.3	7.1	3.5	140.4	853.6
DOE [c]	FY2016 Actual	0.0	0.0	29.0	10.0	55.2	511.6	0.0	79.8	0.0	0.0	685.6
	FY2017 Enacted	0.0	0.0	32.0	10.0	46.8	385.2	0.0	83.4	0.0	0.0	557.4
	FY2018 Request	0.0	0.0	30.0	10.0	44.3	431.9	0.0	71.0	0.0	0.0	587.2
DARPA	FY2016 Actual	15.8	0.0	296.4	0.0	20.3	0.0	89.3	32.0	0.0	0.0	453.7
	FY2017 Enacted	36.2	0.0	300.1	0.0	5.1	0.0	103.3	34.4	0.0	0.0	479.2
	FY2018 Request	67.9	0.0	301.9	0.0	5.1	0.0	113.4	28.5	0.0	0.0	516.9
NASA	FY2016 Actual	3.1	4.1	0.0	32.3	8.5	58.9	2.8	31.3	34.7	6.9	182.6
	FY2017 Enacted	2.9	5.8	0.0	25.3	14.3	60.0	2.7	34.1	41.3	6.7	193.2
	FY2018 Request	2.9	4.6	0.0	0.0	16.6	59.8	2.6	45.3	38.4	5.8	175.9
NIST	FY2016 Actual	7.0	14.5	65.4	4.6	4.1	10.7	13.9	9.4	7.2	2.3	139.1
	FY2017 Enacted	7.0	14.5	65.5	4.2	4.1	10.7	14.0	9.8	7.2	2.3	139.3
	FY2018 Request	6.7	11.9	59.7	4.2	2.6	10.2	12.7	6.0	7.2	2.3	123.5
DHS	FY2016 Actual	4.0	0.0	63.9	0.0	0.0	0.0	4.0	0.0	0.0	0.0	71.9
	FY2017 Enacted	2.0	0.0	66.8	0.0	0.0	0.0	5.0	0.0	0.0	0.0	73.8
	FY2018 Request	4.2	0.0	43.9	0.0	0.0	0.0	4.0	0.0	0.0	0.0	52.1
NNSA	FY2016 Actual	0.0	0.0	0.0	3.5	18.7	0.0	0.0	0.0	0.0	0.0	22.2
	FY2017 Enacted	0.0	0.0	0.0	3.5	30.0	0.0	0.0	0.0	0.0	0.0	33.5
	FY2018 Request	0.0	0.0	0.0	3.5	40.0	0.0	0.0	0.0	0.0	0.0	43.5
NOAA	FY2016 Actual	0.2	0.0	0.0	0.0	0.0	29.7	0.0	3.3	0.0	3.7	36.9
	FY2017 Enacted	0.2	0.0	0.0	0.0	0.0	46.0	0.0	3.3	0.0	3.7	53.2
	FY2018 Request	0.2	0.0	0.0	0.0	0.0	31.6	0.0	3.3	0.0	3.7	38.8
NIJ	FY2016 Actual	0.0	0.0	1.8	0.0	0.0	0.0	0.1	0.0	1.5	0.0	3.4
	FY2017 Enacted	0.2	0.0	0.4	0.0	0.0	0.0	1.0	0.0	0.6	0.0	2.3
	FY2018 Request	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	3.1	0.0	5.1
NARA	FY2016 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
	FY2017 Enacted	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
	FY2018 Request	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
AHRQ	FY2016 Actual	21.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.5
	FY2017 Enacted	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5
	FY2018 Request	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EPA	FY2016 Actual	0.0	0.0	0.0	0.0	3.5	3.0	0.0	0.0	0.0	0.0	6.5
	FY2017 Enacted	0.0	0.0	0.0	0.0	3.5	3.0	0.0	0.0	0.0	0.0	6.5
	FY2018 Request	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	FY2016 Actuals [a]	635.1	147.7	751.5	198.7	321.2	1,333.2	559.0	410.2	202.9	299.2	4,858.6
Total	*FY2017 Enacted [a]*	660.8	141.1	760.6	196.3	322.1	1,177.2	579.8	450.1	199.7	301.3	4,789.0
Total	**FY2018 Request [a]**	590.1	128.0	743.8	146.6	293.3	1,168.9	512.3	409.0	193.3	273.6	4,459.0

BUDGET TABLE NOTES (see Table 2 on previous page)

a) Totals might not sum correctly due to rounding.

b) DoD budget includes funding for OSD and the DoD Service research organizations. DoD Service research organizations include: Air Force Research Laboratory (AFRL), including the Air Force Office of Scientific Research (AFOSR); Army Research Laboratory (ARL), including the Army Research Office (ARO); Naval Research Laboratory (NRL); and Office of Naval Research (ONR). The Communications-Electronics Research, Development, and Engineering Center (CERDEC), Defense Research and Engineering Network (DREN), and High Performance Computing Modernization Program (HPCMP) are under Army. Although DARPA and OSD research organizations are under DoD, they are independent of the research organizations of the DoD Services (Air Force, Army, and Navy). NSA is a research organization under DoD, but it does not report NITRD funding.

c) DOE budget includes funding from DOE's Office of Science (SC) and Office of Electricity Delivery and Energy Reliability (OE).

NITRD Program Budget Analysis

Overview

The budget analysis notes changes of investment greater than $10 million, by agency and by PCA, between the FY2017 investments that are underway and the FY2018 Presidential Budget Request. **In the analysis sections, all years are fiscal years**.

Changes to Budget Categories for FYs 2016-2018 NITRD Investments

NITRD investments for fiscal years (FYs) 2016 through 2018 are reported here for the first time under the updated PCA categories described in "Changes to the NITRD PCAs" on pp. 7–8. The reporting reflects the use of the revised PCA categories by NITRD agencies. Note that the revised PCA categories represent an update of how NITRD investments by the Federal Government are tabulated but not a change in overall scope of the NITRD Program between the 2017 and 2018 Supplements. For a longer-term view, Chart 4 on page 11 indicates which PCAs have continued with little or no change in scope, in some cases with a name change, and which PCAs have been discontinued or created as the NITRD Program has been updated over the years.

Fiscal Year Overview for 2017-2018

In the following analysis of the NITRD Program, the President's 2018 Budget Request is compared with the 2017 enacted budget. Changes in NITRD Program budgets reported in the budget analysis reflect revisions to program budgets due to evolving priorities, as well as Congressional actions and appropriations.

Summary

The President's 2018 Budget Request for the NITRD Program is $4.46 billion, a decrease of $0.33 billion or 6.90 percent, compared to the $4.79 billion enacted in 2017. The overall change is due to both increases and decreases in individual agency NITRD budgets, which are described below.

NITRD Program Budget Analysis by Agency

This section describes changes greater than $10 million between 2017 enacted spending and 2018 requests. Smaller changes are discussed only if they represent shifts in funding focus. Budget numbers in these descriptions are rounded to the nearest tenth from initial agency numbers with three decimals.

AHRQ: *Comparison of 2017 enacted ($16.5 million) and 2018 request ($0 million)*: This is a decrease of $16.5 million in CHuman, due to reduction of duplication across agencies and consolidation with NIH.

DARPA: *Comparison of 2017 enacted ($479.2 million) and 2018 request ($516.9 million)*: The increase of $37.7 million is primarily due to a $31.7 million increase in CHuman for research in the area of human-machine symbiosis, and a $10.1 million increase in LSDMA for research in the areas of modeling and knowledge discovery, with smaller increases and decreases in other PCAs.

DHS: *Comparison of 2017 enacted ($73.8 million) and 2018 request ($52.1 million)*: The $21.7 million decrease largely results from a decrease of $22.9 million in CSIA, due to the FY2018 Cybersecurity research, development, test, and evaluation (RDT&E) budget being significantly decreased to close to the 2015 level of cybersecurity RDT&E investment. There were also smaller increases and decreases in other PCAs.

DoD: *Comparison of 2017 enacted ($962.6 million) and 2018 request ($1,000.4 million)*: The increase of $37.8 million is primarily due to an increase of $26.3 million in CSIA and $27.3 million in SDP, partially offset by a decrease of $18.3 million in LSN, with smaller increases and decreases in other PCAs.

DOE: *Comparison of 2017 enacted ($557.4 million) and 2018 request ($587.2 million)*: The increase of $29.8 million is due an increase of $46.7 million in DOE/SC funding in HCIA to support facility upgrades and other program shifts, partially offset by a decrease of $12.4 million in DOE/SC funding in LSN due to the termination of the Next Generation Networking for Science activity, with smaller decreases in other PCAs. Another significant change is due to the initiation of the Exascale Computing Project (ECP), which shifted funding for this effort from research to a line item project, to improve the transparency of this Departmental priority. ECP is therefore no longer being reported by DOE/SC as a NITRD investment.

DOE/NNSA: *Comparison of 2017 enacted ($33.5 million) and 2018 request ($43.5 million)*: The increase of $10.0 million is due an increase of $10.0 million in EHCS for funding additional R&D activities by computer vendor partners in the DOE Exascale Computing Project's PathForward program.

NASA: *Comparison of 2017 enacted ($193.2 million) and 2018 request ($175.9 million)*: The decrease of $17.3 million is primarily due to a decrease of $25.3 million in EdW in that 2018 SBIR/STTR proposals have not yet been identified or selected; this decrease is partially offset by an increase of $11.2 million in LSN, of which significant research is being directed towards space laser communications, with smaller increases and decreases in other PCAs.

NIH: *Comparison of 2017 enacted ($1,088.3 million) and 2018 request ($853.6 million)*: The $234.7 million decrease largely results from decreases of $80.7 million in CHuman, $14.9 million in EdW, $46.2 million in HCIA, $32.1 million in LSDMA, and $44.2 million in SDP, with smaller decreases in other PCAs.

NIST: *Comparison of 2017 enacted ($139.3 million) and 2018 request ($123.5 million)*: This is a decrease of $15.8 million due to smaller decreases in various PCAs.

NOAA: *Comparison of 2017 enacted ($53.2 million) and 2018 request ($38.8 million)*: This is a decrease of $14.4 million in HCIA. The year-over-year decrease is due to the 2017 enacted amount including one-time funding for collaborative computing and reductions to the HPC Program in 2018.

NSF: *Comparison of 2017 enacted ($1,183.1 million) and 2018 request ($1,061.8 million)*: The decrease of $121.3 million is primarily due to decreases of $12.2 million in CHuman (including Smart and Connected Health and Cyberlearning and Future Learning Technologies); $12.5 million in CSIA (represents reductions in cybersecurity R&D, including in the Secure and Trustworthy Cyberspace program); $22.9 million in EHCS (including Innovations at the Nexus of Food, Energy, and Water Systems and Scalable Parallelism in the Extreme); $38.9 million in LSDMA (represents reductions in programs supporting LSDMA as well as the National Institute for Mathematical and Biological Synthesis, which is ending in 2017); with smaller increases and decreases in other PCAs.

NITRD Program Budget Analysis by PCA

Using the information presented above, this section provides an analysis of the NITRD Program budget by PCA, summarizing the differences greater than $10 million between the 2017 enacted and 2018 requests. The changes are described below.

CHuman: *Comparison of 2017 enacted ($660.8 million) and 2018 request ($590.1 million)*: The $70.7 million decrease is largely due to a decrease of $80.7 million at NIH, $16.5 million decrease at AHRQ, and $12.2 million decrease at NSF, partially offset by a $31.7 million increase at DARPA, with smaller increases and decreases at other agencies.

CNPS: *Comparison of 2017 enacted ($141.1 million) and 2018 request ($128.0 million)*: The $13.1 million decrease is largely due to a decrease of $5.6 million at NIH with smaller decreases at other agencies.

CSIA: *Comparison of 2017 enacted ($760.6 million) and 2018 request ($743.8 million)*: The $16.8 million decrease is largely due to a decrease of $22.9 million at DHS and a $12.5 million decrease at NSF, partially offset by a $26.3 million increase at DoD, with smaller increases and decreases at other agencies.

EdW: *Comparison of 2017 enacted ($196.3 million) and 2018 request ($146.6 million)*: The $49.7 million decrease is largely due to a decrease of $25.3 million at NASA, a $14.9 million decrease at NIH, with smaller increases and decreases at other agencies.

EHCS: *Comparison of 2017 enacted ($322.1 million) and 2018 request ($293.3 million)*: The $28.8 million decrease is largely due to a decrease of $22.9 million at NSF, a $10.0 million decrease at DOE/NNSA, with smaller increases and decreases at other agencies.

LSDMA: *Comparison of 2017 enacted ($579.8 million) and 2018 request ($512.3 million)*: The $67.5 million decrease is largely due to a decrease of $38.9 million at NSF, a $32.1 million decrease at NIH, with smaller decreases at other agencies, partially offset by a $10.1 million increase at DARPA.

LSN: *Comparison of 2017 enacted ($450.1 million) and 2018 request ($409.0 million)*: The $41.1 million decrease is largely due to a decrease of $18.3 million at DoD, a $12.4 million decrease at DOE/SC, with smaller decreases at other agencies, partially offset by an $11.2 million increase at NASA.

SDP: *Comparison of 2017 enacted ($301.3 million) and 2018 request ($273.6 million)*: The $27.7 million decrease is largely due to a decrease of $44.2 million at NIH with smaller decreases at other agencies, partially offset by a $27.3 million increase at DoD.

3. Descriptions of the Program Component Areas

The NITRD Program is organized into ten Program Component Areas (PCAs). This section provides descriptions of the programmatic and coordination activities that support the PCA budgets and overall NITRD budgets reported in the previous section. Each PCA subsection begins with the PCA definition and notes the ways the PCA investments provide benefits to society. It then describes the associated NITRD interagency working group (IWG) or groups through which Federal agency representatives coordinate the budget-relevant activities of that PCA, including details of the IWG strategic priorities, key programs, and planning and collaboration activities that underlie the President's FY2018 Budget Request for the PCA.

The ten NITRD PCAs are listed below with their associated IWGs and other coordination groups.

- **Computing-Enabled Human Interaction, Communication, and Augmentation (CHuman) PCA**
  - Social Computing (SC) IWG
- **Computing-Enabled Networked Physical Systems (CNPS) PCA**
  - High Confidence Software and Systems (HCSS) IWG
  - Cyber-Physical Systems (CPS) IWG
    - Smart Cities and Communities (SCC) Task Force
- **Cyber Security and Information Assurance (CSIA) PCA**
  - Cyber Security and Information Assurance IWG
  - Privacy Research and Development IWG
- **Education and Workforce (EdW) PCA**
- **Enabling R&D for High-Capability Computing Systems (EHCS) PCA**
  - High End Computing IWG
- **High-Capability Computing Infrastructure and Applications (HCIA) PCA**
  - High End Computing IWG
- **Large Scale Data Management and Analysis (LSDMA) PCA**
  - Big Data IWG
    - Human Computer Interaction and Information Management (HCI&IM) Task Force
- **Large-Scale Networking (LSN) PCA**
  - Large Scale Networking IWG
    - Broadband Research and Development (BRD) Group
    - Joint Engineering Team (JET)
    - Middleware And Grid Interagency Coordination (MAGIC) Team
  - Wireless Spectrum Research and Development (WSRD) IWG
- **Robotics and Intelligent Systems (RIS) PCA**
  - Intelligent Robotics and Autonomous Systems (IRAS) IWG
- **Software Design and Productivity (SDP) PCA**
  - Software Productivity, Sustainability, and Quality (SPSQ) IWG

Computing-Enabled Human Interaction, Communication, and Augmentation (CHuman) PCA

The CHuman PCA comprises R&D activities on computing- and information-enabled systems that respect and enhance an individual's ability to interact both with the system itself and with others. This includes R&D on systems that model and improve perceptual, cognitive, and physical capabilities. Examples include large-scale distributed engineering, team science, human-machine teams, novel interaction techniques, and visualization. CHuman systems and research are informed by social, behavioral, and economic science, human-computer interaction, computer-supported cooperative work, social computing, and interaction techniques for contexts in which perceptual and physical abilities are constrained. Also included are systems and models that help teams, groups, and communities accomplish collective goals such as rational decision-making, command and control, collaborative problem-solving, interpersonal interactions, information sharing, and social development. For both individuals and groups, CHuman supports R&D efforts that combine the strengths of humans and computers to improve mission effectiveness and societal benefits including health and well-being, safety and security, and education and training.

The Social Computing (SC) IWG reports its activities under the CHuman PCA.

Advancing Societal Benefits

SC agency investments provide societal benefits in the following key areas:

- **Economic prosperity** by R&D on tools and systems that improve collaboration (e.g., groupware) and analysis (e.g., visualization and data analytics) capabilities for workplace and educational applications, and by supporting development of new enterprises that address societal needs and promote job creation.
- **Education and training** by investing in promoting growth in the science, technology, engineering, mathematics (STEM) workforce and associated skills through (1) designing and improving massive open online courses (MOOCs) to support education within and outside of classrooms; (2) working to increase participation by all of the Nation's students, including underrepresented groups in STEM research and education, through mentoring and outreach at the high school and undergraduate college levels; and (3) developing evidence-based programs that account for individual differences in effective principles of learning.
- **Energy and environment** by funding R&D in sensing and in changing human behavior around resource use to increase sustainability awareness and behavior while mitigating overly intrusive applications.
- **Health and healthcare** by investing in developing (1) sensors to detect biophysical states, enabling rapid detection and tracking of physical health, health risks, and health trends baselined to an individual's physical and mental states and traits; (2) systems that take a collective approach to helping individuals manage personal health data; and (3) approaches to understand and support collaboration among medical workers and develop secure electronic health record systems that maintain individual privacy.
- **National security and defense** by continuing to fund research on tools for data mining and behavioral analysis (applications include sentiment analysis, information dissemination, and threat detection); crowdsourcing tools for collaborative document analysis (applications include intelligence); and projects related to extraction of sociocultural values and norms that can improve warfighter social intelligence in field operations.
- **Open and transparent government** by providing online open access to results of federally funded scientific research programs; by encouraging scientists to post their data and models on

the Open Science platform to facilitate validation and enhancement of scientific research; and by supporting civic participation and partnership with Federal and local agencies.

- **Quality of life** by investing in research to facilitate effective collaboration across long distances and time periods and to increase people's flexibility and freedom to balance work and personal demands; such platforms support robust and trustworthy communications and interactions as well as provide tools to assess the quality of group collaborative processes and organization of the information exchanged in the group.
- **Science and technology leadership** by supporting a range of basic science research around the intersection of humans and technology, in order to (1) advance understanding of human behavior that integrates computational analysis of large-scale data with existing theories of human behavior; (2) understand when and why humans and designed technologies work well together, how they influence each other, and when they fail; and (3) develop more effective methods and tools for developing technologies that account for and adapt to both individual and social behavior.

Social Computing IWG

***NITRD Member Agencies*: DoD, DOE, DOJ, NIH, NIJ, NIST, NSF, ONR**

***NITRD Participating Agencies*: DOS, OFR, USAID, USDA, USSS**

The SC IWG continues to invest in fundamental scientific research to advance sociotechnical and computational systems that support communication and coordination of individuals, groups, societies, and organizations to increase their contributions to our national economic and societal well-being. It also invests in R&D directed at advancing understanding of how to develop virtual organizations and under what conditions human-human and human-machine collaboration and complementarity can enable and enhance innovation in science, engineering, and education.

President's FY2018 Budget Request

Strategic Priorities Underlying This Request

SC agencies support fundamental research on the systems and science of the interplay of people and computing and will strengthen agency coordination to advance aspects of social computing and human-computer systems. These systems impact such realms as collaboration; social media; online coursework and virtual reality for education; peer lending and financial services; human inputs into prediction markets and reputation systems (i.e., tools that aggregate individual input), human-in-the-loop automation, and crowd-sourcing; and socially intelligent devices and systems such as knowledge sharing and decision-support systems, sensor networks, brain-machine interfaces, and software for customization and personalization.

SC agency investments for FY2018 will include the following:

- **Social computing in physical contexts**: Address social as well as technical concerns; conduct R&D in co-robots, human-robot interaction, and mixed human-robot teams (e.g., self-driving cars and unmanned aerial vehicles); pursue augmented and virtual reality systems; and model multiplex system interdependencies, e.g., between social, natural, and physical (human-built) systems.

Key Programs Supporting This Request

The SC agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **Cyber-Human Systems:** Support research and development efforts into computing- and information-enabled systems that enhance an individual's ability to interact both with information systems and with others. *NIH, NSF*
- **Smart and Connected Communities:** Improve physical, sensing-enabled collaboration. *EPA, NIH, NIST, NSF*
- **NRI 2.0: Ubiquitous Collaborative Robots:** Develop co-robots, human-robot teams, and autonomous human-robot systems such as self-driving cars and unmanned aerial vehicles (UAVs). *DoD, DOE/EM, NASA, NSF, USDA/NIFA*
- **Measurement, feedback, and support of human performance:** Develop new IT, methods, and models that use sensed and entered data about human mental and physical state and activities in order to assess human performance; develop systems that adapt to human workload, stress, and performance; and provide feedback to individuals and teams to help them improve their performance in a range of tasks. *ARO, NSF*
- **Designing more effective training systems:** Improve human-computer interaction in high-volume, ill-structured information environments to improve rapidity and quality of decision making. *ARO*

Planning and Coordination Supporting This Request

The following are examples of ongoing SC coordination activities for FY2018:

- **Minerva Research Initiative:** Program initiatives and projects addressing evolving social science and technology challenges for the Department of Defense. *DoD service research organizations, OSD, social science research community*
- **Smart and Connected Health Program:** Next-generation healthcare solutions that include sensor, networking, information, and machine learning technologies; decision support systems; and modeling for person-centered, wellness-focused healthcare. *NIH, NSF*
- **Social computing R&D planning:** Development of a Federal R&D strategic plan in social computing. *CHuman agencies*
- **Social science research and technology development**. *ARO*
- **Distributed Cognition Program**. *ARO, NSF, ONR*

Computing-Enabled Networked Physical Systems (CNPS) PCA

CNPS supports development of scientific foundations and innovative and enabling software and hardware technologies for the engineering, verification and validation, assurance, standardization, and certification of complex, networked, distributed computing systems and cyber-physical (IT-enabled) systems (CPS). The goal is to enable seamless, fully synergistic integration of computational intelligence, communication, control, sensing, actuation, and adaptation with physical devices and information processes to routinely realize high-confidence, optimally performing systems that are essential for effectively operating life-, safety-, security-, and mission-critical applications. These systems must be capable of interacting correctly, safely, and securely with humans and the physical world in changing environments and unforeseen conditions. In many cases, they must be certifiably dependable. The vision is to realize dependable systems that are precise and highly efficient; respond quickly; work in dangerous or inaccessible environments; provide large-scale, distributed coordination; augment human capabilities; and enhance societal quality of life. New science and technology are needed to build these systems with computing, communication, information, and control pervasively embedded at all levels, thus enabling entirely new generations of engineering designs that can enhance U.S. competitiveness across economic and industrial sectors.

The following NITRD groups report their activities under the CNPS PCA:

- High Confidence Software and Systems (HCSS) IWG
- Cyber-Physical Systems (CPS) IWG
    - Smart Cities and Communities (SCC) Task Force

The HCSS and CPS IWGs are highly complementary. The HCSS IWG supports R&D in reliable, robust, stable, and secure design, construction, evaluation, and implementation of software and systems; the CPS IWG supports R&D underpinning integration of cyber and physical elements across all application sectors. The SCC Task Force supports networking and IT R&D for sustainable improvements to cities and communities.

Advancing Societal Benefits

Combined HCSS, CPS, and SCC agency investments provide societal benefits in the following key areas:

- **Economic prosperity** by reducing risks and improving reliability for smart manufacturing technologies; by encouraging use-inspired Federal CPS R&D investment and accelerating translational activities for mature research activities through partnerships with relevant industry partners; by developing innovative data-driven products and services to enable and catalyze efficient, livable cities and communities; and by boosting trade, investment, and employment opportunities in smart cities and communities.
- **Education and training** by working in conjunction with community business and political leaders to develop new methods and advanced technologies that support HCSS education and workforce advances, including hands-on use and application of CPS in both educational and workforce settings; and by fostering integration of research and education through the projects, programs, and activities that the agencies support at academic and research institutions.
- **Energy and environment** by enabling smart grid advancements and by improving digital safety systems and embedded digital devices that are critical enablers for safe use of nuclear energy; by developing real-time, adaptive electric grid cyber-physical systems to increase grid reliability, resilience, safety, and security; and by developing resilient city and community resources, systems, and services to effectively respond to and manage disasters and environmental hazards.
- **Health and healthcare** by improving FDA guidance and policy through research on means to assess and manage medical device safety (e.g., cardiac devices) and discovered medical device vulnerabilities; by developing such health- and healthcare-centered cyber-physical systems as

interactive in-home rehabilitation systems and adaptive, aging-in-place assistance systems; and by enabling sensor development, data capture, and analytics to explore regional health challenges and factors that exacerbate community health risks (i.e., traffic congestion vis à vis asthma).

- **National security and defense** by enabling more robust, reliable, and versatile critical infrastructure and defense systems; by developing autonomous vehicles and unmanned aerial vehicles that implement state-of-the-art CPS; by enabling assured military systems ranging from unmanned vehicles to weapons systems, satellites, and command-and-control devices; by developing secure, resilient CPS and Internet of Things (IoT) systems (e.g., autonomous vehicles and UAVs) that stand up to malicious attacks; and by reducing risks associated with human error.
- **Open and transparent government** by developing HCSS standards and best practices in collaboration with users; by encouraging open data and open platforms supporting HCSS; by working openly and transparently with stakeholders and innovators in industry, academia, and government; by promoting open data and open platform CPS solutions; by developing open guidelines and best practices for CPS applications; and by using open-source smart city software development kits to enable innovation that enables scaling across jurisdictions and state borders.
- **Quality of life** by ensuring reliability and security of services and systems critical to daily functioning, including resiliency to attack; by enabling more sophisticated infrastructure and services in both public and private spaces; by increasing access by blind pedestrians to wayfinding and navigation systems; by developing truck platooning potential for increasing fuel economy; and by capturing diverse data and establishing cross-domain data platforms to increase efficiency and reduce costs for city and community residents.
- **Science and technology leadership** by refining a research agenda for reliable, robust, safe, secure, stable, and certifiably dependable software and systems; by pursuing a research agenda for autonomous systems that allows humans to effectively use and manage large-scale, complex systems that consist of software interacting with both the cyber and physical worlds; by timely development of formal methods in automation and effective assurance technology; and through close engagement with academic researchers, industry, and city and community stakeholders to address the challenges that cities and communities face—inspiring R&D, piloting solutions, and evaluating outcomes to continue the iterative cycle of innovation.

