THE NETWORKING & INFORMATION TECHNOLOGY RESEARCH & DEVELOPMENT PROGRAM

SUPPLEMENT TO THE PRESIDENT'S FY2020 BUDGET

Product of the

SUBCOMMITTEE ON NETWORKING & INFORMATION TECHNOLOGY RESEARCH & DEVELOPMENT

COMMITTEE ON SCIENCE & TECHNOLOGY ENTERPRISE

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

SEPTEMBER 2019

About the National Science and Technology Council

The National Science and Technology Council (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 enterprise. A primary objective of the NSTC is to ensure that science and technology policy decisions and programs are consistent with the President's stated goals. The NSTC prepares research and development strategies that are coordinated across Federal agencies aimed at accomplishing multiple national goals. The work of the NSTC is organized under committees that oversee subcommittees and working groups focused 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. More information is available at https://www.whitehouse.gov/ostp.

About the Subcommittee on Networking & Information Technology Research & Development

The Networking and Information Technology Research and Development (NITRD) Program is the Nation's primary source of federally funded work on pioneering information technologies (IT) in computing, networking, and software. The NITRD Subcommittee of the NSTC Committee on Science and Technology Enterprise guides the multiagency NITRD Program in its work to provide the research and development (R&D) foundations for ensuring continued U.S. technological leadership and meeting the needs of the Nation for advanced IT. The National Coordination Office (NCO) supports the NITRD Subcommittee and the Interagency Working Groups (IWGs) that report to it. More information is available at https://www.nitrd.gov/about/.

About the NITRD National Coordination Office

The National Coordination Office (NCO) supports the NITRD Program, the NITRD Subcommittee, and its IWGs by providing technical expertise, planning, coordination, and a central point of contact for the Program. The NCO is a catalyst for collaboration, information exchange, and outreach for U.S. global leadership in networking and information technology and its applications. Working with NITRD agencies and IWGs, the NCO prepares and publishes the annual NITRD Supplement to the President's Budget. More information is available at https://www.nitrd.gov/about/.

About This Document

This document is a supplement to the President's FY2020 Budget Request to Congress. It describes research and development coordination activities planned for FY2020 by the Federal agencies participating in the Networking and Information Technology Research and Development (NITRD) Program. It reports actual investments for FY2018, estimated investments for FY2019, and requested funding levels for FY2020 by agency and Program Component Area (PCA). For the FY2020 budget request, this Supplement identifies strategic priorities, key programs, and key coordination activities for each NITRD PCA. An appendix to the Supplement, *FY2020 Federal Cybersecurity R&D Strategic Plan Implementation Roadmap*, lists existing and proposed Federal R&D projects and programs that address the Nation's critical cybersecurity challenges; the roadmap is available at https://www.nitrd.gov/pubs/FY2020-Cybersecurity-RD-Roadmap.pdf.

Acknowledgments

This Supplement to the President's Budget was developed through the contributions of NITRD's Federal agency members, the NCO staff, and representatives of other Federal agencies participating in the NITRD Program.

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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 participate in the NITRD Subcommittee.

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- Health Resources and Services Administration (HRSA)

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- Federal Bureau of Investigation (FBI)
- Justice Management Division (JMD)

Department of Labor (DOL)
- Bureau of Labor Statistics (BLS)
- Occupational Safety and Health Administration (OSHA)

Department of Transportation (DOT)
- Federal Aviation Administration (FAA)
- Federal Highway Administration (FHWA)
- Intelligent Transportation Systems Joint Program Office (ITS JPO)

Department of the Treasury (Treasury)

Department of Veterans Affairs (VA)

Equal Employment Opportunity Commission (EEOC)

Federal Communications Commission (FCC)

Federal Trade Commission (FTC)

General Services Administration (GSA)

Intelligence Community (IC)

National Institutes of Health
- National Library of Medicine (NLM)

National Transportation Safety Board (NTSB)

Nuclear Regulatory Commission (NRC)

Office of the Director of National Intelligence (ODNI)
- Intelligence Advanced Research Projects Activity (IARPA)

United States Agency for International Development (USAID)

United States Office of Personnel Management (OPM)

United States Postal Service (USPS)

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1. Introduction

Information technologies (IT)—including networking, computing, and software—comprise the most broadly transformative suite of technologies ever invented. American innovations in these fields since the late 1960s have led the world into a new technological era and opened countless practical capabilities and opportunities on which the security and prosperity of the United States today depend. Also vital to the Nation's prosperity and security are IT advancements that mitigate potential risks posed by adversarial breaches of the country's increasingly interwoven IT-based operations.

As IT capabilities and applications began to advance vigorously in the 1980s, the U.S. Congress recognized the urgency of coordinating federally funded networking and information technology research and development (R&D) to effectively channel public investments in these technologies. Congress established the Networking and Information Technology Research and Development (NITRD) Program in the High-Performance Computing Act of 1991 and has reauthorized it three times, most recently in 2017 by the American Innovation and Competitiveness Act.[1] The NITRD Program's charge is to help coordinate R&D by Federal agencies to efficiently identify, develop, and transition into practical use the advanced networking and IT capabilities needed by the Federal Government and the Nation.

The NITRD Program currently coordinates the IT R&D activities of 24 Federal agency members and over 45 other participating agencies with program interests and activities in IT R&D. The Program is managed by the NITRD Subcommittee of the National Science and Technology Council's Committee on Science and Technology Enterprise, with day-to-day support from its National Coordination Office (NCO). As required by legislation, NITRD and NCO must annually compile and send to Congress a Supplement to the President's Budget that provides the NITRD-relevant R&D budgets requested by member agencies and that details key agency R&D programs and coordination activities.

NITRD Support for Industries of the Future

> *"I am eager to work with you on legislation to deliver new and important infrastructure investment, including investments in the cutting-edge industries of the future. This is not an option. This is a necessity."*
>
> *– President Donald J. Trump, State of the Union, February 5, 2019*

The President and Congress continue to recognize the seminal value to the security and prosperity of the United States of leading the world in IT innovations and applications. The FY2020 NITRD R&D Budget focuses on R&D investment and coordination in pivotal IT-related technologies that support the leading industries of the future—a core science and technology (S&T) investment focus of the Administration. It defines these industries of the future and their associated technologies as *artificial intelligence (AI), advanced manufacturing, quantum information science (QIS), and fifth-generation (5G) wireless communications.*[2] All of these have significant IT components that relate directly to the NITRD Program's R&D coordination mission. American success in these trailblazing fields will rely on both basic and applications-driven research; ongoing support for the R&D infrastructure; public–private R&D partnerships (PPPs) across the U.S. innovation ecosystem; and effective education of the American public and workers in science, technology, engineering, and mathematics (STEM) fields.

[1] https://www.congress.gov/114/plaws/publ329/PLAW-114publ329.pdf

[2] https://www.whitehouse.gov/briefings-statements/america-will-dominate-industries-future/

NITRD Interagency Working Groups (IWGs) and their participating agencies' Program Component Area (PCA) investments work directly and indirectly to support the Administration's priority to advance IT technologies into practical use in the cutting-edge industries of the future, as described below.

- ***Artificial intelligence.*** AI-based information and computing technologies and systems can learn and adapt while collaborating with each other and with people in complex undertakings that address society's practical needs in pioneering ways. Building on the sweeping impacts of IT on society over the last 50 years, synergistic R&D advances in algorithmic capability, computing power, and big data are enabling AI innovations that influence extremely wide-ranging aspects of Americans' lives. Computing support for diagnosis, prediction, decision-making, and remote controls provides powerful new means to secure the Nation; protect individual and public health and safety; expand air, ground, sea, and space transportation and exploration options; refashion agricultural and energy systems; expand the effectiveness of communications, image, and video tools and data; and boost data-management and data-sharing capabilities.

  NITRD-coordinated activities in AI. AI and IT are intricately interrelated, and myriad NITRD activities support advancements in AI both directly and indirectly. The NITRD AI IWG that was formed in 2018 is leading coordination of Federal agency R&D activities in AI and machine learning (pp. 13-15). Other relevant coordination activities include those of NITRD's Enabling R&D for High-Capability Computing Systems IWG (pp. 28–29); Intelligent Robotics and Autonomous Systems IWG (pp. 32–33); and Big Data IWG (pp. 34–35); among others.
- ***Advanced manufacturing.*** The complex, intelligent systems on which manufacturing depends to efficiently produce quality goods in large quantities increasingly rely on computing, information, and networking technologies for digital design, production controls, and sensing, and for accommodating new scales, materials, efficiencies, integration, customization, and remote manipulation. Because advanced manufacturing underpins the Nation's global economic competitiveness, high-paying skilled jobs, and warfighting capabilities, the United States must achieve continuous progress in state-of-the-art IT capabilities for manufacturing. The production of pioneering biotechnology, communications, computing, defense, and Internet of Things (IoT) products and systems, as examples, all require focused IT R&D investment and coordination.

  NITRD-coordinated activities in advanced manufacturing. NITRD-coordinated R&D activities relevant to advanced manufacturing are led by NITRD's Cyber-Physical Systems IWG (pp. 18–20); Intelligent Robotics and Autonomous Systems IWG (pp. 32–33); and Large-Scale Networking IWG (pp. 36–38); with synergetic work performed by other IWGs.
- ***Quantum information science.*** QIS is an enormously challenging but beckoning scientific field that builds on advanced capabilities in computer science, engineering, mathematics, and physical sciences. Indispensable technologies already rely on quantum-scale mechanical processes, including global positioning systems; magnetic resonance imaging; photonics (for cancer therapy, optical fiber communications, etc.); and semiconductor microelectronics. In the near-atomic-scale materials now being explored for uses in computers, sensors, and networks, the quantum effects of particles, light, and energy already can be precisely predicted, despite their complexity. Small-scale quantum computing and simulation demonstrations predict giant leaps forward vis à vis classical computing for tasks requiring rapid processing of big data, simultaneous processing of multiple data operations, and—with good error correction—exact rather than estimated solutions for certain classes of problems. QIS looks to be an ideal route, for example, to advance the field of chemistry by enabling the development of more effective application-specific materials and pharmaceuticals. Attaining next-generation QIS capability will depend on Federal leadership but also on establishing the benefits of QIS to industry to encourage enduring cross-sector R&D partnerships.

NITRD-coordinated activities in QIS. NITRD-coordinated R&D activities of relevance to QIS span the focus areas of the AI IWG (pp. 13–15); the High End Computing IWG (pp. 30–33); and the Big Data IWG (pp. 34–35); among others.

- ***Fifth-generation wireless networking.*** Evolving R&D in 5G wireless communications systems; spectrum S&T; and computing hardware, software, and networks aims to support cost- and energy-efficient super-high-speed, high-volume processing, management, and distribution of information. 5G will upgrade the capabilities of home networks and smart phones significantly. But 5G also will be essential to full realization of high-tech applications that rely on real-time system responsiveness and on remote 3D vision and touch and feel capabilities. These applications will include self-driving cars; expanded means for remote health monitoring and surgery; management of robotic assembly lines; virtual-reality-enabled design, entertainment, simulation, and telework tasks; and "smarter" buildings, farms, highways, and homes—along with myriad discrete IoT products. Proactive improvement and management of U.S. spectrum resources are thus fundamental to the Nation's security, prosperity, health, and equality of opportunity. This requires R&D and deployment approaches that address scientific research, technology, policy, legislation, operations, and economics needs for government, military, academic, industrial, small-business, and diverse private users. The many vital and challenging issues related to upgrading spectrum to 5G and beyond, including potential impacts of 5G on technologies that utilize adjacent spectrum, will require both Federal leadership and community engagement to resolve.

  NITRD-coordinated activities in 5G. NITRD-coordinated R&D activities relevant to 5G systems span those of the Cyber-Physical Systems IWG (pp. 18–20); the Large Scale Networking IWG (pp. 36–38); the Wireless Spectrum R&D IWG (pp. 38–39); and the Health Information Technology R&D IWG (pp. 42–43); among others.

As with all IT-related fields of research, successful advancement of the industries of the future will depend on sustained Federal and cross-sector R&D investments for IT-related security, privacy, and software reliability, along with broad researcher access to first-rate facilities for advanced R&D. These key areas are coordinated by the NITRD High Confidence Software and Systems IWG (pp. 20–21); Cyber Security and Information Assurance IWG (pp. 22–24); Privacy IWG (pp. 24–25); High End Computing IWG activities for high-capability computing infrastructure and applications (pp. 30–31); and the Software Productivity, Sustainability, and Quality IWG (pp. 40–41).

Sustained Federal R&D investment in emerging technologies is critical to promoting and protecting American innovation and international leadership. Combined, NITRD agency R&D budget requests total $5.5 billion (see Table 1, pp. 8–9) aimed at supporting industries of the future and broadly advancing the Nation's IT capabilities to sustain U.S. security and prosperity. Because developing leading capabilities in cutting-edge information technologies is an intensely competitive pursuit globally, the NITRD Program focuses its work on strategic R&D imperatives. In response to Executive Order 13859, "Maintaining American Leadership in Artificial Intelligence,"[3] and in support of *The National Artificial Intelligence Research and Development Strategic Plan: 2019 Update,*[4] this document provides a summary of Federal investments and budget requests in AI R&D (Table 2, p. 10) and a sampling of Federal AI R&D programs coordinated by the AI IWG (pp. 13–15).

[3] https://www.whitehouse.gov/presidential-actions/executive-order-maintaining-american-leadership-artificial-intelligence/

[4] https://www.nitrd.gov/pubs/National-AI-RD-Strategy-2019.pdf

NITRD Budget Reporting and Organizational Structures

The NITRD budget reporting structure is organized by Program Component Area and by agency to facilitate year-to-year budgetary and programmatic comparisons. PCAs are the major subject areas under which interagency projects and activities coordinated through the NITRD Program are funded. Federal agencies that fund or perform networking and IT R&D in the NITRD PCAs generally coordinate their projects and activities through NITRD Interagency Working Groups.

Program Component Areas

For FY2020, there are 11 NITRD PCAs, *which include one new PCA and two updates in PCA definition,* as detailed below. The technical emphases of the remaining eight NITRD PCAs are the same as in FY2019. PCA definitions and more details are available at https://www.nitrd.gov/subcommittee/nitrd-pcas.aspx.

The 11 NITRD PCAs are as follows:

- Artificial Intelligence (*AI*) R&D: ***New***
- Computing-Enabled Human Interaction, Communications, and Augmentation (*CHuman*): ***Updated***
- Computing-Enabled Networked Physical Systems (*CNPS*)
- Cyber Security and Privacy (*CSP*)
- Education and Workforce (*EdW*)
- Enabling R&D for High-Capability Computing Systems (*EHCS*)
- High-Capability Computing Infrastructure and Applications (*HCIA*)
- Intelligent Robotics and Autonomous Systems (*IRAS*)
- Large Scale Data Management and Analysis (*LSDMA*)
- Large Scale Networking (*LSN*)
- Software Productivity, Sustainability, and Quality (*SPSQ*): ***Updated***

The NCO, NITRD Subcommittee, and Office of Science and Technology Policy review the NITRD PCAs annually to ensure they remain relevant and reflect the most current R&D needs of the Nation. For FY2020, the following PCA changes were made: (1) The Artificial Intelligence PCA was added to support the White House focus on United States leadership in development of transformative AI technologies; (2) the definition of the CHuman PCA was updated to remove overlaps with the new AI PCA and to focus on group and collaborative systems, tools, and studies rather than on individuals; and (3) the definition of the SPSQ PCA was updated to better reflect the current state of software research.

Interagency Working Groups

With NCO support, the NITRD Interagency Working Groups work to maximize coordination and thus increase Federal agency efficiency in investing in high-impact basic research, transferring discoveries to the marketplace, updating the national IT R&D infrastructure, and building community alliances.

The 12 NITRD IWGs are as follows:

- Artificial Intelligence R&D (*AI*)
- Big Data
- Cyber-Physical Systems (*CPS*)
- Cybersecurity and Information Assurance (*CSIA*)
- High Confidence Software and Systems (*HCSS*)
- High End Computing (*HEC*)
- Health Information Technology R&D (*HITRD*)
- Intelligent Robotics and Autonomous Systems (*IRAS*)
- Large Scale Networking (*LSN*)
- Privacy R&D (*Privacy*)
- Software Productivity, Sustainability, and Quality (*SPSQ*)
- Wireless Spectrum R&D (*WSRD*)

Following its FY2019 annual review of its interagency working groups, the NITRD Subcommittee sunset the following groups because the activities for which they had been chartered had been accomplished or were being addressed within other IWGs: the Faster Administration of Science and Technology Education and Research Community of Practice; the Human-Computer Interaction and Information Management Task Force; the Smart Cities and Communities Task Force; and the Social Computing IWG. Also, the Subcommittee integrated the Video and Image Analytics activity into the AI IWG as a task force.

