THE NETWORKING & INFORMATION TECHNOLOGY RESEARCH & DEVELOPMENT PROGRAM

SUPPLEMENT TO THE PRESIDENT'S FY2021 BUDGET

Product of the

SUBCOMMITTEE ON NETWORKING & INFORMATION TECHNOLOGY RESEARCH & DEVELOPMENT

COMMITTEE ON SCIENCE & TECHNOLOGY ENTERPRISE

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

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1. Introduction

Information technology (IT) and its enabling computing, networking, and software technologies have radically transformed human society across the globe over the course of just two generations. American innovators, companies, and government led this transformation. As global competition for leadership in high-performance computing (HPC) began to escalate in the 1980s, U.S. legislators saw the imperative to proactively guide research and development (R&D) of HPC and other IT innovations. In the High-Performance Computing Act of 1991, Congress launched what is now called the Networking and Information Technology Research and Development (NITRD) Program; Congress most recently reauthorized the NITRD Program in the American Innovation and Competitiveness Act of 2017.[1] The Program's mandate is to coordinate Federal R&D to identify, develop, and transition into use the secure, advanced IT, HPC, networking, and software capabilities needed by the Federal Government, and to foster public-private partnerships that provide world-leading IT capabilities to the Nation. In support of its role in the National Science and Technology Council (NSTC), the NITRD Subcommittee leads the Federal efforts to coordinate high-impact R&D to meet the Nation's soaring needs in information technologies for the future. It also seeks to build, support, and leverage a diverse, highly skilled American IT workforce and to cultivate vibrant R&D alliances with American academic, private-sector, and nonprofit entities, and with international like-minded bodies. The NITRD Program currently coordinates the IT R&D and technology-transfer activities of 23 Federal member agencies and some 50 other participating agencies.

NITRD Support for Industries of the Future

Both the President and Congress recognize the pivotal value to the Nation of leading the world in innovative technologies and applications that will power the Industries of the Future (IotF): *artificial intelligence (AI), quantum information science (QIS), advanced communications networks (ACN, including 5G), advanced manufacturing,* and *biotechnology*.[2] Many IotF technologies have clearly proven their value during the COVID-19 pandemic (*see sidebar, p. 6*).

> "For 2021, the Administration is prioritizing the science and technology that underpin the Industries of the Future… Together, IotF investments are vital to the Nation's global competitiveness and the health, prosperity, and security of the American people."
>
> *— Analytical Perspectives, Budget of the United States Government, FY 2021, February 10, 2020.*

All these technologies relate directly to the NITRD Program's IT R&D coordination mission. Success in NITRD-coordinated advanced IT-related R&D, including in AI, QIS, and ACN, will rely on both foundational and applications-driven research; ongoing investment in the Nation's R&D infrastructure; public–private R&D partnerships (PPPs) across the U.S. innovation ecosystem; partnerships with like-minded allies; and effective education of the American public and workers in science, technology, engineering, and mathematics (STEM) fields. The NITRD Interagency Working Groups (IWGs) and their participating agencies' Program Component Area (PCA) budgets actively support the Administration's priority focus on IotF. Their unified goal is to "revolutionize our ability to solve previously intractable problems, foster new industries and jobs, and keep the American people safe"[3]—and empower the peoples of the Nation and the world. IotF science and technology fields require government funding; additionally, partnerships multiply available intellectual talent and funding for applications development. NITRD roles in coordinating IotF R&D activities are outlined below.

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

2 For example, see White House Fact Sheet, "America Will Dominate Industries of the Future," Feb. 2019; EOP, OMB, *Analytical Perspectives, Budget of the United States Government, Fiscal Year 2021*, Feb. 2020, pp. 233, 235–236; and the President's Council of Advisors on Science and Technology, *Recommendations for Strengthening American Leadership in Industries of the Future*. Congress is working on several bills to ensure continued U.S. leadership in IotF.