High Confidence Software and Systems IWG

***NITRD Member Agencies*: DHS, DoD service research organizations (AFRL, ONR), DOE, EPA, HHS, NASA, NIH, NIST, NOAA, NSA, NSF, OSD**

***NITRD Participating Agencies*: DOT, FAA, FDA, FHWA, NRC, USDA/NIFA**

The HCSS IWG focuses on attaining high confidence in system and software engineering and on meeting specific R&D challenges to foster a new multidisciplinary research agenda that will enable the United States to lead in the development of next-generation engineered systems that depend on ubiquitous cyber control and require very high levels of system assurance.

President's FY2018 Request

Strategic Priorities Underlying This Request

HCSS agency investments for FY2018 will focus on key research in the following priority areas:

- **Assurance technology:** Develop a sound scientific and technological basis—including formal methods and a computational framework—for assured design, costing, construction, analysis, evaluation, and implementation of reliable, robust, safe, secure, stable, and certifiably dependable systems, and cost of assurance; design and install resilient energy delivery systems capable of surviving a cyber incident; and support development of appropriate regulations and guidance for assurance of safety and security.

- **High-confidence real-time software and systems:** Pursue innovative design, development, and engineering approaches to ensure the dependability, safety, security, performance, and evolution of software-intensive, dynamic, networked control systems; design predictable, fault-tolerant, distributed software and systems; model heterogeneous distributed systems using unified mathematical frameworks; develop safety assurance tools and techniques to build justifiable confidence in aerospace and national airspace systems; build infrastructure for medical device integration and interoperability, patient modeling and simulation, and adaptive patient-specific algorithms.
- **Secure, dependable Internet of Things:** Develop foundational theory and methods that enable IoT devices and systems to operate securely and dependably in interactions with other systems and humans.
- **HCSS education:** Launch an initiative to integrate HCSS theory and methodology into education and increase understanding of and interest in HCSS through development of new curricula at all levels to foster a new generation of U.S. experts.

Key Programs Supporting This Request

The HCSS agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **High-confidence systems and foundations of assured computing:** Pursue formal methods and tools for modeling, designing, measuring, analyzing, evaluating, and predicting performance, correctness, efficiency, dependability, scalability, safety, security, and usability of complex, real-time, distributed, and mobile software and systems; high-assurance environments from commercial off-the-shelf (COTs) technologies; high-assurance virtualization and measurement; architectures, components, composition, and configuration; engineering, analysis, and testing of software and hardware; architecture, tools, and competence for assurance-certifiable safe systems; cost-effective verification and validation (V&V); verification techniques for separation assurance algorithms; safety cases, standards, and metrics; and quantum information processing. *AFOSR, AFRL, ARO, FDA, NASA, NIH, NIST, NSA, NSF, ONR, OSD*
- **Information assurance requirements:**
  - Develop methods and tools for constructing and analyzing security structures (management architectures and protocols, etc.); assurance technologies for cross-domain creation, editing, and sharing of sensitive information in collaboration environments that span multiple security levels; cryptographic algorithms and engineering; and assured compilation of cryptographic designs and specifications to platforms of interest. *NSA, ONR*
  - Develop effective infrastructure tests for health IT standards, specifications, and certification; cross-enterprise document sharing in electronic health systems; standards and quality measurement systems for smart manufacturing, measurement science, and standards for CPS engineering; and build a testbed to help industry, university, and government collaborators develop an open standards platform to facilitate the simultaneous engineering of the physical and virtual components of manufacturing systems. *HHS, NIH, NIST, NSF*
- **Aviation safety:** Support R&D in transformative V&V methods to rigorously assure the safety of aviation systems, including considerations for all classes of aircraft and anticipated future air traffic management capabilities; and develop and demonstrate innovative technologies in the design of architectures with advanced features, focusing on designing for high confidence, standardization, and certification. *AFRL, DHS, FAA, NASA, OSD*

- **Assurance of Flight-Critical Systems (AFCS):** Provide appropriate airworthiness requirements for unmanned aircraft systems that help enable routine access to the National Airspace System (NAS); enable assurance that new technologies envisioned for the Next Generation Air Transportation System (NextGen) are as safe as, or safer than, the current system; provide a cost-effective basis for assurance and certification of complex civil aviation systems; and develop and analyze formal models of air traffic management systems for safety properties incorporating the effects of uncertainty. *AFRL, DHS, FAA, NASA*

Planning and Coordination Supporting This Request

The following are examples of ongoing HCSS coordination activities for FY2018:

- **High Confidence Networked Systems (HiCoNS) annual meeting at CPS Week**. *AFRL, DHS, NASA, NIST, NSA, NSF*
- **Static Analysis Tools Exposition (SATE):** Annual summit on software security for vendors, users, and academics. *NIST, NSA, NSF in collaboration with DHS*
- **Software Assurance Metrics and Tool Evaluation:** Annual workshop for users and developers to compare efficacy of techniques and tools and to develop vulnerability taxonomies. *DHS, NIST, NSA*
- **Safe and Secure Software and Systems Symposium (S5):** Collaborations among industry, academia, and government to improve airworthiness and assurance certification process of future aerospace flight control systems with incremental and revolutionary technological innovations in safety and security V&V techniques that maintain cost and risk at acceptable levels. *AFRL, NASA, NSA, NSF*
- **Annual HCSS Conference:** Showcase for promising research on improving system confidence. *FAA, NASA, NSA, NSF, ONR, OSD*
- **Software Assurance Forum:** Coordination of software certification initiatives and activities for Systems containing Software (ScS). *DHS, DoD service research organizations*, *NIST, NSA, OSD*
- **Safety of flight-critical systems:** Ongoing workshops and technical discussions. *AFRL, NASA, NSA, NSF*
- **Standards and performance impact metrics** for cybersecurity, safety, and reliability of Supervisory Control and Data Acquisition (SCADA) and Industrial Control Systems (ICS). *NIST, other HCSS agencies*
- **Biomedical imagery:** Technical standards for change measurements in patient applications. *FDA, NIH, NIST*
- **Cooperative proposal evaluation.** *AFRL, FAA, FDA, NASA, NIST, NRC, NSA, NSF, OSD*
- **FAA National Systems, Software, and Airborne Electronic Hardware Conference** addressing standardization issues. *FAA, NASA, OSD*
- **NASA Formal Methods Symposium.** Annual forum to foster collaboration between theoreticians and practitioners from agencies, academia, and industry to identify challenges and provide solutions for achieving assurance in mission-critical systems. *AFRL, FAA, FDA, NASA, NIST, NSF, NSA, OSD*

Cyber-Physical Systems IWG

***NITRD Member Agencies*: DHS, DoD service research organizations (AFRL), EPA, NASA, NIH, NIST, NSA, NSF, OSD**

***NITRD Participating Agencies*: DOT, FAA, FDA, FHWA, NIH/NIBIB, USDA/NIFA**

The purpose of the CPS IWG is for senior leadership to coordinate programs, budgets, and policy recommendations for cyber-physical systems R&D as well as the related areas of Smart Cities and the Internet of Things that fall under the broader umbrella of smart, networked sociotechnical systems. This coordination encompasses identifying and integrating current and emerging requirements, conducting joint program planning including identifying potential cross-agency transition opportunities, coordinating major outreach activities, developing joint strategies for the CPS R&D programs conducted by NITRD members, and enabling existing CPS activities to share data, models, testbeds, and software tools among NITRD agencies and stakeholders.

President's FY2018 Request

Strategic Priorities Underlying This Request

The CPS IWG aims to identify R&D gaps in the areas described above by cataloguing major existing R&D activities across the Federal Government. The IWG is coordinating investment and conducting joint program planning, including identifying potential cross-agency transition opportunities and public-private partnerships. The IWG is focusing on the R&D gaps that require close collaborations among industry, university, and government contributors, and address the difficult crosscutting R&D challenges. As a result of this integrated approach, a nationwide CPS research community is facing challenges common across such economic sectors as agriculture, energy, manufacturing, medicine and healthcare, and transportation, and across such agency missions as environmental protection, national security, and space exploration.

CPS agency investments for FY2018 will focus on key research in the following priority areas:

- **Interagency coordination on research and development**: Explore opportunities for developing interagency CPS R&D and research infrastructure, including testbeds and experimental platforms, to enable leading-edge research, development, and deployment in cyber-physical systems.
- **Science and technology for building cyber-physical systems:** Develop a new systems science providing unified foundations, models and tools, system capabilities, standards for interoperability, and architectures that enable innovation in highly dependable cyber-enabled engineered and natural systems; and develop public-domain, cyber-physical testbeds.
- **Management of complex and autonomous systems:** Develop measurement and understanding for improved models of complex systems of systems, shared control and authority, levels of autonomy, human-system interactions, and integrated analytical and decision-support tools; and integrate computer- and information-centric physical and engineered systems.
- **Translation into mission-oriented research:** Leverage multiagency research to move theory into practice, using challenges and competitions, for example, to solve problems in domains such as energy, cyber-physical ground and air transportation systems, and infrastructure systems. Additionally, leverage engagement with industry to emphasize translation of mature research innovations into commercially viable products and services.
- **CPS education:** Launch an initiative to integrate CPS theory and methodology into education and increase understanding of and interest in CPS through development of new curricula at all levels that engage both the physical and cyber disciplines and foster a new generation of U.S. experts.

Key Programs Supporting This Request

The CPS agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **Cyber-physical systems:** Explore the fundamental scientific, engineering, and technological principles that underpin the integration of cyber and physical elements; develop safety models and designs for cyber-physical medical systems, including interoperable, "plug-and-play" medical devices; and develop open CPS testbed platforms. *DoD service research organizations, FDA, NASA, NIH, NIST, NSA, NSF, OSD, VA*

- **Complex systems:** Investigate, via a multiyear effort—including a focus on tomorrow's complex systems such as CPS—challenges of interacting systems of systems, including human-system interactions, and research emergent phenomena to better predict system capabilities and decision making about complex systems; develop new algorithms for functional analysis of real-time software to control effects of multicore memory access on CPS real-time behavior and for flexible and predictable control of multiple, semi-autonomous unmanned aerial vehicles; and demonstrate technology for flexible mission reprogramming, increased endurance, and increased autonomy. *AFRL, FAA, FHWA, NASA, NIH, NIST, NSA, NSF, OSD*

Planning and Coordination Supporting This Request

The following are examples of ongoing CPS coordination activities:

- **CPS R&D:** CPS IWG forum for sharing research results from NSF's multi-agency CPS program and identifying future opportunities for interagency collaboration. *DOT, DHS, NASA, NIH, NIST, NSA, NSF, and USDA.*
- **Global Cities Teams Challenge (GCTC):** Collaborative platform to promote replicable, scalable and sustainable models for incubation and deployment of interoperable, standards-based IoT solutions and demonstrate their measurable benefits in smart cities and communities across the Nation and around the world; this coordination is enabled in part through the Smart Cities and Communities Task Force, as described below. *NIST, NSF*
- **Smart and Autonomous Systems:** Workshops to promote fundamental research into Intelligent Physical Systems (IPS) that are cognizant, taskable, reflective, ethical, and knowledge-rich. *NSF with other CPS agencies*
- **Scholar-In-Residence programs**. *FDA, NSF*

Smart Cities and Communities Task Force

***NITRD Member Agencies*: AFRL, DHS, DOE, EPA, NASA, NIH, NIST, NSA, NSF, OSD, OSTP**

***NITRD Participating Agencies*: CDC, Census, DOC (ITA, NTIA), DOE/EERE, DOE, DOS, DOT, FAA, FDA, FHWA, HUD, NIH/NIBIB**

The SCC Task Force is a body under the CPS IWG; it was formed to coordinate Federal action and partnerships among industry, academia, and other government entities to ensure that communities in all settings and at all scales have access to advanced CPS/IoT technologies and services. The objectives of these technologies and services are to advance societal benefits, especially to enhance quality and sustainability of life, improve health and safety, and further the Nation's economic prosperity.

President's FY2018 Request

Strategic Priorities Underlying This Request

- **Provide an ongoing forum for interagency coordination**: Facilitate agencies' identification of shared interests and synergistic opportunities; facilitate coordination and collaboration through joint funding opportunities; and coordinate multi-agency workshops and other meetings that bring together stakeholders to understand challenges, enable solutions, identify best practices, and grow and nurture the multifaceted research community.
- **Launch and execute a strategic plan and actionable roadmap in Smart Cities and Communities:** Involve agencies both within NITRD and outside of NITRD with interests in the goals of smart cities and communities.

- **Regularly update the online resource of Federal Smart Cities and Communities Programs,** available on the NITRD website https://www.nitrd.gov/apps/smartcity/.

Key Programs Supporting This Request

- **Smart and Connected Communities (S&CC) R&D:** Support interdisciplinary research into the development and integration of smart and connected communities, and their underlying technologies such as sensor networks, data analytics, and control and automation, in order to enhance individuals' quality of life, improve health and safety, and create economic prosperity. *FDA, NASA, NIH, NIST, NSA, NSF, OSD, VA*
- **Global Cities Teams Challenge:** Establish a collaborative platform to promote replicable, scalable, and sustainable models for incubation and deployment of interoperable, standards-based IoT solutions, and demonstrate their measurable benefits in smart cities and communities across the Nation and around the world. *DHS, DOC/ITA, DOS, DOT, NIST, NSF, NTIA*
- **Internet of Things-Enabled Smart City Framework working group**: Analyze existing smart city and community architectures and deployments to identify points of technology convergence—pivotal points of interoperability—as foundations for interoperability for cost-efficient, robust, and replicable smart city solutions. *NIST*

Planning and Coordination Supporting This Request

- **Building R&D capacity:** Multiple workshops with agency partners across the country that explore efforts to build upon NSF's S&CC program. *CDC, Census, DOC (ITA, NTIA), DOE/EERE, DOE, DOS, DOT, FAA, FDA, FHWA, HUD, NIH/NIBIB, NSF, USDA/NIFA*
- **Coordination of Global Cities Teams Challenge:** Multiagency support, including NSF funding GCTC researchers to advance the deployment of IoT within cities and communities, NSF participation in GCTC action cluster meetings across the country, and NIST facilitation and convening activities for the action clusters. *DOC/ITA, DHS, DOS, DOT, NIST, NSF, NTIA*
- **Agriculture:** Multi-agency workshop promoting CPS advances in agriculture, specifically exploring urban and peri-urban farming. *NSF, USDA/NIFA*
- **Connected vehicle R&D:** Connected vehicle testbeds, connected vehicle pilot deployments, human factors for shared control, and vehicle-to-infrastructure systems. *DOT, FHWA, NIST, NSF*

Cyber Security and Information Assurance (CSIA) PCA

CSIA focuses on research and development to detect, prevent, resist, respond to, and recover from actions that compromise or threaten to compromise the availability, integrity, or confidentiality of computer- and network-based systems. These systems provide the IT foundation in every sector of the economy, including critical infrastructures such as power grids, financial systems, and air-traffic-control networks. These systems also support national defense, homeland security, and other Federal missions. Broad areas of emphasis include Internet and network security; security of information and computer-based systems; approaches to achieving hardware and software security; testing and assessment of computer-based systems security; reconstitution of computer-based systems and data; and resilience against cyber attacks on computer-based systems that monitor, protect, and control critical infrastructure.

The following NITRD groups report their activities under the CSIA PCA:

- Cyber Security and Information Assurance IWG
- Privacy Research and Development IWG

Advancing Societal Benefits

R&D funding reported under the CSIA PCA supports agency missions and the Nation by providing the science, mathematics, engineering, and technology necessary to improve cybersecurity and privacy.

Combined CSIA and Privacy agency investments provide societal benefits in the following key areas:

- **Economic prosperity** by providing a foundation that enables safety and innovation in cyberspace and supports job growth through the development and deployment of new digital products and online services, and by supporting improvements in computing and information analysis to increase efficiencies in sectors such as manufacturing and transportation while minimizing potential risks to privacy.
- **Education and training** by closing the cybersecurity talent gap through education and workforce initiatives spanning K-12, higher education, and job training; and by enabling innovative pedagogy that utilizes data analysis of educational profiles to tailor the content, type, and pace of instruction to the needs and abilities of students while minimizing risks to their privacy.
- **Energy and environment** by developing technologies that can reduce the risk of energy disruptions due to cyber incidents through enabling energy delivery systems capable of surviving an intentional cyber assault with no loss of critical functions.
- **Health and healthcare** by developing secure healthcare technologies and solutions to protect private medical information, and by developing privacy protections for personalized medical treatments and records and for researcher management of population-scale health studies.
- **National security and defense** by developing solutions for defending the Nation's cyber infrastructure and cyber capabilities, including telecommunication and computing systems, cyber-physical systems, and critical national cyber-enabled infrastructure; and by developing solutions that effectively support the needs and responsibilities of law enforcement and national security organizations while also providing privacy protections and minimizing privacy risks.
- **Quality of life** by providing advances in safety, privacy protections, and trustworthiness of digital technologies for use by individuals and commercial and government entities as the technologies are applied to increase efficiencies and provide new solutions in many sectors and industries.
- **Science and technology leadership** by sustaining delivery of secure and cyber-resilient technologies through long-term research in areas such as the science of security, security standards and measurements, and social, behavioral, economic, and ethical aspects of security; by maintaining

and upgrading the cybersecurity research and testing infrastructure; by developing scientific foundations for privacy that enable rigorous analysis of the risks, harms, and potential benefits to privacy and society from data collection, processing, and analysis systems; and by fostering privacy-related multidisciplinary research in such disciplines as computer science, social and behavioral sciences, biomedical science, psychology, economics, law and policy research, and ethics.

Cyber Security and Information Assurance IWG

***NITRD Member Agencies*: DARPA, DHS, DoD service research organizations (AFRL, ARL, CERDEC, ONR), DOE/OE, NIH, NIJ, NIST, NSA, NSF, OSD**

***NITRD Participating Agencies*: DOT, IARPA, NRC, ODNI, Treasury**

The CSIA IWG coordinates NITRD agency research and development to deter, detect, prevent, resist, respond to, and recover from actions that compromise or threaten to compromise the availability, integrity, or confidentiality of computer- and network-based systems.

President's FY2018 Request

Strategic Priorities Underlying This Request

Federal strategic priorities for cybersecurity research are outlined in the 2016 Federal Cybersecurity Research and Development Strategic Plan,[4] a component of the 2016 Cybersecurity National Action Plan.[5] In concert with the strategic plan, CSIA agency investments for FY2018 will focus on key research in the following strategic defensive elements:

- **Deter:** The ability to efficiently discourage malicious cyber activities by measuring and increasing the costs to adversaries who carry out such activities, diminishing their spoils, and increasing risks and uncertainty for potential adversaries.
- **Protect:** The ability of components, systems, users, and critical infrastructure to efficiently resist malicious cyber activities and to ensure confidentiality, integrity, availability, and accountability.
- **Detect:** The ability to efficiently detect, and even anticipate, adversary decisions and activities, given that perfect security is not possible and systems should be assumed to be vulnerable to malicious cyber activities.
- **Adapt:** The ability of defenders, defenses, and infrastructure to dynamically adapt to malicious cyber activities by efficiently reacting to disruption, recovering from damage, maintaining operations while completing restoration, and adjusting to be able to thwart similar future activity.

Key Programs Supporting This Request

The CSIA agencies report the following key programs and activities as highlights of their planned investments for FY2018. Agencies are listed in alphabetical order.

- **AFRL:** *Strategic priorities*: Assure and Empower the Mission, Create Next-Generation Cyber Warriors, Enhance Agility and Resilience, and Invent Foundations of Trust and Assurance. *Key programs*: Agile Resilient Embedded Systems, Cyber Agility, Assured by Design, Mission Awareness for Mission Assurance, Autonomous Defensive Cyber Operations, Automated Cyber Survivability, and Resilient and Ultra-Trusted Multi-Level Security Routing.

[4] *Federal Cybersecurity Research and Development Strategic Plan* (Washington, DC: NSTC and NITRD, February, 2016); https://nitrd.gov/cybersecurity/publications/2016_Federal_Cybersecurity_Research_and_Development_Strategic_Plan.pdf.
[5] "Fact Sheet: Cybersecurity National Action Plan" (press release), (Washington, DC: The White House, Feb. 9, 2016); https://obamawhitehouse.archives.gov/the-press-office/2016/02/09/fact-sheet-cybersecurity-national-action-plan.

- **ARL:** *Strategic areas*: Assure Operations in the Physical, Social and Cyber Domain, and Internet of Battlefield Things. *Key programs*: Threat Intelligence Stylometry; Active Cyber Defense; Intrusion Detection with Machine Learning; Cyber Defense of Supervisory Control and Data Acquisition Networks; and Trust, Decision Making, and Influence in Multi-Genre Networks.
- **DARPA:** *Strategic priorities*: Harden systems against cyber attacks, operate through cyber attacks, and win in the cyber domain. *Key programs*: Enhanced Attribution; Cyber Fault-tolerant Attack Recovery; High-Assurance Cyber Military Systems; SafeWare; Space/Time Analysis for Cybersecurity; Vetting Commodity IT Software and Firmware; Leveraging the Analog Domain for Security; Rapid Attack Detection, Isolation, and Characterization Systems; Transparent Computing; Building Resource Adaptive Software Systems; Edge-Directed Cyber Technologies for Reliable Mission Communication; and Extreme DDoS (distributed denial of service) Defense.
- **DHS:** *Strategic priorities*: Conduct R&D in support of the 2016 Federal Cybersecurity R&D Strategic Plan,[6] 2016 National Privacy Research Strategy,[7] and 2015 National Critical Infrastructure Security and Resilience R&D Plan;[8] lead DHS investment initiative in Silicon Valley focused on connecting startup technologies to DHS operations; support the DHS Secure Cyberspace Integrated Product Team (IPT) process; maintain research infrastructure programs; and continue international engagements. *Key programs*: Next Generation Cyber Infrastructure, Software Assurance, Mobile Security, Cybersecurity for Law Enforcement, Cyber Physical Systems, Network Systems Security, Human Aspects of Cybersecurity, Cyber for Critical Infrastructure, Data Privacy and Identity Management, Research Infrastructure, Cybersecurity Outreach and Transition to Practice.
- **DoD (High Performance Computing Modernization Program, HPCMP):** *Strategic Priorities*: Assure the DoD mission throughout the HPCMP by securing the Defense Research and Engineering Network (DREN) and promoting productive environments for the science and technology, test and evaluation, and acquisition engineering communities. *Key Programs*: HPC Architecture for Cyber Situational Awareness; Cybersecurity Environment for Detection, Analysis, and Reporting; Cybersecurity Enhancement Project; Information Security Continuous Monitoring-Jigsaw; Rapid Audit of Unix.
- **DOE/OE:** *Strategic priorities*: Conduct research in support of the Roadmap to Achieve Energy Delivery Systems Cybersecurity;[9] and research, develop, and demonstrate tools and technologies that can be transitioned to the energy sector to prevent, detect, mitigate, and adapt to survive cyber incidents while sustaining critical functions in energy delivery systems. *Key programs*: Cybersecurity for Energy Delivery Systems (CEDS).
- **NIST:** *Strategic priorities*: Conduct R&D in Internet infrastructure protection, cloud computing security, next-generation Internet, cyber-physical systems, Internet of Things, cybersecurity standards and guidelines, cybersecurity testing and measurement, cryptography research, trustworthy software development, security for high-performance computing, and quantum information science. *Key programs*: Cybersecurity Framework, National Cybersecurity Center of Excellence, Robust Inter-Domain Routing, High-Assurance Domains, National Initiative for

[6] *Federal Cybersecurity Research and Development Strategic Plan* (Washington, DC: NSTC and NITRD, February, 2016); https://nitrd.gov/cybersecurity/publications/2016_Federal_Cybersecurity_Research_and_Development_Strategic_Plan.pdf.
[7] *National Privacy Research Strategy* (Washington, DC: NSTC and NITRD, June 2016); https://nitrd.gov/PUBS/NationalPrivacyResearchStrategy.pdf.
[8] DHS, *National Critical Infrastructure Security and Resilience Research and Development Plan* (Washington, DC: DHS, 2015); https://www.dhs.gov/sites/default/files/publications/National%20CISR%20R%26D%20Plan_Nov%202015.pdf.
[9] Energy Sector Control Systems Working Group, *Roadmap to Achieve Energy Delivery Systems Cybersecurity* (2011); http://energy.gov/sites/prod/files/Energy%20Delivery%20Systems%20Cybersecurity%20Roadmap_finalweb.pdf.

Cybersecurity Education, Identity Management, Privacy Engineering, and NIST special publications on computer security and cybersecurity.

- **NSA:** *Strategic priorities*: Conduct R&D of system behavior, secure systems architecture and analysis, trust mechanisms, assurance concepts integration, and cryptography in systems. *Key programs*: Adaptive and Automated Response, Cyber Deception for Defense, System Behavior Analytics, Software Assurance Workbench, Cryptographic Protocol Shapes Analyzer, Threat Fusion and Effective Response, Automated Vulnerability Discovery and Remediation, Foundations of Security and Privacy, New Mechanisms for Trustworthy Platforms, System Security Organization through Policy, Host Integrity at Runtime and Startup Integration, Secure Capabilities for Ultra-Mobile Platforms, and Lightweight Cryptography.
- **NSF:** *Strategic priorities*: Support an interdisciplinary community of researchers in academia and nonprofits across a wide range of security and privacy topics, and support cybersecurity education. *Key programs*: Secure and Trustworthy Cyberspace Program (NSF's flagship, multidirectorate research program); international collaborations (e.g., U.S.-Israel Binational Science Foundation, Netherlands Organisation for Scientific Research, and Brazil Ministry of Science Technology and Innovation); Transition to Practice; CyberCorps: Scholarship for Service; Advanced Technological Education; and Next Generation of Cyber Stars (GenCyber).
- **ONR:** *Strategic priorities*: Achieve cybersecurity and cyber attack tolerance methods for end-point devices, software executable transformation for better efficiency and reduction of attack surfaces, and autonomic cyber systems capable of adaptation to adverse conditions. *Key programs*: Cyber Attack Resilient Cyber-Physical Systems, Tools for Intrinsic Cyber Security, Crypto Factory—Automated Crypto Algorithm Design, and Learn2Reason.
- **OSD:** *Strategic priorities*: Facilitate integration of cyber science and technology (S&T) across DoD, enhance collaboration among DoD research organizations, and create disruptive innovations to shape the cyber fight to provide for DoD advantage. *Key programs*: Behavioral cyber sciences; self-securing weapons, systems, and networks; precision cyber operations; and mathematical foundations of cyber S&T.