The NITRD budgetary categories (PCAs) and the focused coordination activities of its IWGs are closely interrelated. Figure 1 shows the relationships between NITRD's 11 PCAs and its 12 IWGs.

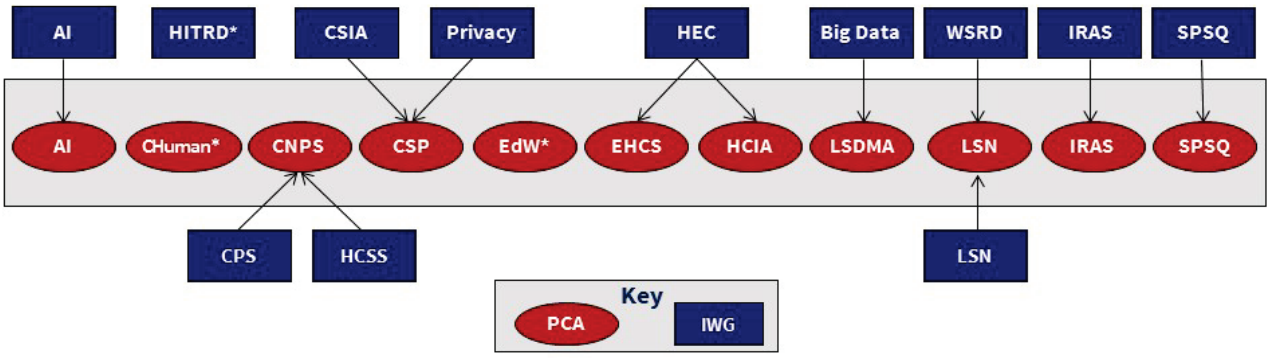

Figure 1. Relationships between the NITRD PCAs and IWGs in FY2020.
The acronyms used in this figure are spelled out in the PCA and IWG lists on the preceding page.
***The HITRD IWG is not affiliated with a PCA. The CHuman and EdW PCAs do not have corresponding IWGs.

As shown in Figure 1, there are no coordinating IWGs for the CHuman and EdW PCAs: the agencies that invest in CHuman or EdW R&D do so within other IWGs or through other coordination committees.

The IWGs engage in the following activities to meet NITRD's R&D coordination goals:

- Align NITRD strategic plans and roadmaps with Administration and agency priorities.
- Update work plans annually, conduct coordination meetings, plan and participate in S&T workshops, seek broad membership, and publish group products.
- Engage effectively with NITRD stakeholders, including supporting interactions and outreach with Federal, non-Federal (industry, academia, state and local governments, etc.), and international stakeholders; conducting interdisciplinary coordination; encouraging public-private partnerships, and supporting workforce development.

Structure of this Supplement

Section 2 provides budget data for NITRD agencies' R&D investments made in FY2018, underway in FY2019, and requested in the President's FY2020 Budget in the eleven NITRD PCAs (Table 1). The Federal agencies' AI R&D investment and budget requests are provided in Table 2. Section 2 also provides an analysis that highlights key aspects of major FY2020 investment changes (more than $10 million) as compared to FY2019.

Section 3 contains subsections for each NITRD PCA and its IWG(s) as applicable; they describe planned FY2020 Federal R&D activities associated with the budget requests presented in Section 2. PCA sections include the official PCA definitions and the affiliated IWGs, including participating agencies, strategic priorities, and the planned FY2020 key programs and coordination activities. *Activities listed in the PCA and IWG subsections are not intended to be exhaustive but rather representative of R&D programs and*

focus areas that agencies propose for funding in FY2020. Due to the interdisciplinary nature of networking and IT R&D, many agencies' PCA investments are coordinated and facilitated through more than one NITRD IWG. For brevity, agencies' proposed programs are listed under only one strategic priority, but they often address more than one priority.

Section 4 describes the Health Information Technology Research and Development IWG separately. HITRD-related activities and investments are highly interdisciplinary; its participating agencies make R&D investments in several PCAs, in line with the HITRD agencies' separate areas of responsibility.

Section 5 defines the abbreviations used in this document.

2. NITRD Budgets by Agency and PCA, FYs 2018–2020

This section presents the NITRD budget by agency and PCA, including FY2018 actual R&D investments, FY2019 estimates, and the FY2020 requests. An analysis of the significant changes between the FY2019 estimates and FY2020 requests provides insight into trends in the NITRD agencies' budget allocations across the eleven NITRD PCAs.[5] Additional information on NITRD-related R&D expenditures from FY2000 to FY2020 may be found at https://www.nitrd.gov/apps/itdashboard/.

Overview

The President's FY2020 budget request for the NITRD Program is $5.5 billion, as depicted in Charts 1 and 2 and Table 1 below. This is a decrease of approximately 3.5 percent, or $0. 20 billion, compared to the $5.7 billion estimate in 2019. The overall change compared to the FY2019 budget request is due to both increases and decreases in individual agency NITRD budgets, which are described in the budget analysis section that follows Table 1. The NITRD agency budget requests for AI R&D for FY2020, totaling $973.5 million, are detailed in Table 2.[6]

Budget Charts

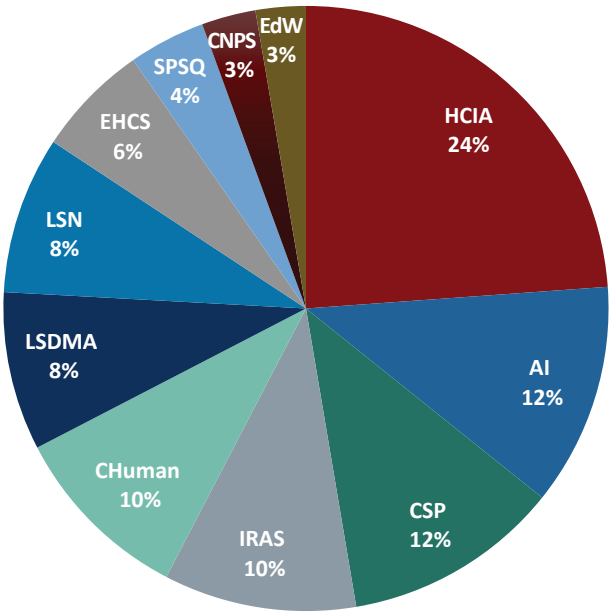

Chart 1. FY2020 Budget Request, as percentages of the total NITRD request, by PCA.

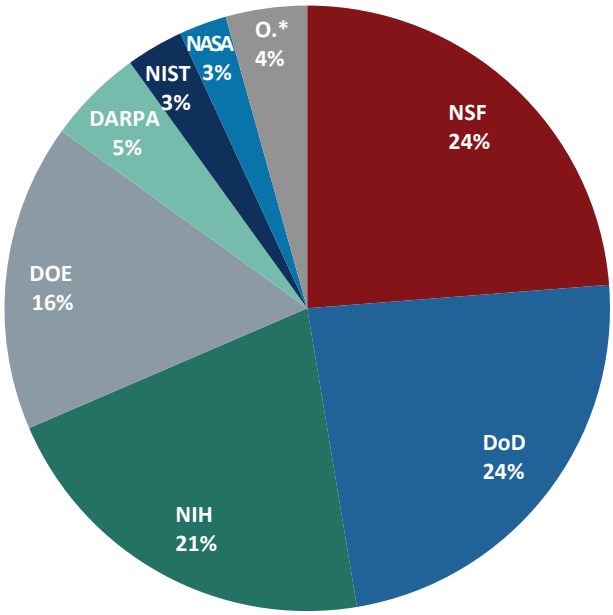

Chart 2. FY2020 Budget Request, as percentages of the total NITRD request, by agency.

***Other:** DHS, DOA, DOE/NNSA, DOI, DOT, FDA, NARA, NIJ, NOAA, and VA

[5] FY2019 estimates reflect annualized amounts provided in the Consolidated Appropriations Act, 2019, PL 116-6.

[6] DOD and DARPA budget figures for AI R&D are not publicly available.

Table 1. Agency Budgets by PCA, FYs 2018–2020

FY2018 Budget Actuals, FY2019 Budget Estimates, and FY2020 Budget Request (Dollars in Millions)

Agencies are listed in alphabetic order.

Agency	Fiscal Year	11 NITRD Program Component Areas											Total[a]
		AI[b]	CHuman	CNPS	CSP	EdW	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
	FY18 Actual	0.0	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5
AHRQ	*FY19 Estimate*	*0.0*	*16.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*16.5*
	FY20 Request	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
DARPA[c]	FY18 Actual	---	12.5	0.0	283.2	0.0	5.1	0.0	0.0	13.0	19.1	0.0	332.9
DARPA[c]	*FY19 Estimate*	*---*	*13.0*	*0.0*	*230.7*	*0.0*	*5.1*	*0.0*	*0.0*	*0.0*	*47.4*	*0.0*	*296.2*
DARPA[c]	**FY20 Request**	**---**	**13.0**	**0.0**	**217.2**	**0.0**	**5.1**	**0.0**	**0.0**	**0.0**	**43.9**	**0.0**	**279.2**
	FY18 Actual	15.5	0.0	0.6	12.1	1.0	0.0	0.0	1.0	0.5	4.9	1.0	36.7
DHS	*FY19 Estimate*	*17.9*	*0.0*	*14.5*	*12.7*	*1.0*	*0.0*	*0.0*	*2.2*	*5.8*	*17.7*	*1.0*	*72.7*
	FY20 Request	**15.1**	**0.0**	**8.4**	**18.4**	**1.0**	**0.0**	**0.0**	**5.8**	**9.7**	**12.7**	**1.0**	**72.1**
DoD [c,d]	FY18 Actual	---	140.1	36.1	192.9	35.6	40.3	265.4	125.6	71.8	163.9	15.2	1,087.0
DoD [c,d]	*FY19 Estimate*	*---*	*162.3*	*33.9*	*200.0*	*33.5*	*37.8*	*262.9*	*154.5*	*127.9*	*221.0*	*15.1*	*1,248.8*
DoD [c,d]	**FY20 Request**	**---**	**173.1**	**42.1**	**193.3**	**32.8**	**22.8**	**259.5**	**154.5**	**210.4**	**188.7**	**13.8**	**1,291.0**
	FY18 Actual	37.6	0.0	0.0	41.5	10.0	41.6	502.8	0.0	12.5	79.0	0.0	724.9
DOE[e]	*FY19 Estimate*	*72.5*	*0.0*	*0.0*	*44.4*	*10.0*	*36.5*	*597.9*	*0.0*	*30.0*	*84.0*	*0.0*	*875.3*
	FY20 Request	**108.0**	**0.0**	**0.0**	**32.8**	**10.0**	**68.2**	**596.1**	**20.0**	**20.8**	**80.0**	**0.0**	**935.9**
DOE/NNSA	FY18 Actual	0.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	40.0
DOE/NNSA	*FY19 Estimate*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
DOE/NNSA	**FY20 Request**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**40.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**40.0**
	FY18 Actual	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
DOI	*FY19 Estimate*	*1.5*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.6*
	FY20 Request	**1.6**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.7**
DOT	FY18 Actual	9.8	0.0	1.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	17.1
DOT	*FY19 Estimate*	*9.4*	*0.0*	*1.8*	*0.0*	*0.0*	*0.0*	*0.0*	*7.0*	*0.0*	*0.0*	*0.0*	*18.2*
DOT	**FY20 Request**	**8.2**	**0.0**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**	**7.0**	**0.0**	**0.0**	**0.0**	**16.2**
	FY18 Actual	0.0	0.0	0.0	0.0	0.0	3.5	3.0	0.0	0.0	0.0	0.0	6.5
EPA	*FY19 Estimate*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.5*	*3.0*	*0.0*	*0.0*	*0.0*	*0.0*	*6.5*
	FY20 Request	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
FDA	FY18 Actual	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0
FDA	*FY19 Estimate*	*38.9*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*38.9*
FDA	**FY20 Request**	**38.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**38.5**
	FY18 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2
NARA	*FY19 Estimate*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.0*	*0.2*
	FY20 Request	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**0.2**
NASA	FY18 Actual	4.8	0.0	0.0	0.0	0.0	8.9	54.3	53.5	5.4	1.3	6.1	134.3
NASA	*FY19 Estimate*	*4.8*	*0.0*	*0.0*	*0.0*	*0.0*	*8.9*	*59.0*	*53.5*	*5.4*	*2.4*	*7.4*	*141.4*
NASA	**FY20 Request**	**4.8**	**0.0**	**0.0**	**0.0**	**0.0**	**8.8**	**58.0**	**53.5**	**5.4**	**1.5**	**7.4**	**139.3**
	FY18 Actual	222.9	310.8	21.1	2.9	42.2	24.2	205.7	265.1	30.1	2.8	145.6	1,273.5
NIH	*FY19 Estimate*	*236.7*	*329.0*	*26.1*	*3.0*	*43.9*	*25.4*	*222.4*	*280.0*	*31.1*	*2.9*	*151.8*	*1,352.3*
	FY20 Request	**202.5**	**282.4**	**21.3**	**2.6**	**38.5**	**22.6**	**184.1**	**241.9**	**26.8**	**2.5**	**131.4**	**1,156.8**
NIJ	FY18 Actual	5.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.6	0.0	7.9
NIJ	*FY19 Estimate*	*2.5*	*2.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.0*	*0.0*	*0.0*	*6.0*
NIJ	**FY20 Request**	**2.5**	**2.5**	**0.0**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.0**	**0.0**	**0.0**	**7.0**

Table 1. Agency Budgets by PCA, FYs 2018–2020 (Dollars in Millions) (Continued)

Agency	Fiscal Year	11 NITRD Program Component Areas											Total[a]
		AI[b]	CHuman	CNPS	CSP	EdW	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
	FY18 Actual	10.4	7.6	11.7	75.6	3.6	4.3	9.5	6.8	12.3	11.9	2.6	156.3
NIST	*FY19 Estimate*	*12.9*	*7.6*	*12.2*	*75.6*	*3.6*	*4.3*	*9.5*	*6.6*	*12.3*	*12.6*	*2.6*	*159.8*
	FY20 Request	**20.3**	**7.6**	**12.2**	**75.6**	**3.6**	**4.3**	**9.5**	**6.6**	**12.3**	**12.6**	**2.6**	**167.2**
NOAA	FY18 Actual	0.6	0.2	0.0	0.0	0.0	0.0	51.2	0.0	0.0	3.3	3.0	58.3
NOAA	*FY19 Estimate*	*0.8*	*0.2*	*0.0*	*0.0*	*0.0*	*0.0*	*50.7*	*0.0*	*0.0*	*3.3*	*3.0*	*57.9*
NOAA	**FY20 Request**	**0.8**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**35.7**	**0.0**	**0.0**	**3.3**	**3.0**	**42.9**
	FY18 Actual	230.6	113.7	75.0	105.4	79.6	180.0	187.2	44.6	171.2	128.7	70.5	1,386.3
NSF	*FY19 Estimate*	*239.9*	*95.7*	*77.6*	*110.1*	*81.3*	*161.9*	*184.3*	*46.7*	*189.2*	*131.4*	*71.8*	*1,389.9*
	FY20 Request	**245.6**	**87.1**	**70.6**	**97.5**	**60.2**	**161.3**	**170.8**	**43.8**	**178.2**	**118.0**	**66.6**	**1,299.5**
Treasury	FY18 Actual	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Treasury	*FY19 Estimate*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Treasury	**FY20 Request**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	FY18 Actual	1.0	0.5	3.0	0.0	1.0	0.0	0.0	3.5	1.0	0.0	0.0	10.0
USDA	*FY19 Estimate*	*1.3*	*0.7*	*3.9*	*0.0*	*1.3*	*0.0*	*0.0*	*4.6*	*1.3*	*0.0*	*0.0*	*13.1*
	FY20 Request	**1.3**	**0.7**	**3.9**	**0.0**	**1.3**	**0.0**	**0.0**	**4.6**	**1.3**	**0.0**	**0.0**	**13.1**
VA	FY18 Actual	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
VA	*FY19 Estimate*	*5.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.1*
VA	**FY20 Request**	**5.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**5.2**
TOTAL[a]	FY18 Actuals	560.3	602.7	148.5	713.5	173.0	347.9	1,279.1	506.5	319.5	415.5	243.9	5,310.5
TOTAL[a]	*FY19 Estimate*	*644.2*	*627.6*	*170.0*	*676.6*	*174.5*	*283.4*	*1,389.8*	*555.1*	*404.2*	*522.7*	*252.6*	*5,700.5*
TOTAL[a]	**FY20 Request**	**654.4**	**566.7**	**159.4**	**638.4**	**147.4**	**333.1**	**1,313.6**	**537.7**	**466.1**	**463.2**	**225.8**	**5,505.8**

Budget Table Notes

a. Totals might not sum exactly due to rounding.

b. The AI budget reported under the AI PCA is not the complete budget for AI; refer to Table 2 and the Budget Analysis section for details on how to interpret the AI figures.

c. The Department of Defense (DoD) and Defense Advanced Research Projects Agency (DARPA) budget figures for AI R&D are not publicly available.

d. The DoD budget includes funding for the Office of the Secretary of Defense (OSD) and the DoD Military Services' research organizations, which include the Air Force Research Laboratory (AFRL), including the Air Force Office of Scientific Research (AFOSR); Army Futures Command (AFC) Combat Capabilities Development Command (CCDC); Army Research Laboratory (ARL), including the Army Research Office (ARO); Army Research Institute; and the Office of Naval Research (ONR), including the Naval Research Laboratory (NRL). The Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance Center (C5ISR), Ground Vehicle Systems Center (GVSC), 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 budgeted separately from other research organizations of the DoD Services (Air Force, Army, and Navy). The National Security Agency (NSA) is a research organization under DoD, but it does not report NITRD funding.

e. The Department of Energy (DOE) budget includes funding from DOE's Office of Science (DOE/SC); Office of Cybersecurity, Energy Security, and Emergency Response (DOE/CESER, formerly part of the Office of Electricity Delivery and Energy Reliability); Office of Energy Efficiency and Renewable Energy (EERE); Office of Fossil Energy (FE); Office of Electricity (OE); and the Advanced Research Projects Agency-Energy (ARPA-E). The DOE/National Nuclear Security Administration (NNSA) budget is listed separately.