3 EOP, OMB, *Analytical Perspectives, Budget of the United States Government, Fiscal Year 2021*, Feb. 2020, pp. 233.

- ***Artificial intelligence R&D.***[4] AI-based information and computing technologies can learn, analyze, synthesize, discover, and adapt while collaborating with each other and with people in complex undertakings that address society's practical needs in pioneering ways. Synergistic and rapid R&D advances in computing power and algorithmic capability, and access to large datasets and streaming data are enabling AI innovations that touch nearly every aspect of Americans' lives today. AI-based HPC supports imaging, diagnosis, prediction, simulation, decision-making, and autonomous control that provide powerful new means to secure the Nation; protect individual and public health and safety; expand air, ground, sea, and space transportation and exploration options; modernize agricultural and energy systems; and deliver effective education. The AI research community recognizes the need and is devising policies to ensure that AI systems and standards are designed and deployed to be safe, trustworthy, explainable, and unbiased so AI benefits society equitably. The United States engages in ongoing discourse and research partnerships with like-minded allies on topics such as ethical AI and using AI to catalyze rapid and effective responses to COVID-19 and other global challenges.

  NITRD-coordinated activities in AI. AI and IT are intricately interrelated, and myriad NITRD activities support advancements in AI both directly and indirectly. NITRD's AI IWG leads the coordination of Federal R&D activities in AI and machine learning under the AI PCA (pp. 14–15). However, as the AI Budget Table 2 shows (pp. 10-11), NITRD coordinates AI-related activities among all member agencies under all PCAs, especially in the Computing-Enabled Human Interaction, Communication, and Augmentation PCA (p. 16); Enabling R&D for High-Capability Computing Systems PCA (pp. 22–23); High-Capability Computing Infrastructure and Applications PCA (pp. 23–25); Intelligent Robotics and Autonomous Systems PCA (pp. 25–26); and Large-Scale Data Management and Analysis PCA (pp. 26–27).

  At the intersection of HPC, AI, and QIS R&D, NITRD's many R&D coordination efforts are mutually reinforcing. Continuous advances in all these fields, taken together, are significantly accelerating basic scientific discoveries and their translation to significant products and applications. As a result of the vigorous synergies among these technologies, the Administration has determined it will double nondefense R&D funding in AI and QIS by FY2022. The total nondefense agency funding request for AI R&D in FY2021 is 54% higher than the FY2020 request.

- ***Quantum information science R&D.***[5] QIS is an enormously challenging but game-changing scientific field that builds on advanced capabilities in computer science, engineering, communications, mathematics, and physical sciences to address the most complex scientific and societal problems. Indispensable modern 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 and utilized. Quantum networking is poised to revolutionize today's internet, improve secure communications,

[4] **Examples of Federal guidance on AI R&D:** Establishment of NSTC Select Committee on AI, May 2018; Executive Order on Maintaining American Leadership in Artificial Intelligence, Feb. 2019; *National Artificial Intelligence R&D Strategic Plan: 2019 Update*, June 2019; *American Artificial Intelligence Initiative: Year One Annual Report*, Feb. 2020; National Security Commission on Artificial Intelligence (NSCAI) reports, including quarterly R&D memos and recommendations for pandemic response and preparedness, 2020; Artificial Intelligence for the American People website—see Section 5, "AI with American Values," Feb. 2020.

[5] **Examples of Federal guidance on QIS R&D:** National Strategic Overview for Quantum Information Science, Sept. 2018; *National Quantum Initiative Act,* Dec. 2018; National Quantum Initiative Advisory Committee established, Aug. 2019; *A Strategic Vision for America's Quantum Networks*, Feb. 2020. EOP, OMB, *Analytical Perspectives, Budget of the United States Government, Fiscal Year 2021* Feb. 2020, pp. 233, 235–236.

and enable dramatic advances in computing. Achieving a quantum internet would provide powerful resources for drug discovery, weather forecasting, sensing, navigation, and innovations across the scientific spectrum. Attaining next-generation QIS capability will depend on Federal leadership, enduring cross-sector R&D partnerships, and a strong quantum-ready workforce.

NITRD-coordinated activities in QIS. NITRD-coordinated R&D investments of relevance to QIS span the focus areas of the AI PCA (pp. 14–15); Cybersecurity and Privacy PCA (pp. 18–20); Enabling R&D for High-Capability Computing Systems PCA (pp. 22–23); and Large-Scale Networking PCA (pp. 27–30).