Planning and Coordination Supporting This Request

The following are examples of ongoing CSIA coordination activities for FY2018:

- **Co-funding**
  - National Centers of Academic Excellence in Information Assurance Education. *DHS, NSA*
- **Collaborative research**
  - Cyber-Security Collaborative Research Alliance, and Network Science Collaborative Technology Alliance. *ARL*
  - Cyber Forensics Working Group. *DHS law enforcement components, DoD, FBI, NIST*
  - NSF Partnership with industry on Cyber-Physical Systems Security and Privacy. *NSF*
  - Secure, Trustworthy, Assured and Resilient Semiconductors and Systems. *NSF, Semiconductor Research Corporation (SRC)*
  - SEI Cyber Research. *OSD, Software Engineering Institute*
  - Nanoscale hardware security. *AFOSR, National Nanotechnology Coordination Office, SRC*
  - Cyber physical systems security. *DHS, DOT, FDA, NASA, NIST, NSF*
  - Cyber Resilient Energy Delivery Consortium (CREDC). *DHS, DOE/OE*
  - Cybersecurity Center for Secure, Evolvable Energy Delivery Systems (SEEDS). *DHS, DOE/OE*
  - Science of Security. *NSA*

- **Agency-sponsored conferences and workshops**
  - **DHS:** IT Security Entrepreneur Forum, Innovation Summit, SINET Showcase, Transition to Practice Technology Demonstration Day and Research and Development Showcase and Technical Workshop, and Global Cybersecurity Innovation Summit (GCIS).
  - **NIST:** Cyber-Physical Systems Public Working Group Workshops, Cryptographic Key Management Workshop, Cybersecurity Framework Workshop, Software and Supply Chain Assurance Forum, and International Conferences on Software Security and Reliability.
  - **NSF:** CyberCorps Scholarship for Service Job Fair and PI (Principal Investigator) Meeting, GREPSEC: Underrepresented Groups in Security Research, Workshop on Data Science for Secure and Privacy-Aware Big Data Management and Mining, Workshop on Advancing Ethics for Trustworthy Cyberspace and Data, Workshop on Theory and Science of Obfuscation as a Methodology for Privacy and Security, and National Workshop on Redefining Cyber Forensics.
  - **ODNI:** Computational Cybersecurity in Compromised Environments workshops.
  - **Multiagency conferences and workshops**:
    - Cloud Forums. *DHS, GSA, NIST*
    - Annual IT Security Automation Conference. *DHS, NIST, NSA*
    - Annual National Initiative for Cybersecurity Education Conference and Expo. *DHS, NIST, NSA, NSF, OSD*
    - Small Business Innovation Research (SBIR) Conference. *DHS, NIST, OSD*
    - Mobile Security Forum. *NIST, NSA*
- **Collaborative deployment**
  - Cyber-Physical Systems Global City Teams Challenge. *DHS, NIST*
  - DNS security (domain name system security extensions, or DNSSEC) and routing security. *AFRL*, *DHS*, *NIST*
  - The National Vulnerability Database. *DHS*, *NIST*
  - U.S. Government Configuration Baseline. *NIST*, *NSA*
- **Technical standards**
  - Development, maintenance, and coordination of validation programs for cryptographic standards. *NIST*, *NSA*
  - Participation in Internet Engineering Task Force security groups to develop standard representations for implementations of security-relevant data. *DHS*, *NIST*, *NSA*, *OSD*
  - Smart Grid Interoperability Panel—Smart Grid Cybersecurity Committee. *DOE*/*OE*, *NIST*
- **Testbeds**
  - Defense Technology Experimental Research testbed. *DHS*
  - Incorporation of national-scale cybersecurity situational awareness, regional network isolation, and localized ICS forensics in a power grid R&D testbed. *DARPA, DOE/INL, DOE, private sector organizations (EPRI, NERC, NRECA)*
  - Continued joint development of research testbeds such as Defense Technology Experimental Research Program, Information Marketplace for Policy and Analysis of Cyber-risk & Trust, Distributed Environment for Critical Infrastructure Decision-making Exercises, Army Cyber-Research Analytics Laboratory, Cyber Integrated Modeling and Experimentation Range Army, Mobile Networks Testbed Emulation, and high-performance computing centers. *ARL, ARO, CERDEC, DHS, DoD (HPCMP), DOE/OE, NSF, ONR, Treasury*
- **DoD Cyber Community of Interest (COI)**
  - Oversight and coordination among DoD cyber S&T programs. *DARPA, DoD service research organizations, NSA, OSD*

- **International collaboration**
  - U.S.-Israel Binational Science Foundation joint program; the Netherlands Organization for Scientific Research; and Brazil Ministry of Science Technology and Innovation. *NSF*
  - United Kingdom Network and Information Sciences International Technology Alliance. *U.S. Army*
  - International engagements and co-funding activities with Australia, Canada, Israel, Japan, the Netherlands, New Zealand, Singapore, Sweden, and the United Kingdom. *DHS*
  - The Technical Cooperation Program, Command, Control, Communications, and Information Systems Group: Information assurance and defensive information warfare R&D cooperation among military components of Australia, Canada, New Zealand, the United Kingdom, and the United States. *AFRL, ARL, ARO, CERDEC, NSA, ONR, OSD*
- **Cyber education**
  - Centers of Academic Excellence. *NSA*
  - CyberCorps: Scholarship for Service, Advanced Technological Education. *NSF*
  - National Initiative for Cybersecurity Education. *DHS, NIST, NSA, NSF, ODNI, OSD*
  - Cybersecurity competitions. *DHS*

Privacy Research and Development IWG

***NITRD Member* Agencies: DARPA, DHS, DoD service research organizations, NARA, NIH, NIST, NSA, NSF, OSD**

***NITRD Participating Agencies*: Census, FCC, FTC, NTIA**

The Federal R&D funding for privacy R&D supports agency missions and the Nation by providing the science and technology necessary to provide meaningful protections for personal information and individual privacy.

President's FY2018 Request

Strategic Priorities Underlying This Request

The Privacy R&D IWG was established to coordinate the privacy-related multidisciplinary R&D efforts of NITRD agencies. This R&D is aimed broadly at producing knowledge and technologies that identify and mitigate emerging risks to privacy and that enable individuals, companies, and the government to benefit from technological advancements while minimizing their potential negative societal impacts.

In June 2016, NSTC released the *National Privacy Research Strategy* (NPRS) detailing priorities for privacy research.[10] In conjunction with the strategy release, the NITRD Program established the Privacy Research and Development Interagency Working Group. Federal funding for privacy R&D is included within the current NITRD PCAs, the majority of it in the CSIA PCA.

Privacy agency investments for FY2018 will focus on key research in the following NPRS priority areas:

- Foster a multidisciplinary approach to privacy research and solutions.
- Understand and measure privacy desires and impacts.
- Develop system design methods that incorporate privacy desires, requirements, and controls.
- Increase transparency of data collection, sharing, use, and retention.
- Assure that information flows and use are consistent with privacy rules.

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[10] *National Privacy Research Strategy* (Washington, DC: NSTC and NITRD, June 2016); https://www.nitrd.gov/PUBS/NationalPrivacyResearchStrategy.pdf.

- Develop approaches for remediation and recovery.
- Reduce privacy risks of analytical algorithms.

Key Programs Supporting This Request

The Privacy R&D agencies report the following key programs and activities as highlights of their planned investments for FY2018. Agencies are listed in alphabetical order.

- **DARPA:** Develop solutions for building systems in which private data can only be used for the intended purpose and no other.
- **DHS:** Data Privacy R&D Program: Address privacy concerns with mobile computing, sensor platforms, and big data and algorithms; and support the development of solutions for privacy-respecting anomaly detection and counter-fraud technologies.
- **DoD service research organizations:** Address the control, management, access restriction, and use of individuals' personal information and identity verification; and develop mechanisms and policies to enhance protection of private information in collaborative environments.
- **NIH:** Protect genetic privacy and identity and improve privacy-preserving technologies for medical research and healthcare.
- **NIST:** (1) Privacy Engineering Program: Develop standards-based tools and practices to understand and mitigate privacy risks and integrate privacy controls into information systems; (2) Trusted Identities Program: Support the development of technologies for secure, efficient, easy-to-use, and interoperable identity solutions for users to access online services in a manner that promotes confidence, privacy, choice, and innovation.
- **NSA:** Develop practical approaches to implementing privacy protections in big data analytics systems.
- **NSF:** Support an interdisciplinary community of researchers in academia and nonprofits across a wide range of privacy topics, such as privacy policy formulation, specification, enforcement, and analysis; algorithmic foundations for privacy and tools; economics of privacy; usability aspects of privacy; and privacy-preserving solutions for data integration, mining, querying, and cloud computing.

Planning and Coordination Supporting This Request

The following are examples of ongoing Privacy R&D coordination activities for FY2018:

- **Workshops**
  - Privacy Controls Workshop. *DOT, NIST*
  - Secure and Trustworthy Cyberspace (SaTC) Workshop on Privacy and Security. *NSF*
  - Workshop on Testing Effectiveness of Consumer Disclosures; PrivacyCon; Spring Privacy Series: Mobile Device Tracking, Alternative Scoring Products, Consumer Generated and Controlled Health Data; Fall Technology Series: Ransomware, Drones, and Smart TV. *FTC*
- **Technical standards**
  - Development, maintenance, and coordination of recommendations and standards for privacy-preserving technologies. *NIST*
- **International collaborations**
  - NSF and the Netherlands Organisation for Scientific Research.
  - DHS international engagements and co-funding activities in security and privacy with Australia, Canada, Israel, Japan, the Netherlands, New Zealand, Singapore, Sweden, and the United Kingdom.

Education and Workforce (EdW) PCA

The EdW PCA addresses education and workforce challenges, from the individual to societal levels, through advances and novel application of networking and information technology. This PCA includes the broad range of information, communication, and related technologies that can be used to support and advance learning, teaching, standards, and assessment, including identifying gaps and approaches for enhancing preparation of next-generation IT professionals, along with associated evaluation activities. EdW activities are not coordinated by a NITRD-supported interagency working group at this time. The agencies that report budgets for this PCA are as follows:

NITRD Member Agencies**: DoD, DoD service research organizations, DOE, NASA, NIH, NIST, NNSA, NSF**

Advancing Societal Benefits

The U.S. economy and society critically depend on a healthy educational pipeline of students knowledgeable in science, technology, engineering, and mathematics (STEM) subjects. To satisfy increasing workforce demands, EdW R&D is critical to creating new educational opportunities at all levels to energize and enrich the quality of next-generation IT professionals. EdW R&D also includes providing new retraining and reskilling on-ramps to boost the technical capabilities of the current workforce and to secure new societal opportunities born out of robust IT workforce capabilities and innovative IT solutions to issues of national importance.

EdW agency investments provide societal benefits in the following key areas:

- **Economic prosperity** by preparing a well-educated IT workforce that garners good salaries and bolsters a technically competitive and expanding economy.
- **Education and training** by investing in the growth of a STEM workforce with advanced job skills through (1) designing and improving such new educational paradigms as MOOCs to support broader educational opportunity both within and outside of classrooms; and (2) working to increase participation by all of the Nation’s students, including underrepresented groups in STEM research, education, and employment, though high school, undergraduate, and post-graduate mentoring and outreach, and through developing evidence-based programs that account for principles of effective learning.
- **Health and healthcare** by supporting better-informed health and healthcare choices and decision making, and by contributing to first-rate R&D that helps solve the Nation’s health challenges.
- **National security and defense** by enabling more high-paying jobs to be filled by Americans rather than through outsourcing, and by facilitating the Nation’s ability to better understand, forecast, and respond to internal and external threats.
- **Open and transparent government** by sharing evidence-based teaching and training methods and best practices for new communications and community outreach models that work.
- **Quality of life** by producing higher incomes and increasing standards of living.
- **Science and technology leadership** by fulfilling workforce demands and enriching the high-quality employment pipeline by providing a technically competent workforce to advance science and technology.

President’s FY2018 Request

Strategic Priorities Underlying This Request

EdW R&D efforts advance the ability to create, sustain, and support the necessary IT workforce pipeline and development of cyber aware citizens, and thus to extend the benefits of robust IT systems throughout the Nation’s interrelated social, economic, innovation, and governance structures.

EdW agency investments for FY2018 will focus on key research in the following priority areas:

- **Create new educational opportunities in IT at all levels**, beginning with K-12, to grow and sustain the pipeline of skilled teachers and workers, advance the skillsets of the current workforce to fill near-term shortages of skilled researchers and technical practitioners, and improve the technical capabilities of the broad range of users of conventional IT tools and methods.
- **Design effective lifelong-learning programs** to help individuals keep up with technological change.
- **Coordinate and collaborate** among Federal agencies and the business and educational communities in developing educational programs, tools, and technologies that enable, maintain, and support a persistent and robust education ecosystem.
- **Measurable success** will include the target goals of numbers of teachers and workers skilled in IT across the Nation.

Key Programs Supporting This Request

The EdW agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **K–12 computer science (CS) education knowledge:** Continue efforts to build on the knowledge base through support for researcher-practitioner partnerships. *NSF*
- **CS undergraduate education:** Work with colleges and universities to explore novel approaches for CS undergraduate education programs that are responsive to both the large influx of students and the increased multidisciplinary interests of many of those students. *NSF*
- **National Initiative for Cybersecurity Education (NICE):** Promote cybersecurity awareness, education, training, and workforce development. *NIST*
- **Building Infrastructure Leading to Diversity (BUILD):** Focus on providing training awards designed to learn how to attract biomedical researchers, including students from diverse backgrounds, into the biomedical research workforce and encourage their persistence in this career field. *NIH*
- **National Research and Mentoring Network (NMRN):** Establish an interconnected, nationwide set of skilled mentors linked to mentees to address the need for increased access to high-quality research mentorship and networking opportunities, including developing mentoring best practices, providing training for mentors, and providing professional opportunities for mentees. *NIH*

Planning and Coordination Supporting This Request

The following are examples of ongoing EdW coordination activities for FY2018:

- **CS For All:** Computer Science education for all. *NSF, agencies participating in the NSTC Federal Coordination in STEM Education (FC-STEM) Interagency Working Group*
- **DoD STEM Strategy:** Strategy focused on developing and retaining a diverse STEM-proficient workforce and network to drive naval S&T innovation, including driving the highest standards of scientific discovery. *DoD, ONR*
- **NICE** *(see above)***:** Partnership between government, academia, and the private sector (including industry partners) that builds on existing successful programs, facilitates change and innovation, and brings leadership and vision to increase the number of skilled cybersecurity professionals helping to keep the Nation secure. *NIST*

Enabling R&D for High-Capability Computing Systems (EHCS) PCA

EHCS focuses on research and development that enables advancements in high-capability computing systems (HCS). This R&D spans programs in hardware, software, architecture, system performance, computational algorithms, data analytics, development tools, and software methods for extreme data- and compute-intensive workloads, as well as in fundamentally new approaches to high-capability computing systems.

The NITRD High End Computing (HEC) IWG reports relevant activities under the EHCS PCA.

Advancing Societal Benefits

HEC agency investments in the EHCS PCA provide societal benefits in the following key areas:

- **Economic prosperity** by researching promising computing technologies that may define the next computing revolution and lay the foundation for extending the U.S. global computing advantage by developing more capable, energy-efficient HCS, HCS ecosystems, and tools that enable design, modeling, simulation, and analysis that accelerate R&D, shorten time to market, improve quality, accelerate scientific discovery, and fuel breakthrough innovations that drive economic growth and competitiveness.
- **Education and training** by funding and mentoring young scientists and engineers in the research community who will be an asset to the Nation and continue advancing the field of high-capability computing systems.
- **Health and healthcare** by developing more capable HCS, computational methods, and novel approaches to analyzing the deluge of healthcare-related data, which enables deeper insights into the workings of human biology and pushes the frontiers of predictive oncology, opening up new possibilities to finding cures for human maladies.
- **National security and defense** by providing computing systems with significantly increased capability, and by developing breakthrough HCS technologies, computational platforms, analytics, and tools that enable capabilities to address demanding DoD and national security issues.
- **Quality of life** by developing software methods, tools, analytics, and systems for extreme data and compute-intensive workloads on HCS to solve challenges at the nexus of food, energy, and water systems.
- **Science and technology leadership** by advancing the field of HCS with rapidly increasing performance, new computing technologies, and development of algorithms, tools, libraries, workflows, data analysis, and visualization that unlock the potential to tackle scientific and computational challenges on a grander scale than previously possible and that enable scientific discovery and innovative breakthroughs.

High End Computing IWG

***NITRD Member Agencies*: DARPA, DoD, DOE/NNSA, DOE/SC, EPA, NASA, NIH, NIST, NSA, NSF, OSD**

***NITRD Participating Agencies*: IARPA**

High-capability computing systems have become indispensable to government, academia, and industry for enabling and accelerating scientific discoveries and innovative breakthroughs across a diverse range of fields such as advanced manufacturing, biology, energy sciences, meteorology, climatology, astronomy, medicine, physics, and engineering design. The HEC agencies lead the R&D of increasingly capable computing technologies, user environments, applications, computational methods, and fundamentally new HCS approaches that may lay the foundation to extend the U.S. global computing advantage and open up new possibilities for the advancement of HCS. EHCS R&D aims to enable successful development and effective use of future high-capability computing systems and to drive solutions in support of Federal agency mission needs and societal benefits.

President's FY2018 Request

Strategic Priorities Underlying This Request

For decades, HEC agencies have led the development and deployment of increasingly capable computing technologies, user environments, and applications that have impacted the entire high-capability computing industry. However, the HCS community continues to face great challenges in creating effective high-capability computing systems using technologies that are increasingly driven by the consumer marketplace. New high-capability systems will require significant advances in energy efficiency, data transport, concurrency, resiliency, security, and programmability. These challenges must be met to achieve and exploit the orders-of-magnitude increase in HCS capabilities that are needed to solve the increasingly complex and data-intensive problems of science, engineering, manufacturing, and national security. To address the growing complexity and long-term costs of emerging platforms, HCS researchers seek to exploit heterogeneous advanced processor technologies, novel memory and storage technologies, and innovative approaches to software creation, and to provide innovative solutions for energy savings, reliability, and scalability. HCS researchers also are exploring paths forward to future high-capability computing systems after the limits of current semiconductor technology are reached.

To meet these challenges, HEC agency investments for FY2018 will focus on key research in the following priority areas:

- **Extreme-scale computation:** Research new algorithms and methods to support application and system software development and node and system design; prepare today's scientific and data-intensive computing applications to fully exploit the capabilities of exascale systems; develop, test, and evaluate prototype HCS technologies, systems, and software while simultaneously evolving applications to achieve extreme-scale readiness; acquire exploratory and emerging computational platforms; and supplement these with data-intensive architectures.
- **New directions in HCS hardware, software, computer science, and system architectures:** Develop novel scientific frameworks, power-efficient system architectures, heterogeneous and specialized system acceleration, programming environments, measurement science, thermal management, and hardware and software prototypes to take computing performance and communications "beyond Moore's Law" and to advance potential new breakthroughs in biological, quantum, neuromorphic, and superconducting computing.
- **Productivity:** Develop and organize capabilities for scientific research, including computational concepts, methods, and tools for computational science and big data analytics; develop new programming languages for future computing architectures; explore ways to increase the productivity of geographically disperse collaborative teams that develop future HCS applications; and exploit new programming methods that extend and enhance usability and programmability of high-capability computing systems.
- **Broadening impact:** Conduct crosscutting activities by HEC agencies, individually or collectively, that span multiple major priorities and serve to extend the breadth and impact of high-capability computing to meet the Nation's highest science, engineering, national security, and competitiveness priorities, including expanding the workforce for high-capability computing systems.

Key Programs Supporting This Request

The HEC agencies report the following key programs and activities as highlights of their planned EHCS investments for FY2018. Agencies are listed in alphabetical order. **(* denotes an NSCI program/project**)

- **Extreme-scale computation**
  - **DoD High Performance Computing Modernization Program**: Acquire supplemental exploratory/emerging computational platforms including data-intensive supercomputing architectures for DoD applications, and applied research and new tools for next-generation hardware architectures, including design of highly scalable algorithms, multiscale approaches, parallel I/O, and exploitation of emerging accelerator hardware.
  - **DOE/NNSA:** Continue work on the Exascale Computing Project (ECP) PathForward program*****, which includes R&D vendor partnerships on exascale node and system designs and co-design engagements to mitigate negative application performance impacts from advanced architectures via proxy applications, abstraction layers, resilience techniques, and burst buffer technologies.
  - **DOE/SC:** Continue work on the ECP in partnership with DOE/NNSA*, including work on the PathForward program and co-design to make sure that the node and system designs meet the needs of science applications and extensive investment in application readiness. Increased R&D on memory and storage systems.
  - **EPA:** Develop software methods in environmental modeling to address extreme-data and compute-intensive workloads and explore the use of coprocessors for next-generation scientific software modernization.
  - **NASA:** Research and develop solutions to HCS-associated big data challenges such as I/O, real-time feature detections, and statistical analysis; develop SBIR programs in efficient computing, user productivity environments, and ultrascale computing; and research energy-efficient modular HCS.
  - **NIH:** Develop computational algorithms for data analysis at the extreme scale for biomedical simulations.
  - **NSF:** Continue work on the Scalable Parallelism in the Extreme (SPX) program*****. This program supports research addressing the challenges of increasing performance in this modern era of parallel computing, which include areas spanning from services and applications to microarchitecture; developing programmable, scalable, and reusable platforms in the national HPC and scientific cyberinfrastructure ecosystem; increasing the coherence of data analytic computing and modeling and simulation; and pioneering capable extreme-scale computing. Other research programs include the Energy-Efficient Computing: Devices to Architectures (E2CDA) program*****, a research collaboration with the Semiconductor Research Corporation (SRC) to minimize the energy impacts of processing, storing, and moving data within future computing systems while being synergistic with other research activities that address other aspects of this overarching energy-constrained computing performance challenge.
  - **OSD**: Continue investing in the OSD-developed Cyber Hardened Embedded and Exascale Architecture (CHEETAH) chip, a novel advanced computing architecture designed to meet DoD signal and image processing needs with excellent power efficiency to enable many embedded applications. The end-goal of CHEETAH is a cyber-hardened, programmable, and power-efficient (>100B ops/watt) teraflop embedded processor with the ability to simultaneously support communications, sensing, and electronic warfare requirements. Detailed design work in FY2017 has shown these performance levels are within reach with 14 nm Trusted Foundry fabrication. The CHEETAH architecture now supports double, single, and half precision formats, to support key machine learning and artificial intelligence (MLAI) activities. FY2018 investments will focus on completing the detailed design of the CHEETAH processor.
- **New directions in HCS hardware, software, computer science, and system architectures**
  - **DOE/SC:** Investigate quantum and neuromorphic computing, including quantum applications and development of quantum testbeds and machine learning to benefit science applications.

- **IARPA:** Continue the Cryogenic Computing Complexity (C3) program to develop technologies for a computer based on superconducting logic with cryogenic memory. Other research program includes Machine Intelligence from Cortical Networks (MICrONS).
- **NASA:** Exploit alternative architectures such as quantum and neuromorphic computing systems.
- **NIST:** Research neuromorphic computing and quantum information science and engineering, including quantum information theory, quantum computing assessment (techniques and tools to assess the capabilities of candidate technologies), quantum technology demonstration (evaluating feasibility of applications of quantum resources in computing and communications); and continuing research collaboration with a university on how quantum computing can be used to effectively store, transport, and process information. Other research includes characterization of "beyond-CMOS technologies", including 2D heterostructures and superconducting devices.
- **NSA:** Research probabilistic and neuromorphic computing, and explore hybrid memory cube technology and innovative solutions that meet the HCS challenges of tomorrow for energy, productivity, and resilience.
- **NSF:** Continue to support the Scalable Parallelism in the Extreme (SPX) program*****, which includes research toward architecture and software approaches that drive performance improvements in the post-Moore's-Law era. Other programs include the Transdisciplinary Research In Principles Of Data Science (TRIPODS) program, which aims to bring together the statistics, mathematics, and theoretical computer science communities to develop the theoretical foundations of data science through integrated research and training activities.

- **Productivity**
  - **NIST:** Provide leadership and guidance for cloud computing paradigms to catalyze their use within industry and government; and develop interoperability, portability, and security standards for cloud computing.
  - **NSF:** Support the Computer Assisted Programming for Heterogeneous Architectures (CAPA) program*****, in partnership with industry, to develop partially or fully automated software to address programmer effectiveness, performance portability, and performance predictability.
- **Broadening impact**
  - **DARPA:** Research lifelong learning algorithms and systems that can modify their architectures and functions in response to dynamic changes in inputs and goals.
  - **DoD (HPCMP):** Develop the next-generation computational workforce within DoD through the HPC Internship Program and the User Productivity Enhancement, Technology Transfer and Training (PETTT) Program.
  - **DOE/SC:** Develop the next-generation of computational scientists through the Computational Science Graduate Fellowship.
  - **EPA:** Increase the HCS user base by educating EPA scientists on the availability and use of HCS.
  - **NASA:** Build the next generation of the HCS development and application workforce through internship and fellowship programs.