Table 2. Agency FY2020 Budget Requests for AI R&D (Dollars in Millions)[a]

Agency	11 NITRD Program Component Areas											Total[b]
	AI[b]	CHuman	CNPS	CSP	EdW	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
DARPA[c]	---	---	---	---	---	---	---	---	---	---	---	---
DHS/Coast Guard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	4.3
DHS/CWMD	1.8	0.0	4.8	0.0	0.0	0.0	0.0	1.5	3.9	0.0	0.0	12.1
DHS/CISA	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	3.2
DHS/S&T	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9
DHS/TSA	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
DoD[c]	---	---	---	---	---	---	---	---	---	---	---	---
DOE/CESER	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
DOE/OE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.8
DOE/FE	37.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.0
DOE/SC	71.0	0.0	0.0	0.0	0.0	9.8	38.7	0.0	0.0	0.0	0.0	119.5
DOI/USGS	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
DOJ/NIJ	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5
DOT/FAH	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
DOT/FAA	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
DOT/FMCSA	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
DOT/FRA	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
DOT/OST	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
DOT/PHMSA	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
FDA	38.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.5
NASA	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8
NIH	202.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	202.5
NIST	20.3	0.0	0.0	0.0	0.0	0.3	0.0	3.0	0.0	0.3	0.0	23.8
NOAA/ORF	0.8	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	1.4
NOAA/PAC	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
NSF/R&RA	245.6	31.5	38.9	20.5	10.5	15.9	25.3	43.8	44.0	6.6	5.2	487.6
USDA/NIFA	1.3	0.0	1.2	0.0	0.1	0.0	0.0	1.6	0.1	0.0	0.0	4.4
VA	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2
TOTAL[b]	**654.4**	**31.6**	**44.9**	**25.5**	**10.7**	**25.9**	**64.7**	**54.2**	**49.6**	**6.8**	**5.2**	**973.5**

a. See p. 11 for additional information and examples.
b. Totals may not add due to rounding.
c. DoD and DARPA budget figures for AI R&D are not publicly available.

Abbreviations Key for Agency Subcomponents

DHS/CWMD: DHS Countering Weapons of Mass Destruction Office
DHS/CISA: DHS Cybersecurity and Infrastructure Security Agency
DHS/S&T: DHS Science and Technology Directorate
DHS/TSA: DHS Transportation Security Administration
DOE/CESER: DOE Office of Cybersecurity, Energy Security, and Emergency Response
DOE/OE: DOE Office of Electricity
DOE/FE: DOE Office of Fossil Energy
DOE/NNSA: DOE National Nuclear Security Administration
DOE/SC: DOE Office of Science
DOI/USGS: DOI U.S. Geological Survey
DOJ/NIJ: DOJ National Institute of Justice
DOT/FAH: DOT Federal-aid Highway Program
DOT/FAA: DOT Federal Aviation Administration
DOT/FMCSA: DOT Federal Motor Carrier Safety Administration
DOT/FRA: DOT Federal Railroad Administration
DOT/OST: DOT Office of the Secretary
DOT/PHMSA: DOT Pipeline and Hazardous Materials Safety Administration
NOAA/ORF: NOAA Operations, Research, and Facilities
NOAA/PAC: NOAA Procurement, Acquisition, and Construction
NSF/R&RA: NSF Research and Related Activities

Budget Analysis

Artificial Intelligence

In response to Executive Order 13859, "Maintaining American Leadership in Artificial Intelligence,"[7] and in support of *The National Artificial Intelligence Research and Development Strategic Plan: 2019 Update,*[8] this NITRD Budget Supplement reports for the first time a summary of Federal investments in AI (except for DoD and DARPA investment levels, which were not available). Since artificial intelligence as a topic intersects with multiple PCAs, NITRD worked with the Federal agencies to establish a new process for accurately accounting for these AI investments. The FY2020 request sets a baseline going forward for reporting and tracking AI R&D investments, consistent with the AI Executive Order. Because of the difference in the reporting process and AI scope newly defined this year, the level of AI investments reported in this budget supplement is not comparable to any prior-year reports of AI investments.

Table 2 shows two types of AI investments—those under the AI PCA and those with primary emphases in areas other than AI, which are reported in other PCAs:

- *Examples of AI investments reported under the AI PCA:* R&D on general methods for machine vision, R&D that is primarily machine learning, R&D on the cybersecurity challenges unique to AI such as the ability to exploit flaws in an AI system's goals, R&D on algorithms for computational linguistics, and R&D on special neuromorphic computing architectures or chips optimized for neural nets.
- *Examples of AI investments reported in other PCAs:* R&D on robots is reported under IRAS, even if the robots employ machine vision; R&D on the larger data management and analysis ecosystem is reported under LSDMA, even if it contains an element of machine learning; R&D on the broad problem of human-machine interaction is reported under CHuman, even if it contains an element of natural language processing; AI R&D that supports cybersecurity research is reported under CSP; and general research in neuromorphic computing is reported under EHCS.

The FY2020 funding level provided for AI in Table 2 indicates both the non-defense Federal programs directly related to AI ($654.4 million) and the AI-related efforts reported in the other PCAs ($319.1 million); together, these total a Federal FY2020 non-defense budget request in AI of $973.5 million.

Budget Analysis by Agency

The following budget analysis notes changes of investment greater than $10 million, by agency, between the FY2019 Estimate and the FY2020 Presidential Budget Request (PBR). The FY2019 estimates reflect enacted levels provided in the Consolidated Appropriations Act, 2019, PL 116-6.

AHRQ: The decrease of $16.5 million is due to no funds being requested for CHuman-related programs.

DARPA: The decrease of $17 million is due to a decrease of $13.5 million in CSP due to the completion of several basic and applied cyber research programs in FY 2019, with a smaller decrease in LSN. DARPA reported no investments for AI.

DoD: The increase of $42.2 million is due to increases of $82.5 million in LSDMA and $10.8 million in CHuman, partially offset by decreases of $15 million EHCS, $32.3 million in LSN, and smaller increases and decreases in other PCAs. DoD reported no investments for AI.

[7] https://www.whitehouse.gov/presidential-actions/executive-order-maintaining-american-leadership-artificial-intelligence/

[8] https://www.nitrd.gov/pubs/National-AI-RD-Strategy-2019.pdf

DOE: The increase of $60.6 million is due to increases of $49 million in AI across the Office of Science (DOE/SC) to advance the foundations of AI for scientific application and to leverage advances in AI at DOE/SC scientific user facilities, with smaller increases and decreases at other offices; $31.7 million in EHCS for the Computer Science and Research and Evaluation Prototypes activities related to large requested increases in FY2020 for increased efforts in Quantum Information Science, Artificial Intelligence, and Machine Learning; $20 million in IRAS for Advanced Research Projects Agency-Energy (ARPA-E), partially offset by decreases of $11.6 million in CSP due to several projects at DOE/CESER that have successfully concluded, with smaller decreases in other PCAs.

DOE/NNSA: The increase of $40 million is due to an increase of $40 million in EHCS for funding directed to the DOE Exascale Computing Project (ECP) PathForward program.

NIH: The overall reduction of $195.5 million in areas covered by NITRD represents a 10% reduction in requested FY2020 funds and is consistent with NIH's overall reduction of 13.9% in the FY2020 request. Higher priority is given to supporting areas of technology development and artificial intelligence.

NOAA: A decrease of $15 million for HCIA activities is due to reduction in Oceanic and Atmospheric Research Supercomputing activities.

NSF: The decrease of $90.4 million for NSF is the result of decreases in investments aligned with all the PCAs, except for the AI PCA, which had a slight increase due to increased investments in this priority research area.

3. Program Component Areas

Artificial Intelligence (AI) Research and Development PCA

AI R&D advances the ability of computer systems to perform tasks that have traditionally required human intelligence; this includes R&D in machine learning (ML), computer vision (CV), natural language processing (NLP) and understanding, intelligent decision support systems, and autonomous systems, as well as the novel application of these techniques to various domains, where not principally covered by other PCAs.[9]

The AI IWG and the Video and Image Analytics Task Force report their R&D investments and activities under the AI PCA.

Artificial Intelligence (AI) IWG

Participating Agencies: **Air Force, Army, DARPA, DHS, DoD, DOE, DOJ, DOS, DOT, DTRA, FBI, FDA, GSA, IARPA, NARA, NASA, Navy, NIFA, NIH, NIJ, NIST, NSA, NSF, NTIA, ONC, OSD, OSTP, USPTO, VA**

The AI IWG coordinates Federal R&D in AI; it also supports and coordinates activities tasked by the NSTC Select Committee on AI and Subcommittee on Machine Learning and Artificial Intelligence. This vital work promotes U.S. leadership and global competitiveness in AI R&D. The *National AI Research and Development Strategic Plan: 2019 Update*[10] outlines the Federal strategic priorities for AI research.

Strategic Priorities

- Coordinate long-term Federal investments in AI R&D, such as algorithms to enable robust and reliable perception, general AI systems that exhibit the flexibility and versatility of human intelligence, and combinatorial optimization to obtain prodigious performance.
- Promote safe and effective methods for human–AI collaboration to achieve optimal efficiency and performance by developing advanced AI techniques for human augmentation and improved visualization and AI-human interfaces.
- Develop methods for designing AI systems that align with ethical, legal, and societal goals, and behave according to formal and informal human norms.
- Improve the safety and security of AI systems so that they operate in a controlled, well-defined, and well-understood manner.
- Develop shared public datasets and environments for AI training and testing to increase the benefits and trustworthiness of AI.
- Improve measurement and evaluation of AI technologies through benchmarks and standards to address safety, reliability, accuracy, usability, interoperability, robustness, and security.
- Grow the Nation's AI R&D workforce to ensure the United States leads the automation of the future.
- Expand public-private partnerships to strengthen the R&D ecosystem.

Key Programs

Coordinate long-term Federal investments in AI R&D

- *AI Next:* Lead innovation in AI basic research and advanced technology development to create new, powerful capabilities in robust AI, adversarial AI, high-performance AI, and next-generation AI. *DARPA*
- *Mathematical Multifaceted Integrated Capability Centers:* Develop computational foundations for addressing DOE-relevant problems via integrated, mathematical approaches. *DOE*

[9] The Budget Analysis section on AI (p. 11) describes how NITRD distinguishes between PCA investments related to AI.

[10] https://www.nitrd.gov/pubs/National-AI-RD-Strategy-2019.pdf

- *Joint AI Center:* Accelerate delivery of AI-enabled capabilities, scaling the impact of AI, and synchronizing DoD AI activities to expand Joint Force advantages. *DoD*
- *Joint Design of Advanced Computing Solutions for Cancer:* Develop deep learning pilot frameworks and learning ecosystems to improve precision oncology and cancer research outcomes. *DOE, NIH*
- *Real or near-real-time decision-making:* Analyze and prioritize inputs from diverse data sources to apply real-time or near-real-time situational awareness to a range of circumstances, particularly for first-responders, through academic research and testing and deploying of systems. *DHS*
- *Air Traffic Management—eXploration:* Integrate planning, reasoning, and knowledge representation into decision support for urban air mobility and traditional air traffic management operations. *NASA*
- *Advanced Exploration Systems:* Develop prototype systems, demonstrate key capabilities, and validate operational concepts specifically for future human missions beyond low-Earth orbit, focused on crew safety, mission operations in deep space, and future vehicle development. Mission operations in deep space will require increased autonomy due to communication delays between ground and space. Potentially beneficial AI technologies include automated planning and scheduling, plan execution and replanning, fault management, and crew decision support, among others. *NASA*
- *Agriculture and Food Research Initiative (AFRI):* Use AI and other research to gain a macro-, meso-, and process-level understanding of future agricultural needs, interactions, and evolutions. *NIFA*
- *National AI R&D Institutes:* Accelerate (a) foundational areas of ML, CV, NLP, and autonomy, and safety, security, robustness, and explainability of AI systems; (b) translational research at the intersection of AI and various science and engineering domains as well as sectors such as agriculture, transportation, and personalized medicine; (c) workforce development, including growing human capital and institutional capacity to nurture a next generation of AI researchers and practitioners; and (d) advanced computing infrastructure, including access to data and compute capabilities enabling AI innovations. *NSF*
- *Robust Intelligence:* Perform foundational research across computational disciplines to understand and enable intelligent systems in complex, realistic contexts *NSF*
- *Spectrum monitoring:* Research the use of AI techniques to automatically detect and classify wireless signals and systems. *NTIA*
- *National Spectrum Strategy:* Research the use of AI techniques in spectrum management to, more efficiently analyze spectrum use and facilitate spectrum sharing. *NTIA*

Promote safe and effective methods for human–AI collaboration

- *Communicating with Computers:* Enable people and computers to communicate using natural communication modes, including language, gesture, and facial expressions. *DARPA*
- *Center for Advanced Mathematics for Energy Research Applications:* Develop mathematical bases and computational building blocks to address complex problems and increase automation. *DOE*
- *National Robotics Initiative 2.0 (NRI-2.0):* Integrate ubiquitous and collaborative robots that work seamlessly beside or cooperatively with people to assist humans in every aspect of life. *AFOSR, DoD, DOE, NSF, ONR, USDA*

Develop methods for designing AI systems that align with ethical, legal, and societal goals

- *AFRI:* Examine issues relevant to privacy concerns and models that incentivize sharing of public, private, and syndicated data across the food and agricultural enterprises, and consider policies to address the "digital divide." *NIFA*
- *The Future of Work at the Human-Technology Frontier:* Advance research to understand and develop the human-technology partnership, design new technologies to augment human performance, illuminate the emerging socio-technological landscape, understand the risks and benefits of new technologies, understand and influence the impact of AI on workers and work, and foster lifelong and pervasive learning. *NSF*