- ***Advanced communications networks (including 5G) R&D.***[6] R&D in ACN aims for orders-of-magnitude improvements in the speed and connectivity, and reduction in latency, of the Nation's—and the world's—communications systems. It aims to support cost- and energy-efficient super-high-speed, high-volume processing, management, and distribution of information. ACN will upgrade the capabilities of home networks and smart phones significantly. But ACN also will be essential to full realization of high-tech applications that rely on real-time system responsiveness and remote 3D vision and touch and feel capabilities. These applications will include self-driving cars; modernizing remote health monitoring; management of robotic assembly lines; virtual-reality-enabled design, simulation, and telework; and "smarter" buildings, farms, highways, and homes—along with myriad Internet of Things (IoT) products. R&D and deployment approaches must address scientific research, technology, policy, legislation, operations, and economic needs for all users. Proactive improvement in management of U.S. spectrum resources is vital—and the challenging issues related to spectrum require both Federal leadership and community engagement to resolve. As the COVID-19 pandemic has shown, the United States must place a premium on expanding digital infrastructure and rural broadband to significantly increase citizens' equality of access to online education, healthcare, and government services, as well as everyday communications.

  NITRD-coordinated activities in ACN. NITRD-coordinated R&D activities relevant to ACN span the focus areas of the AI PCA (pp. 14–15); Computing-Enabled Networked Physical Systems PCA (pp. 17-18); Intelligent Robotics and Autonomous Systems PCA (pp. 25–26); Large Scale Networking PCA, which includes the Wireless Spectrum R&D IWG (pp. 27–30); and Health Information Technology R&D IWG (whose participating agencies report under various PCAs) (p. 32).

- ***Advanced manufacturing and biotechnology R&D.***[7, 8] Although neither advanced manufacturing nor biotechnology are direct subjects of NITRD R&D coordination, the intelligent systems on which they increasingly depend include high-performance computing and numerous information and networking technologies. These enable complex simulation and digital design; sensing and production quality controls; accommodation to new scales, hybrid materials, integration, customization, genetic mapping, and remote manipulation; and improved data security and privacy. At the time of this writing, multiple IT capabilities are being utilized to hasten discovery and production of medicines and vaccines to combat COVID-19. Because advanced manufacturing and biotechnology are critical to the Nation's global economic competitiveness, high-paying skilled jobs, healthcare, food production, and defense and security capabilities, the United States must achieve continuous progress in state-of-the-art IT capabilities that support advanced manufacturing and biotechnology.

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[6] **Examples of Federal guidance on ACN/5G R&D***:* *Research and Development Priorities for American Leadership in Wireless Communications*, May 2019; *Emerging Technologies and their Expected Impact on Non-Federal Spectrum Demand, May, 2019*; *National Strategy to Secure 5G of the United States of America*, March 2020; *S.893 - Secure 5G and Beyond Act of 2020*, March 2020.

[7] **Examples of Federal guidance on Advanced Manufacturing***:* Manufacturing USA; Strategy for American Leadership in Advanced Manufacturing, Oct. 2018;

[8] **Examples of Federal guidance on Biotechnology***:* All of Us Research Program, May 2018; The National Biodefense Strategy, Sept. 2018; DARPA Biotechnologies Office Innovation in Biotechnology webpage; *see also the sidebar on p. 6.*

NITRD-coordinated activities in advanced manufacturing and biotechnology. NITRD-coordinated R&D activities relevant to advanced manufacturing and biotechnology are addressed by NITRD's AI PCA (pp. 14–15); Computing-Enabled Networked Physical Systems PCA (pp. 17–18); Intelligent Robotics and Autonomous Systems PCA (pp. 25–26); Large-Scale Networking PCA (pp. 27–30); and Health Information Technology R&D IWG (p. 32); along with synergetic work performed by other IWGs.

Summary of NITRD FY2021 Federal R&D Budget Request

Combined, the FY2021 Federal agency R&D budget request totals $6.5 billion (Table 1, pp. 8–9) aimed at supporting the Industries of the Future and broadly advancing the Nation's IT capabilities to sustain U.S. security, health, and prosperity. As part of this total, the FY2021 Federal budget request in nondefense AI R&D totals $1.5 billion (Table 2, pp. 10–11), and that in ACN totals $189 million (Table 3, p. 12).