Planning and Coordination Supporting This Request

Coordination among the HEC IWG agencies in support of EHCS focuses on computer science advancements to improve the performance and efficiency of the current generation of HCS hardware and software as well as on avenues of fundamental research to create revolutionary new architectures and systems. The complexity of high-capability hardware architectures, systems software, and supporting technologies is such that Federal program managers and researchers depend on having a constant flow of information among colleagues and technical experts to keep current with developments, gain new knowledge, and share best practices and lessons learned.

In addition to the joint technical and planning workshops and the proposal and technical reviews that HEC IWG agencies routinely conduct, the following are examples of ongoing HEC coordination activities for FY2018 under each of the EHCS strategic priorities:

- **Extreme-scale computation**
  - **Computing MOU.** *DoD, DOE/NNSA, DOE/SC*
  - **Extreme-scale R&D technologies, and Modeling and Simulation Working Group**. *HEC IWG agencies*
  - **Big Data:** Exploration of synergies and convergences between HCS and the big data (BD) realm to ensure that HCS capabilities support the many emerging data-intensive applications and domains. *HEC IWG agencies, Big Data IWG agencies*
  - **Broad applicability and use of capable exascale computing:** Continued collaboration among multiple Federal agencies for broad use and applicability of exascale computing. *HEC IWG agencies, other agencies*
- **New directions in HCS hardware, software, computer science, and system architectures**
  - **Quantum information theory and science:** Study of information, communication, and computation based on devices governed by the principles of quantum physics. *DOE/SC, IARPA, NASA, NIST, NSA, NSF*
  - **Cloud-based HCS:** Exploration of supercomputing in the cloud through public and private service providers to determine applicability and efficiencies for a subset of Federal HCS needs. *DOE/SC, NASA, NIH, NSF*
  - **Memory and machine learning program**. *DOE/SC, IARPA, NSA*
  - **Other "beyond-Moore's Law" computing technologies research**. *DOE/SC, NIST, NSA, NSF*
- **Productivity**
  - **Benchmarking and performance modeling:** Collaborations on developing performance measurement test cases with applications commonly used by the Federal HCS community for use in system procurements and evaluation of Federal HCS system productivity. *DoD (HPCMP), DOE/NNSA, DOE/SC, NASA, NSA, NSF*
  - **HCS metrics:** Coordination on developing effective metrics for application development and execution on high-capability computing systems. *DoD, DOE/NNSA, NASA, NSA, NSF*
- **Broadening impact**
  - **HCS hardware and software:** Facilitation of access to and sharing of knowledge gained and lessons learned from HCS hardware and software development efforts. *DoD, DOE/NNSA, DOE/SC, NASA, NIST, NOAA, NSF*
  - **HCS tools:** Coordination of R&D of operating and runtime systems, development environments, productivity tools, languages, compilers, and libraries. *DOD (HPCMP), DOE/NNSA, DOE/SC, NASA, NSA, NSF*
  - **Support for the NSCI** [11]
    - Participation in the cross-agency steering group and support for ongoing interagency implementation of the NSCI. *HEC IWG agencies, other agencies*
    - Increasing the applicability of exascale computing for science applications by exploring how the next generation of computing architectures will interface with NIH biomedical research through DOE's co-design efforts. *DOE, NIH*

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[11] The NITRD NCO helps to coordinate agency efforts in support of the NSCI. Appendix B reviews the FY2016 accomplishments of this national initiative.

High-Capability Computing Infrastructure and Applications (HCIA) PCA

HCIA focuses on large-scale, shared information technology infrastructure that supports or enables high-capability computing R&D, including computation- and data-intensive systems and applications, and associated software, communications, storage, and data management infrastructure.

The NITRD High End Computing (HEC) IWG reports relevant activities under the HCIA PCA.

Advancing Societal Benefits

HEC agency investments in the HCIA PCA provide societal benefits in the following key areas:

- **Economic prosperity** by providing HCIA resources including application and system expertise, and by developing scientific and engineering algorithms and application software and tools, for various disciplines to spur technological and business innovations and to accelerate development of new technologies, products, services, and job creation vital to U.S. economic competitiveness and growth.
- **Education and training** by developing the current and next-generation HCIA workforce through internships, fellowships, and other programs that include education and outreach, like the Extreme Science and Engineering Discovery Environment's (XSEDE's) Training, Education and Outreach Services.
- **Health and healthcare** by supporting scientific computing efforts such as biomolecular, physiological, and multiscale modeling that use HCIA resources and investments in computational science that allow for harnessing data and technology to drive advances in precision medicine and all areas of disease research.
- **National security and defense** by applying advanced HCIA modeling techniques to investigate various simulations and/or interactions in support of DoD priorities such as simulation and analysis of hypersonic vehicles; new energetic and armor protection materials; RF (radio frequency) antenna design analysis for next-generation radar for aircraft, ships, and ground-based platforms; and nuclear stockpile stewardship.
- **Quality of life** by providing HCS resources, including supporting infrastructure and expertise, and by developing applications and tools that contribute to improving the daily lives of Americans.
- **Science and technology leadership** through HCIA investments that support basic and applied R&D programs in energy, medicine, biotechnology, high-energy physics, and advanced scientific computing that are vital to continued U.S. leadership in science and technology.

High End Computing IWG

***NITRD Member Agencies*: DoD, DOE/SC, EPA, NASA, NIH, NIST, NOAA, NSA, NSF**

The Federal R&D funding reported under the HCIA PCA supports agency missions and the Nation by providing high-capability computing system (HCS) platforms and associated application software, communications, storage, data management, application and system expertise, and infrastructure to a diverse array of initiatives that advance U.S. scientific capabilities such as cybersecurity, the human brain, big data, climate, nanotechnology, advanced materials, advanced manufacturing, and precision medicine. These investments enable researchers in academia, industry, federally funded research and development centers, and other institutions to model and simulate highly complex processes and to analyze extreme-scale data over a broad range of disciplines—including aerospace, astronomy, biology, biomedical science, chemistry, ecological computation, energy and environmental sciences, finance, geodynamics, materials science, measurement science, meteorology, nanoscale science and technology, and physics—to make breakthrough scientific and technological discoveries and innovations.

President's FY2018 Request

Strategic Priorities Underlying this Request

Federal investments in high-capability computing facilities and infrastructure, advanced applications, and next-generation computing technologies and systems provide the means for industry, academia, and Federal laboratories to develop and apply pioneering computational capabilities in support of diverse science, engineering, and national security missions. These investments also provide the flexibility and expertise to meet new challenges and national priorities as they emerge.

HEC agency investments in HCIA for FY2018 will focus on key research in the following priority areas:

- **Leadership-class and production high-capability computing systems:** Provide increasingly capable HCS with the capacities needed to meet critical agency mission needs and support the science and engineering research communities across the United States; ensure that emerging computer technologies support industrial, national security, and scientific applications; and reduce the energy requirements and environmental impact of computing technology at all scales.
- **Advancement of high-capability computing applications:** Support the computational requirements of various disciplines by developing scientific and engineering algorithms and applications software and tools for current and next-generation HCS platforms; develop mission-responsive computational environments; and lead critical applied research in algorithms and software for emerging architectures in order to preserve the performance of existing codes.
- **High-capability computing infrastructure:** Provide user communities across a wide variety of skills and backgrounds with efficient, effective, and dependable access to HCS facilities and resources, including testbeds, communications, storage, software tools, and applications and system support; and enhance existing infrastructure capabilities for computational and data-enabled science, modeling, simulation, and analysis.
- **Productivity:** Share lessons learned and best practices for acquisition and enhancement of HCS resources in a cost-effective and energy-efficient manner; reduce total ownership costs of high-capability computing systems; integrate resources for improved productivity among all users; increase science and engineering throughputs at HCS centers; design and develop requirements for energy efficiency in HCS centers and integrate these into acquisitions requirements; and design and develop collaborative work environments for high-capability simulation and data analytics through high-speed networks and advanced data storage and management.
- **Broadening impact:** Conduct crosscutting activities by HEC agencies, individually or collectively, that span multiple major priorities and serve to extend the breadth and impact of high-capability computing to meet the Nation's highest science, engineering, national security, and competitiveness priorities, including expanding the HPC workforce.

Key Programs Supporting This Request

The HEC agencies report the following key programs and activities as highlights of their planned HCIA investments for FY2018 under each of the main HEC priorities. Agencies are listed in alphabetical order. (*** denotes an NSCI program/project**)

- **Leadership-class and production high-capability computing systems**
  - **DoD (HPCMP):** Provide large-capacity and high-capability HPC systems to the DoD science and technology, test and evaluation, and acquisition engineering communities; and provide shared above-secret capabilities to address critical DoD mission requirements.

- **DOE/SC:** Provide large-capacity HPC systems to the Office of Science at the NERSC; provide large capability leadership class systems to the open research community at DOE's Argonne and Oak Ridge Leadership Computing Facilities.
- **EPA:** Provide data-intensive systems for mission-related research.
- **NASA:** Grow high-capability computing capacity using modular computing technology.
- **NIH:** Support broad-based HCIA for biomedical computing applications by extending and modernizing HCS facilities and networking on the NIH campus to serve the intramural community and core facilities for bioinformatics, biostatistics, and computational biology, and provide support for high-capacity computing systems to the extramural research community through research resource programs.
- **NOAA:** Provide computational systems to support improved predictive services for weather and climate through continued operation of the Gaea 1102 Teraflops (TF) Climate Computing HPC at DOE's Oak Ridge National Laboratory and the Jet 340 TF Hurricane Forecast Improvement Project; support allocations on DOE/SC's Titan HPC (roughly equivalent to 500 TF) and Theia 1000 TF Sandy Supplemental HPC; expand Theia with another 1000 TF of fine-grained computing; and execute an interagency agreement to transfer ownership of Zeus (383 TF) to the FBI.
- **NSF:** Provide a diverse set of high-performance computational resources in support of science and engineering discovery, including the acquisition and deployment of a new leadership-class HPC system that will succeed the NSF-funded Blue Waters supercomputer, together with additional investments in the HPC ecosystem to support continued U.S. leadership in science and engineering. NSF's investments will be in alignment with the recommendations of the recent National Academies of Sciences, Engineering, and Medicine study, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering 2017-2021*.[12]

- **Advancement of high-capability computing applications**
  - **DoD (HPCMP):** Provide multiphysics applications development for the acquisition engineering community for air vehicles, ground vehicles, ships, and RF antennas through programs such as Computational Research and Engineering Acquisition Tools and Environments (CREATE); and continue support for the Frontier Projects for accurate physics-based modeling and simulation to support DoD's highest-priority, highest-impact computational work.
  - **DOE/SC:** Refactor scientific applications to support effective use of the exascale system architectures and enhancing capabilities for data-intensive science.
  - **EPA:** Develop the analytics and computational science required for mission-related research with applicability to programs in air quality, water quality, and their interactions with human health; and continue software development of next-generation modeling capabilities to support the goals of the Air, Climate, and Energy (ACE) Research Program.
  - **NASA:** Build capacity in the High-End Computing Capability (HECC) project to support large-scale modeling, simulation, and data analysis across NASA's earth and space science, space exploration, and aeronautics research missions, and in the NASA Center for Climate Simulation project to support weather and climate modeling simulations and earth science big data research at NASA and other partnering institutions.
  - **NIH:** Support multiscale modeling of biomedical processes, from the cellular level to tissue-level to organs and whole systems.
  - **NIST:** Continue work on modeling and simulation and data analytics for metrology, as well as visualization metrology, which includes uncertainty quantification associated with

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[12] National Academies of Sciences, Engineering, and Medicine, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017–2020* (Washington, DC: The National Academies Press, 2016); https://www.nsf.gov/news/news_summ.jsp?cntn_id=138529.

visualization of scientific data and calibration and correction of visualization hardware. Also, continue support for development of modeling and simulation techniques and tools to accelerate materials discovery and deployment; for applications in physics, chemistry, and engineering (e.g., nanostructures, nanofabrication experiments, RF propagation for medical implant communication systems, and texture compression); and for development of fundamental mathematical tools and algorithms for applications such as cybersecurity, biometrics, computational modeling of suspensions, pattern recognition in images, and micromagnetics modeling.
  - **NOAA:** Prepare most of the NOAA software suite for next-generation architectures.
  - **NSF:** Continue support for the Computational Data-Enabled Science and Engineering (CDS&E) program* that aims to stimulate major scientific and engineering breakthroughs through new computational and data analysis approaches; the Software Infrastructure for Sustained Innovation (SI^2) program* for HCS scientific software development; and the Scientific Software Innovation Institutes (including the Molecular Science Institute and Science Gateways Community Institutes), which will serve as long-term hubs for scientific software development and maintenance.
- **High-capability computing infrastructure**
  - **DoD (HPCMP):** Provide data analysis and visualization, application support, and HPC system expertise to the DoD S&T, test and evaluation, and acquisition engineering communities.
  - **DOE/SC:** Provide HPC and data analysis support to SC, including SC user facilities, and open research community.
  - **EPA:** Provide technology infrastructure to combine existing and future data at various temporal and spatial scales, and provide associated software communications, tools, and data management infrastructure.
  - **NASA:** Recompete and award the NASA Advanced Computing Services service contract.
  - **NIH:** Continue investment in the National Cancer Institute's Cancer Genomics Cloud Pilots; support the new shared, cloud computing environment under the Big Data to Knowledge (BD2K) program called the "Data Commons"; and provide high-capacity infrastructure and computational tools for analysis of high-throughput biomedical data and research.
  - **NOAA:** Continue to develop small experimental systems of various architectures (Xeon Phi, NVidia GPU, etc.), and provide software engineering support and associated tools to re-architect NOAA's applications to run efficiently on next-generation fine-grain HPC architectures through the Software Engineering for Novel Architectures project.
  - **NSA:** Continue to support development of modeling and simulation tools that evaluate computer architectures and systems.
  - **NSF:** Provide infrastructure and data capacity to science application activities through the CDS&E, SI^2, Data Infrastructure Building Blocks (DIBBs), and XSEDE programs, and XD (which includes services and human expertise).
- **Productivity**
  - **NASA:** Invest in system and application performance and analysis tools.
  - **NIST:** Continue support for the Virtual Measurement Laboratory, which provides an immersive visualization environment that allows users to dynamically analyze and interact with quantitative data.
  - **NSF:** Continue support for XD Metric Services, a comprehensive HPC system management tool, to further develop it for open-source and job-level performance monitoring.

- **Broadening impact**
  - **DoD (HPCMP):** Support workforce development through the HPC Internship Program and service academy projects.
  - **DOE/SC:** Continue support for NERSC, ALCF and OLCF, which includes training, hackathons, application readiness and other outreach activities to prepare the scientific community for future system upgrades.
  - **NSF:** Continue support for education, training, and outreach activities to increase the competencies and diversity of the current and next-generation workforce and scientific community.

Planning and Coordination Supporting this Request

The agencies that report investments under the HCIA PCA provide tens of billions of computing hours on the Nation's most powerful computing platforms to enable researchers from academia and industry to address ultracomplex scientific challenges; coordinating this activity remains a major collaborative focus among HEC agencies and other stakeholders. A second major collaborative focus is selecting, evaluating, procuring, and operating Federal high-end platforms—a complex, labor-intensive process that the HEC agencies work together to streamline. A third major collaborative focus is development of sharable computational approaches for investigation and analysis across the sciences.

The following are examples of HEC coordination activities for FY2018 under the HCIA strategic priorities:

- **Leadership-class and production high-capability computing systems**
  - **Leadership-class and production computing:** Coordination to make the highest-capability HCS resources available to the broad research community and industry. *DoD (HPCMP), DOE/SC, NASA, NIST, NOAA, NSF*
- **Advancement of high-capability computing applications**
  - **Multiscale modeling in biomedical, biological, and behavioral systems:** Interagency collaboration to advance modeling of complex living systems. *DoD, NIH, NSF*
  - **XSEDE, Petascale Computing Resource Allocations (PRAC)*:** Provision of 4-5 billion core compute hours to the open science community, spanning research of multiple agencies, with all disciplines represented. *HEC IWG agencies, other agencies*
  - **Computational toxicology:** Integration of HCS technologies with molecular biology to improve methods for risk assessment of chemicals. *DoD, FDA, NIH*
  - **Simulation study of cement hydration**. *NIST, NSF*
  - **Interagency Modeling and Analysis Group:** Focus on multiscale modeling and simulations. *DOE, FDA, NIH, NSF, other agencies*
  - **Joint Initiative on Quantitative Approaches to Biomedical Big Data (QuBBD):** Interdisciplinary and multidisciplinary collaborations. *NIH, NSF*
- **High-capability computing infrastructure**
  - **Remote Sensing Information Gateway (RSIG):** Interfaces that allow users to integrate their selected environmental datasets into a unified visualization. *EPA, NASA, NOAA*
- **Productivity**
  - **System reviews, benchmarking, metrics**. *DoD (HPCMP), DOE/SC, DOE/NNSA, NASA, NOAA, NSA, NSF*
- **Broadening impact**
  - **Interagency participation in proposal review panels, PI meetings**. *HEC IWG agencies*

- **Extending awareness:** Exploration of ways to increase awareness of the importance of U.S. leadership in HCS. *HEC agencies*
- **Explore ways to maximize HCS resources for compute and data allocations**. *HEC IWG agencies*
- **Education/workforce development:** Support for a Federal HCS inventory portal for learning and workforce development resources. *HEC IWG agencies*
- **Metrics:** Exploration of alternatives to the LINPACK benchmark to establish more meaningful measures for performance of U.S. HCS systems. *HEC IWG agencies*
- **Energy-efficient computing:** Promotion of energy-efficient computing practices, and exploring means to dramatically reduce HCS energy consumption and energy costs. *DoD (HPCMP), NASA*
- **Technology transfer:** Transfer of computational skills and technologies to partners in industry and academia. *HEC IWG agencies*
- **NSCI:** Coordination with other agencies on maintaining and enhancing U.S. leadership in HCS. *HEC IWG agencies, other agencies*

Large Scale Data Management and Analysis (LSDMA) PCA

Large-scale data management and analysis includes research to develop the ability to analyze and extract knowledge and insight from large, diverse, and disparate sources of data, including the mechanisms for data capture, curation, management, analysis, and access.

The following NITRD groups report their activities under the LSDMA PCA:

- Big Data IWG
  - Human Computer Interaction and Information Management (HCI&IM) Task Force

Advancing Societal Benefits

Big Data agency investments provide societal benefits in the following key areas:

- **Economic prosperity** by providing access to new and diverse data and data handling techniques, such as Machine Learning, Open Data, and Blockchain technology, that can drive innovative and trustworthy decisions and result in government that is more efficient, and increases in economic activity and services and employment that benefit all levels of society.
- **Education and training** by providing curriculum development and resources for the next generation of data scientists and engineers, such as by sponsoring National Academy of Science workshops to develop undergraduate data science curriculum and by developing programs that allow learners of all ages to gain exposure to methods and tools to manage and analyze Big Data.
- **Energy and environment** by enabling analysis, integration, forecasting, and trend detection based on high-volume real-time observations from observing platforms in space, on land, and in the ocean.
- **Health and healthcare** through various programs such as ENIGMA, a global effort spanning 300 scientists and vast biomedical datasets to work on major human brain diseases by integrating images, genomes, connectomes, and biomarkers on an unprecedented scale with new computation for integration, clustering, and learning from complex biodata types.
- **National security and defense** by overcoming the critical issues of complexity and scalability in diverse data environments and in high-impact areas such as intelligence, software engineering, and command and control, and by improving coordination and transition of big data tools and techniques within the national security community, including the use of social media for effective screening and vetting.
- **Open and transparent government** by developing new policies and techniques for cost-effective public access to Federal agency data and by assisting agencies in managing their electronic records by developing standards and enabling more records to become available online.
- **Quality of life** by creating tools to harness Big Data, including those that process complex mobile sensor data, to support activities such as just-in-time healthcare delivery, improved personal security, and effective emergency response.
- **Science and technology leadership** by developing a vendor-neutral, technology- and infrastructure-agnostic architecture that allows stakeholders to perform analytics for their own data sources; an interoperable and scalable data infrastructure that enables the combining of heterogeneous data sets independent of the data's source and structure; and data science measurements and benchmarking capabilities that improve the reliability and accuracy of data-driven decisions for both Federal and non-Federal stakeholders.

Big Data IWG

***NITRD Member Agencies*: DARPA, DHS, DOE/NNSA, DOE/SC, EPA, HHS/AHRQ, NARA, NASA, NIH, NIST, NOAA, NSA, NSF, OSD**

***NITRD Participating Agencies*: USAID, USGS**

The Big Data IWG aims to identify big data R&D requirements across the Federal Government and to develop a common set of best practices and support structures for data capture, curation, management, and access.

President's FY2018 Request

Strategic Priorities Underlying This Request

The overarching goal of Big Data R&D activities for FY2018 is the development of the foundations, systems, and translational approaches to empower transparent and trustworthy data-driven discovery and decision making—regardless of the infrastructure, the technology, or the data source.

Big Data agency investments for FY2018 will focus on key research in the following priority areas:

- **Data and data analytics:** Require new measurement and benchmarking capabilities to assure trustworthiness and usability while also moving users from correlation-based analysis to causal modeling. Interoperability of diverse data types and sources remains a major hurdle that limits accessibility, transparency, and accountability.
- **Enhancement of visualization tools and manipulation of large data sets:** Increase usability of data for a wide range of users through research into information integration. This includes enhancements to create, share, and incorporate datasets into unified, thoughtful, responsive visualizations for the purpose of analysis at all levels, including researchers, citizen scientists, resource *managers*, and connected communities.
- **Workforce development:** Address the shortage of data science expertise necessary to move these projects forward.
- **Data sharing, privacy, and resiliency:** Address these continuing limiting concerns.

Key Programs Supporting This Request

The Big Data agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **Foundational research:** Find new tools and methodologies to use the massive amount of data and information that is available to solve difficult problems. Two DARPA programs, Big Mechanism and Deep Extraction from Text, strive to go from data to information to a holistic system of information by the machine-reading of thousands of research papers. In FY2017 the NSF launched the TRIPODS program for research on the foundations of Data Science. Phase I of this program (FYs 2017-2019) supports 10-12 projects engaged in convergent research among computer scientists, mathematicians, and statisticians. Phase II is expected to support a few national centers in this topic area. Other programs include efforts to improve Internet search, networks safety, software security, and protection of individual privacy. *DARPA, NSF*
- **Infrastructures and tools that enable interoperability and usability of data:** Develop means to allow users to access diverse data sets that interoperate both within a particular domain and across multiple domains. Developing this access involve building teams, infrastructure components, and governance models (i.e., frameworks and standards) to reconcile data and allow it to "mash up" (mesh) regardless of the data source and structure. The NIH Data Commons and Big Data Spokes program, and the NASA/NOAA/EPA Remote Sensing Information Gateway

(RSIG) are examples of this type of investment. Since 2016, NITRD has been supporting a community activity geared towards the development of an open knowledge network as semantic information infrastructure to enable the next generation of knowledge applications. *DARPA, DHS, NARA, NIH, NIST, NSF*

- **Real-time analytics:** Reduce the time delay between data ingest and analysis and decision making that, while important in all applications, can be absolutely critical in others. For example, DHS is investing in analytical frameworks to address data latency, compromise, and failure in networks that support first responders. *DARPA, DHS, NIH, NIST, NSF*
- **Data governance and testing:** Develop data science measurement and benchmarking capabilities of complex data and data analytics methods to improve data-driven discovery and decision making. Examples are NIST standards and measurements for data science and NARA testbed investigations related to records management across the Federal Government. *DHS, NARA, NIH, NIST, NSF*
- **Operational tools and technologies:** Target effective technology product development and translate advances in applied research into operational tools and technologies. *DHS, NARA, NIH, NIST*
- **Workforce development:** Develop and offer innovative data science research and training opportunities to build workforce capacity, strengthen teams, and rapidly advance science. *NIH, NSF*

Planning and Coordination Supporting This Request

All Big Data member agencies report multiple planning and coordination activities with other Federal agencies, State and local governments, the private sector, nonprofits, and academia. The following are examples of ongoing Big Data coordination activities for FY2018:

- **DARPA:** The Memex project, designed to improve Internet search capabilities, has developed techniques that are being used to uncover human trafficking activities. Memex techniques have resulted in many active investigations and in convictions by the District Attorneys of New York and San Francisco, the New Jersey State Police, and the Houston Police Department. These techniques also have been used in various offices within DoD and other Federal agencies.
- **DHS:** The DHS Big Data research portfolio includes developing screening tools for U.S. Citizenship and Immigration Services and U.S. Customs and Border Protection, and big data analytics for the Federal Emergency Management Agency and U.S. Immigration and Customs Enforcement. Reaching beyond DHS, its Big Data researchers work with NSF on the Big Data Hubs program that builds regional public-private partnerships, with IARPA on various research deliverables, and with private industry research and development partners. Real-time Analytics for Multi-Latency, Multi-party, Metro-scale Networks (RAMMMNets) is a new DHS collaboration with NSF that examines data latency issues in large-scale networks.
- **EPA:** EPA coordinates with NASA and NOAA under the RSIG program on 3D and 2D visualizations with analytics, and novel integration of scientific and environmental data.
- **HCI&IM:** The Human-Computer Interaction and Information Management Task Force was established to support the Big Data IWG's priority for FY2018 of "enhancement of visualization tools and manipulation of large data sets" with a focus on the development of a "science of visualization". This includes the development of a framework or taxonomy of visualization tasks, relevant perceptual and cognitive principles, and measures for evaluating the understandability or effectiveness of visualizations. The HCI&IM Task Force will host the Frontiers of Visualization II Workshop, develop a workshop report, and continue to work closely with the BD IWG on this important area of interest.
- **NARA:** NARA collaborates with NSF on Big Data cyberinfrastructure to provide sustainable access to large Federal data and digital object collections, with the Army Research Lab on scalable auto-

classification and summarization technologies, and with the Naval Sea Systems Command on long-term preservation and reuse of engineering records.