Improve the safety and security of AI systems

- *Exploratory Research on Artificial Intelligence and Society:* Pursue R&D for safe, robust, trustworthy AI that addresses issues of fairness, bias, and transparency; human-AI interaction and education; and social impacts of AI, together with the Partnership on AI, a multistakeholder organization that brings together diverse entities that build, utilize, and understand AI technology *NSF*
- *Explainable AI:* Develop ML techniques that produce explainable models with a high level of learning performance, and enable human users to understand, appropriately trust, and effectively manage the emerging generation of artificially intelligent partners. *DARPA*
- *Secure AI:* Define and understand AI vulnerabilities and conduct research to improve the resiliency of AI methods to various forms of attack. *NIST*
- *Secure, Assured, Intelligent Learning Systems:* Develop defensive measures to protect sensitive training data and statistical information contained within AI models. *IARPA*
- *Autonomous systems policies:* Research and analyze policy issues raised by autonomous systems and related technologies, including studies of the institutional requirements for governance of autonomous systems and new risk communication paradigms for robotics and AI. *DHS*
- *TrojAI:* Develop tools to inspect AI for Trojans to combat Trojan attacks in AI. *IARPA*

Develop shared public datasets and environments for AI training and testing

- *Applied AI/ML/Deep Learning:* Formulate problem sets and data to support academic and industry participation in the development of analytic systems, algorithms, and methodology to support the automation of homeland security missions. *DHS*
- *Simulated and Synthetic Data for Infrastructure Modeling:* Provide the mathematical bases, including ML algorithms and heuristics, for creating simulated or synthetic data, and develop data creation techniques such as data localization, homogenization, down-sampling, and aggregation. *NSF*
- *Spectrum Monitoring:* Publish large datasets of wireless signals from a neighborhood-size spectrum monitoring system for activity classification by AI systems, and publish spectrum datasets. *NTIA*
- *Quality of Experience:* Make publicly available high-quality video datasets such as those for the training of AI systems for use in research. *NTIA*

Improve measurement and evaluation of AI technologies

- *Fundamental and Applied Research and Standards for AI Technologies:* Conduct research to advance AI measurement science and develop best practice guidance and standards. *NIST*

Expand public–private partnerships

- *Fairness in AI:* Support computational research on fairness in AI to improve public knowledge and acceptance of AI systems and their ability to effectively tackle societal challenges. *NSF, industry partner*

Grow the Nation's AI R&D workforce *(Please see the EdW PCA.)*

Key Coordination Activities

- *Advanced Information Systems Technology:* Develop and apply AI and ML to Earth Science. *NASA*
- *Principal Investigator (PI) meetings:* Review research, identify new applications, and discuss science and technology gaps and barriers. *DARPA, DoD, DOE, DHS, DOT, NASA, NIFA, NIH, NIJ, NIST, NSA, NSF*
- *Implement the National Artificial Intelligence R&D Strategic Plan 2019 Update*. *All AI IWG agencies*
- *Maintain the AI R&D Progress Report*[11] to document Federal AI R&D programs. *All AI IWG agencies*
- *Joint Artificial Intelligence Center:* Coordinate military service and defense agency AI efforts. *DoD, OSD*
- *Video and Image Analytics (VIA) Taskforce:* Coordinate R&D on new analytic technologies to make video data and tools more accessible; improve the efficiency, usability, and effectiveness of video management systems; and pursue new uses of video to advance science, health, and public safety. Publish an action plan for advancing VIA R&D. *DARPA, DHS, DOJ, FBI, FHWA, IARPA, NIJ, NIST, NRL, NSF*

[11] This report will be provided at https://www.nitrd.gov/publications/ when available.

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

CHuman R&D advances information technologies that enhance people's ability to interact with IT systems, other people, and the physical world; this includes R&D in social computing, human–human and human–machine interaction and collaboration, and human and social impacts of IT.

CHuman activities are coordinated directly through the NITRD Subcommittee and through other IWGs as appropriate.

***Reporting Agencies*: AHRQ, Air Force, DARPA, DHS, DoD, DOE, DOT, Navy, NIH, NIJ, NIST, NSF, ONC, USDA**

Federal agency and interagency R&D and coordination activities reported under the CHuman PCA focus on broadening effective human-to-IT interconnections in applications that include commerce, disaster response, healthcare, innovation, military action, and social communications, as well as on identifying and mitigating potential harms and maximizing the benefits of socially interactive IT applications.

Strategic Priorities

- Develop cohesive sociotechnical systems that support collaboration and innovation by integrating diverse human teams having knowledge of human behavior with ubiquitous computing, networking, data analytic, and knowledge representation systems.
- Improve interfaces between humans and intelligent systems—including robots, intelligent agents, autonomous vehicles, and machine learning systems—to accomplish complex missions.
- Advance social informatics models, systems, and interfaces that manage, verify, and disseminate information online, including in emergencies, and including being able to detect and protect against adversaries' malicious attempts to disseminate misinformation.
- Promote education and workforce development in understanding human-IT interactions by developing new curricula based on evolving educational and technological models.

Key Programs

Develop cohesive sociotechnical systems that support collaboration and innovation

- *Cyber-Human Systems:* Improve the fundamental understanding of how, and the processes by which, interactive systems should be designed to achieve human-computer symbiosis and computer-mediated human communication, collaboration, and competition. *NSF*
- *Smart & Connected Communities:* Address technological and social dimensions, and their interactions, in smart community environments. *NSF*
- *Smart and Connected Health:* Integrate technical advances in computing with new socio-behavioral, cognitive, and system/process models around healthcare and quality of life. *NSF*
- *Mobile Health (mHealth):* Support exploratory and developmental R&D to develop or adapt novel mHealth technology specifically for low-/middle-income countries; measure health outcomes. *NIH*
- *Learning Health Systems (LHS) grants:* Research how health IT can best support learning health systems, particularly in ambulatory care settings. *AHRQ*
- *Systems Operating on Complex Data Originating from a Human:* Define efficiency standards for systems that collect, package, and exchange data that quantify human actions, behaviors, or characteristics, and establish ways to measure those systems' effectiveness. *NIST*
- *Health IT Safety Grants:* Research safe health IT practices specifically related to the design, implementation, usability, and safe use of health technologies by all users. *AHRQ*
- *Consumer Health IT Grants:* Conduct research to determine how patient-facing technologies can best improve the quality and effectiveness of care. *AHRQ*

- *Clinical Decision Support (CDS):* Advance the science of CDS by supporting clinicians, vendors, and implementers in developing shareable, standards-based, patient-centered tools. *AHRQ*
- *Patient Reported Outcomes (PRO) Initiative:* Develop technical specifications that employ Fast Healthcare Interoperability Resource standards to collect PRO data. *AHRQ, ONC*

Improve interfaces between humans and intelligent systems

- *Future of Work at the Human-Technology Frontier, including Cyberlearning for Work at the Human-Technology Frontier:* Determine how evolving (intelligent) technologies shape and support both work and workers, and vice versa; and pursue projects combining educational and technical advances for STEM education and workforce development, especially around intelligent systems. *NSF*
- *Collaborative Research in Computational Neuroscience:* Explore modeling and use of neuro-biological systems, with application to ML and brain-computer interfaces. *NSF*
- *The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative:* Revolutionize understanding of the human brain in multiple ongoing initiatives that include clinical studies to advance recording and modulating the human central nervous system. *DARPA, FDA, IARPA, NIH, NSF*
- *Usability research grants:* Apply cognitive science, user-centered design, and usability principles to improve user-centered measurement and evaluation methods, guidelines, and standards; human–system interactions; and intuitive, work-flow-friendly electronic health records. *AHRQ, NIST*

Advance social informatics models, systems, and interfaces

- *Convergence:* Conduct problem-driven, interdisciplinary research in areas that include new forms of and systems for work, production, and creativity, and advance social informatics models, systems, and interfaces that manage, verify, and disseminate information online. *NSF*
- *Secure and Trustworthy Cyberspace:* Pursue broad, multidisciplinary research in security and privacy, including information authenticity, flows, protection, and provenance. *NSF*

Promote education and workforce development in understanding human-IT interactions (*Please see the EdW PCA.*)

Key Coordination Activities

- *Exploratory Research on Artificial Intelligence and Society:* Pursue safe, robust, trustworthy AI; fairness, bias, and transparency; human-AI interaction and education; and social impacts of AI with the Partnership on AI, a multistakeholder organization that brings together academics, researchers, nonprofits, and companies building, utilizing, and understanding AI technology. *NSF*
- *NRI-2.0:* Integrate ubiquitous and collaborative robots that work seamlessly beside or cooperatively with people to assist humans in every aspect of life. *AFOSR, DoD, DOE, NSF, ONR, USDA*
- *Cyber-Physical Systems:* Advance control, data analytics, autonomy, design, Internet of Things, information management, and mixed initiatives including human-in- or on-the-loop, networking, privacy, real-time systems, safety, security, and verification. *DHS, DOT, NIH, NIST, NSF, USDA*

Computing-Enabled Networked Physical Systems (CNPS) PCA

CNPS R&D advances information technology-enabled systems that integrate the cyber/information, physical, and human worlds; this includes R&D of cyber-physical systems, Internet of Things, and related complex, high-reliability, networked, distributed computing systems.

The Cyber-Physical Systems IWG and High Confidence Software and Systems IWG report their R&D investments and activities under the CNPS PCA.

Cyber-Physical Systems (CPS) IWG

Participating Agencies: **Air Force, Census, DHS, DOE/OE, DOS, EEOC, FAA, FDA, FHWA, ITA, ITS JPO, NASA, NIFA, NIH, NIJ, NIST, NRC, NRO, NSA, NSF, NTIA, OSD, USACE, USPS**

The CPS IWG coordinates Federal R&D in CPS and related areas that fall under the broad umbrella of smart, networked, sociotechnical systems. The R&D coordination enabled by the CPS IWG promotes U.S. technological leadership and global competitiveness across many sectors.

Strategic Priorities

- Conduct R&D across applications to develop the core science and engineering (S&E) of complex CPS technologies to supply foundations, models and analysis tools, system capabilities, interoperability standards, and architectures to enable innovation in cyber-enabled engineered or natural systems.
- Integrate and apply breakthroughs in CPS R&D to real-world problems by investing in multidisciplinary, multisector collaborations that will meaningfully engage all relevant stakeholders and address both the technological and social dimensions of the problems.
- Overcome the barriers to application and identify new CPS R&D challenges in sectors such as smart cities/communities (SCC), manufacturing, agriculture, transportation, energy, and health/medicine, and within cross-cutting domains of autonomy, safety, security, and privacy.
- Promote inclusive education and workforce development that leverages multidisciplinary curricula and authentic experiences to develop new and retrain existing workforces suited to research, development, and deployment (RD&D) of CPS technology across application domains.

Key Programs

Conduct R&D across application areas to develop the core S&E of complex CPS technologies

- *CPS:* Enable engineering of complex CPS through research in control, data analytics, autonomy, design, information management, Internet of Things (IoT), human-in- or on-the-loop, networking, privacy, real-time systems, safety, security, and verification. *DHS, FHWA, NIFA, NIH, NSF*
- *CPS/IoT Foundations and Research Infrastructure:* Develop measurement solutions, methods for formal reasoning about trustworthiness, methods for testing/certification, and implementation practices for scalable, interoperable, safe, secure, and resilient CPS and IoT solutions. *NIST*
- *Multiple NSF Core Programs:* Pursue foundational research in core CPS technologies, including networking, control, verification, data analytics, IoT, privacy, and real-time systems. *NSF*
- *Resilient Distribution Systems:* Support R&D for distribution management, microgrids, dynamic control and communication, data collection, security, management, and sensors. *DOE/OE*

Integrate and apply breakthroughs in CPS R&D to real-world problems

- *Urban Air Mobility:* Revolutionize urban mobility by enabling safe, efficient, convenient, affordable, and accessible air transportation for people and cargo. *NASA*
- *Food and Agriculture Cyberinformatics and Tools:* Conduct R&D in big data analytics and tools for scientific domains supporting plant health, production, and products. *NIFA, NSF*

- *Air traffic management (ATM) and operations:* Develop a modernized ATM system capable of leveraging CPS advances, including in unmanned systems, through R&D in modeling/scheduling, data fusion/mediation, model-based airworthiness, and prototype software. *FAA, NASA*
- *Global City Teams Challenge:* Enable cross-sector teams to develop replicable smart city solutions and teams-of-teams to develop application-specific technology blueprints. *DHS, ITA, NTIA, NSF*
- *Smart & Connected Communities:* Create the S&E foundations for smart, connected communities through interdisciplinary, integrative research in cooperation with communities. *NSF*
- *Smart Cities/IoT Test Bed:* Develop a wireless test bed for spectrum management research and develop techniques for interference detection/mitigation and spectrum forensics. *NTIA*
- *Smart Grid Interoperability:* Maintain and update a framework for emerging grid architectures, markets, and IoT technologies. *NIST*

Overcome the barriers to application and identify new CPS R&D challenges across sectors

- *Accessible Transportation Technologies Research Initiative:* Explore emerging technologies to enable fully accessible transportation for mobility-impaired persons. *DoD, DOL, DOT, FHWA, HHS, ITS JPO*
- *Automated Driving Performance Measurement and Assurance:* Analyze methods for measuring automated driving systems performance under defined drive cycles and the use of modeling and simulation for trustworthiness design assurance. *DOT, NIST, NSF*
- *Connected Vehicle (CV) Pilots:* Deploy and assess CV technologies in multiple transportation environments to improve safety and mobility of commercial and personal vehicles. *ITS JPO*
- *Food Safety, Nutrition, and Health:* Enhance the microbial, chemical, and physical safety and quality of foods through support for R&D in biosensors, AI, and other topics. *NIFA*
- *Energy Storage:* Develop materials and device technologies that improve the cost and performance of energy storage systems and promote adoption into grid infrastructure. *DOE/OE*
- *BRAIN Initiative:* Develop and apply devices and models to functionally understand neurocircuitry to uncover new ways to treat, cure, or prevent brain disorders. *DoD, FDA, IARPA, NIH, NSF*
- *Smart and Connected Health:* Develop and integrate computer and information S&E approaches to support the transformation of health and medicine to better support the wide-ranging healthcare needs of the American people. *NIH, NSF*
- *NIH Research Project Grants:* Promote extramural research funding for tools and devices to support health monitoring, assessment, and assistance. *NIH*
- *Advanced Manufacturing:* Develop novel manufacturing technologies through support for fundamental, multidisciplinary research to transform capabilities, methods, and practices. *NSF*

Promote inclusive education and workforce development (*Please see the EdW PCA.*)

Key Coordination Activities

- *Principle Investigator meetings:* Review research, identify new applications, and discuss S&T gaps and barriers. *DoD, DOE, DHS, DOT, NASA, NIFA, NIH, NIST, NSA, NSF*
- *CPS:* Collaborate on the annual solicitation, led by NSF, to bring in new research ideas spanning multiple technology spaces and priorities. *DHS, FHWA, NIFA, NIH, NSF*
- *CPS Virtual Organization:* Leverage the platform for joint program reviews and research tool integration. *NSA, NSF*
- *Joint proposal evaluation:* Promote portfolio synergy. *AFRL, FHWA, NASA, NIST, NSA, NSF*
- *Smart Grid Task Force:* Ensure awareness, coordination, and integration of Federal activities related to smart grid technologies, practices, and services. *DHS, DOC, DoD, DOE/OE, USDA, others*

- *Smart and Secure Cities and Communities Challenge Expo/SCC Leadership Forum:* Highlight public-private partnerships developing replicable, trustworthy SCC applications, and convene meetings of SCC RD&D leaders. *DHS, NIST, NSF, NTIA*

High Confidence Software and Systems (HCSS) IWG

Participating Agencies: **Air Force, Army, DHS, DoD, DOE/CESER, DOE/OE, FAA, FDA, FHWA, ITS JPO, NASA, Navy, NIH, NIST, NRC, NSA, NSF, OSD**

The HCSS IWG coordinates Federal R&D on next-generation engineered systems that depend on cyber control and require very high levels of system assurance, including military and commercial aircraft and vehicles, critical infrastructure, and other safety-critical systems, both human-guided and autonomous.

Strategic Priorities

- Pursue foundational and applied research and develop standards to mature the scientific basis for designing, building, securing, and assuring complex CPS and IoT technologies.
- Assure autonomous and AI technologies to support the application of autonomous and AI technologies, especially in safety-critical and high-dependability applications.
- Facilitate transition to practice (TTP) of tools and technologies to public and private sector users.
- Promote education and workforce development by developing integrative curricula, promoting authentic research experiences, and facilitating training in novel tools and techniques.