Crosscutting NITRD R&D Activities

As with all IT-related fields of R&D, successful advancement of the Industries of the Future will depend on sustained Federal and cross-sector R&D investments in IT-related security, privacy, and software reliability, and on broad researcher access to first-rate facilities for advanced R&D and testing. These key areas are coordinated by the NITRD Cyber Security and Privacy IWGs (pp. 18–21); the High End Computing IWG's activities for High-Capability Computing Infrastructure and Applications (pp. 23-25); and the Software Productivity, Sustainability, and Quality IWG (pp. 30–31).

Focused IT R&D also is needed to enable the citizenry and workforce of the future. Education and workforce R&D investments, reported under the Education and Workforce PCA (pp. 21–33), are relevant to all NITRD PCAs and IWGs to advance the use of information technology in new and ongoing education, training, assessment, and standards activities, and in preparation of the next generation of computationally literate citizens and professionals. Also, as the coronavirus pandemic has shown, robust, secure, and accessible online educational modalities for all educational levels are critical to national resilience.

Updates to NITRD Budget Reporting and Organizational Structures

NITRD budget reporting (Section 2) is organized by Program Component Area and agency to facilitate year-to-year budgetary and programmatic comparisons. PCAs are the major subject areas under which Federal agencies report their funding request for the activities that the NITRD Program coordinates. The NITRD PCAs are reviewed annually to ensure NITRD actively addresses evolving R&D needs. For FY2021, there are 11 NITRD PCAs, which include four updates, as identified below, in PCA definitions to improve clarity in defining agencies' R&D investments. The technical emphases of the remaining seven NITRD PCAs are the same as in FY2020. 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
- Computing-Enabled Human Interaction, Communications, and Augmentation (CHuman)
- Computing-Enabled Networked Physical Systems (CNPS)–*Updated*
- Cyber Security and Privacy (CSP)–*Updated*
- 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)–*Updated*
- Large Scale Networking (LSN)
- Software Productivity, Sustainability, and Quality (SPSQ)-*Updated*

With NCO support, the NITRD Interagency Working Groups strive 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 11 NITRD IWGs are as follows:

- Artificial Intelligence R&D (AI)
- Big Data
- Computing-Enabled Networked Physical Systems (CNPS)
- Cybersecurity & Information Assurance (CSIA)
- 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)

The NITRD IWGs are also reviewed annually. During FY2020, the NITRD Subcommittee merged the High Confidence Software and Systems IWG and the Cyber-Physical Systems IWG to form the Computing-Enabled Networked Physical Systems IWG. The Subcommittee also sunset the Fast Track Action Committee on Future Computing after it successfully completed its goals.

Although the NITRD PCAs and the focused coordination activities of its IWGs are closely interrelated, there are not one-to-one correlations between all the PCAs and all the IWGs. Figure 1 shows the relationships between NITRD's 11 PCAs and its 11 IWGs.