- **NIH:** The NIH, under the BD2K program, will launch a Data Commons Pilot Phase to test ways to store, access, and share findable, accessible, interoperable, and reusable (FAIR) biomedical data and associated tools in the cloud. Coordination with other Federal agencies engaged in similar activities is paramount to the success of this activity.
- **NIST:** The NIST Big Data Public Working Group is a community of interest among multiple industry, academic, and government entities with the goal of developing consensus on important fundamental concepts related to Big Data, such as definitions, taxonomies, secure reference architectures, and a technology roadmap.
- **NSF:** NSF has joint research projects with DHS, NARA, and NIH (as described above) as well as with the Office of Financial Research that supports research related to financial stability. Another example is the NSF and USDA joint project on Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS) designed to address the growing demand for food, water, and energy through the use of big data tools and techniques. NSF's Big Data Regional Innovation Hubs and Spokes program also develops partnerships at the state and local government levels, and also with the Department of Transportation on transportation-related challenges.
- **USGS:** USGS participates with NSF on the Biodiversity Information Serving Our Nation (BISON) project. BISON is a web-based Federal mapping resource for visualization of species occurrence data in the United States and its territories.

Large Scale Networking (LSN) PCA

LSN focuses on coordinating Federal agency networking R&D in leading-edge networking technologies, services, and enhanced performance. This R&D includes programs in fundamental networking research and infrastructure, software defined networks, future Internet architectures, wireless networks, big data networking, testbeds, and end-to-end performance and performance measurement. Program coordination also spans network security and identity management; dynamic interdomain networking; public service networks; the science and engineering of complex networks; network infrastructures for advanced discovery environments; network-enabling technology; networking education, training, and outreach; and cyberinfrastructure for scientific and applications R&D.

The following NITRD groups report their activities under the LSN PCA:

- Large Scale Networking IWG
  - Broadband Research and Development (BRD) Group
  - Joint Engineering Team (JET)
  - Middleware And Grid Interagency Coordination (MAGIC) Team
- Wireless Spectrum Research and Development (WSRD) IWG

Advancing Societal Benefits

Combined LSN and WSRD agency investments provide societal benefits in the following key areas:

- **Economic prosperity** by providing new networking technology as a basis for new and evolving high-wage jobs, multibillion-dollar IT industries, broadband wireless to support U.S. communities, and improved networking infrastructure in support of science objectives and social computing capabilities; and by advancing spectrum awareness and dynamic access programs that enable more intensive usage of current spectral resources.
- **Education and training** by providing education and training for the next generation of networking professionals, users, and teachers.
- **Energy and environment** by providing the spectrum necessary for energy and environmental sensors to transmit accurate and timely data for more efficient energy usage and environmental understanding.
- **Health and healthcare** by developing mobile health technology; precision medicine (informatics, data repository, integration of genomic information with clinical responses); DataScience@NIH (biomedical digital assets access, research, training, data-system ecosystem); the National Center for Biotechnology Information (data, tools, access to resources for genomic and biomedical research); and the Platforms for Advanced Wireless Research (PAWR) program.
- **National security and defense** by developing mobile, dynamic, secure, and reliable wireless broadband for the battlefield and for global-reach missions; by increasing the robustness, security, and reliability of Internet services; by enabling spectrum-maneuverable communications in diverse, congested, and contested environments; and by developing new capabilities for assessing battlefield risks.
- **Quality of life** by providing advances in communications and communications services, broadband wireless for smart cities and communities, healthcare services, crisis response, and infrastructure for social networking; and by enabling increased spectrum availability for wireless broadband that supports innovative applications for first responders, businesses, remote and mobile education and healthcare, social media, and others.

- **Science and technology leadership** by providing user access to big data science instruments; by developing the next generations of networking technology and services; by providing leading-edge networking for university science communities; by providing collaboration facilities and distributed (cloud) resources for science R&D; and by developing network topology and spectrum utilization to overcome congestion and mitigate interference, and venues to promote fundamental research.

Large Scale Networking IWG

***NITRD Member Agencies*: DARPA, DoD service research organizations (AFRL, CERDEC, ONR), DOE/SC, DREN, NASA, NIH, NIJ, NIST, NOAA, NSA, NSF, OSD**

***NITRD Participating Agencies*: FAA, FCC, USDA/ARS, USGS**

The U.S. economy and society critically depend on information technology, applications, and infrastructure for commerce, socioeconomic interactions, and scientific research in addressing national priorities. To provide the continuing capability of networking to support these objectives, the LSN agencies conduct and support R&D of leading-edge networking technology, services, tools, and applications, and they implement networking infrastructure that contributes strongly to U.S national priorities. These contributions include development of new technologies to increase performance, reliability, and security, and to reduce costs of networks.

President's FY2018 Request

Strategic Priorities Underlying This Request

The missions of the LSN agencies, though varied, all require ultra-high-speed communications, ultra-scale data-transfer capabilities, and virtualization and collaboration capabilities with demanding constraints on end-to-end performance, security, reliability, resilience, and availability. The advanced Federal research network infrastructure supports national security and privacy needs, enables the transfer of data from scientific instruments, and transports data among the world's leading science centers and observational systems on the ground, on the sea, in the air, and in space. Each year, the LSN agencies identify a small number of priority areas in which focused research collaboration will promote advances in networking that address these needs, enable Federal agency mission requirements, and benefit all. The big data testbed, for example, identifies architectures and deploys best practices for network transport of big data in support of advanced science applications.

LSN agency investments for FY2018 will focus on key research in the following priority areas:

- **Advanced network technology:** Identify approaches, best practices, and testbed implementations for software defined networking (SDN), software defined infrastructure (SDI), and SDN exchanges (SDXs); tactical communications and emerging network technologies (e.g., dynamic, ad hoc, multihop, secure, robust wireless networks and virtual/data-centric environments); spectrum efficiency, access, awareness, and sharing; low-probability-of-detection and anti-jam networks; identity management; distributed computing, cloud computing, and collaboration capabilities; spectrum management; and protocols, specifications, and tools such as Internet Protocol version 6 (IPv6), DNSSEC, Science DMZ, Trusted Internet Connections (TICs), and the perfSONAR open-source network monitoring toolkit for running network tests across multiple domains.
- **End-to-end big data applications:** Build on big data testbed demonstrations and expand the networking support of big data transfers, extend leading-edge network technology for big data, monitor network performance, and work with application users to improve end-to-end throughput, reliability, and security of big data transfers. Also, provide 100 gigabit-per-second (Gbps) and faster networking to support big data from science instruments.

- **Internet architecture:** Develop future Internet architecture, extreme data networking, cloud networking and services, 100–1000 Gbps networking and testbeds, and grid services supporting science research, collaborative science, and high-performance computing.

Key Programs Supporting This Request

The LSN agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **SDN, SDI, and SDX:** Develop, deploy, and operate dynamic, secure, interdomain, layer 1–3, operational and virtualized networking capabilities. *AFRL, CERDEC, DOE/SC, NASA, NIST, NSA, NSF, ONR*
- **Network architectures and protocols for future networks** (FIA-NP, GENI, NSFFutureCloud, NeTS)**:** Develop and test network architecture concepts to enable reliable, secure, flexible, and dynamic networking capabilities for heterogeneous, smart, self-managed, hybrid, peer-to-peer networks; support sustainable environments; achieve efficient size, weight, and power (SWaP) networking; and pursue virtualization at scale. *AFRL, CERDEC, DOE/SC, DREN, NASA, NIST, NSF, ONR, OSD*
- **Big data networking and infrastructure:** Provide end-to-end architectures, integrated storage, applications, computational resources (e.g., Science DMZ, SATCOM), and testbeds at differing scales (up to terabit-plus); hold big data flow demonstrations annually; couple science big data sources (e.g., light sources, the Large Hadron Collider) with data analytics; promote cooperation and test advanced applications on DOE/SC's 400/1000 Gbps Advanced Networking Initiative (ANI), NSF's Global Environment for Networking Innovations (GENI), international 100+ Gbps infrastructure, and R&D testbeds to demonstrate performance at scale of new architectures (e.g., SDN, wireless); and translate research to end-to-end applications (e.g., US Ignite, GENI, and Smart and Connected Communities [S&CC]). *DOE/SC, DREN, NASA, NIST, NOAA, NSA, NSF*
- **Wireless networking:** Develop technology, standards, testbeds, and tools to enable better interconnectivity; seamless multidomain, mobile network architecture (e.g., PAWR); heterogeneous and layer interoperability; infrastructure for nuclear command, control, and cooperation (C3); secure tactical intranets; electronic warfare and communications coexistence; management for wideband (e.g., SWaP reduction, data fusion, heterogeneous interfaces, spectrum management, efficiency, sensing and sharing, low probability of detection, and anti-jam); robust, secure, resilient, dynamic, mobile, delay-tolerant networking (DTN); Shared Spectrum Access for Radar and Communications (SSPARC); RadioMap; spread-spectrum; long-term evolution (LTE) advanced WiFi and WiMAX; and airborne networks and sensor networks. *AFRL, CERDEC, DARPA, NASA, NIST, NSA, NSF, ONR*
- **Strategic technologies for networking:** Provide basic research, development, and demonstration of new and heterogeneous technologies for robust, secure, reliable, evolvable, optical, photonic, and advanced wireless networking; underwater communications; autonomous dynamic ad hoc routing infrastructure; tactical and directional networking; and medical devices and assistive technologies. *AFRL, CERDEC, DOE/SC, NIH, NIST, NSF, ONR*
- **Advanced discovery environments:** Provide grid and cloud services infrastructure that supports extreme-scale scientific knowledge discovery; provide security, management, and support for multidomain collaborations, cyber-physical systems, data distribution and management, visualization, software stacks for large-scale scientific collaborations, high-bandwidth implementation, standards for smart grid interoperability, and testbeds; and provide support for weather modeling, GovCloud, Open Science Grid (OSG), and XSEDE. *DOE/SC, NASA, NIH, NIST, NOAA, NSF*

- **Computational research infrastructure:** Support high-speed, advanced computer networks optimized for large-scale data flows in order to enable research advances in multiple fields. Examples include Campus Cyberinfrastructure (CC*), International Research Network Connections (IRNC), the Energy Sciences Network (ESnet), N-Wave (NOAA's science network), Science DMZ, Hawaii and Alaska connectivity, and NIH's medical databases. *DOE/SC, DREN, NASA, NIH, NIST, NOAA, NSF*
- **Networking for healthcare, communities, disaster recovery, crisis management, and public safety:** Provide networking for mHealth (mobile health systems), precision medicine, DataScience@NIH, the Broadband Opportunity Council (BOC), the Disaster Information Management Research Center (DIMRC), and medical implant and public-safety communications systems. *NIH (National Library of Medicine), NIST, NSF*
- **End-to-end network management:** Enable cross-domain end-to-end performance measurement for advanced networking; enable autonomous secure management; and provide tools for and implement performance measurement and services (e.g., perfSONAR). *CERDEC, DOE/SC, NASA, NIST, NSF*
- **Network security:** Develop technologies for detection of anomalous behavior; for standards, modeling, and measurement to achieve end-to-end security over wireless networks and heterogeneous, multidomain networks and infrastructure; for critical infrastructure protection, delay-tolerant networking, trustworthy networking, protected satellite communications (SATCOM), cybersecurity defenses, IPv6, DNSSEC, DDoS protection, border gateway protocol protection, and TICs; and for authentication, policy, and cryptography. *AFRL, CERDEC, DOE/SC, NASA, NIH, NIST, NSA, NSF, ONR*
- **Networking modeling and design:** Develop concepts, methods, architectures, protocols, and measurements for modeling networks as complex, autonomous, and dynamic systems. *AFRL, CERDEC, DOE/SC, NIST, NSF, ONR*

Planning and Coordination Supporting This Request

The following are examples of LSN coordination activities for FY2018:

- **400 Gbps/terabit networking research**. *DOE/SC, NSF, other LSN agencies*
- **Applications development:** GENI, US Ignite, S&CC, weather modeling, bioinformatics, and standards. *DOE/SC, DREN, NIH, NIST, NOAA, NSF*
- **Big data networking and demonstrations:** Networking and demonstrations for extreme-scale science and data flows; SDN/SDI/SDX experimentation, network management, and perfSONAR deployment; DTN; experimental design for complex systems; network security; network performance measurement; and GENI, OpenFlow, US Ignite, NIST Big Data Public Working Group, and SDN testing. *All LSN agencies*
- **Coordination by LSN Teams**
    - **Broadband Research and Development Group:** In February 2017 the NITRD Subcommittee authorized formation of the BRD Group to define and prioritize research proposals and data collection and data sharing requirements in the four key areas described in the National Broadband Research Agenda (NBRA): technology, deployment, adoption, and socioeconomic impacts.[13] BRD Group efforts aim to boost cross-agency and cross-sector collaboration in continuing the dynamic growth in the U.S. Information and Communications Technology sector

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[13] *The National Broadband Research Agenda: Key Priorities for Broadband Research and Data* (Washington, DC: NTIA, NSF, January 2017); https://ntia.doc.gov/files/ntia/publications/nationalbroadbandresearchagenda-jan2017.pdf.

and in addressing remaining disparities in broadband access, adoption, and choice across the Nation. *DHS, DoD, DOE, DOL, ED, FCC, HHS/HRSA, HUD, NIH, NIJ, NOAA, NSF, NTIA, USDA*

   - **Joint Engineering Team:** JET coordinates efforts nationally and internationally to resolve technical networking issues and develop collaborative testbeds for exploring advanced technologies at scale. It provides coordination of end-user requirements, science user interfaces, and engineering of research networks and testbeds (JETnets); networking for advanced demonstrations; end-to-end big data transport and storage networks; security best practices, application testbeds (DNSSEC, IPv6, perfSONAR, and performance measurement), and TIC and TIC access provider (TICAP) coordination; interdomain and end-to-end metrics and monitoring; tool sharing and exchange; international coordination; and transit and services cooperation. *DOE/SC, DREN, NASA, NIH, NIST, NOAA, NSA, NSF, ONR*
   - **Middleware And Grid Interagency Coordination team:** MAGIC coordinates nationally and internationally to provide collaborative environments and to cooperate on identity management. It provides research for evolution of distributed computing, cloud and grid computing services, and middleware; cloud and grid standards and implementation status (XSEDE, Open Science Grid); best practices for resource architecture, access, and management; security and privacy (e.g., identity management); and international coordination. *DOE/SC, NASA, NIST, NSF*

- **DoD interservice collaboration:** Research on robust, reliable, secure wireless and heterogeneous networking; spectrum access and management; SDN; DTN; dynamic spectrum access; The Technical Cooperation Program (TTCP); Joint Tactical Edge Networks Group; SATCOM; cybersecurity; services for federation, management, information, discovery, and secure delivery; modeling analysis and design; network performance; and resilient tactical networks. *AFRL, CERDEC, ONR*
- **End-to-end performance measurement and metrics.** *DOE/SC, DREN, NASA, NIST, NSF*
- **Information exchange:** Multiagency participation in review panels, informational meetings, principal investigator meetings; coordination among program managers; and JET and Internet2 joint technical meetings. *AFOSR, DOE/SC, NASA, NIST, NSA, NSF, ONR*
- **Infrastructure cooperation:** National and transoceanic connectivity for scientific instrument access, data management, security, performance measurement, TICs, and TICAP access providers. *DOE/SC, DREN, NASA, NOAA, NSF*
- **Software Defined Infrastructure:** Testing of SDN/SDX/SDP applications in at-scale testbeds. *DOE/SC, DREN, NASA, NIST, NSA, NSF*
- **Wireless Networking:** Broadband, dynamic, mobile, spectrum sharing and deployment, and deployment for city applications and environments. *All LSN agencies*
- **Multiagency workshops:** SDN Planning for Interdomain Functionality; Low Latency Networking. *All LSN agencies*

Wireless Spectrum R&D IWG

***NITRD Member Agencies*: DARPA, DHS, DOD service research organizations (AFRL, CERDEC, ONR), NASA, NIJ, NIST, NOAA, NSF, OSD**

***NITRD Participating Agencies*: FAA, FCC, NTIA**

The WSRD Interagency Working Group focuses on wireless spectrum research and development across the Federal Government. The goal is to facilitate efficient and effective investment in spectrum-sharing technologies and systems research by building cooperation between activities in the Federal Government, industry, and academia.

President's FY2018 Request

Strategic Priorities Underlying This Request

WSRD agency investments for FY2018 will focus on key research in two general priority areas that reflect the goal of developing technologies and methodologies that will increase spectrum efficiency, flexibility, and adaptability:

- **Develop standardized and improved measurements, testing, and analysis for the spectrum-sharing community at large** (NIST, NTIA).
- **Develop capabilities to mitigate interference and provide interoperable, secure, and resilient communications** in increasingly dense, complex, and dynamic environments (DOD, NASA, NIJ).

WSRD collaborative activities for FY2018 will focus on providing venues for planning and coordination of R&D activities, including data calls, meetings, and workshops, to better understand the opportunities and gaps in this research area.

Key Programs Supporting This Request

The WSRD agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **Accelerating Technology to Market**
  - **National Advanced Spectrum and Communications Test Network (NASCTN):** Provide a neutral forum for testing, spectrum-sharing challenges, and accelerating innovation. *NIST*
  - **Fundamental Radio-Frequency Metrology:** Enable state-of-the art measurement techniques, systems, and standards. *NIST*
- **Next-Generation Wireless Research**
  - **5G and Beyond, and 100G**: Enable mobile connectivity with high quality and low latency. *DARPA, NIST, NSF*
  - **Platforms for Advanced Wireless Research (PAWR):** Enable experimental exploration of robust new wireless devices, communication techniques, networks, systems, and services. *NSF*
  - **Communications for unmanned aerial vehicle (UAV) swarms**: Support electronic intelligence gathering and communications networking for advancing forces by deploying micro-UAVs to battlefields in bulk. *NRL*
  - **Free Space Optical (FSO)**: Provide high-data-rate communications through dust, rain, and fog. *NRL, NASA*
- **Dynamic Spectrum Access (DSA) and Spectrum Diversity**
  - **Spectrum Efficient, Energy Efficient, and Secure (SpecEES):** Enable next-generation systems in a dynamic spectrum environment. *NSF*
  - **Tactical Targeting Network Technology (TTNT):** Develop a dynamic spectrum system to coordinate air and land attacks. *NRL*
  - **Shared Spectrum Access for Radar and Communications (SSPARC)** and **Enhancing Co-existence for Force Protection (ECFP)** in radar and communication systems. *CERDEC, DARPA*
  - **Future growth in high-frequency (>20 GHz) data transmissions**. *NASA, NSF*
  - **High-capacity airborne wideband (multiband) communication links:** Enable secure relay of high-volume data in spectrally congested and contested environments. *AFRL*
  - **Science Sensor RF Interference Mitigation and Sharing:** Enable weather and science sensor observations in increasingly noisy and spectrum sharing environments. *NASA, NSF*

- **Robust, Secure, and Dependable Systems and Networks**
  - **Adaptable, Programmable and secure Aerial Layer Networking:** Enable spectrum agility and resilience across heterogeneous users. *AFRL*
  - **Integrated Topside** (Electromagnetic Maneuver Command and Control): Minimize frequency conflicts and interference and reduce blackout regions in both space and frequency. *NRL*
- **Dynamic Spectrum Planning and Management: Situational Awareness, Modeling, and Simulation**
  - **RadioMap:** Provide an accurate picture of real-time radio spectrum use across frequency and geography in complex radio environments. *DARPA*
  - **Optimized dynamic RF route management**. *NRL*
- **Multivendor, Multisystem Integration**
  - **Network Command and Control** across heterogeneous networks having multivendor, multiplatform radio enclaves using an agnostic monitoring and messaging protocol. *AFRL*
  - **Public safety communications:** Provide research, development, testing, and evaluation to foster nationwide public safety interoperability. *NIST*
  - **All-Digital Radio On-Demand Adaptive CommKit (ADiRONDACK):** Enable design of an adaptive software-defined small aperture antenna capable of beam shaping and operating over a broad range of selectable frequency bands. *AFRL*

Planning and Coordination Supporting This Request

The following are examples of ongoing WSRD coordination activities for FY2018:

- **Organizations**
  - Interdepartmental Radio Advisory Committee (IRAC). *NASA, NSF*, *NTIA*, *other agencies*
  - Center for Advanced Communications (CAC). *NIST*, *NTIA*
  - C4I (Command, Control, Communications, Computers, and Intelligence) Community of Interest. *AFRL, OSD*
  - Committee on Radio Frequencies. *NASA, NSF*
  - Defense Information Systems Agency (DISA) and Defense Spectrum Organization (DSO) Spectrum Sharing Test & Demonstration (SSTD) Working Groups. *AFRL*
  - DOD Electromagnetic Spectrum S&T Working Groups. *AFRL*
  - Future Generation Wireless Roadmap Working Group. *NIST*
  - Interdepartmental Radio Advisory Committee (IRAC). *NSF*, *NTIA*
  - Millimeter-Wave Channel Model Alliance. *NIST, NSF*
  - National Advanced Spectrum and Communications Test Network. *DOD, NIST*, *NTIA*
  - National Spectrum Consortium. *AFRL, DOD*
  - Spectrum Technology Working Group. *DOD service research organizations, OSD*
- **Spectrum Sharing Programs/Projects**
  - 100 Gbps RF Backbone (100G). *AFRL*, *DARPA*
  - Advanced RF Mapping (Radio Map). *AFRL*, *DARPA*
  - Advanced Spectrum Systems and Testing. *DoD, DOE*
  - Improved Spectrum Sharing Waveforms. *DOE*, *DOJ*
  - Model Cities. *NSF*, *NTIA*
  - Spectrum Collaboration Competition (SC2) challenge. *AFRL*, *DARPA*, *NSF*
  - Spectrum Monitoring. *Coast Guard, Navy*, *NIST*, *NTIA*
  - Spectrum Sensor Data Definitions. *NIST, NSF*
  - Wireless Spectrum Communications (WSComm). *DOJ*

- NOAA/NESDIS Radio Frequency Interference Monitoring System project. *NOAA, NTIA*
- DISA/DSO Spectrum Sharing Test and Demonstration propagation measurements and subject matter expert (SME) support. *DoD, NTIA*
- Cybersecurity Collaborative Research Alliance (*CRA*). *ARL, CERDEC*
- Cyber Guard. *DOE*
- Future Internet Architecture meetings. *NSF*
- Electric Grid Exercise (GridEx). *DOE, NERC*
- Intelligent Transportation Systems. *DOT, NTIA*
- Large-Scale Network Modeling and Simulation. *ARL, CERDEC*
- Socio-Cognitive Networking. *ARL, CERDEC*

Robotics and Intelligent Systems (RIS) PCA

The RIS PCA includes Federal agency research and development that involves robotics and intelligent systems to advance physical and embodied computational agents that complement, augment, enhance, or emulate human physical capabilities or human intelligence. This R&D includes robotics hardware and software design, application, and practical use; machine perception; intelligent cognition, adaptation, and learning; mobility and manipulation; human-robot interaction; distributed and networked robotics; increasingly autonomous systems; and related applications.

The Intelligent Robotics and Autonomous Systems (IRAS) IWG reports its activities under the RIS PCA.

Advancing Societal Benefits

IRAS agency investments provide societal benefits in the following key areas:

- **Economic prosperity** through innovation that will spur job growth with the adoption of robot systems and technologies assisting the workforce, automation of public systems and services, and standards for use of collaborative robots that could lower the cost of new technologies and potentially increase the level of interoperability in robotic and autonomous systems.
- **Health and healthcare** by enhancing healthcare robotics for people with disabilities, supporting caregivers, and producing surgical robotics technologies that minimize the impacts of invasive surgery.
- **National security and defense** by developing technologies capable of operating under degrees of uncertainty, including search and rescue, infrastructure inspection, and protection using robotics technologies that enhance interactions with operators.
- **Quality of life** through advances in technologies ranging from precision agriculture to ensuring the quality of the Nation's food sources, to aiding seniors or those with limited mobility within their homes. IRAS also seeks to aid first responders, provide for enhanced worker safety, and assist in humanitarian assistance and disaster recovery by developing and deploying emergency response robots and remote systems to improve safe and rapid response to and recovery from natural and man-made disasters, off-normal events, operational upsets, accidents, and emergencies.

Intelligent Robotics and Autonomous Systems IWG

***NITRD Member Agencies*: DoD service research organizations, NASA, NIH, NIJ, NIST, NSA, NSF, OSD**

***NITRD Participating Agencies*: CDC/NIOSH, DOE/EM, DOT, USDA/NIFA**

The U.S. economy and society critically depend on information technology, applications, and infrastructure for commercial, socioeconomic interactions, and scientific research in addressing the priorities of the Nation. Since the inception of the National Robotics Initiative in 2011, IRAS R&D has demonstrated its impact through new opportunities in healthcare and rehabilitation, surgery, manufacturing, agriculture, space exploration, infrastructure, service, education, and national defense. A future that encompasses robotic systems capable of working in tandem with humans and augmenting human capabilities will rely on R&D in the core technologies needed to increase trust, safety, and security. IRAS provides visibility in robotics and autonomous systems R&D and supporting technologies drawn from a variety of diverse fields, including control systems, mechanical design, artificial intelligence, machine learning, computer vision, formal methods, and cognitive science.

President's FY2018 Request

Strategic Priorities Underlying This Request

IRAS priorities are a reflection of the changing landscape in IT R&D. The IRAS agencies all seek to improve the way society perceives and uses collaborative robots (co-robots) in everyday life by supporting human-robot teams, as well as teams of robots that act autonomously in the physical world. IRAS priorities exemplify the scope of concerns among the member agencies that involves understanding the applications of IRAS to help people more effectively learn, conduct research, and innovate.