Key Programs

Pursue foundational and applied research and develop standards

- *CPS:* Develop the core research to engineer complex CPS requiring dependable, high-confidence, or provable behaviors, including in the context of autonomous systems that learn from experience. *DHS, FHWA, NIFA, NSF*
- *Formal Methods in the Field:* Convene researchers in formal methods and computer and information science and engineering to jointly develop rigorous and reproducible methodologies for the design and implementation of correct-by-construction systems and applications, including cyber-human systems, with provable guarantees. *NSF*
- *Software and Hardware Foundations:* Advance the design, verification, operation, utilization, and evaluation of computer hardware and software. *NSF*
- *Trusted Systems, Components, and Data for Smart Manufacturing:* Develop and deploy advances in measurement science, standards, and test methods to enable trust in smart manufacturing systems, components, and data. *DHS, DoD, NIST*
- *Boutique Analysis:* Improve the assurance of security-critical algorithms, protocols, software, and hardware relevant to national security systems through research on foundational technology and techniques to apply to niche problem areas. *DOE labs, NRL, NSA*
- *Centaur-Styled Analysis:* Develop technologies that leverage both human and machine capabilities for discovery and remediation of vulnerabilities and flaws, automating difficult and time-consuming tasks, assuring and engineering trusted AI-based systems, and enabling human analysts to conduct sophisticated operations in real time. *ARL, DoD, DOE labs, NSA, ONR*
- *Resilient Hull, Mechanical, and Electrical Systems:* Develop technologies that leverage the physical properties of CPS to ensure resilience of naval assets to cyber-attacks. *NRL, ONR*
- *Trusted and Resilient Software:* Apply automation to software repair and diversity to shift software analysis to earlier in the development lifecycle and reduce human errors. *AFRL*

Assure autonomous and AI technologies

- *Advanced Aerial Mobility Project:* Pursue research in the design, verification, validation, and certification of novel air vehicles with increasingly autonomous functions undergoing diverse operational concepts, including urban air mobility. *FAA, NASA, NTSB*
- *Mitigating Adversarial ML:* Develop tools and techniques to enable measurement and modeling of adversarial capabilities to influence applications of ML in national security systems. *ARL, NSA*
- *Learn2Reason:* Symbiotically integrate formal and statistical ML in closed systems to enable planning and action for autonomous CPS. *ONR*
- *Robust and Secure ML Models and Algorithms:* Develop robust, efficient, and secure, training methods, learning architectures, and learning models, and develop analysis and monitoring capabilities for learning-enabled components. *AFRL*

Facilitate transition to practice

- *System-Wide Safety:* Develop, analyze, and assure algorithms and methods for current and emerging airspace operations, develop assurance techniques and algorithms, and apply these in support of international aviation standards development. *AFRL, FAA, NASA, industrial partners*.
- *Robust Low-Level Cyber-Attack Resilience for Military Defense:* Integrate novel technologies for cyber-attack-resilient CPS seamlessly into tactical vehicles. *ARL, AFRL, GVSC, ONR*
- *Highway R&D/Technology Innovation and Deployment:* Support demonstration and replication of hardware-in-the-loop technology for connected vehicles and vehicle/pedestrian test cases, and identify AI applications for traffic and pedestrian safety. *FHWA, ITS JPO*
- *Dear Colleague Letter supporting TTP in CPS and SCC programs:* Support high-impact TTP activities in currently funded research, e.g., accelerated maturation of research technology readiness levels, research integration with industrial and/or transition partners, and expanding pilot activities. *NSF*

Promote education and workforce development

- *Scholar-in-Residence:* Develop new methodologies for medical device certification. *DHS, FDA, NSF*
- *National Research Council Associates Program:* Support postdoctoral researchers who conduct connected vehicle research. *FHWA*

Key Coordination Activities

- *PI Meetings, NSF CPS Program, and other joint proposal evaluations:* See related entries in the CPS IWG section above.
- *Joint Federated Assurance Center Science & Technology Portal:* Facilitate communication between programs and performers to share ideas and assist in technology transition. *OASD/R&E*
- *HCSS conferences:* Collaborate with the annual HCSS Conference, Software Certification Consortium, and NASA Formal Methods Symposium. *AFRL, FAA, NASA, NIST, NSA*
- *Research Transition Teams:* Transition research in verification and validation of increasingly autonomous air vehicles into the certification process, and transition validated tools and techniques for assurance of both conventional and emerging vehicles and operations. *FAA, NASA*
- *Summer of Collaboration:* Host working meetings on assurance of autonomous systems. *AFRL, NASA*

Cyber Security and Privacy (CSP) PCA

CSP involves R&D to protect information and information systems from cyber threats and to prevent adverse privacy effects arising from information processing, including R&D to deter, detect, prevent, resist, respond to, recover from, and adapt to threats to the availability, integrity, and confidentiality of information and information systems, as well as R&D of privacy-protecting information systems and standards.

The Cyber Security and Information Assurance IWG and the Privacy R&D IWG report their R&D investments and activities under the CSP PCA.

Cyber Security and Information Assurance (CSIA) IWG

Participating Agencies: **Air Force, Army, DARPA, DHS, DOE/CESER, DOT, IARPA, Navy, NIH, NIJ, NIST, NRC, NSA, NSF, OSD, Treasury**

The CSIA IWG coordinates Federal R&D to protect information and information systems from cyber threats. This R&D supports the security and safety of U.S. information systems that underpin a vast array of capabilities and technologies in many sectors, including power generation, transportation, finance, healthcare, manufacturing, and national security.

Strategic Priorities

The 2016 *Federal Cybersecurity Research and Development Strategic Plan*[12] outlines Federal strategic priorities for cybersecurity research. The plan's priorities for cybersecurity R&D align with NIST's *Framework for Improving Critical Infrastructure Cybersecurity*,[13] which provides guidance on managing and reducing cybersecurity risks faced by businesses and organizations. Guided by the strategic plan, CSIA agency investments for FY2020 will focus on key research in the following priority areas:

- **Deter:** The ability to efficiently discourage malicious cyber activities by increasing the costs, risks, and uncertainty to adversaries and diminishing their spoils.
- **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 systems should be assumed to be vulnerable to malicious cyber activities.
- **Adapt:** The ability to dynamically adapt to malicious cyber activities by reacting to disruption, recovering from damage, and adjusting to be able to thwart similar future activity.

Critical CSIA R&D supporting areas, as described in the strategic plan, also are noted.

Key Programs

Deter: Develop methods to assess adversary levels of effort, results, and risks; provide for effective and timely attribution of malicious cyber activities to their sources; design robust investigative tools; and support information sharing for attribution. Key activities include:

- Cyber deception. *ARL, C5ISR, ONR*
- Cyber attribution. *DARPA*
- Proactive cyber defense. *AFRL, ARL, C5ISR*

[12] https://www.nitrd.gov/pubs/2016-Federal-Cybersecurity-Research-and-Development-Strategic-Plan.pdf
[13] https://nvlpubs.nist.gov/nistpubs/CSWP/NIST.CSWP.04162018.pdf

Protect: Develop technologies that limit software and system vulnerabilities through design, construction, and verification, and that enforce security though authentication, access control, and cryptography. Key activities include:

- Automated and autonomous cyber defense and operations. *AFRL, ARL, DARPA, ONR, OSD*
- Assured AI and systems engineering. *AFRL, DARPA, NIST, NSA*
- Resilient cyber, cyber-physical, and Internet-of-Things systems. *ARL, C5ISR, DARPA, DHS, DOE/CESER, NIST, NSA, NSF, ONR*
- Application, network, mobile, and hardware security. *AFRL, ARL, C5ISR, DARPA, DHS, DOE/CESER, NIST, NSA, NSF, ONR, OSD*
- Configuration and vulnerability management. *NIST, NSA*

Detect: Develop technologies to ensure that system and network owners and users have situational awareness and understanding of ongoing (authorized and unauthorized) activities and can reliably detect malicious cyber activities. Key activities include:

- Cyber situational awareness. *AFRL, ARL, C5ISR, DARPA, DOE/CESER, HPCMP*
- Detection of analog emissions. *DARPA*
- Botnet and malware detection and mitigation. *DARPA, NIST, ONR*
- Machine learning for security. *NIST, NSA, NSF*

Adapt: Develop technologies to provide real-time assessment of system changes and anomalies, provide adaptive response to actual and emerging disruptions, and enable automated recovery. Key activities include:

- Autonomous, agile, and biologically resilient cyber technologies. *AFRL, ARL, C5ISR, DARPA, DOE/CESER, NSA, ONR, OSD*
- Countering denial-of-service attacks. *DARPA, NSF*

Additional Critical CSIA R&D Supporting Areas for R&D Investment

- *Scientific foundations:* Establish the theoretical, computational, and data mining R&D principles to address future threats:
  - Artificial intelligence and security. *AFRL, ARL, DARPA, NIST, NSF, ONR, OSD*
  - Quantum-based and quantum-resistant security. *AFRL, ARL, DOE/CESER, NIST, NSA, NSF*
  - Cryptography. *NIST, NSA, NSF, ONR*
  - Formal methods. *AFRL, DARPA, NSA, NSF, OSD*
- *Risk management:* Develop techniques for assessment of an organization's assets, vulnerabilities, and potential threats so that security investments can be risk-informed:
  - Cyber risk analysis. *ARL, DHS, DOE/CESER, NIST*
  - Supply chain risk management. *NIST, NSA, ONR*
  - Cybersecurity Framework and Privacy Framework. *NIST*
- *Human aspects:* Improve understanding of how users, defenders, and adversaries interact with information technologies, and of the social, behavioral, and economic aspects of cybersecurity:
  - Studies in sociotechnical dimensions. *ARL, NSF, NSA, OSD*
  - Studies in usability of security. *NIST, NSF*
- *Transition to practice:* Support testing, evaluation, and commercialization activities that engage the private sector; transition R&D to practice, and streamline and accelerate the acquisition process:
  - Transition-to-practice programs. *DOE/CESER, NIST, NSF*
  - Commercialization Accelerator Program. *DHS*
- *Workforce Development:* Foster programs in cybersecurity education, professional development, and training to sustain cybersecurity innovations by the national workforce. *AFRL, NIST, NSA, NSF, ONR*

- *Research infrastructure:* Maintain and develop tools, test environments, and datasets at the right scale and fidelity to support a broad range of experimentation and analysis across the cybersecurity challenges:
  - Testbeds. *AFRL, ARL, DOE/CESER, NIST, NSF, ONR*
  - Data repositories. *NSF*

Key Coordination Activities

- *Federal Cybersecurity R&D Strategic Plan Implementation Roadmap:* As directed by the Cybersecurity Enhancement Act of 2014 (P.L. 113-274), the CSIA IWG annually updates the *Implementation Roadmap for the Federal Cybersecurity R&D Strategic Plan*.[14] *All CSIA IWG Agencies*
- *Collaborative research:*
  - Cyber Research Alliance. *ARL, C5ISR*
  - Cyber Resilient Energy Delivery Consortium. *DOE/CESER*
  - Cyber-physical systems security. *DOT, NIST, NSF*
  - National Cybersecurity Center of Excellence. *NIST*
- *Agency-sponsored conferences and workshops:*
  - Annual cyber technology demonstrations. *DARPA, NIST, NSA, OSD*
  - Cyber and cyber-physical security public working groups. *NIST*
  - National Initiative for Cybersecurity Education Conference and Expo. *NIST, NSA, NSF*
  - Cybersecurity research workshops. *NSF*
- *Technical standards:*
  - Cryptographic standards. *NIST, NSA*
  - Internet Engineering Task Force public working groups. *NIST, NSA, OSD*
- *DoD Cyber Community of Interest (COI):* Provide oversight and coordination among DoD cyber S&T programs. *AFRL, ARL, C5ISR, DARPA, NSA, ONR, OSD*
- *Cyber education:*
  - Centers of Academic Excellence. *NSA*
  - CyberCorps: Scholarship for Service, Advanced Technological Education. *NSF*
  - National Initiative for Cybersecurity Education. *NIST, NSA, NSF, OSD*
- *International collaborations:*
  - Science programs with Israel, Netherlands, and Brazil. *NSF*
  - Joint cybersecurity R&D programs with Australia, Canada, Israel, Japan, Netherlands, New Zealand, Singapore, Sweden, and the United Kingdom, and with South Korea. *AFRL, DHS*
  - The Technical Cooperation Program—Command, Control, Communications, Information Systems—with Australia, Canada, New Zealand, and the United Kingdom. *AFRL, ARL, C5ISR, NSA, ONR, OSD*

Privacy Research and Development IWG

Participating Agencies: **Air Force, Army, Census, DARPA, DHS, FTC, NARA, Navy, NIH, NIST, NSA, NSF, NTIA, OSD**

The Privacy IWG coordinates Federal R&D aimed at preventing adverse privacy effects arising from information processing, including R&D of privacy-protecting information systems and standards. This R&D supports advances in large-scale data analytics that can improve healthcare, eliminate barriers to

[14] https://www.nitrd.gov/pubs/FY2020-Cybersecurity-RD-Roadmap.pdf

education and employment, and increase efficiencies in the transportation and financial sectors while minimizing risks to individual privacy and possible harms such as discrimination, loss of autonomy, and economic losses. Privacy activities follow the plan of the 2016 *National Privacy Research Strategy*.[15]

Strategic Priorities

- Foster a multidisciplinary approach to privacy research and solutions (applies to all programs).
- 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 uses are consistent with privacy rules.
- Reduce privacy risks of analytical algorithms.

Key Programs

Understand and measure privacy desires and impacts

- Develop models and solutions that can help people manage their privacy in different contexts. *DHS, NSA, NSF*

Develop system design methods that incorporate privacy desires, requirements, and controls

- Develop practical approaches for implementing privacy protections in data analytics systems, in statistical data provided by the Federal Government, and in multiparty computation. *Census, DARPA, DHS, NIH, NIST, NSA, NSF*
- Apply formal privacy safeguards to the 2020 Census and the American Community Survey. *Census*
- Develop privacy framework and standards-based tools and privacy engineering practices. *NIST*

Increase transparency of data collection, sharing, use, and retention

- Drone Privacy Intrusion Detection Program. *DHS*
- Privacy in Smart Home Networks Project. *NIST*

Assure that information flows and uses are consistent with privacy rules

- Address privacy in networking, mobile computing, and sensor platforms. *DHS, NIH, NSA, NSF*
- Protect genetic privacy and improve identity- and privacy-preserving technologies for medical research. *NIH, NIST, NSF*

Reduce privacy risks of analytical algorithms

- Develop techniques to assure privacy protections and fairness in ML algorithms. *NIST, NSA, NSF*

Key Coordination Activities

- *Workshops:* Annual workshops on privacy research topics such as privacy controls, privacy framework, algorithmic transparency, and consumer privacy protections. *FTC, NIST, NSF*
- *Technical privacy guidelines:* Development and coordination of recommendations, guidelines, and standards for privacy-preserving technologies and privacy risk assessment methodologies (e.g., NIST SP 800-53, NIST SP 800-122, and NIST IR 8053). *DHS, DoD, NIST*
- *Research competitions:* Unlinkable Data Challenge, to advance differential privacy. *NIST*
- *International collaborations:*
  - International privacy standards engagements. *NIST*
  - U.S.-Netherlands co-funded research activities in privacy. *NSF*

[15] https://www.nitrd.gov/pubs/NationalPrivacyResearchStrategy.pdf

Education and Workforce (EdW) PCA

EdW R&D advances use of information technology to improve education and training; this includes IT to enhance learning, teaching, assessment, and standards, as well as preparation of next-generation cyber-capable citizens and professionals.

EdW activities are coordinated directly through the NITRD subcommittee and through other IWGs as appropriate. Agencies also coordinate related activities broadly through the NSTC Committee on Science, Technology, Engineering, and Math Education.