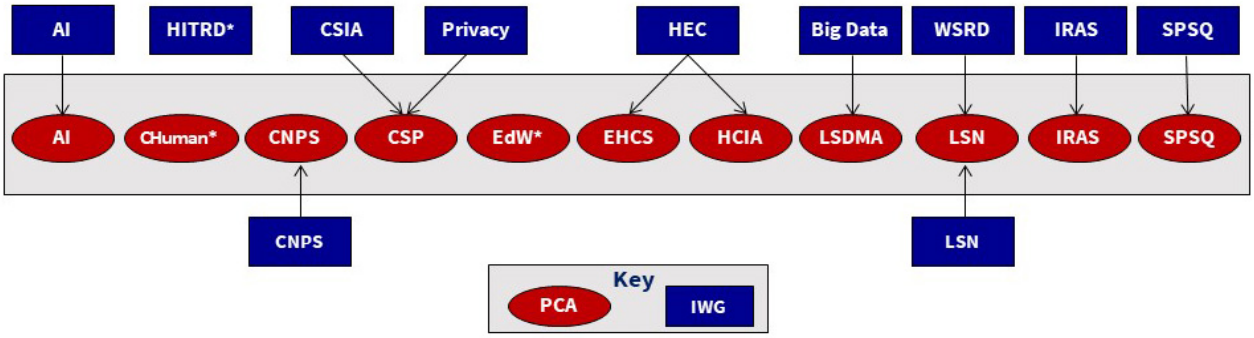


Figure 1. Relationships between the NITRD PCAs and IWGs for FY2021.
The acronyms in this figure are spelled out in the PCA and IWG lists above.
***The HITRD IWG is not affiliated with a PCA. The CHuman and EdW PCAs do not have coordinating IWGs; the agencies that invest in CHuman or EdW R&D do so within other IWGs or through other coordination committees.

Structure of this Supplement

Section 2 provides budget data for NITRD agencies' R&D investments made in FY2019, enacted in FY2020, and requested in the President's FY2021 Budget in the 11 NITRD PCAs. Section 2 also provides an analysis that highlights key aspects of FY2021 investment changes of greater than $10 million as compared to FY2020 enacted budgets. Sections 3 and 4 describe the major R&D activities reported under the PCAs and coordinated by the NITRD IWGs.[9]

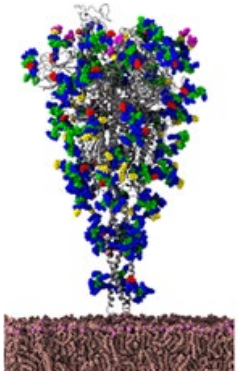
[9] Due to space limitations, not all agency programs are listed in the Key Programs and Coordination Activities sections of the PCA and IWG pages. Program titles are shown in title case, whereas program types are shown in sentence case.

NITRD-Linked IT R&D Underpins U.S. Resilience & Leadership in Fighting COVID-19

From its 1991 start as the High Performance Computing and Communications Program to 2020, the NITRD Program has coordinated investments by Federal agencies to advance the information technologies that governments, businesses, academia, and citizens globally are depending on during the COVID-19 pandemic to stay connected, be productive, and speed discovery of therapeutics and vaccines. Cumulatively, NITRD investments have enabled the computing and high-speed and wireless networking capabilities that support teleworkers, distance learners, and researchers; the software and algorithms that enable these capabilities along with complex big data analysis; and security capabilities that protect such systems against adversaries. Many routine activities were shifted online—from business conferences to family gatherings, medical appointments to food shopping. The following are some examples of actions that NITRD agencies are taking to address the impacts of COVID-19.

Compiling Machine-Readable COVID-19 Datasets: Early on, OSTP called for AI experts to collaborate to develop new natural language processing text- and data-mining techniques to speed up extraction of high-priority scientific information from published COVID-19 research papers. OSTP, NIH, and several partners began by compiling a COVID-19 Open Research Dataset10 of 13,000 papers (now 195,000+) on SARS-CoV-2 and other coronaviruses, formatted them for easier parsing by algorithms, and generated an initial question set. The effort has led to dozens of new rapid-search tools and algorithms aimed at accelerating COVID-19 research.

Harnessing Compute Power to Fight COVID-19: A unique public-private consortium spearheaded by OSTP, DOE, NSF, and IBM connects 30 Federal Government, industry, and academic world-class supercomputing systems with researchers and support services at academic labs to speed understanding of the virus. The COVID-19 High Performance Computing Consortium 11 has 43 members pursuing 78 active research projects in areas like bioinformatics, epidemiology, and molecular modeling. Studies include complex simulation of the virus's transmissibility (e.g., fluid dynamics studies of aerosolized droplets or regional population spread curves) and cryo-electron microscopy studies that provide near-atomic-resolution imaging of the virus's critical infecting ("spike") proteins to determine details of the infection process as a basis for identifying potential countermeasures (e.g., drugs or "neutralizing antibodies").



SARS-CoV-2 spike protein of the corona virus, as simulated at an academic lab using NSF's Frontera supercomputer, in work funded by NIH and NSF. Source: NSF Fact Sheet 4-10-20.