IRAS agency investments for FY2018 will focus on key research in the following priority areas:

- **Autonomous robots:** Develop robotic systems capable of independently determining a course of action based upon their understanding of the task at hand, their environment, and their own states and capabilities. Autonomy should be sufficiently general, adaptive, and robust in a wide variety of tasks to perform reliably in uncertain or unstructured environments that include humans and other agents that may be friendly, neutral, or adversarial.
- **Remote-access and -entry robots:** Develop and deploy robots and remote systems to enter areas and spaces that are otherwise inaccessible or preclude direct access by workers, due to unsafe, unstable, or unknown physical conditions or due to configurations that are hard to reach or beyond reach without taking extraordinary mechanical measures.
- **Worker-wearable robotic devices:** Develop and deploy human-worn and human-attachable robotic devices to enhance worker safety through injury prevention and to improve worker performance and productivity through augmentation (maintaining current human capability) and amplification (increasing human capability beyond normal).
- **Enhancement of co-robot capabilities:** Exploit the advantages of both humans and machines for better and faster human decision making; help humans perform better in combat; and employ innovative cooperative operations between manned and unmanned platforms.
- **Standards for smart manufacturing:** Develop and validate metrics, test methods, information models, protocols, and tools to enable and advance assembly-centric robot system performance.
- **Support for farmers and agricultural development:** Enable engineering, sensing, automation, and cyber systems for precision agriculture.

Key Programs Supporting This Request

As new products and technologies emerge for IT-enabled sensing and acting in the physical world, it becomes important to establish open standards and platforms to encourage the sharing of new technologies with and among the research community. Research is needed that focuses on human interactions with systems that operate in the physical world, particularly around issues of safety, trust, and predictability of response. Additional research is needed in areas such as human interaction, robust autonomy, sensing, the development of hardware and software abstractions for physical IT systems, and trustworthy physical IT systems.

The IRAS agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **NRI 2.0: Ubiquitous Collaborative Robots:** Focus on ubiquitous collaborative robots, including teams of multiple robots and humans; multiple types of tasks; learning from other robots, people, and external IT resources; customizable and personalizable robotic systems; lowering the barriers to entry; innovative approaches to infuse robotics into education; and advancing the robotics workforce. (This change in focus from the original NRI solicitation began in FY2017.) *DoD, DOE/EM, NASA, NSF, USDA/NIFA*

- **Science of Safety:** Use robotic systems and tooling (such as wearable robotics devices) to help enhance human capabilities while improving worker safety and assisting with tasks that can be physically demanding or stressful. *DOE/EM, NASA, NIST*
- **Human-worn robotics and wearable performance augmentation standards:** Investigate standards in the realm of human-worn robotics and outline an initial roadmap for the next generation of standards in this domain. *CDC/NIOSH, DHS, DoD, DOE/EM, FDA, NIST, NSRDEC, OSHA*
- **Robot Operating System (ROS):** Develop and deploy a "ROS-Government" (ROS-G) effort to synergize and consolidate separate agency initiatives and projects for developing ROS-Military (defense), ROS-Industrial (manufacturing), ROS-SE (security-enhanced), and ROS-DOE (legacy nuclear cleanup); and develop a core capability within the open-source community while satisfying the unique technical, programmatic, and security-related needs for U.S. government applications. *DoD, DOE/EM, NASA, NIST, NSF*

Planning and Coordination Supporting This Request

The following are examples of ongoing IRAS IWG coordination activities for FY2018:

- **Robotics and Intelligent Systems Framework:** Initiation of a framework to detail current research and future needs in robotics R&D.
- **Cyber-physical systems**. *DOT, NASA, NIH, NSF, USDA*
- **NRI PI Meeting**. *DoD, DOE, NASA, NIH, NSF, USDA*
- **Development of standards and test methods**. *CDC/NIOSH, DHS, DoD, DOE, FDA, NIST, NSRDEC, OSHA*

Software Design and Productivity (SDP) PCA

SDP focuses on the science and technology needed to advance timely and affordable creation and sustainment of quality software. The research addresses software qualities, including low defect rates, security, resilience, and robustness. SDP includes R&D around software productivity, software quality, software cost, software economics, measurement of software and its production, responsiveness to change, and software sustainability. SDP R&D contributes to productivity, quality, and sustainability for secure systems development, high-capability computing systems, big data (i.e., large-scale data management and analysis), health IT, medical devices, cyber-physical systems, the Internet of Things, and software-defined infrastructure.

The Software Productivity, Sustainability, and Quality (SPSQ) IWG reports its activities under the SDP PCA.

Advancing Societal Benefits

SPSQ agency investments provide societal benefits in the following key areas:

- **Economic prosperity** by facilitating fast, affordable development and sustainment of low-defect, low-vulnerability software; speeding innovations in products and processes; reducing costs and enhancing productivity to improve U.S. economic competitiveness; facilitating e-commerce at the business and consumer levels; and improving industrial process control systems.
- **Education and training** by providing on-demand access by learners of all ages to vast education and knowledge resources on producing higher-quality software; this access will enable advancement of the frontiers of science and technology and development of the next generation of entrepreneurs and innovators.
- **Energy and environment** by supporting high-fidelity modeling and simulation, enabling better energy efficiency and weather and climate prediction, and speeding development of renewable energy sources and cleaner technologies; and by developing interoperable sensors for the Internet of Things.
- **Health and healthcare** by speeding innovations in Health IT products and processes that will enable longer, healthier lives; for example, healthcare-related IT and software will facilitate provision of skilled healthcare in medical facilities, in the home, and at remote locations, and increasing the efficiency of computation will lead to advancements in precision medicine.
- **National security and defense** by speeding innovations in products and processes that can help DoD better respond to budget pressures and exhibit the speed and agility needed to stay ahead of adversaries; by reducing the number and severity of vulnerabilities; and by transforming strategic communications and reducing battlefield risks for military personnel.
- **Open and transparent government** by enabling rapid growth in electronic access of individuals to government information, broadening participation by the public, and increasing efficiency in government services.
- **Science and technology leadership** by implementing high-fidelity numerical simulation (reliable computing) and large-scale data analysis, enabled by high-end computing (the NSCI) and Big Data capabilities, to allow the United States to sustain leadership across a vast array of science and technology areas that support all of the above priorities.

Software Productivity, Sustainability, and Quality IWG

***NITRD Member Agencies*: DoD Service Research Organizations (AFRL, NRL, U.S. Army AMC, RDECOM, CERDEC, S&TCD, CSIA), DHS, NASA, NIH, NIJ, NIST, NOAA, NSA, NSF, OSD, OSTP**

***NITRD Participating Agencies*: BLS, FDA, NRC**

SPSQ contributes to the Nation and society by coordinating research in science and technology that facilitates fast, affordable development and sustainment of low-defect, low-vulnerability software that speeds innovations in products and processes driving national productivity and competitiveness. The value that software contributes to major systems is increasing rapidly and becoming ever more fundamental to system capability. A large percentage (by some measures, the majority) of time and cost of software development, operation, and sustainment is attributable to the effort needed to discover, avoid, mitigate, and eliminate software defects, presenting a major obstacle to reducing software vulnerabilities. In a dynamic, competitive economy that relies on rapid development of software to bring innovations to the marketplace, the economics favor meeting time-to-market and cost objectives at the expense of defect-free software.

President's FY2018 Request

Strategic Priorities Underlying This Request

Complex software-based systems today power the Nation's most advanced defense, security, and economic capabilities. Such systems also play central roles in science and engineering discovery and thus are essential in addressing this century's grand challenges (e.g., low-cost, carbon-neutral, and renewable energy; clean water; next-generation healthcare; extreme manufacturing; and space exploration). These large-scale systems typically must remain operational, useful, and relevant for decades. The SPSQ agencies are working to identify and define the core elements for a new science of software development that will make engineering decisions and modifications transparent and traceable throughout the software lifecycle (e.g., design, development, evolution, and sustainment). A key goal of this science framework is to enable software engineers to maintain and evolve complex systems cost-effectively and correctly long after the original developers are no longer available and the computers and operating systems have evolved. This new science of software development will also benefit the many companies producing software-reliant products that comprise an increasing portion of the economy.

SPSQ agency investments for FY2018 will focus on key research in the following priority areas:

- **Secure and Productive Software Development Grand Challenge:**
  Support the roles of software design and productivity in grand challenge areas such as healthcare, manufacturing, sustainability, and computational science and/or engineering to provide the technical capabilities to thwart and reverse adversaries' asymmetrical advantages with sustainably secure software development. The Secure and Productive Software Development Grand Challenge focuses on developing fast, affordable, low-defect software production and sustainment technology for current software developers to use in scientific application domains (e.g., health applications, Smart and Connected Communities, and software-defined infrastructure).
- **Improve high-performance computing application developer productivity:**
  Develop new approaches to building, sustaining, assuring, and programming HPC systems that make it possible to express programs at more abstract levels and then automatically map them onto specific machines. Foster the transition of improved development tools into actual practice, making the development, sustainment, and assurance of applications for HPC systems no more difficult than it is for other classes of large-scale systems.

- **Rethink software design:**
  Pursue new approaches to software design, from basic concepts of design, evolution, and adaptation to advanced systems that seamlessly integrate human and computational capabilities, including the following:
  - *Foundational/core research on science and engineering of software*: Develop new computational models and logics, techniques, languages, tools, metrics, and processes for developing and analyzing software for complex software-intensive systems (e.g., develop a fundamental approach to software engineering that can provide systems that are inherently and verifiably correct, assured, efficient, effective, reliable, and sustainable).
  - *Next-generation software concepts, methods, and tools*: Reformulate the development process, the tool chain, and the partitioning of tasks and resources; and support open technology development (open-source and open-systems methods); technology from nontraditional sources; multidisciplinary and crosscutting concepts and approaches; and next-generation software concepts, methods, and tools, all of which will be needed for emerging technologies such as multicore, software-as-a-service, cloud computing, end-user programming, quantum information processing, and modeling of human-machine systems.
  - *Capabilities for building evolvable, sustainable, long-lived software-intensive systems*: Explore new means to create, keep current, and use engineering artifacts to support long-lived software-intensive systems; develop new approaches to reliably meet changing requirements and assure security and safety; and pursue long-term retention and archiving of software-development data and institutional knowledge.
- **Explore fundamental principles:**
  Understand, design, analyze, and build software systems that are verifiable—regardless of size, scale, complexity, and heterogeneity—and software that is correct, assured, efficient, effective, and predictable. Build the software foundations for emerging quantum information science and quantum information processing.
- **Develop predictable, timely, cost-effective software-intensive systems:**
  Develop disciplined methods, technologies, and tools for systems and software engineering, rapidly evaluating alternative solutions to address evolving needs; enable measuring, predicting, and controlling software properties and tradeoffs; automate deterministic engineering tasks; support virtualized and model-based development environments; and provide scalable analysis, test generation, optimization, and verification with traceability to requirements. Related issues include:
  - *Software application interoperability and usability*: Develop interface and integration standards, representation methods to enable software interoperability, data exchanges, interoperable databases, supply-chain system integration, and standardized software engineering practices for model development.
  - *Cost and productivity issues in development of safety-critical, embedded, and autonomous systems*: Research composition, reuse, power tools, training, and education to address systems that can be inaccessible after deployment (e.g., spacecraft) and need to operate autonomously.
- **Transform SPSQ frontiers:** Invest in challenging, potentially transformative research; prepare and engage a diverse STEM workforce; sharpen the merit-review process to better identify such research; and emphasize interdisciplinary and system-oriented approaches that can lead to transformational concepts.
- **Improve health IT interoperability:** Improve conformance testing, testability, and community knowledge of specifications.

- **Advance supply chain interoperability for digital manufacturing research:** Apply model-based engineering, product manufacturing information standards, and systems engineering standards.
- **Assess software quality:** Provide reference datasets and test programs for software assurance and metrics.
- **Focus on Smart Grid security guidelines:** Support the multidisciplinary aspects of Smart Grid security.

Key Programs Supporting This Request

The SPSQ agencies report the following key programs and activities as highlights of their planned investments for FY2018:

- **Software Infrastructure for Sustained Innovation:** Conduct the agency-wide SI^2 program for development and integration of next-generation software infrastructure to advance scientific discovery and education at all levels in the sciences, mathematics, and engineering. *NSF*
- **Software and Hardware Foundations Program:** Develop scientific and engineering principles and new logics, languages, architectures, and tools for specifying, designing, programming, analyzing, and verifying software and software-intensive systems; formal methods; verification and validation tools for sound development of reliable and assured software; formal definitions of weaknesses; standards for certification; and techniques that enable prediction of cost and schedule for large-scale software projects. *AFRL, DHS, NASA, NIST, NOAA, NSF, ONR, OSD*
- **Computer systems research:** Rethink and transform the software stack for computer systems in different application domains (e.g., new reference architectures for embedded systems); and investigate systems that involve computational, human or social, and physical elements. *AFRL, NASA, NIST, NSF, ONR, OSD*
- **Intelligent software design:** Investigate approaches to design software-intensive systems that operate in complex, real-time, distributed, and unpredictable environments; develop invariant refinement of software properties; pursue automation and scaling of testing, validation, and system-level verification; advance automated analysis of model-based software development; develop transformational approaches to drastically reduce software life-cycle costs and complexity, and to extend software life span; and improve languages and modeling tools that support interoperability, data exchange among engineering tools, large-scale simulations, and federated information systems. *AFRL, NASA, NIST, NOAA, NSF, ONR, OSD*
- **Interoperability standards, knowledge capture processes:** Develop representation schemes for interoperability among computer-aided engineering systems; standards for instrument, mathematical, and measurement data; ontological approaches to facilitate integration of supply-chain systems; interoperability of databases; and interoperability testing tools. Also, develop infrastructure for capture and reuse of domain expertise. *NIST, NOAA, ONR, OSD*
- **Cyber-Enabled Materials, Manufacturing, and Smart Systems (CEMMSS)** (collaboration led by NSF): Develop several comprehensive, integrated programs across focus areas, e.g., cyber manufacturing, advanced materials, and smart systems, to encourage new connections, discoveries, and/or emerging fields of science and engineering. Progress towards CEMMSS goals shows evidence of (1) an integrated and thriving ecosystem of cyber-enabled systems and advanced materials; (2) improved interdisciplinary education based on longitudinal study of education outcomes; and (3) development of an advanced research infrastructure that is used by CEMMSS scientists and engineers. NSF expects to continue to grow the Nation's cyber manufacturing program, building upon NSF core programs through the development and use of robust, reliable, usable, and sustainable software. *DoD, DOE, DOT, NIST, NSF*

- **Quantum Information Sciences:** Support the Federal S&T Interagency Working Group on Quantum Information Science ("IWG on QIS"). *DOE, NIST, NSF*
- **Office of the Secretary of Defense Third Offset Strategy**: Develop software for defense innovation to sustain U.S. national strategic advantage by bolstering and extending conventional deterrence against any powers able to produce or acquire technologically advanced weapons systems. Five common technological-operational components are: (1) deep-learning systems, (2) human-machine collaboration, (3) human-machine combat teaming, (4) assisted human operations, and (5) network-enabled, cyber-hardened weapons. *DoD Service Research Organizations*

Planning and Coordination Supporting This Request

The SPSQ agencies' current collaboration activities focus on domain areas in which large-scale, software-intensive, and cyber-physical systems predominate—such as in aviation, air-traffic control, and global climate and weather modeling—and on building a forward-looking research agenda to improve the engineering and evolution of such systems.

The following are examples of ongoing SPSQ coordination activities for FY2018:

- **Software verification and validation:** Ongoing collaboration to develop effective approaches for next-generation air transportation. *AFRL, NASA, ONR, OSD*
- **Articulate SPSQ national needs, opportunities, and priorities:** Forums to provide a focus for the future of software engineering research and to discuss and formulate software and productivity research goals and priorities. *SPSQ agencies*
- **Automated combinatorial testing of software systems:** Methodology and infrastructure for automated testing that reduces the number of tests required. *NASA, NIST*
- **Bioinformatics and computational biology software**: Support software cores for Mobile Health (mHealth), the All of Us research program; clinical software for translational research centers; and development and maintenance of biomedical computational software in support of NIH's broader missions in seeking fundamental knowledge about the nature and behavior of living systems. *NIH, other SPSQ agencies*
- **Next-generation aircraft:** Collaboration on concepts, modeling, and simulation tools. *DoD Service research organizations*, *NASA, OSD*
- **Reducing software vulnerabilities:** Development of effective, economic solutions to software vulnerabilities. *SPSQ agencies*
- **Workshops among government, industry, and academia**: Routine sponsorship of such workshops as NSF Secure and Trustworthy Cyberspace PI, and Computational Science and Engineering Software Sustainability and Productivity Challenges to ensure that collaboration activities are widely shared. *SPSQ IWG agencies*

4. Additional NITRD Interagency Coordination Activities

The NITRD NCO is providing staff support to the information-sharing and strategy-setting activities of five interagency coordination groups in new and emerging challenge areas for Federal IT R&D. These groups do not at this time report budgets under the NITRD PCAs:

- Artificial Intelligence (AI) Research and Development Task Force[14]
- National Broadband Research Agenda (NBRA) Task Force[15]
- Faster Administration of Science and Technology Education and Research (FASTER) Community of Practice (CoP)
- Health Information Technology R&D (HITRD) Interagency Working Group
- Video and Image Analytics (VIA) Interagency Working Group

Artificial Intelligence Research and Development Task Force

***NITRD Member Agencies*: DARPA, DHS, DoD, DOE, NASA, NIH, NIST, NRL, NSA, NSF, ONR, OSTP**

***NITRD Participating Agencies*: DOJ, DOT, IARPA, Presidential Innovation Fellows**

The NITRD Task Force on Artificial Intelligence R&D was formed in June 2016 in response to a request by the new NSTC Subcommittee on Machine Learning and Artificial Intelligence (MLAI) for the NITRD Subcommittee's help in defining the Federal strategic priorities for AI R&D, with a particular focus on areas that industry is unlikely to address. The National Artificial Intelligence R&D Strategic Plan was produced by the AI Task Force and published in October 2016 by the NSTC.[16] The plan establishes a set of objectives for federally funded AI research occurring both within and outside of government, such as in academia. The ultimate goals of this research are to produce new AI knowledge and technologies that provide a range of positive benefits to society while minimizing any potential negative impacts. The NITRD community has begun implementation of the Federal AI R&D Plan under the auspices of the MLAI Subcommittee and supported by the NITRD NCO. This will include regular meetings of the agency stakeholders to coordinate their AI R&D activities.

AI R&D supports many national and agency priorities. New AI-based products and services can create new markets and improve the quality and efficiency of existing goods and services across multiple industries to increase economic prosperity for the Nation. Education, training, and lifelong learning can be facilitated through virtual tutors that develop customized learning plans to challenge and engage individuals based on their interests, abilities, and educational needs. People can live healthier and more active lives using AI-assisted precision medicine and health information and devices tailored for each individual. Smart homes and personal virtual assistants can reduce time lost in repetitive tasks while improving home security, reducing environmental impacts, and providing services to persons who are temporarily or predominantly homebound. Machine learning agents can enhance national and homeland security by processing large amounts of intelligence data to identify relevant patterns of activity by

[14] The AI R&D Task Force completed its work in October 2016 and was disbanded.

[15] The NBRA Task Force completed its work in January 2017 and was disbanded.

[16] *The National Artificial Intelligence Research and Development Strategic Plan* (Washington, DC: NSTC and NITRD, June 2016); https://www.nitrd.gov/PUBS/national_ai_rd_strategic_plan.pdf.

adversaries. Similar agents can also help protect critical infrastructure and major economic sectors that are vulnerable to attacks.

National Broadband Research Agenda Task Force

***NITRD Member Agencies*: DHS, DoD, DOE, EPA, NSF**

***NITRD Participating Agencies*: ARC, CEA, CEQ, DOC/NTIA, Census, DOI, DOL, DOJ, DOT, DPC, ED, FCC, GSA, HHS/HRSA, HUD, IMLS, NEC, Treasury, USDA, VA**

A National Broadband Research Agenda Task Force was created in August 2016 under the NITRD Subcommittee. The goal of the task force was to assemble a written agenda for improving collection, research, and analysis of data on broadband deployment and adoption throughout the Nation. The agenda aims to facilitate collection of usable, granular data on broadband connectivity and usage. The task force published the National Broadband Research Agenda (NBRA) in January 2017[17] based on inputs from a broad set of stakeholders including academics, businesses, State government representatives, nonprofits, individual citizens, and key Federal agencies. The NBRA Task Force was sunsetted with the Agenda's publication. To ensure that NBRA objectives and research questions are addressed effectively and to foster more rapid and widespread deployment of broadband technology, NITRD established a Broadband R&D (BRD) Group under the LSN IWG in April 2017 to provide continuing coordination of R&D programs and deployment initiatives among Federal agencies with programs and interests in broadband.

National and agency priorities for broadband R&D include improving economic prosperity for individuals and businesses by amplifying the access that fast Internet provides to jobs, markets, and related opportunities; quality of life by enhancing personal communications and access to information; national security by improving public safety communications; health and healthcare by expanding access to new remote and individualized health technologies; education and training by broadening access to online educational opportunities; open and transparent government by simplifying citizens' access to their representatives, government documents, and government services; and science and technology leadership by enabling such Internet-enabled programs as citizen science data-gathering initiatives.

Faster Administration of Science and Technology Education and Research CoP

***NITRD Member Agencies*: DoD/AFRL, DHS, NARA, NIH, NIST, NOAA**

***NITRD Participating Agencies*: FDIC, IARPA, Treasury, VA**

The FASTER Community of Practice is an association of science agency chief information officers and/or their advanced technology specialists, organized under NITRD to improve interagency communication and coordination. The primary focus of FASTER is on the IT challenges specific to supporting the Federal scientific research enterprise. Through coordination and collaboration, FASTER seeks to share information on protocols, standards, best practices, technology assessments, and testbeds, and to accelerate the deployment of promising technologies from research into operations.

FASTER seeks to enhance open and transparent government by sponsoring information-sharing exchanges and events that are responsive to shared interagency interests in Federal digital information sources, open data, and enhancing public access to federally funded research results. FASTER also focuses on issues affecting quality of life, accessibility, and equal access to information for citizens. It encourages collaboration between Federal agencies and industry to facilitate progress towards solutions in portability, interoperability, and security for cloud computing and cyberinfrastructure. A number of FASTER meetings are open to the public; these are advertised in advance on the NITRD website and in the Federal Register.

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[17] *The National Broadband Research Agenda: Key Priorities for Broadband Research and Data* (Washington, DC, NTIA and NSF, January 2017); https://www.ntia.doc.gov/files/ntia/publications/nationalbroadbandresearchagenda-jan2017.pdf.

Health Information Technology Research & Development IWG

***NITRD Member Agencies*: HHS (AHRQ), DoD, NIH, NIST, NSF, ONC**

***NITRD Participating Agencies*: CDC, FDA, HHS/HRSA, HUD, NIDILRR, VA**

The HITRD Interagency Working Group was established in 2010 to provide a forum for sharing information about Federal health IT R&D programs, coordinating health IT R&D plans and activities, and promoting synergies across Federal health IT investments. HITRD agencies work collaboratively to articulate health IT R&D needs to policy- and decision-makers and to pursue interagency opportunities that advance IT research, data sharing, integration and connectivity, and innovative health IT systems. HITRD recently initiated development of a strategic R&D framework to identify opportunities and challenges in health IT research. As a result of the framework, the HITRD group identified a number of scientific challenges that the group will begin to address in a series of workshops and publications.

HITRD's focus is on advancing information technology research that provides societal benefits in terms of improving health, healthcare, and quality of life through technologies that support effective health monitoring, individualized screening, diagnosis and treatment, disease prevention, disaster and emergency response, and widespread access to health and healthcare information and resources. HITRD activities also promote the Nation's education and training priority through R&D investments that help build and sustain a vibrant community of professional health IT researchers and practitioners.

Video and Image Analytics IWG

***NITRD Member Agencies*: AFRL, ARL, DARPA, DHS, FBI, NASA, NIH, NIJ, NIST, NOAA, NRL, NSA, NSF**

***NITRD Participating Agencies*: CIA, DoD IIS, DOT, GSA, IARPA, JIDO, NGA, ODNI (NCSC, NCTC), USDA, VA**

The Video and Image Analytics Interagency Working Group was formally chartered in the spring of 2015 to develop a joint strategy for Federal R&D in visible world video and image analysis technologies. This strategy is intended to include interagency support for core R&D and crosscutting technology challenges in computer vision, interagency collaboration and coordination on emerging video analysis applications of national importance, and Federal coordination of VIA standards. The VIA IWG is currently engaged in developing an interagency R&D strategic plan with the goals of advancing fundamental and applied research; reinvigorating the VIA R&D portfolio; developing resource-sharing mechanisms; pursuing public engagement and outreach; promoting technology transfer; developing workforce and research resources; and promoting standards and/or best practices that support emerging Federal needs. An initial impact of the strategy-setting process is that it has fostered interagency efforts focused on public safety video and engagement with communities.

The need for VIA technologies spans a broad spectrum of national priorities and agency missions. The strategic goals mentioned above will have a multiplicative effect on technologies to improve the safety of the Nation and the quality of life for all Americans. VIA technologies are used to enhance public safety, homeland security and national defense, and justice and forensics, among other areas. VIA applications and real-time forensic tools can help protect our cities, our borders, our troops, and Federal facilities here and abroad; monitor fisheries and wildlife to better manage those populations; identify crops and invasive plant species to improve agricultural practices; support efficiency and safety in urban and transportation infrastructures; and facilitate the development of automation-assisted vehicles.

Appendix A. The Federal Cybersecurity R&D Strategic Plan Implementation Roadmap

This section provides implementation details for the Federal Cybersecurity Research and Development Strategic Plan, [18] developed by the NITRD Cyber Security and Information Assurance (CSIA) Interagency Working Group. This Strategic Plan Implementation Roadmap is provided per statutory requirement for public provision of this information pursuant to the Cybersecurity Enhancement Act of 2014, Public Law 113-274, Section 201(a)(2)(D), Implementation Roadmap, and under direction from the NITRD Subcommittee of the National Science and Technology Council Committee on Technology.

Agencies participating in the CSIA Working Group report their research and development (R&D) programs in the CSIA Program Component Area in alignment with the research objectives of the Federal Cybersecurity Research and Development Strategic Plan. The four strategic defensive elements of the strategic plan consist of Deter, Protect, Detect, and Adapt:

- **Deter:** The ability to efficiently discourage malicious cyber activities by measuring and increasing the costs to adversaries who carry out such activities, diminishing their spoils, and increasing risks and uncertainty of consequences for cyber attacks.
- **Protect:** The ability of components, systems, users, and critical infrastructure to efficiently resist malicious cyber activities and to ensure confidentiality, integrity, availability, and accountability.
- **Detect:** The ability to efficiently detect, and even anticipate, adversary decisions and activities, given that perfect security is not possible and systems should be assumed to be vulnerable to malicious cyber activities.
- **Adapt:** The ability of defenders, defenses, and infrastructure to dynamically adapt to malicious cyber activities by efficiently reacting to disruption, recovering from damage, maintaining operations while completing restoration, and adjusting to be able to thwart similar future activity.