Reporting Agencies: **DHS, DOC, DoD, DOE/SC, DOL, ED, FCC, ITS JPO, Navy, NIFA, NIH, NIST, NSA, NSC, NSF, ODNI, OPM**

Agency and interagency R&D activities reported under the EdW PCA leverage IT to improve the learning and teaching of America's technical workforce, and to prepare all Americans—with a special emphasis on women and other underrepresented groups—for an increasingly digital-reliant society. NITRD agencies' EdW investment planning is also guided by the 2018 Federal STEM Education 5-year plan, *Charting a Course for Success: America's Strategy for STEM Education*.[16]

Strategic Priorities

- Create new educational opportunities in IT, including in AI, at all educational levels in the near term to ensure the flow of technically skilled American teachers and workers into jobs, advance the skillsets of the current workforce to fill shortages of researchers and practitioners, and improve the breadth and depth of individuals' capabilities in using IT and AI tools and methods.
- Design effective lifelong learning programs to help Americans keep up with technological and societal changes over the long term, to ensure that the public can make use of IT-enabled resources and that the domestic workforce is available and qualified for the jobs of the future.
- Promote collaboration in support of a persistent and robust U.S. IT education ecosystem by coordinating and collaborating among Federal agencies and with the business, educational, and nonprofit communities in developing educational programs, tools, and technologies.
- Advance domain-specific education and training for STEM and IT.

Key Programs

Create new educational opportunities in IT, including AI, at all educational levels in the near term

- *K–12 computer science (CS) education:* Support researcher-practitioner partnerships that expand CS education to all American classrooms. *NSF*
- *CS undergraduate education:* Work with colleges and universities to explore novel approaches for CS undergraduate education programs that are responsive to the large influx of and multidisciplinary interests of American students. *NSF*
- *Agriculture and Food Research Initiative:* Promote research and extension experiential learning for undergraduates to develop exceptional skills, including IT and AI skills. *NIFA*
- *Research Project Grant Program:* Train researchers and graduate students in the tools and methods of computational science and bioinformatics. *NIH*

Design effective lifelong learning programs

- *Cyberlearning for Work at the Human-Technology Frontier:* Educate learners of all ages in STEM so that they are equipped with the IT skills required for future jobs, including functioning in highly technological environments and in collaboration with emerging intelligent systems. *NSF*

[16] https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

- *LHS Institutional Mentored Career Development:* Work with Patient-Centered Outcomes Research Institute (PCORI) to train clinicians and research scientists to conduct patient-centered outcomes research on generation/adoption/application of evidence to improve care quality and safety. *AHRQ*

Promote collaboration in support of a persistent and robust U.S. IT education ecosystem

- *National Initiative for Cybersecurity Education (NICE):* Promote and energize a robust network and an ecosystem of cybersecurity education, training, and workforce development to increase the number of skilled cybersecurity professionals helping to keep the Nation secure. *DHS, DOC, DoD, DOE/SC, DOL, ED, FCC, NIST, NSA, NSC, NSF, ODNI, OPM, academic and industry partners*
- *Please also see Key Coordination Activities below.*

Advance domain-specific education and training for STEM and IT

- *Agriculture and Food Research Initiative Education and Workforce Development:* Develop the next generation of research, education, and extension professionals in food and agricultural science that include crop and animal systems engineers and consultants. (*Relevant to the CPS IWG and CNPS PCA*.) *NIFA*
- *Center for Ultra-wide-area Resilient Electric Energy Transmission:* Develop the next generation of electric power and energy systems engineers. (*Relevant to the CPS IWG and CNPS PCA*.) *DOE labs, DOE/OE, NSF*
- *ITS Professional Capacity Building:* Conduct outreach and provide training and technical assistance to enable ITS deployment by the public-sector transportation workforce. (*Relevant to the CPS IWG and CNPS PCA*.) *ITS JPO*
- *Research Traineeships, Harnessing the Data Revolution, and Data Science Corps:* Encourage innovative models for data science training for both the existing workforce and for graduate students. (*Relevant to the Big Data IWG and CHuman PCA*.) *NSF*
- *Transdisciplinary Research in Principles of Data Science Institutes:* Promote long-term, interdisciplinary research and training activities between theoretical foundations of data science and other disciplines. (*Relevant to the Big Data IWG*.) *NSF*

Key Coordination Activities

- *NSTC Federal Coordination in STEM Education Subcommittee, IWG on Convergence:* Enable coordination across all IWG member agencies, including NITRD agencies, and the private sector in support of growing the K–12 computer science education knowledge base and expanding access to pre-K–12 CS education at all American schools. *DHS, DOC, DoD, DOE, DOJ, DOL, DOT, ED, HHS, Interior, NASA, NSF, OMB, OSTP, USDA*
- *DoD STEM strategy:* Focus on developing and retaining a diverse STEM-proficient workforce and network to drive S&T innovation at the highest standards of scientific discovery. *DoD, ONR*
- *NICE Strategic Plan:* Continue implementation of the strategy that sets forth NICE's vision, mission, values, goals, and objectives. *DHS, DOC, DoD, DOE/SC, DOL, ED, FCC, NIST, NSA, NSC, NSF, ODNI, OPM*
- *NICE Interagency Coordinating Council:* Convene NICE Federal Government partners for consultation, communication, and coordination of policy initiatives and strategic directions related to cybersecurity education, training, and workforce development. *DHS, DOC, DoD, DOE/SC, DOL, ED, FCC, NIST, NSA, NSC, NSF, ODNI, OPM*
- *Workforce cybersecurity education and training provisions of the Cybersecurity Executive Order:* Continue to address activities directed by Presidential Executive Order 13800: "Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure."[17] *DHS, DOC, NIST, NSF*

[17] https://www.whitehouse.gov/presidential-actions/presidential-executive-order-strengthening-cybersecurity-federal-networks-critical-infrastructure/

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

EHCS R&D advances high-capability computing and development of fundamentally new approaches in high-capability computing; this includes R&D in hardware and hardware subsystems, software, architectures, system performance, computational algorithms, data analytics, development tools, and software methods for extreme data- and compute-intensive workloads.

The High End Computing IWG reports its relevant R&D investments and activities under the EHCS PCA.

High End Computing (HEC) IWG

Participating Agencies: **DoD, DARPA, DOE/SC, DOE/NNSA, EPA, IARPA, NASA, NIH, NIST, NOAA, NSA, NSF, OSD, USGS**

The HEC IWG coordinates Federal R&D of innovative future computing technologies and supercomputers to extend U.S. leadership in advanced computing and enable transformative research that supports the Nation's economic competitiveness, security, and leadership in science, engineering, and technology. EHCS investments ensure the development of technologies critical in preparing for the next computing revolution and overcoming challenges such as the expected end to Moore's Law, post-Dennard scaling, the growing deluge of data, and the rapid changes in the technological landscape, while ensuring effective use of high-capability computing (HCC) systems to support endeavors vital to the Nation. HCC advances impact the entire spectrum of computing devices and open new opportunities for innovation in areas such as precision medicine, smart and connected communities, and the next wave of autonomous machines.

Strategic Priorities

- Advance extreme-scale computation: Develop technologies critical to the delivery of capable exascale computing systems, prepare scientific applications to fully exploit exascale capabilities, explore novel approaches for data-intensive high-capability computing (HCC) and analytics, and pursue research to increase performance.
- Open new directions in high-capability computing: Take computing "beyond Moore's Law" by advancing potential breakthroughs in quantum, neuromorphic, and probabilistic computing and by developing novel scientific frameworks, power-efficient system architectures, memory, programming environments, measurement science, and advanced computing prototypes.
- Boost productivity: Develop new architecture benchmarks, common tools for computational modeling and simulation and data analysis, and research methods to improve programmability.
- Increase impact: Conduct crosscutting activities that serve to extend the breadth and impact of HCC, including developing the next generation of the HCC workforce.

Key Programs

Advance extreme-scale computation

- Continue work on the Exascale Computing Project in developing the ECP software stack and applications software, and the PathForward Program to ensure that node and system designs meet exascale goals. *DOE/NNSA, DOE/SC*
- Explore emerging platforms for data-intensive HCC and machine learning. *HPCMP*
- Develop algorithms and prepare scientific applications to ensure software performance and portability for ECP architectures. *NASA*
- Develop extreme-scale computational approaches for biomedical simulations. *NIH*
- Develop methods for quantifying reproducibility and uncertainty in scientific computing and develop algorithms and software innovations to process extreme data. *NIST*

- Continue research to increase performance in parallel computing and to develop new computational and data analysis approaches to enable major S&E breakthroughs. *NSF*

Open new directions in high-capability computing

- Advance quantum computing by:
  - Providing quantum testbeds for research and evaluation of quantum technologies and research quantum computer science and algorithms. *DOE/SC, NSF*
  - Continuing work on quantum computing through partnerships with industry. *NASA, NIST, NSF*
  - Continuing research in quantum information science. *NIST, NSF*
  - Establishing foundries for rapid prototyping and development of quantum devices and materials. *NSF*
- Continue research in neuromorphic computing and deep learning. *NIST, NSA, NSF*
- Research probabilistic computing, explore ways to increase power savings across all computing components, and explore advanced memory concepts to accelerate development of next-generation memory technology and architectures. *NSA*
- Support the Foundational Microarchitecture Research partnership with industry to deliver future CPU performance growth beyond Moore's Law. *NSF*

Boost productivity

- Research and develop metrics for evaluating quantum device performance. *DOE/SC, NIST*
- Develop data systems and computational kernels for data sharing and code reuse. *NASA*
- Develop benchmarks for performance evaluation of differing architectures. *NOAA*
- Develop tools for detection and analysis of failures due to reliability issues, and develop common modeling, simulation, and emulation platforms for investigating cutting-edge technologies. *NSA*

Increase impact

- Develop the future HEC workforce. *DOE/SC, NSF*
- Support translational research and education activities in all aspects of HCC that lead to deployable, scalable, and sustainable systems. *NSF*

Key Coordination Activities

- Explore HCC, Big Data, and machine learning coherence to ensure support for emerging data-intensive applications and domains. *Big Data IWG agencies, HEC IWG agencies,*
- Continue joint exascale system procurement, including co-funding of nonrecurring engineering activities. *DOE/NNSA, DOE/SC*
- Continue collaborations to enhance research in cancer and drug discovery with HCC capabilities, analytics, and tools. *DOE/NNSA, DOE/SC, NIH*
- Design and develop advanced computing prototypes. *DoD services labs, DOE labs, IARPA, NSA*
- Investigate ARMv8 as a potentially viable high-performance computing (HPC) architecture path for the next decade. *DOE/NNSA, HPCMP*
- Support the Joint Center for Quantum Information and Computer Science. *NIST, NSA*
- Support workforce development through the Quantum Science Summer School. *DOE, NSF*

High-Capability Computing Infrastructure and Applications (HCIA) PCA

HCIA investments advance operation and utilization of systems and infrastructure for high-capability computing, including computation- and data-intensive systems and applications; directly associated software, communications, storage, and data management infrastructure; and other resources supporting high-capability computing.

The High End Computing IWG reports its relevant R&D investments and activities under the HCIA PCA.

High End Computing (HEC) IWG

Participating Agencies: **DoD, DOE/NNSA, DOE/SC, EPA, IARPA, NASA, NIH, NIST, NOAA, NSA, NSF, OSD, USGS**

In addition to coordinating EHCS R&D investments and programs, the HEC IWG coordinates the operation and modernization of HCC infrastructure as well as developing algorithms and applications to accelerate scientific discoveries and technological innovations in areas such as advanced weapons, materials discovery and design, energy applications, earth and space science, early-stage research of advanced technologies, detection and treatment of diseases, and many other applications of national interest. HCIA investments provide researchers from academia, government, and industry tens of billions of computing hours annually on the Nation's most powerful computing platforms and provide the ecosystem and expertise the United States needs to exploit its HCC capabilities fully.

Strategic Priorities

- Provide leadership-class and production high-capability computing systems: Acquire, operate, and provide HCC systems of varying capabilities needed to meet critical national needs and to support research and education across all S&E.
- Advance HCC applications: Develop algorithms and applications software for current and next-generation HCC platforms to maintain and improve the performance of existing codes and continue to develop the HCC infrastructure and ecosystem needed to advance HCC applications.
- Provide access to the HCC ecosystem: Provide diverse user communities with efficient, effective, and dependable access to HCC facilities and resources, including testbeds, communications, storage, software tools, applications, computational expertise, and system support; and enhance existing infrastructure capabilities for computational and data-enabled science, modeling, simulation, and analysis.
- Support productivity and increase impact: Lower barriers to HCC access and usability by developing and integrating resources to support productivity, designing and developing collaborative work environments for high-capability simulation and data analytics, and expanding the computational workforce.

Key Programs

Provide leadership-class and production high-capability computing systems

- Provide leadership-class HCC at Leadership Computing Facilities Argonne (Frontier, Summit) and Oak Ridge (Aurora); continue operation of the production system Cori at the National Energy Research Scientific Computing Center (NERSC); and acquire and deploy the NERSC-9 system. *DOE/SC*
- Support DoD Supercomputing Resource Centers and provide HCC capability in a container for tactical at-the-edge use cases. *HPCMP*
- Provide HCC capacity to NASA S&E communities and support NASA's digital transformation through the NASA Center for Climate Simulation (Discover HCC system) and the NASA Advanced Supercomputing Facility (Electra and Pleiades systems). *NASA*

- Provide HCC resources Anton 2 and Biowulf for biomedical research. *NIH*
- Operate internal and external HCC systems of diverse leading-edge architectures. *NOAA*
- Operate and support HCC through the Leadership-Class Computing Program; HCC resources through the National Center for Atmospheric Research/Wyoming Supercomputing Center Program; a diverse set of mid-tier HCC resources through the Advanced Computing Systems and Services Program; and local campus HCC clusters through the Major Research Instrumentation Program. *NSF*

Advance HCC applications

- Develop DoD multiphysics software applications. *HPCMP*
- Prepare application software for porting to new architectures. *NASA, NOAA*
- Develop analytics and support multiscale modeling of biomedical processes for improved disease treatment and advancing our understanding of the human body. *NIH*
- Develop parallel algorithms, algorithmic and mathematical tools for modeling, large-scale high-performance image processing techniques, and computation methods required for applications in measurement science; also, develop infrastructure for interactive 3D visualization of data. *NIST*
- Support the development of a software and data cyberinfrastructure ecosystem. *NSF*

Provide access to the HCC ecosystem

- Provide researchers access to leadership computing facility resources through the Innovative and Novel Computational Impact on Theory and Experiment Program. *DOE/SC*
- Provide DoD users computational tools and techniques, data analysis and visualization tools, application support, and HCC system expertise. *HPCMP*
- Provide shared interoperable cloud computing environments, high-capacity infrastructure, and computational analysis tools for high-throughput biomedical research. *NIH*
- Support the eXtreme Science and Engineering Discovery Environment (XSEDE) for shared user HCC services, storage, visualization, and data services. *NSF*

Support productivity and increase impact

- Support the HPC Portal for desktop web browser access to HCC capabilities. *HPCMP*
- Continue support for the NERSC and the Oak Ridge and Argonne Leadership Computing Facilities, including training, application readiness, and outreach to prepare the scientific community for future system upgrades. *DOE/SC*
- Continue supporting the Science Gateways Community Institute and developing the XDMoD (XSEDE Metrics on Demand) tool to monitor and optimize HCC performance and software programs. *NSF*
- Support the expansion of the HCC workforce. *HPCMP, NASA*

Key Coordination Activities

- Provide HCC compute core hours[18] for HCC applications. *DOE/SC, HPCMP, NASA, NIH, NSF*
- Participate collaboratively in annual system and proposal review panels and PI meetings. *HEC IWG agencies, other agencies*
- Update the Federal HEC Information Portal https://www.nitrd.gov/apps/hecportal/, which provides public resources on engagement opportunities, learning, workforce development, software, and other Federal HCC resources. *HEC IWG agencies*
- Support activities that advance strategic computing leadership, including public-private partnerships focused on the emerging computing paradigms and ecosystems. *HEC IWG agencies, other agencies*

[18] Specific computing term that refers to the number of processor units (cores) used to run a simulation multiplied by the duration of the job in hours.

Intelligent Robotics and Autonomous Systems (IRAS) PCA

IRAS R&D advances intelligent robotic systems; this includes R&D in robotics hardware and software design and application, machine perception, cognition and adaptation, mobility and manipulation, human-robot interaction, distributed and networked robotics, and increasingly autonomous systems.

The IRAS IWG reports its R&D investments and activities under the IRAS PCA.