Undertaking an All-of-NITRD Response: [12] Separately and in concert, NITRD member agencies are actively pursuing solutions to the myriad issues brought about by the COVID-19 pandemic through their active research networks and unique domains of interest. The Departments of Defense and Energy are using their supercomputing resources and expertise to conduct studies such as computational chemistry investigations of target proteins, virtual drug screening of COVID-19 vaccine candidates, and identification of possible preventative treatments or post-exposure therapies to accelerate their development toward clinical trials. NIST and NLM, with private and academic partners, are implementing a Text Retrieval Challenge to use information retrieval and text processing to build ranked lists of test collections to support virus research. NSF is making one-year awards for rapid response research proposals for COVID-19, as well as broader projects that will build on acquired knowledge and sustain greater collaboration for nonclinical technical research (e.g., on rapid test systems or physiological monitoring of COVID-19 symptoms) and sociological research (e.g., on virus-related stress or educational equity). The NITRD agencies also are encouraging small, medium, and large businesses to develop and deploy innovative technologies, products, processes, and services to help address the COVID-19-related health and economic challenges.

Supporting IT Innovation into the Future: The indispensable roles of advanced computing and networking in sustaining social and economic interactions, remote study and work, and fast-tracking of medical interventions for COVID-19 underscore the urgency of continuing investments in digital infrastructure and the need for NITRD to continue coordinating groundbreaking Federal R&D to broaden the capability, speed, security, equity of access, privacy, and affordability of information technologies for the Nation's future.

[10] https://www.kaggle.com/allen-institute-for-ai/CORD-19-research-challenge

[11] https://covid19-hpc-consortium.org/

[12] For more examples of NITRD Agencies' activities to combat COVID-19, please see https://www.nitrd.gov/coronavirus/.

2. NITRD R&D Budgets by Agency and PCA, FYs 2019–2021

This section reports NITRD R&D budgets by PCA and agency, including overall Federal IT-related R&D investments (Table 1) and R&D investments in two high-priority areas, Artificial Intelligence R&D (Table 2) and Advanced Communications Networks R&D (Table 3). Tables 1–3 provide FY2019 actual R&D investments, FY2020 enacted and supplemental budgets,[13] and FY2021 budget request. A budget analysis section describes changes of investment greater than $10 million, by agency, between the FY2020 enacted budgets and the FY2021 President's Budget Request (PBR). Additional information about NITRD R&D investments from FY2001 to FY2021 is available at https://www.nitrd.gov/apps/itdashboard/.

Overview

The President's overall FY2021 budget request for Federal agencies' NITRD-related R&D is $6.5 billion, as depicted in Charts 1 and 2 and Table 1. This is an increase of approximately 18 percent compared to the $5.5 billion requested in FY2020.[14] The nondefense NITRD agencies' requested investment in AI R&D for FY2021 is $1.5 billion, an increase of approximately 54 percent compared to the $973.5 million requested for AI R&D in FY2020. The agencies' requested investment in ACN R&D for FY2021 is $189 million; this FY2021 request sets a baseline for reporting and tracking ACN R&D investments.

Budget Charts

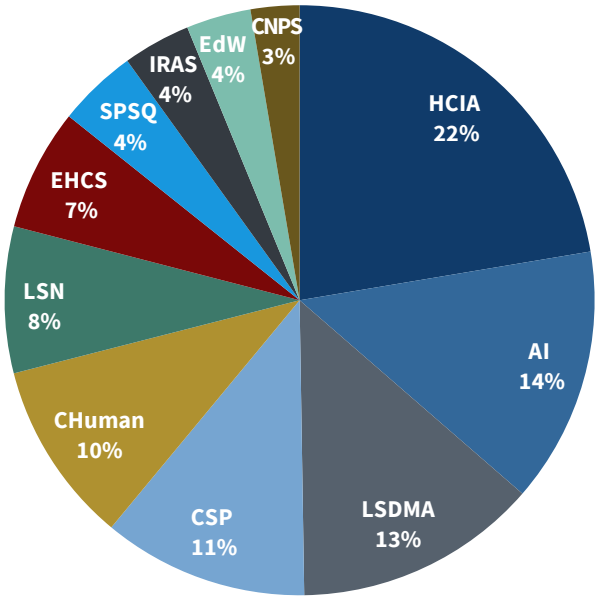


Chart 1. FY2021 Budget Request, as percentages of the total NITRD request, by PCA.