Listed in the roadmap table below are projects and programs being planned or carried out in fiscal years 2017, 2018, and possibly beyond, to meet the objectives of the Federal Cybersecurity Research and Development Strategic Plan in the four strategic defensive areas. The listed programs and projects represent the key agency activities in these areas; however, the table is not an exhaustive listing of all projects. For example, NSF's Secure and Trustworthy Cyberspace (SaTC) Program is comprised of some 800 active individual grants to hundreds of researchers and their academic institutions. Likewise, the programs and projects in the table vary substantially in their size and the amount of funding.

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[18] *Federal Cybersecurity Research and Development Strategic Plan* (Washington, DC: NSTC and NITRD, February, 2016); https://nitrd.gov/cybersecurity/publications/2016_Federal_Cybersecurity_Research_and_Development_Strategic_Plan.pdf.

Table A1. Federal Cybersecurity R&D Strategic Plan Implementation Roadmap

Federal Cybersecurity R&D Programs, by Agency	Deter	Protect	Detect	Adapt
AFRL and AFOSR				
Agile and Resilient Embedded Systems (ARES)		X	X	X
Assured by Design (AbD)		X	X	X
Automated Cyber Survivability (ACS)		X	X	X
Autonomous Defensive Cyber Operations (ADCO)	X	X	X	X
Command and Control of Proactive Defense (C2PD)	X	X	X	X
Cyber Agility	X	X	X	X
Cyber-Based Mission Assurance on Trust-enhanced Hardware (CMATH)		X	X	X
Cybersecurity & Information Assurance; Trust & Influence	X	X	X	X
Mission Awareness for Mission Assurance (MAMA)			X	X
Mission-Centric Cyber Assurance (MCCA)		X	X	X
Resilient and Ultra-Trusted MLS Routing (RAUTR)		X	X	X
ARL				
Threat Intelligence Stylometry	X			
Dynamic Risk Assessment			X	
Active Cyber Defense	X	X		X
Cyber Behaviors		X		
Intrusion Detection with Machine Learning			X	
Cyber Defense of SCADA			X	X
Army Cyber Research and Analytics Laboratory (ACAL)			X	
Trust, Decision Making, & Influence in Multi-Genre Networks		X		
Interrogator – Intrusion Detection Framework			X	
Forensic Analysis Tools (Dshell)	X		X	
DARPA				
Active Cyber Defense (ACD)	X			
Enhanced Attribution (EA)	X			
Automated Program Analysis for Cybersecurity (APAC)		X		
Cyber Fault-tolerant Attack Recovery (CFAR)		X		
High-Assurance Cyber Military Systems (HACMS)		X		
Space/Time Analysis for Cybersecurity (STAC)		X		
Vetting Commodity IT Software and Firmware (VET)		X		
Leveraging the Analog Domain for Security (LADS)			X	
Plan X			X	
Rapid Attack Detection, Isolation and Characterization Systems (RADICS)			X	
Transparent Computing			X	
Edge-Directed Cyber Technologies for Reliable Mission Communication (EdgeCT)				X
Extreme DDoS Defense (XD3)				X

Federal Cybersecurity R&D Programs, by Agency	Deter	Protect	Detect	Adapt
DHS				
Next Generation Cyber Infrastructure		X	X	
Cyber Security for Law Enforcement	X			
Data Privacy and Identity Management	X	X		
Software Assurance		X	X	X
Mobile Network and Device Security		X	X	X
Network Systems Security		X	X	X
Cyber Physical Systems		X	X	
Homeland Security Open Source Technologies (HOST)		X		
Cyber for Critical Infrastructure		X	X	
Transition to Practice	X	X	X	X
Cybersecurity Research Infrastructure		X	X	X
Human Aspects of Cyber Security	X	X	X	X
Network Intrusion Attribution	X		X	
Securing the Internet Infrastructure		X	X	X
DoD (HPCMP)				
HPC Architecture for Cyber Situational Awareness		X	X	X
Cybersecurity Environment for Detection, Analysis, and Reporting		X	X	
Cybersecurity Enhancement Project		X	X	
Information Security Continuous Monitoring—Jigsaw		X	X	
Rapid Audit of Unix		X		
DOE/OE				
Cybersecurity for Energy Delivery Systems (CEDS)		X	X	X
NIST				
Cryptographic standards, validation, and research		X		
Identity management		X		
Cloud computing and virtualization	X	X		X
Mobile security		X		X
Internet infrastructure protection		X	X	X
Access control and privilege management		X		
Advanced security testing and measurement		X	X	X
Information security risk management		X	X	X
Privacy engineering		X		
Security of cyber-physical systems (CPS)		X	X	
Biometric standards and testing	X	X		
NSA				
Adaptive and Automated Response				X
Cyber Deception for Defense	X			X
System Behavior Analytics			X	
Software Assurance Workbench		X	X	

Federal Cybersecurity R&D Programs, by Agency	Deter	Protect	Detect	Adapt
Cryptographic Protocol Shapes Analyzer		X	X	
Threat Fusion and Effective Response		X	X	
Automated Vulnerability Discovery and Remediation		X	X	
New Mechanisms for Trustworthy Platforms		X		
System Security Organization through Policy		X	X	
Host Integrity at Runtime and Startup Integration		X	X	
Secure Capabilities for Ultra-Mobile Platforms		X	X	
Lightweight Cryptography		X		
NSF				
Secure and Trustworthy Cyberspace Program (SaTC)	X	X	X	X
ONR				
Cyber Attack Resilient Cyber-Physical Systems (RHIMES)	X	X	X	X
Tools for Intrinsic Cybersecurity (TPCP)	X	X	X	X
Automated Cryptographic Algorithm Design (Crypto Factory)	X	X		X
Autonomic Computing	X	X	X	X
Transparent software complexity reduction	X	X		X
Bottom-up formal verification	X	X		
Deception infrastructure (CyberMoat)	X	X		
OSD				
Cyber Applied Research: Behavioral Cyber Sciences	X	X		X
Cyber Applied Research: Self-securing weapons, systems, and networks	X	X	X	X
Cyber Applied Research: Precision Cyber Operations	X	X		

APPENDIX B. FISCAL YEAR 2016 ACCOMPLISHMENTS OF THE NATIONAL STRATEGIC COMPUTING INITIATIVE

Introduction

High performance computing (HPC) is essential to the Nation's security, global economic competitiveness, and scientific progress. Over the past sixty years, U.S. leadership in computing, including in HPC, has been maintained through continual research, development, and deployment of new computing technologies that increase the performance and capabilities of critically important real-world applications. Sustaining U.S. leadership in HPC in the coming decades requires a sustained national response to the increasing international competition in the research, development, deployment and use of new HPC technologies. The National Strategic Computing Initiative (NSCI) is supported by coordinated Federal investment in research to ensure the continued vibrancy in innovative choices for HPC technologies to ensure enduring broad competitive advantage. Under the NSCI, Federal agencies with a variety of missions, roles, and HPC expertise bring a rich set of partnership approaches to collaboratively expand the innovative and productive use of HPC across government, academia, and industry.

In order to maximize the benefits of HPC for economic competitiveness, security, and scientific progress, the U.S. government has created a coordinated Federal strategy for research, development, and deployment in HPC and related advanced computing technologies. The NSCI is a whole-of-government effort designed to create a cohesive, multi-agency strategic vision and Federal investment strategy, executed in collaboration with industry and academia, to maximize the benefits of HPC for the United States. The NSCI is guided by four overarching principles:

- The United States must deploy and apply new advanced computing technologies broadly for national security, economic competitiveness, and scientific progress.
- The United States must foster public-private partnerships, relying on the respective strengths of government, industry, and academia to maximize the benefits of advanced computing.
- The United States must adopt a whole-of-government approach that draws upon the strengths of and seeks cooperation among all executive departments and agencies with significant expertise or equities in advanced computing, while also collaborating with industry and academia.
- The United States must develop a comprehensive technical and scientific approach to transition advanced computing research on hardware, system software, development tools, and applications efficiently into development and, ultimately, into operations.

The NSCI identifies five strategic objectives that are essential to spurring the creation and deployment of advanced computing technologies that are vital in achieving the NSCI visions as laid out in the NSCI Strategic Plan.[19] The five NSCI Strategic Objectives are:

1. **Capable Exascale:** Accelerate delivery of a capable exascale computing system that integrates hardware and software capability to deliver approximately 100 times the performance of current 10 petaflops systems across a range of applications representing government needs.
2. **Coherent Data Analytic Computing and Modeling and Simulation:** Increase the coherence between the technology base used for modeling and simulation and that used for data analytic computing.

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[19] *National Strategic Computing Initiative Strategic Plan* (Washington, DC: OSTP and OMB, July 2016); https://www.whitehouse.gov/sites/whitehouse.gov/files/images/NSCI%20Strategic%20Plan.pdf.

3. **Computing Beyond Moore's Law:** Establish, over the next 15 years, a viable path forward for future HPC systems even after the limits of current semiconductor technology are reached (the "post-Moore's-Law era").
4. **An Enduring National HPC Ecosystem:** Increase the capacity and capability of the national HPC ecosystem by employing a holistic approach that addresses relevant factors such as networking technology, workflow, downward scaling, foundational algorithms and software, accessibility, and workforce development.
5. **Public-Private Collaboration:** Develop an enduring public-private collaboration to ensure that the benefits of the research and development advances are, to the greatest extent, shared among the United States Government and the Nation's industrial and academic sectors.

Since the launch of the NSCI, Federal agencies have taken steps to create the foundation for a successful initiative based on these five objectives. The following section provides highlights of the work that was accomplished by the NSCI agencies during fiscal year (FY) 2016.

Highlights of Accomplishments for FY2016

Highlights of the agencies' work in FY2016 to advance the NSCI are listed below within the categories of the five NSCI Strategic Objectives.

1. Capable Exascale

Considerable progress has been made in the past decade in developing and deploying computer systems that provide sustained petascale (10^{15} operations per second) performance in scientific and engineering simulations. Petascale-class computer systems are operating today across several Federal agencies. These systems provide essential capabilities in support of Federal missions in national security, global economic competitiveness, and science discovery. Petascale-class computers are also used in many commercial sectors, including aerospace, pharmaceuticals, and oil and gas exploration, and play a key role in U.S. economic competitiveness.

The next step up in performance, to exascale (10^{18} operations per second), has been assessed thoroughly over the last seven years and is now believed to be possible with extensions of the existing technology base in microelectronics. Strong national security, global economic competitiveness, and science discovery requirements alone provide ample justification for this objective, but commercial applications are also envisioned. Manipulation and analysis of large datasets, derived from experimental facilities, observations, and computer simulations, are playing increasing roles in science and national security applications. To address this objective, a whole-of-government approach will be required, including coordination among the lead agencies, the foundational research and development (R&D) agencies, and the deployment agencies to address basic research and co-design[20] processes.

The following projects support this objective:

- **Exascale Computing Project.** *DOE/NNSA, DOE/SC*
  DOE/SC and NNSA established the Exascale Computing Project (ECP) focused on the software and hardware research and development needed to deploy an exascale system in 2021 and a capable exascale system in 2023. The Exascale Mission Need Statement was approved in July 2016, and identification of the research plan was approved by the DOE Deputy Secretary on January 3, 2017. Twenty-five application projects and more than fifty software technology projects from within the Department have been selected to participate in ECP.

[20] Co-design processes concurrently develop hardware and software components of complex computer systems to optimize overall application performance.

- **Advanced computing solutions in cancer research.** *DOE/NNSA, DOE/SC, NIH/NCI*
  The National Cancer Institute (NCI) and the Department of Energy are working together on the Joint Design of Advanced Computing Solutions for Cancer (JDACS4C). This interagency collaboration aligns with the Precision Medicine Initiative, the Cancer Moonshot, and the National Strategic Computing Initiative. It aims to advance cancer research through the application of exascale computing capabilities. The collaboration involves four DOE national laboratories and multiple NCI components, including the Division of Cancer Treatment and Diagnostics, Division of Cancer Control and Population Sciences, the Center for Biomedical Informatics and Information Technology, and the Frederick National Laboratory for Cancer Research. Collaborative exploration is underway in three pilot areas reflecting scientific priorities of the NCI: to understand complex cancer biology; develop patient-derived models to accelerate the identification of new promising cancer treatments; and establish an integrated network for cancer patient information to better understand the impact of new diagnostics, treatments, and patient factors in cancer outcomes at the population level. The efforts of the collaboration are bolstered by the DOE-supported CANcer Distributed Learning Environment (CANDLE) project in ECP addressing a shared need across the pilots to develop predictive models using large-scale data. *This effort also contributes to NSCI Strategic Objective 4.*
- **Modular Supercomputing Facility Pilot Project.** *NASA*
  This HPC pilot project deploys technologies to prove the ability to field significant high-end computing assets while dramatically limiting the need for traditional cooling support. The project includes site preparation and deployment of an adiabatic module capable of powering 500 KW of compute. The infrastructure includes a secured concrete pad, a 2.5 MVa transformer, and switch gear. The module provides an intelligent operating environment that controls the flow of external air into the module, where it can be adjusted to cool through a moisturized filter or heated /dehumidified by mixing with exhaust air from the computers. The prototype computer system is a 1,152-node system capable of providing 1.2 petaflops, ranked 96th in the Top 500 list as of November 2016. The system is fully operational and is currently operating at a PUE (Power Usage Efficiency) of 1.03. NASA is measuring a 97% drop in electricity used for cooling and a 99% drop in the water used relative to the current facility. NASA will continue collecting data throughout FY2017.
- **Co-design: Global Modeling and Assimilation.** *NASA*
  NASA is working to understand the performance and scalability of the Goddard Earth Observing System (GEOS) atmospheric modeling and assimilation systems. GEOS is used at NASA for multiyear reanalysis of satellite observation data and the creation of synthetic atmospheric states to simulate existing and new observational systems. In looking forward toward even higher-resolution simulations for instrument and mission designs, NASA has worked to better understand the current state of the performance of the system, how the performance of the code scales, and how the current scaling compares to other comparable applications across the weather and climate community, such as the model used by the National Weather Service. One of the primary areas of research has been in studying the potential performance gain of mixed-mode parallelism, using MPI and OpenMP threads. Given the trends in processor technology, a mixed-mode parallel approach is needed to reach the next level of resolution and performance.
- **Novel techniques for prediction and analysis of failures in HPC systems.** *NSA (Advanced Computing Systems Research Program (ACS))*
  NSA, in collaboration with external labs and research institutions, explored novel techniques for predicting and analyzing failures in HPC systems. The approaches have been initially validated within a system simulation environment; current work is targeted toward improving the techniques and validating them in an existing HPC system.

2. Coherent Data Analytic Computing and Modeling and Simulation

There is an historical separation between usage modalities for data analytic computing and modeling/simulation. Data analytics focuses on inferring new understanding from what is already known, to allow acting on that information. Data assimilation, data compression, image analysis, machine learning, visualization, and data mining are all forms of data analytics. Both modeling/simulation and data analytics are essential and growing contributors to advancing understanding in science and engineering as well as informing policy and economic decision making. Increasingly complex multidisciplinary, multi-model simulations in multiple dimensions of both space and time are being supported by software investments by both Federal agencies and industries. Data analytics at ever growing scale, and often dynamic, is of increasing interest to both the public and private sectors as well. Many of the challenges facing both computing modes are similar; hence, there is an opportunity to develop more coherent platforms that satisfy both simulation/modeling and data analytics. Although some opportunities exist for convergent hardware advances at the component level, current challenges associated with this objective surface most clearly within and across software layers of the HPC environment.

The following projects support this objective:

- **Data Analytics Storage Systems.** *NASA*
  Facing tremendous growth in exascale model output, future HPC environments require tightly coupled compute resources with I/O devices optimized for streaming reads and writes to deal with the extremely large data sets. During FY2016, NASA started building a Data Analytics Storage System (DASS), which is a combination of industry compute and storage components architected to solve “Big Data” problems. The DASS is being designed to be both a POSIX file system and an Object Store. NASA is using a high-performance file system, which provides the POSIX interface to Hadoop/Spark and a custom spatiotemporal indexing approach that uses knowledge of the natively stored, structured scientific data to create a custom index for Hadoop queries. Rather than move the data to the application, this hardware and software architecture allows for the data analytics application to be moved into proximity to the data storage location.
- **Assessment of Data Analytics at Scale.** *NIST*
  NIST began an assessment of measurement needs for data analytics at scale, with initial emphasis on very-large-scale video analytics. Activities supporting this effort include the following:
    - Leading the development of an interagency R&D strategy for visible world video and image analytics under the auspices of the NITRD Video and Image Analytics Working Group. That document will provide the umbrella strategy for at least 30 major organizations across the Federal Government, laying the groundwork for future interagency collaborations.
    - Initiated a Data Science Evaluation Series to drive improvements in performance and reliability of large-scale data analytics tasks through community-wide participation in measurement and analysis tasks. The 2016 pilot evaluation focused on analysis of sensor, video, and other data related to vehicular traffic.
    - Initiated efforts to characterize reliability of measurements based on very-large-scale imagery.
    - Developing an effort on software and data validation and verification with one focus being terascale image reconstruction and processing.
- **Expanding the use of data informatics for improved environmental intelligence.** *NOAA*
  In FY2016, NOAA supported innovative projects aligned with the following three themes: (1) nontraditional NOAA users (e.g., users outside of the weather and climate disciplines); (2) data analytics; and (3) scientific workflow tools. These projects include engaging the power of citizen science for image analysis of marine mammals, the development of bioinformatics

computing capacity to support NOAA genomics research, building HPC-centric capabilities to support data analytics in aviation weather, and the development of voice recognition technologies for NOAA crab and groundfish survey applications.

- **Computer system simulation tools and models.** *NSA (ACS)*
  NSA collaborated with external partners to develop multiple computer system simulation tools and models. Many of these have been used to explore potential novel architectures for both data analytics and traditional high-performance computing. A set of training materials were developed to educate new users, and multiple tutorials were held, including one at Supercomputing 2016. More than 20 research institutions and companies are utilizing these tools to support architectural explorations of next-generation computing systems. *This effort also contributes to NSCI Strategic Objectives 4 and 5.*
- **Jet Energy-loss Tomography with a Statistically and Computationally Advanced Program Envelope (JETSCAPE) Collaboration.** *NSF*
  NSF has issued an award[21] to develop sophisticated numerical modeling, simulation, and data analytics tools for nuclear physics. The JETSCAPE Collaboration, a multi-institutional, interdisciplinary team of physicists, computer scientists, and statisticians, will develop a comprehensive software framework that will provide a systematic, rigorous approach to meet this challenge. The JETSCAPE Collaboration will also support training programs, workshops, summer schools, and MOOCs to build the expertise needed to modify and maintain this framework. *This effort also aligns with Objective 4.*

3. Computing Beyond Moore's Law

This objective explores fundamentally new foundations for U.S. global computing advantage well into the middle of this century. Success will demand execution of two parallel lines of effort over a 10–20-year period: the research and development of technologies that will move digital computing performance past the limits of CMOS (complementary metal oxide semiconductor), and the research and development of alternative computing paradigms that will open new possibilities.

While very-large-scale efforts may allow incremental semiconductor approaches to be feasible at the exascale and beyond, this approach will eventually plateau due to the physical limitations inherent in semiconductor technologies. Considering this barrier, future computing technologies will explore fundamentally different materials and unique architectural approaches to address requirements such as increased density or lower energy.

The alternative computational paradigms—whether quantum, neuromorphic, or other alternatives—may solve some classes of problems that are intractable with digital computing and provide more efficient solutions for some other classes of problems. To achieve this vision, it is as essential to research the range of computational problems served by these approaches as it is to further the basic R&D that will enable them. For those problems that will remain in the digital computing domain, increasing performance beyond exascale or further reductions in energy cost may not be feasible with current semiconductor technologies. To address these challenges, NSCI activities must explore and create new highly scalable, programmable, power efficient, and economically viable computing technologies.

[21] http://www.nsf.gov/awardsearch/showAward?AWD_ID=1550300

The following projects support this objective:

- **Alternate Computing Paradigms Project.** *DOE/SC*
  DOE has invested in a suite of efforts to continue developing the research base for "post-Moore's-Law era" computing. These activities include meetings, such as a workshop on neuromorphic computing and a science roundtable with representatives from national laboratories and universities on quantum-based sensors; release of a request for proposals on machine learning research; and creation of strategic partnerships with the private sector to establish testbeds for Post Moore's Law computing systems in energy-efficient machines that mimic the brain's abilities.
- **Beyond Moore's Law Investigation.** *DOE/SC*
  DOE held several workshops/meetings to help define the technical challenges and program approaches for a Beyond Moore's-Law program for digital microelectronics. These meetings included participation from DOE Lab representatives, industry leaders, academia, and other stakeholders. The approach involves the integration of research activities across the spectrum of microelectronics science, computer science, engineering, and applications through the co-design process (i.e., integration across materials, devices, components, architecture, and algorithms) to ensure their readiness for use at the end of the R&D cycle.
- **Beyond Moore's Law Computing for Stockpile Stewardship.** *DOE/NNSA*
  NNSA is investigating the application of quantum and neuromorphic computing algorithms and hardware to NNSA computing needs. The goal is to gain a detailed understanding and investigate the best technical approaches and benefits of these emerging technologies for NNSA applications and to develop a roadmap for their integration into the NNSA HPC platforms.
- **Cryogenic Computing Complexity (C3) Program.** *IARPA*
  IARPA's C3 program will deliver a working prototype superconducting computer at the end of five years (2019) and evaluate superconducting computing as a post-Moore technology for high-performance computing applications. Superconducting technology will provide significant power, space, and cooling advantages over conventional electronics. C3 made significant advances in 2016:
  - Researchers demonstrated working memory elements that switch at least one million times without error, which is sufficiently reliable for a working memory.
  - Researchers designed, fabricated, and tested key decoder, read, and write circuits.
  - Researchers delivered benchmark circuits and successfully tested components of an eight-bit processor.
- **Machine Intelligence from Cortical Networks (MICrONS) Program.** *IARPA*
  IARPA's MICrONS program uses leading theories of cortical computation and the known structure and function of cortical microcircuits to guide the development of novel machine learning algorithms. The first generation of these algorithms, delivered in December 2016, uses predictive coding, divisive normalization, and sparse coding principles to accelerate learning and improve performance on challenging visual recognition tasks. In parallel with these efforts, the MICrONS program has built software infrastructure for managing petabyte-scale neuroscience data sets in the cloud and has used this resource in conjunction with advanced brain imaging technologies to build the largest-ever map of the structure and function of cortical microcircuits in a behaving animal. Insights gained from analyzing these data will guide machine learning algorithm development efforts during future years.
- **Logical Qubits (LogiQ) Program.** *IARPA*
  IARPA's LogiQ program seeks to build and operate an extensible logical quantum bit (qubit) from several imperfect physical qubits with active error correction. The program kicked off in February

2016. Since then, LogiQ researchers have developed system designs for realizing a full quantum error correction demonstration and have improved on the many building blocks that will be required. Successes so far include suppressing time-correlated gate errors using dynamically corrected gates, and demonstration of small-error-detecting codes. In addition, LogiQ has deployed state-of-the-art characterization protocols and software. Success in LogiQ will inform the feasibility of quantum computers and reveal the correct focus for future efforts.

- **Workshop "DNA-based Massive Information Storage."** *IARPA*
  In April 2016, IARPA held the workshop on "DNA-based Massive Information Storage" in Arlington, VA, to explore the feasibility of using DNA as a next-generation data storage medium. DNA has an extraordinary information storage density—with a theoretical limit above 1 exabyte/mm^3 (eight orders of magnitude denser than magnetic tape)—and stability measured in centuries. This workshop explored how recent advances in information theory and methods for DNA synthesis and sequencing might be combined with semiconductor technology to implement a low-power and compact "DNA hard drive" with exabyte storage capacity for archival data.

  Exploratory studies and seedling projects. *IARPA*
  During 2016 IARPA conducted exploratory studies and seedling projects supporting NSCI Goal 3 on the following topic areas: Optical processor for filtering and selection, Studies in Quantum Science (STIQS), Developmental Interim Rudimentary Analysis Capability (DIRAC) for quantum information systems, Single Flux Quantum Software, Novel Quantum Algorithms, and Rapid Machine-learning Processing Applications and Reconfigurable Targeting of Security (RAMPARTS).
- **Quantum Computing Projects.** *NASA*
  NASA has supported several R&D programs within its Quantum Computing Project:
  - Quantum annealing (QA) explorations on D-Wave 2X: NASA quantified performance improvements on D-Wave 2X over D-Wave Two on a parameterized family of scheduling problems. NASA developed complete quantum-classical preprocessing, programming, and annealing run parameter strategies for scheduling problems. NASA demonstrated machine learning using the D-Wave 2X as a Boltzmann sampler and has developed a more recent, even more powerful approach.
  - For fault diagnosis, NASA has developed a suite of libraries generating benchmarks for the most difficult model-based diagnosis (strong fault model) in combinatorial circuits, and it has performed extensive numerical simulations that indicate that fault diagnosis benchmarks are more challenging to solve than any previous QA benchmarks.
  - NASA developed an analytical approach to dealing with the strong noise regime, with applications to verification and calibration of hardware multi-qubit dynamics and to quantifying the limits of speedup over quantum Monte Carlo (QMC) from finite range quantum tunneling. Researchers also quantified the deviation from fair sampling, proposed a new approach to fair sampling, and quantified the limits of QA speedup over QMC from quantum tunneling.
- **In-Operando Measurements and Characterization for Future Computing Technologies.** *NIST*
  NIST has initiated a research program to enable the design, assessment, and operation of advanced devices, device materials, and concepts such as precise placement of individual atoms, new fabrication methods, new imaging modalities of complex structures, low-dimensional material heterostructures, and cryogenic compatible processing and memory elements.