Intelligent Robotics and Autonomous Systems (IRAS) IWG

Participating Agencies: **Air Force, AFOSR, Army, ARL, DHS, DOE/EM, DOT, NASA, Navy, NIFA, NIH, NIJ, NIOSH, NIST, NRL, NSA, NSF, ONR, OSD**

The IRAS IWG coordinates R&D in various aspects of autonomous robots, including accelerating development and use of collaborative robots and other intelligent physical systems. IRAS focuses on developing robust, safe, efficient, and ethical robots and intelligent systems that can assist people in their work and everyday lives. Advanced robotic systems can enhance safety, minimize human risk, support the elderly and disabled, and boost the performance of workers and of warfighters in support of individual wellbeing and the Nation's economic security and national defense.

Strategic Priorities

- Promote safe and efficient human-robot teaming, including evaluating human-robot interface and communication systems for safe, trustworthy, and transparent collaboration to increase quality of work and life.
- Improve verification and validation of robotic and autonomous systems, including developing metrics, information models, methods, protocols, and tools to test and validate system safety and performance, and the measurement science infrastructure needed to specify and evaluate the capabilities of remotely operated or autonomous aerial, ground, underground, or aquatic systems.
- Advance intelligent physical systems to improve the system's ability to robustly sense, model, act, plan, learn, and behave ethically in complex and uncertain situations such as emergency response, mine rescue, and unstructured environments, and including surgical robotics and therapeutic and assistive technology for people with sensorimotor, communication, cognition, or vision impairments.
- Improve wearable robotic fabrics and devices including exoskeletons and exosuits; these provide rehabilitation for injured or disabled persons and enhance worker safety (e.g., under musculoskeletal overload) and performance in various settings.

Key Programs

Promote safe and efficient human-robot teaming

- *Human/Autonomous System Interaction and Collaboration:* Create cognitively compatible intelligent autonomous systems and robots that can team with humans, enabling peer-to-peer collaboration among humans, robots, intelligent agents, and autonomous systems. *DoD*
- *Scalable Teaming of Autonomous Systems:* Integrate mission-level task allocation/assignment, robust self-organization, adaptation, collaboration, space management operations, and sensing/synthetic perception. *DoD*
- *Center for Occupational Robotics Research:* Study risk factors associated with robot-related workplace injuries and develop and evaluate engineering controls and workplace interventions for safe, intuitive, and useful collaborative and co-existing robot systems. *NIOSH*
- *Mind, Machine, and Motor Nexus:* Integrate treatment of human intent, perception, and behavior in interaction with embodied, intelligent engineered systems mediated by motor manipulation. *NSF*
- *Measurement Science for Manufacturing Robotics (MSMR), Performance of Human-Robot Interaction:* Deliver a suite of test methods, protocols, and information models to enable effective, human-

robot collaboration in manufacturing and to advance interactive robot technologies to facilitate safe and efficient teaming of people and robots toward meeting production goals. *NIST, NRL*

- *NRI-2.0:* Support fundamental research that accelerates development and use of robots in the United States that work beside or cooperatively with people. *AFOSR, DoD, DOE, DOE/EM, NASA, NIFA, NIOSH, NSF, ONR, USDA*
- *Robust Intelligence:* Understand and enable intelligent systems in complex, realistic contexts using representation and the ability to learn and adapt performance at human levels and beyond. *NSF*
- *Smart and Autonomous Systems:* Develop intelligent physical systems that combine perception, cognition, communication, and actuation to perform physical work in various settings, not limited to robotics, self-driving vehicles, underwater exploration vehicles, and smart grids. *DoD, NSF*

Improve validation and verification of robotic and autonomous systems

- *Automated Driving Systems (ADS):* Test the safe integration of ADS into the Nation's on-road transportation system and ensure significant data gathering and sharing of project data with the public throughout the project in near real time. *DOT*
- *MSMR:* Develop and deploy measurement science, standards, and test methods that advance manufacturing robotic system performance, collaboration, agility, autonomy, safety, and ease of implementation to enhance U.S. innovation and industrial competitiveness. *DoD, NIST*
- *Testing, Evaluation, Verification, and Validation:* Create methods, metrics, and tools to assist in requirements development and analysis, evidence-based design and implementation, accumulation of evidence through R&D and operational testing, run-time behavior prediction and recovery, and assurance arguments for autonomous systems. *DoD*

Advance intelligent physical systems

- *Future of Work at the Human-Technology Frontier:* Advance the cognitive and physical capabilities of human-technology interactions. *NSF*
- *Machine Perception, Reasoning, and Intelligence:* Develop common representations and/or architecture for rapid collaboration, learning and reasoning, understanding of situations and environments, combined with robust physical capabilities. *DoD*

Improve wearable robotic fabrics and devices

- *Compliant and Configurable Soft Robotics Engineering, Programmable Skins for Moldable and Morphogenetic Soft Robots:* Address morphological computation and surface actuation to control volumetric shape and materials and integration strategies for combinatorial robotic skins. *DoD, NSF*
- *Interoperability:* Investigate open/common architectures, modular systems, interchangeable parts, composable systems, and synergized capabilities as strong foundations for future systems. *DoD*

Key Coordination Activities

- *Principal Investigator meetings:* Review research, identify new applications, and discuss S&T gaps and barriers. *DoD, DOE, DHS, DOT, NASA, NIFA, NIH, NIST, NSA, NSF*
- *Advanced Robotics for Manufacturing Institute:* Develop open-source, interoperable metrics and performance test methods with academic and industrial partners. *Army, Air Force, Navy, NASA, NIST*
- *ASTM Committee E54 on Homeland Security Applications:* Develop performance standards for response robots. *DHS, DoD, DOJ, DOS, NIST*
- *ASTM Committee F48 on Exoskeletons and Exosuits:* Develop standards for terminology, safety, and performance for exoskeletons and exosuits. *DHS, DoD, DOE, NIH, NIOSH, NIST, NRC, OSHA*
- *Safety and other standards development:* Work in PPPs to develop standards for industrial vehicles, collaborative robots, mobile manipulators, exoskeletons, etc. *DoD, DOE, DHS, NIH, NIOSH, NIST, OSHA*
- *OSHA National Alliance:* Work with industry and international partners to reduce workplace hazards related to intelligent/autonomous systems. *DoD, NIOSH, OSHA*

Large Scale Data Management and Analysis (LSDMA) PCA

LSDMA R&D advances extraction of knowledge and insight from data; this includes R&D in the capture, curation, management, access, analysis, and presentation of large, diverse, often multisource, data.

The Big Data IWG reports its R&D investments and activities under the LSDMA PCA.

Big Data IWG

Participating Agencies: **Army, Census Bureau, DARPA, DHS, DOE/NNSA, DOE/SC, NARA, NASA, NIH, NIST, NOAA, NSA, NSF, OSD, USAID, USGS**

The Big Data IWG coordinates Federal R&D to enable effective analysis, decision-making, and discovery based on large, diverse, real-time data. Expanding capabilities to collect, store, access, and analyze big data will accelerate scientific discovery and innovation, lead to new areas of research and inquiry, provide vast resources to enhance national security, and create new capabilities that support economic growth and novel solutions to pressing national issues.

Strategic Priorities

- Maximize use of large-scale data resources through foundational research into innovative tools and methodologies to solve difficult problems.
- Establish the trustworthiness of data-driven discovery and decision-making to ensure the reliability, accuracy, generalizability, and performance of solutions.
- Enable the interoperability of diverse data types and sources that is scalable and enables data integration among heterogeneous datasets to support innovative solutions.
- Support real-time analytics by reducing latency between data ingest, analysis, and decision-making.
- Develop and retain the necessary workforce through research and training opportunities.
- Transition research to practice by translating R&D into operational tools and technologies.

Key Programs

Maximize use of large-scale data resources through foundational research

- *Synergistic Discovery and Design:* Develop tools to enable robust design in complex domains despite the lack of complete scientific models. *DARPA*
- *Federated Data Commons Model:* Enable previously impossible novel scientific research, including hypothesis generation, discovery, and validation. *NIH*
- *All of Us Research Program:* Accelerate research and improve health by gathering data from one million or more people living in the United States. *NIH*
- *Big Data Interoperability Framework:* Develop consensus on Big Data concepts. *NIST*
- *Information Integration and Informatics:* Support research to realize the full transformative potential of data, information, and knowledge. *NSF*
- *Cyberinfrastructure for Sustained Scientific Innovation:* Address the evolving needs in data integration, interoperability, and software cyberinfrastructure. *DOE/SC, NSF*
- *Machine learning:* Apply ML techniques to geothermal exploration and production. *DOE*
- *Harnessing the Data Revolution:* Support novel interdisciplinary approaches to data science. *NSF*

Establish the trustworthiness of data-driven discovery and decision-making

- *Cybersecurity Innovation for Cyberinfrastructure:* Develop and deploy security solutions that ensure the integrity, resilience, and reliability of the end-to-end scientific workflow. *NSF*
- *Media Forensics:* Develop techniques to automatically detect manipulations, provide information about them, and assess the integrity of visual media. *DARPA*
- *Open-Source and Social Media Analytics:* Apply advancements in data use to these areas. *DHS*

Enable the interoperability of diverse data types and sources

- *World Modelers:* Integrate qualitative causal analyses with quantitative models and diverse data to enable deeper understanding of complex, dynamic national security questions*. DARPA*
- *Data and Information-Sharing Architectures and Analytics for Trade, Border, and Transport Security:* Create, leverage, and use effective and efficient next-generation architectures. *DHS*
- *Biomedical Data Translator:* Integrate existing translational medicine data sources. *NIH*
- *Big Data Governance and Metadata Management:* Develop a scalable framework that makes data discoverable, accessible, and usable. *NARA, NIST*

Support real-time analytics

- *Warfighter Analytics using Smartphones for Health:* Develop algorithms to use smartphone sensor data for real-time assessment of warfighter health. *DARPA*
- *Real-time Analytics for Multi-latency, Multi-party, Metro-scale Networks:* Create and understand next-generation components, algorithms, and systems. *DHS*
- *Real-Time Learning and Decision-Making in Engineered Systems:* Develop safe, reliable, and efficient data-enabled S&E infrastructure and workflows. *DOE/SC, NSF*
- *Novel Computational Environments for Rapid Decision Making:* Develop and establish a framework and capability for conducting large-scale decision analytics. *Army, NIST*
- *Accelerating the Tactical Decision Process with High-Performance Computing on the Edge:* Develop approaches for moving analytical capabilities closer to data sources. *Army, NIST*

Develop and retain the necessary workforce (*Please see the EdW PCA.*)

Transition research to practice

- *Rapid Deployment Research and Development Capabilities:* Characterize and match sustainable big data solutions to diverse missions. *DHS*
- *Stimulating Peripheral Activity to Relieve Conditions:* Use extensive physiological databases, modeling, and analysis of nerve signals for patient therapy. *NIH*
- *Helping to End Addiction Long-term:* Use data, modeling, and analysis to develop new strategies that will help people achieve meaningful and sustained recovery from addictions. *NIH*
- *Data Science Evaluations:* Perform cross-comparisons of data analytic algorithms and their generalizability. *NIST*
- *Advanced Cyberinfrastructure Core Research:* Support translational research and education activities in all aspects of advanced cyberinfrastructure to transform S&E research. *NSF*
- *TRIPODS + X:* Foster relationships between researchers in S&E domains and foundational data scientists through the organizations engaged in Transdisciplinary Research In Principles Of Data Science (TRIPODS) projects. *NSF*

Key Coordination Activities

- *Data-Driven Discovery of Models:* Develop and evaluate automated model discovery systems that enable subject matter experts with no data science background to create empirical models of real, complex processes. *DARPA, NIST*
- *Big Data Regional Innovation Hubs:* Build regional public-private partnerships to solve regional data science problems in both the public and private sectors. *DHS, DOT, NSF*
- *Partnership in Science and Engineering Research:* Collaborate on scientific and engineering research to bolster national security, support job creation, economic growth, and advanced technologies for both civilian and military use. *AFRL, NSF*
- *Trustworthy Digital Repositories:* Develop and update standards to ensure data can be preserved and remain understandable across technology changes. *NARA, NASA, NIH*

Large Scale Networking (LSN) PCA

LSN involves R&D of networking technologies and services, including R&D in networking architectures, wireless networks, software-defined networks, heterogeneous multimedia networks, testbeds, grid and cloud research and infrastructure, network services and cloud computing middleware, identity management, and end-to-end performance enhancement and performance measurement.

The LSN IWG—including the Broadband Research and Development Group, Joint Engineering Team, and Middleware and Grid Interagency Coordination Team—and the Wireless Spectrum Research and Development IWG report their R&D investments and activities under the LSN PCA.

Large Scale Networking (LSN) IWG

Participating Agencies: **Air Force, ARL, ARS, DARPA, DoD, DOE/SC, DREN, FCC, IARPA, NASA, ONR, NIH, NIST, NOAA, NRL, NSA, NSF, OSD, USGS**

The LSN IWG coordinates Federal R&D in networking technologies and services, including network architectures, wired and wireless network infrastructures, grid and cloud middleware research, and communication protocols, to enable robust transfer of data among ground, sea, air, and space systems.

Strategic Priorities

- Develop concepts, techniques, architectures, and protocols for future networks.
- Develop cloud infrastructure enhancements.
- Develop enhanced, next-generation network architecture capabilities for data analytics.
- Develop, evaluate, and standardize technologies to achieve security and resilience in emerging wireless networks and multidomain internets and to protect core network infrastructure.
- Develop technology, standards, testbeds, and tools to improve wireless networks

Key Programs

Develop concepts, techniques, architectures, and protocols for future networks

- Provide connectivity/communications in contested/congested environments. *AFRL, C5ISR*
- Advance quantum communications and networking. *AFRL*, *DOE/*SC, *NIST*, *NSF*
- Enable Energy Sciences Network core replacement and high-speed data links (400G). *DOE/SC*
- Provide fourth-generation commercial services in high-performance, wide area networks. *DREN*
- Advance communications-as-a-service and convergent networks. *ONR*
- Enhance secure network function virtualization (NFV), software-defined networks (SDNs), information-centric networking (ICN) technologies, and applications to new domains. *NIST*
- Deliver increased capacity to N-Wave Enterprise Network and new HPC research resources. *NOAA*
- Expand computer and network systems core program. *NSF*
- Develop new SDN technologies, measurement techniques, and next-generation network research and testbeds/demonstrations. *DOE/SC, DREN, NIST, NSF*

Develop cloud infrastructure enhancements

- Enable mission-responsive information exchange from enterprise to tactical edge. *AFRL*
- Adopt a federated distributed computing and data ecosystems strategy. *DOE/SC*
- Pursue mission-focused data analytics. *DOE/SC, ONR*
- Expand proof-of-concept, cloud-based international satellite data ingestion and security validation. *DOE/SC, DREN, NOAA*
- Provide SDN and software-defined Internet exchange and perimeter (SDX/SDP) application testing and demonstrations. *DOE/SC, DREN, NIST, NSF*

- Develop standards, metrics, and guidance for adoption of cloud computing technologies. *NIST*
- Conduct network technology and systems R&D, develop new hardware for future cloud systems, and advance reproducibility research for cloud systems. *DOE/SC, NSF*

Develop enhanced, next-generation network architecture capabilities for data analytics

- Expand workload management system access to leadership class supercomputers. *DOE/SC, DREN*, *NASA*
- Develop programmable frameworks for network management. *ONR*
- Support high-performance networks and high-performance forwarding. *DOE/*SC, *NIST, NASA*
- Expand monitoring and measurement of different internal physical systems. *NOAA*
- Advance the design of edge computing and edge networking infrastructure. *NSF*
- Provide services for applications in precision medicine, mobile health, telemedicine. *DOE/SC, NIH*
- Couple big data sources with near-real-time data analytics, accelerate commercialization of 100 Gbps networking technologies, and address data analytics at scale. *DOE/SC*
- Enhance efficiency of big data transfers over high-bandwidth connections. *DOE/SC, DREN, NASA*
- Advance cooperation and test beds for large data transfers and new architectures. *DOE/SC*
- Translate research to end-to-end applications. *DOE/SC, NSF*
- Deliver next-generation supercomputing support for advanced analytic modeling. *DOE/SC, NOAA*
- Explore future Internet architectures based on ICN. *NIST, NSF*

Develop, evaluate, and standardize technologies to enhance network security and resiliency