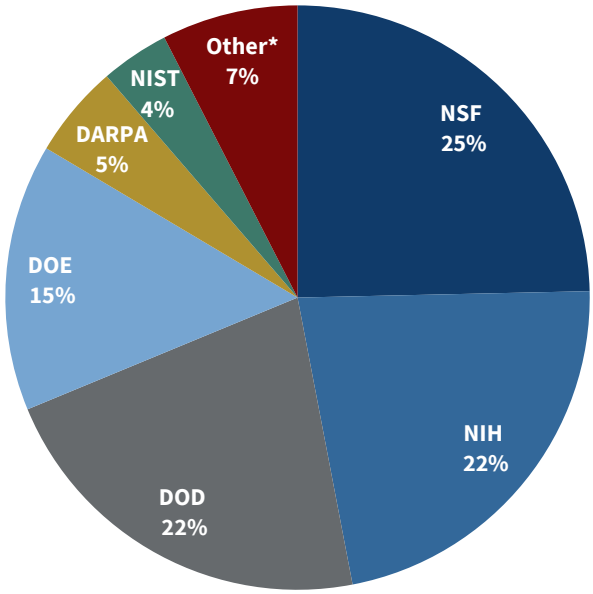


Chart 2. FY2021 Budget Request, as percentages of the total NITRD request, by agency.

***Other:** DHS, DOE/NNSA, DOI, DOT, FDA, NASA, NIJ, NIOSH, NOAA, Treasury/FCEN, USDA, and VA

[13] FY2020 Supplemental estimates, reported by NOAA and NSF, are based on funding from the Coronavirus Preparedness and Response Supplemental Appropriations Act, 2020; the Families First Coronavirus Response Act; the Coronavirus Aid, Relief, and Economic Security Act; and the Paycheck Protection Program and Health Care Enhancement Act.

[14] See https://www.nitrd.gov/pubs/FY2020-NITRD-Supplement.pdf for the FY2020 NITRD budget request.

Table 1. Agency Budgets by PCA, FYs 2019–2021 (p. 1 of 2)

FY2019 Budget Actuals, FY2020 Budgets Enacted & Supplemental,[a] and FY2021 Budget Request ($ in millions)