- **Prototype devices for alternative computational paradigms.** *NIST*
  NIST is developing the measurements and prototype devices required to support alternative computational paradigms, including both neuromorphic and quantum computing; this included:
  - Exploring a range of metrological tools relevant to alternative approaches to neuromorphic computing.
  - Developing novel statistical procedures for characterizing the fidelity of qubit states in different physical systems, e.g., trapped ions, neutral atoms, photons and superconducting qubits. The underlying concept is based on randomized benchmarking for quantum gates.
  - Developing new improved ion traps that have integrated UV detectors with the goal of routinely entangling 10-20 ions.
  - Developing the metrology and characterization tools required for single atom structure for both traditional and quantum computing, including the growth, hydrogen lithography, and characterization of isotopically pure 28Si films.
  - Creating the metrology for single-photon transistors that could be used for ultra-high-speed classical or quantum computing.
  - Developing a suite of tools for characterizing quantum many-body states.
  - Developing a broad program in transducing quantum signals from one motif to another with the goal of efficient transduction of quantum signals essential for a quantum computer.
- **Advanced concepts and technologies for neuromorphic computing.** *NSA (ACS)*
  NSA collaborated with the Air Force Research Lab and other labs and research institutions to explore and develop a wide variety of advanced concepts and technologies to support neuromorphic computing. *This effort also contributes to NSCI Strategic Objective 5.*
- **Probabilistic computing**. *NSA (ACS)*
  NSA collaborated with other labs and research institutions to explore algorithms, architectures, and technologies focused on probabilistic computing for a variety of computing applications. The results have been presented at a variety of workshops and conferences and in technical journals.
- **Energy-Efficient Computing: from Devices to Architectures (E2CDA).** *NSF*
  NSF has issued 16 awards under E2CDA, a joint solicitation with industry (Semiconductor Research Corporation) for research to minimize the energy impacts of processing, storing, and moving data within future computing systems.[22] *This effort also aligns with NSCI Objective 5.*

4. An Enduring National HPC Ecosystem

The Nation's economic and scientific competitiveness requires significant investment and innovation in large-scale computational infrastructure (software, hardware, and people). The need for change is driven by the growing complexity and size of simulations; the expansion of the role of large-scale computation in emerging frontiers of science; and the need for dynamic interaction of computation with other elements of the cyberinfrastructure, e.g., instruments, large data repositories, and mobile devices. For HPC to be effective within a dynamic, data-rich, and collaborative ecosystem, it must be easily "accessible". However, greater accessibility and interweaving with production environments increase the exposure of HPC capabilities to the full spectrum of cyber threats. Increased investments in people, applications, and a variety of innovative technologies are required, as well as creative approaches to ensure that overall productivity is maximized and sustained.

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[22] https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505212

The following projects support this objective:

- **High Performance Computing (HPC) Portal.** *DoD (HPCMP)*
The HPC Portal is a framework for building easier-to-use HPC applications and provides zero-footprint secure access to DoD supercomputers via a web browser. In 2016, a microservices architecture was implemented to enhance performance for the current user base; it can be affordably scaled to a much larger user base. This will eliminate the need for users to download and install special software on their local machines, while providing the security necessary to protect the confidentiality, integrity, and availability of sensitive engineering designs or any other export-controlled data or software. The HPCMP will continue to support lowering barriers to entry and improving user productivity on HPC systems through this and other HPCMP programs.
- **Report: Joint Agency Assessment of Responses to the Request for Information (RFI) on "Science Drivers Requiring Capable Exascale High Performance Computing."** *DOE, NIH, NSF*
In support of efforts to develop an interagency common understanding of the science drivers and applications that will be advanced by exascale resources, in the fall of 2015, NSF, DOE, and NIH published a Joint RFI under public notice NOT-GM-15-1222. In the summer of 2015, DOE issued a similar RFI to the DOE National Laboratories, and in the winter of 2015, an RFI was issued to the NIH Intramural Research Principles community. The resulting Science Drivers report[23] provides a joint assessment by NIH, DOE, and NSF of the scientific and engineering research community's science drivers requiring capable exascale high performance computing.
- **High-Performance Computing Security Workshop.** *NIST with input from DOE, DOD, NSF, NASA*
NIST hosted a workshop on HPC security September 29-30, 2016, that was jointly planned by many NSCI agencies. The purpose of the workshop was to identify security priorities and principles that should be incorporated into the NSCI strategy to bring together stakeholders from industry, academia, and government, and to identify gaps that should be addressed. NIST is working with the participants from industry, academia, and HPC user facilities to create the workshop report. *This effort also contributes to NSCI Strategic Objective 5.*
- **Improved computing capability for advanced environmental intelligence.** *NOAA*
NOAA increased its HPC capacity for R&D with the introduction of new systems. In September 2016, the R&D HPC Program introduced c4, which is the newest addition to the Gaea supercomputer located at Oak Ridge National Laboratory in Oak Ridge, Tennessee. Gaea is operated under a collaborative agreement with the Department of Energy. c4 is a 2.25 Petaflop (PF) Cray XC40 supercomputer that will increase Gaea's existing capability to 4.02 PF. The system was made available for general use in October of 2016. In December 2016, NOAA formally accepted the latest addition to its HPC portfolio. A 2000 core fine-grain system with 800 graphical processing units (GPU) was made available to NOAA scientists and their collaborators as an augmentation of the Theia HPC system at the NOAA Environmental Security Center in Fairmont, WV. The augmentation almost triples the peak performance of Theia, from 1.1 petaflops to 3 petaflops. These systems will be used to advance NOAA environmental modeling research and to explore the performance of NOAA models on a new architecture at a large scale. Together, these systems bring NOAA's total peak performance to over 8 petaflops for its R&D HPC computing, in addition to nearly 6 petaflops of peak performance on NOAA's Weather and Climate Operational Supercomputing System (WCOSS).

[23] https://www.bisti.nih.gov/SiteAssets/Pages/Home/NIH-DOE-NSF_Joint_Assessment.Exascale_RFI_02-13-17.pdf

- **New models and software development efforts to improve the performance of operational weather prediction.** *NOAA*
  In July 2016, NOAA announced the selection of a new dynamical core, which is the engine of a numerical weather prediction model, and will begin developing a state-of-the-art global weather forecasting model to replace the current forecast system. The new dynamic core, Finite-Volume on a Cubed-Sphere (FV3), brings a new level of accuracy and numerical efficiency to the model's representation of atmospheric processes such as air motions. This makes possible simulations of clouds and storms, at resolutions not yet used in an operational global model. NOAA R&D HPC was critical to the development of FV3, and NOAA's WCOSS will execute the new forecast system when it becomes operational in 2019.[24] NOAA's Software Engineering for Novel Architectures (SENA) project has begun supporting the Next Generation Global Prediction System (NGGPS) modeling effort. Analysis and refactoring of FV3, the selected dynamical core for the NGGPS described above, is underway. This effort should not only prepare the model for fine-grain architectures but also enhance performance on traditional architectures. SENA researchers have also been working on optimized I/O libraries for fine-grain systems. The SENA project has put together an experimental system comprised of forward-looking architectures so that developers can understand the viability of software and hardware for such systems. Smaller efforts have been undertaken in the area of deep learning to determine which portions of NOAA's workload could benefit from hardware and software tuned for deep learning.
- **Advanced concepts and technologies for neuromorphic computing.** *NSA (ACS)*
  NSA collaborated with the Air Force Research Lab and private sector research institutions to explore and develop a wide variety of advanced concepts and technologies to support neuromorphic computing. *This effort also aligns with NSCI Objective 5.*
- **Increased capacity and capability of diverse HPC resources and services.** *NSF*
  - Given the growth in use of HPC to advance fundamental research in scientific and engineering discovery, NSF strategically complements the larger academic investments in HPC with a unique portfolio of national resources beyond the reach of a single institution and open competitively to all U.S. researchers. Collectively, these resources and services contribute to a diverse pool of forward-looking computational data-intensive capabilities critical to NSCI Objectives 2 and 4.
  - Sustained leadership in the use of HPC to advance research relies on robust and innovative community methods, algorithms, and software approaches to solving increasing complex multidisciplinary challenges. Continuing to lay the groundwork for future investments in the NSCI, NSF issued two awards[25] for the creation of the first Scientific Software Innovation Institutes, the largest awards in the Software Infrastructure for Sustained Innovation Program. In addition, a small conceptualization award was made in anticipation of community software infrastructure necessary for U.S. academic participation in analysis of data from new experiments at the Large Hadron Collider at CERN (the European Organization for Nuclear Research). Each of these three awards will support the development of sustainable community scientific software platforms.

5. Public-Private Collaboration

HPC in the United States has been developed historically through close partnerships between Federal agencies and industry. Urgent national security imperatives in cryptography and nuclear weapons

[24] http://www.noaa.gov/media-release/noaa-to-develop-new-global-weather-model
[25] http://www.nsf.gov/awardsearch/showAward?AWD_ID=1547580

programs were the early drivers of these collaborations. Since the 1960s, HPC has played an increasingly dominant role in scientific discovery and the innovation that underpins U.S. economic competitiveness. U.S. Government agencies, including DOD, DOE, NSF, and DOC, have been deeply engaged.

The NSCI is structured to build on these strengths and expand upon this history. As such, Strategic Objective 5 embodies the following principles to:

- Enable access to the developing technologies through ongoing co-design activities.
- Recognize the opportunities for U.S. innovation from exascale technologies from the component level to larger-scale systems.
- Ensure that research and development advances under the NSCI are shared to the greatest extent possible among relevant government, industrial, and academic partners.
- Incentivize or encourage growth in the U.S. and global HPC marketplace.

The following FY2016 projects support this objective:

- **ECP PathForward Program.** *DOE/NNSA, DOE/SC*
  The ECP team released an RFP to fund exascale computer technology providers to work on critical R&D technologies relating to exascale node and system designs that would most likely be proposed in response to future exascale systems RFPs. The funded projects will engage in a holistic co-design process that will involve the ECP application and software teams.
- **Quantum computing industry partnerships.** *NASA*
  NASA's work in public-private partnerships will enable NASA to explore quantum heuristics beyond quantum annealing on vendor hardware, while NASA continues to experiment with quantum annealing on quantum annealers.
- **Collaborations with individual researchers.** *NSA (ACS)*
  NSA hosted over 1200 visitors in FY2016, and collaborated with 16 visiting researchers who spent some or all of the year at NSA's Laboratory for Physical Sciences (LPS) facility.
- **National Academies of Sciences, Engineering, and Medicine study.** *NSF*
  NSF commissioned a National Academies of Sciences, Engineering, and Medicine study to examine priorities and associated trade-offs for advanced computing investments and strategy during 2017-2020. The 2016 report[26] is informing NSF's role and plans for all NSCI Objectives.
- **EAGER: Evaluating and Disseminating Effective Practices in Partnerships between HPC Centers and Industry.** *NSF*
  This NSF award[27] aims to identify, analyze, and document effective practices in establishing public-private partnerships between HPC centers and industry. The results will be publicly available to ensure broad dissemination across agencies, academia, and industry.

[26] National Academies of Sciences, Engineering, and Medicine, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017–2020* (Washington, DC: The National Academies Press, 2016); https://www.nsf.gov/news/news_summ.jsp?cntn_id=138529
[27] http://www.nsf.gov/awardsearch/showAward?AWD_ID=1560770

Appendix C. Definitions of FY2018 NITRD Program Component Areas

CHuman—Computing-Enabled Human Interaction, Communication, and Augmentation

Research and development activities on computing- and information-enabled systems that respect and enhance an individual's ability to interact both with the system itself and with others. This includes R&D around systems that model and improve perceptual, cognitive and physical capabilities. Examples include large-scale distributed engineering, team science, human-machine teams, novel interaction techniques and visualization. CHuman systems and research are informed by social, behavioral, and economic science, human-computer interactions, computer-supported cooperative work, social computing, and interaction techniques for contexts in which perceptual and physical abilities are constrained. Also included are the systems and models that help teams, groups, and communities accomplish collective goals such as rational decision-making, command and control, collaborative problem-solving, interpersonal interactions, information sharing and social development. For both individuals and groups, CHuman supports R&D efforts that combine the strengths of humans and computers to improve mission effectiveness and societal benefits including health and well-being, safety and security, and education and training.

CNPS—Computing-Enabled Networked Physical Systems

CNPS supports development of scientific foundations and innovative and enabling software and hardware technologies for the engineering, verification and validation, assurance, standardization, and certification of complex, networked, distributed computing systems and cyber-physical (IT-enabled) systems (CPS). The goal is to enable seamless, fully synergistic integration of computational intelligence, communication, control, sensing, actuation, and adaptation with physical devices and information processes to routinely realize high-confidence, optimally performing systems that are essential for effectively operating life-, safety-, security-, and mission-critical applications. These systems must be capable of interacting correctly, safely, and securely with humans and the physical world in changing environments and unforeseen conditions. In many cases, they must be certifiably dependable. The vision is to realize dependable systems that are precise and highly efficient; respond quickly; work in dangerous or inaccessible environments; provide large-scale, distributed coordination; augment human capabilities; and enhance societal quality of life. New science and technology are needed to build these systems with computing, communication, information, and control pervasively embedded at all levels, thus enabling entirely new generations of engineering designs that can enhance U.S. competitiveness across economic and industrial sectors.

CSIA—Cyber Security and Information Assurance

CSIA focuses on research and development to detect, prevent, resist, respond to, and recover from actions that compromise or threaten to compromise the availability, integrity, or confidentiality of computer- and network-based systems. These systems provide the IT foundation in every sector of the economy, including critical infrastructures such as power grids, financial systems, and air-traffic-control networks. These systems also support national defense, homeland security, and other Federal missions. Broad areas of emphasis include Internet and network security; security of information and computer-based systems; approaches to achieving hardware and software security; testing and assessment of computer-based systems security; reconstitution of computer-based systems and data; and resilience against cyber attacks on computer-based systems that monitor, protect, and control critical infrastructure.

EdW—Education and Workforce

Education and workforce issues in networking and information technology, ranging from the individual to societal levels. This includes the broad range of information, communication, and related technologies that can be used to support learning, teaching, and assessment, including identifying gaps and approaches for intentional preparation of next-generation IT professionals along with associated evaluation activities.

EHCS—Enabling-R&D for High-Capability Computing Systems

Research and development to enable advancements in high-capability computing systems, spanning the hardware, software, architecture, system performance, computational algorithms, data analytics, development tools, and software methods for extreme data- and compute-intensive workloads; and developing fundamentally new approaches to high-capability computing systems.

HCIA—High-Capability Computing Infrastructure and Applications

Large-scale, shared information technology infrastructure that supports or enables high-capability computing R&D, including computation- and data-intensive systems and applications, and associated software, communications, storage, and data management infrastructure.

LSDMA—Large-Scale Data Management and Analysis

Large-scale data management and analysis to develop the ability to analyze and extract knowledge and insight from large, diverse, and disparate sources of data, including the mechanisms for data capture, curation, management, and access.

LSN—Large-Scale Networking

LSN focuses on coordinating Federal agency networking R&D in leading-edge networking technologies, services, and enhanced performance. This includes programs in fundamental networking research and architectures, future Internet architectures, wireless networks, software-defined networks, heterogeneous multimedia networks, testbeds, and end-to-end performance and performance measurement. Program coordination also spans network security, privacy, and identity management; dynamic inter-domain networking; public service networks; the science and engineering of complex networks; network infrastructures for advanced discovery environments; network-enabling technology; networking education, training, and outreach; and cyberinfrastructure for scientific and applications R&D.

RIS—Robotics and Intelligent Systems

Robotics and intelligent systems to advance physical and embodied computational agents that complement, augment, enhance, or emulate human physical capabilities or human intelligence. This includes robotics hardware and software design, application, and practical use; machine perception; intelligent cognition, adaptation, and learning; mobility and manipulation; human-robot interaction; distributed and networked robotics; increasingly autonomous systems; and related applications.

SDP—Software Design and Productivity

Science and technology needed to advance timely and affordable creation and sustainment of quality software. The research addresses software qualities, e.g., low defect rates, security, resilience, and robustness. SDP includes R&D around software productivity, software quality, software cost, software economics, measurement of software and its production, responsiveness to change, and software sustainability. SDP R&D contributes to productivity, quality, and sustainability for sustainably secure systems development, high-capability computing systems, big data (i.e., large-scale data management and analysis), health IT, medical devices, cyber physical systems, Internet of Things, and software-defined infrastructure.

Appendix D. List of Abbreviations

ACS	Advanced Computing Systems research program (NSA)
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AHRQ	Agency for Healthcare Research and Quality (HHS)
AMC	U.S. Army Materiel Command
ANI	Advanced Networking Initiative
ARC	Appalachian Regional Commission
ARL	Army Research Laboratory
ARO	Army Research Office
BD2K	Big Data to Knowledge program (NIH)
BLS	U.S. Bureau of Labor Statistics
BOC	Broadband Opportunity Council
BRD	Broadband Research and Development Group (NITRD)
BUILD	Building Infrastructure Leading to Diversity program (NIH)
CDC	Centers for Disease Control and Prevention (HHS)
CDS&E	Computational and Data-Enabled Science and Engineering program (NSF)
CEA	Council of Economic Advisors (EOP)
CEMMSS	Cyber-Enabled Materials, Manufacturing, and Smart Systems
CEQ	Council on Environmental Quality (EOP)
CERDEC	Communications-Electronics Research, Development, and Engineering Center (U.S. Army)
CHuman	Computing-Enabled Human Interaction, Communication and Augmentation (PCA)
CIA	Central Intelligence Agency
CMOS	complementary metal oxide semiconductor
CNPS	Computing-enabled Networked Physical Systems (PCA)
COI	community of interest
CoP	community of practice
COTs	commercial off-the-shelf technologies
CPS	cyber-physical systems
CPS	Cyber Physical Systems IWG
CSE	computational science and engineering
CSIA	Cybersecurity and Information Assurance (PCA and IWG)
CSIA	Cyber Security and Information Assurance Division (U.S. Army)
DARPA	Defense Advanced Research Projects Agency
DDoS	distributed denial of service
DHS	Department of Homeland Security
DISA	Defense Information Systems Agency
DNSSEC	domain name system security extensions
DOC	Department of Commerce
DoD	Department of Defense
DoDIIS	DoD Intelligence Information Systems
DOE	Department of Energy
DOE/EERE	DOE Office of Energy Efficiency and Renewable Energy
DOE/EM	DOE Office of Environmental Management
DOE/INL	DOE Idaho National Laboratory
DOE/NNSA	DOE National Nuclear Security Administration
DOE/OE	DOE Office of Electricity Delivery and Energy Reliability
DOE/SC	DOE Office of Science
DOJ	Department of Justice
DOS	Department of State
DOT	Department of Transportation
DPC	Domestic Policy Council (EOP)
DREN	Defense Research and Engineering Network (DoD)
DSA	dynamic spectrum access
DTN	delay-tolerant networking
DTRA	Defense Threat Reduction Agency (DoD)
ECP	Exascale Computing Project (DOE)
ED	Department of Education
EDD	embedded digital device
EdW	Education and Workforce (PCA)
EHCS	Enabling R&D for High-Capability Computing Systems (PCA)

ENIGMA	Enhancing Neuro Imaging Genetics through Meta Analysis global network
EOP	Executive Office of the President
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FAA	Federal Aviation Administration (DOT)
FASTER	Faster Administration of Science and Technology Education and Research Community of Practice
FBI	Federal Bureau of Investigation
FCC	Federal Communications Commission
FC-STEM	Federal Coordination in STEM Education
FDA	Food and Drug Administration
FDIC	Federal Deposit Insurance Corporation
FHWA	Federal Highway Administration (DOT)
FIA-NP	Future Internet Architectures Next Phase program (NSF)
FTAC	Fast Track Action Committee
FY	fiscal year
Gbps	Gigabits per second
GCTC	Global Cities Teams Challenge
GENI	Global Environment for Networking Innovations program (NSF)
GSA	General Services Administration
HCI&IM	Human Computer Interaction and Information Management (PCA)
HCIA	High-Capability Computing Infrastructure and Applications (PCA)
HCS	High-capability computing systems
HCSS	High Confidence Software and Systems (PCA)
HEC	High End Computing (IWG)
HHS	Department of Health and Human Services
HHS/HRSA	HHS Health Resources and Services Administration
HITRD	Health Information Technology Research and Development Community of Practice
HPC	high-performance computing
HPC Act	High-Performance Computing Act, originally enacted in 1991 and in 2017 amended in Public Law 114-329
HPCMP	High Performance Computing Modernization Program (DoD)
HUD	U.S. Department of Housing and Urban Development
I/O	input/output
IARPA	Intelligence Advanced Research Projects Activity
ICS	industrial control systems
IIS	Intelligence Information Systems (DoD)
IMLS	Institute of Museum and Library Services
Internet2	a higher-education consortium for advanced networking and applications deployment in academic institutions
IoT	Internet of Things
IPv6	Internet Protocol version 6
IRAS	Intelligent Robotics and Autonomous Systems (IWG)
IT	information technology
ITA	International Trade Administration (DOC)
IWG	Interagency Working Group
JET	Joint Engineering Team (LSN subgroup)
JIDO	Joint Improvised-Threat Defeat Organization (DTRA)
LSDMA	Large Scale Data Management and Analysis (PCA)
LSN	Large Scale Networking (PCA and IWG)
MAGIC	Middleware and Grid Interagency Coordination Team (LSN subgroup)
MLAI	Machine Learning and Artificial Intelligence (NSTC Subcommittee)
MOOC	massive open online course
MOU	Memorandum of Understanding
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NBRA	National Broadband Research Agenda
NCSC	National Counterintelligence and Security Center (ODNI)
NCTC	National Counterterrorism Center (ODNI)
NERC	North American Electric Reliability Corporation
NERSC	National Energy Research Scientific Computing Center (DOE/SC)

NeTS	Networking Technology and Systems program (NSF)
NGA	National Geospatial-Intelligence Agency (DoD)
NICE	National Initiative for Cybersecurity Education
NIDILRR	National Institute on Disability, Independent Living, and Rehabilitation Research (HHS)
NIH	National Institutes of Health (HHS)
NIH/NIBIB	NIH National Institute of Biomedical Imaging and Bioengineering
NIJ	National Institute of Justice (DOJ)
NIOSH	National Institute for Occupational Safety and Health (HHS/CDC)
NIST	National Institute of Standards and Technology
NITRD	Networking and Information Technology Research and Development (Program or Subcommittee of the NSTC Committee on Technology)
NLM	National Library of Medicine (NLM)
NOAA	National Oceanic and Atmospheric Administration
NPRS	National Privacy Research Strategy
NRC	Nuclear Regulatory Commission
NRECA	National Rural Electric Cooperative Association
NRI	National Robotics Initiative
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NSA	National Security Agency
NSCI	National Strategic Computing Initiative
NSF	National Science Foundation
NSRDEC	Natick Soldier Research Development and Engineering Center (U.S. Army)
NSTC	National Science and Technology Council
NTIA	National Telecommunications and Information Administration (DOC)
N-Wave	NOAA's high-speed network
ODNI	Office of the Director of National Intelligence
OFR	Office of Financial Research (Treasury)
ONC	Office of the National Coordinator for Health Information Technology (HHS)
ONR	Office of Naval Research
OpenFlow	Open protocol for software-defined networks
OSD	Office of the Secretary of Defense
OSTP	White House Office of Science and Technology Policy
PAWR	Platforms for Advanced Wireless Research (NSF)
PCA	Program Component Area
PCAST	President's Council of Advisors on Science and Technology
PerfSONAR	performance-focused Service-Oriented Network monitoring Architecture
PF	Petaflop(s), a thousand teraflops
PI	principal investigator
R&D	research and development
RDECOM	Research, Development and Engineering Command (U.S. Army)
RF	radio frequency
RIS	Robotics and Intelligent Systems (PCA and IWG)
ROS	Robot Operating System
RSIG	Remote Sensing Information Gateway
S&CC	Smart and Connected Communities program (NSF)
S&T	science and technology
S&TCD	Space & Terrestrial Communications Directorate (U.S. Army)
SATCOM	satellite communications
SBIR	Small Business Innovation Research (Federal programs)
SC	Social Computing (IWG)
SCC	Smart Cities and Communities (NITRD task force)
SciDAC	Scientific Discovery through Advanced Computing program (DOE/SC)
Science DMZ	Science demilitarized zone, a computer subnetwork structured both to be secure and to handle high-volume data transfers typical of scientific and high-performance computing
SDI	software defined infrastructure
SDN	software defined network
SDP	software defined perimeter
SDP	Software Design and Productivity (PCA)
SDX	software-defined Internet exchange

SEI Software Engineering Institute

SEW Social, Economic, and Workforce Implications of IT and IT Workforce Development (PCA prior to FY2018)

SI^2 Software Infrastructure for Sustained Innovation program (NSF)

SpecEES Spectrum Efficiency, Energy Efficiency, and Security (NSF)

SPSQ Software Productivity, Sustainability, and Quality (IWG)

SRC Semiconductor Research Corporation

SSPARC Shared Spectrum Access for Radar and Communications

STEM science, technology, engineering, and mathematics

SWaP size, weight, and power

TACC Texas Advanced Computing Center

TF teraflop(s), a trillion floating-point operations per second

TIC trusted Internet connection

TICAP trusted Internet connection access provider

Treasury Department of the Treasury

TRIPODS Transdisciplinary Research In Principles of Data Science (NSF)

UAV unmanned aerial vehicle

USAF U.S. Air Force

USAID United States Agency for International Development

USDA U.S. Department of Agriculture

USDA/NIFA USDA National Institute of Food and Agriculture

USGS U.S. Geological Survey (Interior)

US Ignite A U.S. nonprofit partnership fostering creation of next-generation Internet applications to meet national priorities

USSS United States Secret Service

V&V verification and validation

VA Department of Veterans Affairs

WSRD Wireless Spectrum Research and Development (IWG)

XD eXtreme Digital program (NSF)

XSEDE Extreme Science and Engineering Discovery Environment (NSF)

National Science and Technology Council

Subcommittee on Networking and Information Technology Research and Development

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