- Advance cyber situational awareness, expanded by an ML platform. *AFRL*
- Enhance cybersecurity capabilities, including SDN and NFV. *C5ISR, DREN, NIST*
- Enable AI in infrastructure configuration. *C5ISR*
- Monitor network traffic at commercial exchange points and support Science DMZ. *DOE/SC*
- Develop new services for security operations centers and their tools. *NOAA*
- Enhance cyber technology innovations for trustworthy networks, data security, and infrastructure monitoring. *C5ISR, DOE/SC, NSF, NIST, ONR*

Develop technology, standards, testbeds, and tools to improve wireless networks

- Develop nontraditional waveforms and technologies for resilient communications. *C5ISR*
- Share multilevel information across tactical wireless networks. *DARPA*
- Advance networked free space optical communications. *ONR*
- Increase deployment of Industrial IoT and future wireless networks. *NIST*
- Promote NOAA Enterprise Wireless projects (e.g., Voice Over Wireless). *NOAA*

Key Coordination Activities

- *Software defined technologies and demonstrations:* Promote SDN/SDX/SDP applications testing and demonstrations, tactical-edge SDN collaboration, and complex systems experimental design. *DoD (e.g., C5ISR), DOE/SC, DREN, NIST, NRL, NSF*
- *National/transoceanic 100 Gbps connectivity:* Provide research network connections program support for international R&E collaborations. *DOE/SC, DREN, NASA*, *NOAA, NSF*
- *Wireless networks:* Improve information sharing across tactical wireless networks. *C5ISR, DARPA, Marine Corps, SOCOM*
- *Health network:* Expand multiagency neuroscience research collaborations. *FDA, IARPA, NIH, NSF*
- *Networking for disaster recovery and crisis management:* Expand and promulgate Disaster Information Management Research Center resources. *NIH*, *NLM*, *NASA*

- *Broadband Research and Development Group:* Provide interagency collaboration and focus on addressing disparities in nationwide broadband access, adoption, and usage. *Census*, *DARPA*, *DHS, DOE/SC, DOL, ED, FCC, HRSA, NIH, NIJ, NIST, NRL*, *NSF, NTIA, OSD, USDA*
- *Joint Engineering Team:* Coordinate on networking, advanced technologies, end-user requirements, science user interfaces, research and storage networks; end-to-end big data transport/application testbeds; trusted Internet connections; interdomain, end-to-end metrics; and tool sharing. *DOE/SC, DREN, FCC, NASA*, *NIH, NIST, NOAA, NRL*, *NSF*
- *Middleware and Grid Interagency Coordination Team:* Coordinate on identity management, distributed computing, middleware, and cloud and grid computing services and information exchanges; cloud and grid standards and implementation; best practices for resource architecture, access, and management; and security and privacy. *DOE/SC, FCC, NIST, NRL, NSF*

Wireless Spectrum R&D (WSRD) IWG

Participating Agencies: **Air Force, Army, DARPA, DEA, DHS, DOE, FAA, FCC, JMD, NASA, Navy, NIJ, NIST, NOAA, NSF, NTIA, OSD**

The WSRD IWG coordinates Federal spectrum-related R&D activities to facilitate efficient, effective R&D investments that promote efficient use of wireless spectrum through advanced technologies and systems.

Strategic Priorities

- Increase spectrum efficiency, flexibility, and adaptability.
- Design robust, secure, dependable systems and networks that rely on use of wireless spectrum.
- Provide capabilities for devices to monitor their spectrum environments and adapt in real time.
- Expand communications capacity using higher-frequency bands (>20 GHz) and optical links.
- Accelerate deployment of spectrum R&D into usable tools via testing, modeling, and simulation.

Key Programs

Increase spectrum efficiency, flexibility, and adaptability

- *Spectrum management:* Enable wireless communications that are spectrum-efficient, energy-efficient, secure, and adaptable for co-location and relocation through the development of new methods, models, and measurements, including for new 5G systems. *DOE, NIST, NSF*
- *Next-Generation Software-Defined Radio Frequency (RF):* Deliver waveforms tailored to mission and spectral environment and adaptable across hardware designs. *AFRL*
- *Spectrum efficiency:* Define spectrum efficiency within space, frequency, and time to establish meaningful and quantifiable metrics. *DARPA, DoD, FCC, NTIA*
- *Spectrum sharing:* Develop new spectrum-sharing methods, models, and measurement methods to expand availability of wireless spectrum. *NIST, NSF*
- *Adaptive and Reconfigurable RF Microsystems:* Provide spectrum-agile wideband transmitters coupled with high-dynamic-range, interference-resilient receivers. *AFRL*

Design robust, secure, and dependable systems and networks

- *Aerial Layer Networking:* Provide secure tactical intranetworking for military communications through multibeam directional connectivity and airborne data exchange between security domains. *AFRL, Navy, NSA*
- *Wireless Spectrum Communications: Filter Bank Multicarrier Spread Spectrum:* Enable anti-jamming, low probability of detection, interception, and exploitation. *DEA*
- *Secure communications and electronic countermeasures:* Expand countermeasures to include quantum communications, 5G wideband encryption, supply chain, and optimized massive-MIMO (multiple-input and multiple-output) security. *DOE*

- *Security improvements for unmanned aircraft systems:* Improve UAS security measures, including grid control, link identification, and cellular security. *DOE*

Provide capabilities for devices that can monitor their environments and adapt in real time

- *Electromagnetic Spectrum – Visual Instance of the Environment for Warfighters:* Share spectrum situational awareness using visualization, ML, and network-based techniques for collaborative planning and decentralized decision-making. *AFRL, OSD*
- *Spectrum monitoring:* Develop infrastructure and best practices to acquire data and make it available to the spectrum community; this includes signal monitoring and optimized zero-wait channel coordination. *DOE, FCC, NSF, NTIA*
- *Radio Frequency and Interference Monitoring System:* Protect satellite earth stations from LTE (long-term evolution) uplink interference. *NOAA, NTIA*

Expand communications capacity using higher-frequency bands (>20 GHz) and optical links

- *Viability Assessment for Long-range Ultra-Broadband Terahertz Communications:* Demonstrate air-to-air capability using existing RF hardware to verify. *AFRL, NIST*
- *Laser Airborne Terminal Enhancement with RF Networking Systems:* Develop optical network nodes with increased capacity and robustness. *AFRL, NASA, NRL*
- *Millimeter Wave Propagation:* Construct models based on lab and field measurement. *NTIA, NSF*
- *5G and Higher Frequency Allocations:* Demonstrate effective and secure unmanned aircraft system (UAS) and wideband communications >20 GHz. *DOE, NSF*

Accelerate deployment of R&D into usable tools through testing, modeling, and simulation

- *Hybrid RF-Optical Link Adaptation Risk-reduction and Stockbridge Controllable Contested Environment:* Design and build innovative testing facilities. *AFRL, FAA, NASA, NRL*
- *Space-Earth RF Propagation Modeling and Transponder Experiments:* Characterize channel effects and improve beacon transmission and data collection. *Air Force, NASA, NIST*
- *National Advanced Spectrum and Communications Test Network:* Provide a neutral trusted forum and a national network of Federal, academic, and commercial test facilities to evaluate spectrum-sharing technologies. *DoD, NASA, NIST, NOAA, NSF, NTIA*
- *Next-Generation Wireless:* Establish accurate measurements, system calibrations, and models to support next-generation wireless communications (e.g., 5G and beyond). *NIST*
- *DOE Test Facilities:* Enhance National Laboratories testing capabilities, e.g., Next Generation Wireless Test Bed (*DOE/INL*), Future Cities Testing (*DOE/ORNL*), and Extreme Environments Testing (*DOE/NNSS*).

Key Coordination Activities

- *Interdepartmental Radio Advisory Committee:* Assist in assigning frequencies to Federal users and in developing and executing policies. *NASA, NSF*, *NTIA, and 17 other agencies*
- *5G Millimeter-wave Channel Model Alliance:* Facilitate global efforts to define the radio channels where next-generation 5G wireless will operate. *NIST, NSF*, *NTIA*
- *Platforms to Advance Wireless Research:* Enable testing of new wireless devices, communication techniques, networks, systems, and services in real environments. *FCC, NSF*
- *Spectrum Collaboration Challenge:* Hold a competition to demonstrate the use of machine learning to improve access to RF spectrum. *AFRL, DARPA, NSF*
- *Committee on Radio Frequencies:* Protect passive spectrum use. *NASA, NSF*
- *3rd Generation Partnership Project Forum:* Participate in LTE and 5G standards development. *AFRL, NASA, NIST, NTIA*
- *The Technical Cooperation Program—quantum networking:* Collaborate with international partners and with federally funded research and development centers to explore quantum bits for networking to provide ultrasecure optical links. *AFRL, DOE, IARPA, NIST*

Software Productivity, Sustainability, and Quality (SPSQ) PCA

SPSQ R&D advances timely and affordable development and sustainment of low-defect, low-vulnerability software; this includes R&D to significantly improve software production processes, productivity, quality, economics, sustainability, measurement, assurance, and adaptability, and to achieve guarantees of essential requirements such as security, privacy, usability, reliability, and autonomy.

The SPSQ IWG reports its R&D investments and activities under the SPSQ PCA.

Software Productivity, Sustainability, and Quality (SPSQ) IWG

Participating Agencies: **AF, Army, BLS, NASA, Navy, NIH, NIJ, NIST, NOAA, NRC, NSA, NSF, ONR, OSD**

The SPSQ IWG coordinates Federal R&D to achieve orders-of-magnitude reduction in software defects and in the time and cost of developing and sustaining software. With the U.S. Government, economy, and military depending on increasingly complex software, improved software development technology is essential to promoting U.S. innovation and competitiveness, contributing to American prosperity, security, and leadership in emerging technology areas.

Strategic Priorities

- Advance discovery and innovation to enable fast and affordable development and sustainment of low-defect, low-vulnerability software.
- Enhance software quality and productivity of developers, users, and the economy by developing and deploying technologies to increase execution efficiency, reduce vulnerability, and increase security against information leaks in legacy, current, and future software systems.
- Provide trust and resilience in software to enable it to resist and recover from malicious attacks in real time.
- Modernize and manage research infrastructures to improve the safety, security, and reliability of digital systems that incorporate software, hardware, and data.
- Support software-related STEM education and training to develop the future workforce.

Key Programs

Advance discovery and innovation

- *Software Foundations:* Support transformative research in the design, verification, operation, utilization, and evaluation of computer software, including research focused on S&E of software to transform the relationship between requirements, design, and evolution; formal methods for specification, development, and verification of software systems; and design and implementation of programming languages and compilers. *NSF*
- *Formal Methods in the Field:* Develop rigorous and reproducible methods for designing and implementing correct-by-construction systems and applications with provable guarantees through joint research projects between formal methods researchers and researchers in other areas of computer S&E. *NSF*
- *Robust and Secure Machine Learning Models and Algorithms:* Develop robust, secure, and efficient learning architectures, training methods, and models, and dynamic assurance cases to continuously certify deployed systems that are self-healing and/or learning-enabled. *AFRL*
- *Assumption-driven Design:* Overcome obstacles to the effective use and scaling of techniques for trustworthy system design and refinement that systematically identify, track, and validate security-relevant assumptions. *NSA*

Enhance software quality and productivity of developers, users, and the economy

- *Total Platform Cyber Protection:* Investigate tools to reduce software vulnerabilities and improve execution efficiency by removing unnecessary code and abstraction layers from existing software, exposing unnecessary process flows and features in commercial off-the-shelf software, and validating transformation correctness. *ONR*
- *Software Engineering for Novel Architectures:* Employ existing techniques and develop and deploy new techniques, with academic partners, to productively rewrite/refactor NOAA's model inventory for nontraditional architectures and future exascale computers. *DoD, DOE, NOAA*
- *Software Assurance Metrics and Tool Evaluation:* Provide standard reference data of flawed and fixed code, provide a periodic forum for evaluation of static analysis tools, and precisely define and organize software weaknesses. *IARPA, NIST, NSA*
- *Assured Software:* Create a suite of AI-enhanced human-on-the-loop (to provide supervisory control) software tools to identify, quantify, and ultimately minimize flaws in CPS. *AFRL*

Provide trust and resilience in software

- *Trusted and Resilient Software:* Develop techniques to produce and deploy software that can be trusted to do only what it is designed to do and to maintain mission integrity in spite of an attack, including automated, real-time repair, software diversity, dynamic assurance cases, and formal methods for software sustainment. *AFRL*
- *System-Wide Safety Project:* Develop, deploy, and transfer technology to support software assurance and productivity in aerospace systems that are software intensive and increasingly autonomous. *AFRL, FAA, NASA, industry partners*

Modernize and manage research infrastructures

- *Cyberinfrastructure for Sustained Scientific Innovation:* Support research that addresses emerging needs in scientific software cyberinfrastructure and serves large, multidisciplinary research communities. *NSF*
- *BRAIN Initiative:* Develop and test sustainable, high-quality software technologies to enable new ways to model, analyze, treat, cure, or prevent brain disorders. *FDA, IARPA, NIH, NSF*
- *Research Project Grants:* Develop and sustain software for biomedical and public health research, including novel applications of deep learning, clinical informatics, and high-performance computing modeling and simulation. *NIH*
- *Nuclear Surety and Certification for Emerging Systems:* Reduce manual effort in software assurance through automation, develop new techniques and models to quantify software quality and cyber resilience in a cyber threat environment, and develop new techniques for software and system composability. *AFRL*

Support software-related STEM education and training *(Please see the EdW PCA.)*

Key Coordination Activities

- *Earth System Predication Capability:* Coordinate across the Federal environmental research and operational prediction communities to improve global prediction, including by identifying hardware and software challenges and R&D needs. *Air Force, DOE, Navy, NASA, NOAA, NSF*
- *Joint Federated Assurance Centers:* Support robust, secure software development. *AFRL, DOD*

4. Other NITRD Interagency Coordination Activities: Health Information Technology R&D IWG

The NITRD NCO provides staff support to the information-sharing and strategy-setting activities of the Health and Information Technology Research and Development (HITRD) Interagency Working Group. Due to the interdisciplinary nature of HITRD, Federal agencies funding work in this group do not presently report budgets under one specific NITRD PCA but rather report under several PCAs, depending on the principal focus areas of their work.

HITRD focuses on R&D efforts that will lead to more efficient and effective healthcare and improve the quality of American lives through technologies that support effective health monitoring; individualized screening, diagnosis, and treatment; disease prevention; disaster and emergency response; and broad access to health and healthcare information and resources. HITRD activities also contribute to building and sustaining a vibrant community of professional health IT researchers and practitioners.

HITRD member agencies report their HITRD-related R&D investments and activities in the following PCAs:

- AHRQ reports all of its HITRD spending under the CHuman PCA.
- NSF reports its HITRD spending under the CHuman, CNPS, EdW, and IRAS PCAs.
- NIST reports its HITRD spending under the CHuman and CNPS PCAs

Other agencies participating in the HITRD IWG are DHA, FDA, HRSA, NIH, ONC, and VA.

Strategic Priorities

- Accelerate the R&D and implementation of next-generation health IT tools and services.
- Design effective health IT for the full community of users.
- Promote infrastructure and standards for accessible, interoperable, reusable health data, devices, and related applications.
- Build the health IT workforce of the future.

Key Programs

Accelerate the R&D and implementation of next-generation health IT tools and services

- *Clinical Decision Support (CDS) Initiative:* Advance CDS science by supporting implementers, clinicians, and technology vendors to develop more shareable CDS tools. *AHRQ, CDC, CMS, VA*
- *Health IT Safety Grants:* Research safe health IT practices specifically related to the design, implementation, usability, and safe use of health IT by all users. *AHRQ*
- *LHS Grants:* Research how health IT can best support learning health systems, particularly in ambulatory care settings. *AHRQ*
- *precisionFDA:* Provide an open source, cloud-based space for researching next-generation sequencing methods and testing. *CDC, FDA, USAMRIID, NIH, NIST, OSTP*
- *Strategic Plan for Data Science:* Address the intersection of biomedical research and the advancement of data science. *NIH*
- *IoT Health:* Develop advanced networking frameworks, evaluation testbeds, and mathematical models that facilitate online communication of health and biological data. *NIST*
- *NRI-2.0:* Develop collaborative robots for assisted devices and medical procedures. *NIH, NSF*
- *Smart and Connected Health:* Transform health IT tools and services through fundamental advances in computer and information science and engineering. *NIH, NSF*
- *Research Project Grant Program:* Promote extramural research funding for intelligent tools and devices to support health monitoring, assessment, and assistance. *DoD, NIH*