Agency[b]	Fiscal Year[a]	11 NITRD Program Component Areas											Totals[d]
		AI[c]	CHuman	CNPS	CSP	EdW	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
AHRQ	FY19 Actual	0.0	16.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.4
	FY20 Enacted	*0.0*	*16.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*16.5*
	FY21 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[e, f]	FY19 Actual	- -	13.0	0.0	262.9	0.0	5.1	0.0	0.0	29.3	80.2	0.0	390.6
	FY20 Enacted	- -	*13.0*	*0.0*	*251.1*	*0.0*	*5.1*	*0.0*	*0.0*	*33.6*	*79.2*	*0.0*	*382.0*
	FY21 Request	- -	**11.2**	**0.0**	**236.2**	**0.0**	**5.1**	**0.0**	**0.0**	**37.6**	**44.0**	**0.0**	**334.1**
DHS	FY19 Actual	31.3	0.0	16.4	16.1	1.0	0.0	0.0	1.7	5.0	22.1	1.0	94.4
	FY20 Enacted	*34.5*	*0.0*	*8.6*	*14.5*	*1.0*	*0.0*	*0.0*	*2.2*	*6.1*	*17.1*	*1.0*	*84.9*
	FY21 Request	**26.6**	**0.0**	**6.4**	**10.0**	**1.0**	**0.0**	**0.0**	**2.2**	**1.0**	**11.9**	**1.0**	**60.1**
DOD[e, f]	FY19 Actual	- -	178.9	31.9	272.6	37.2	38.7	257.1	170.2	138.9	238.4	51.7	1,415.5
	FY20 Enacted	- -	*207.8*	*42.7*	*283.8*	*87.1*	*48.7*	*277.9*	*180.9*	*141.9*	*194.5*	*60.4*	*1,525.7*
	FY21 Request	- -	**197.6**	**31.8**	**256.0**	**88.7**	**61.3**	**273.8**	**115.6**	**148.5**	**179.6**	**61.4**	**1,414.2**
DOE[g]	FY19 Actual	134.5	0.0	7.2	37.8	10.0	39.7	613.3	68.7	67.1	84.0	0.0	1,062.4
	FY20 Enacted	*106.2*	*0.0*	*1.5*	*41.1*	*10.0*	*71.1*	*637.8*	*0.0*	*17.4*	*90.0*	*0.0*	*975.2*
	FY21 Request	**83.7**	**0.0**	**0.0**	**38.1**	**10.0**	**115.6**	**632.6**	**0.0**	**0.0**	**80.0**	**0.0**	**960.0**
DOE/NNSA	FY19 Actual	21.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.8
	FY20 Enacted	*20.6*	*0.0*	*0.0*	*0.0*	*0.0*	*40.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*60.6*
	FY21 Request	**25.6**	**0.0**	**0.0**	**0.0**	**0.0**	**6.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**31.6**
DOI	FY19 Actual	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7
	FY20 Enacted	*5.9*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.9*
	FY21 Request	**4.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4.2**
DOT	FY19 Actual	8.0	0.0	1.0	0.0	0.0	0.4	0.0	1.0	0.0	0.0	0.5	10.9
	FY20 Enacted	*9.8*	*0.0*	*1.5*	*0.0*	*0.0*	*0.7*	*0.0*	*7.0*	*0.0*	*0.0*	*0.7*	*19.7*
	FY21 Request	**7.9**	**0.0**	**1.0**	**0.0**	**0.0**	**0.7**	**0.0**	**8.0**	**0.0**	**0.0**	**0.4**	**18.1**
EPA	FY19 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
	FY20 Enacted	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.5*	*3.0*	*0.0*	*0.0*	*0.0*	*0.0*	*6.5*
	FY21 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	FY19 Actual	39.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0
	FY20 Enacted	*39.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*39.0*
	FY21 Request	**38.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**38.0**
NARA[h]	FY19 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FY20 Enacted	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	FY21 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**
NASA	FY19 Actual	26.3	0.0	1.7	0.0	0.0	3.0	66.3	19.4	0.2	0.0	1.7	118.6
	FY20 Enacted	*26.3*	*0.0*	*1.5*	*0.0*	*0.0*	*0.4*	*66.3*	*30.4*	*0.2*	*0.0*	*1.5*	*126.7*
	FY21 Request	**26.3**	**0.0**	**1.8**	**0.0**	**0.0**	**0.4**	**67.2**	**28.8**	**0.2**	**0.0**	**1.8**	**126.4**
NIH	FY19 Actual	52.0	347.1	32.8	4.5	55.5	82.1	266.3	15.4	500.0	38.8	155.3	1,549.8
	FY20 Enacted	*53.9*	*368.3*	*31.6*	*4.7*	*58.6*	*86.5*	*291.4*	*15.9*	*488.1*	*29.9*	*163.2*	*1,592.1*
	FY21 Request	**49.4**	**331.5**	**29.3**	**4.3**	**53.5**	**79.2**	**260.6**	**14.5**	**449.8**	**28.9**	**149.4**	**1,450.4**
NIJ	FY19 Actual	6.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	9.1
	FY20 Enacted	*3.0*	*1.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.0*	*0.0*	*0.0*	*5.5*
	FY21 Request	**3.0**	**1.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.0**	**0.0**	**0.0**	**5.5**
NIOSH	FY19 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.8
	FY20 Enacted	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.2*	*0.0*	*0.0*	*0.0*	*1.2*
	FY21 Request	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.2**	**0.0**	**0.0**	**0.0**	**1.2**
NIST	FY19 Actual	12.7	10.5	13.4	79.3	5.3	4.5	11.3	6.8	12.1	25.6	1.2	182.7
	FY20 Enacted	*22.1*	*15.2*	*16.6*	*82.1*	*7.6*	*6.6*	*10.7*	*9.0*	*17.6*	*32.0*	*1.0*	*220.5*
	FY21 Request	**47.1**	**15.2**	**16.6**	**82.1**	**7.6**	**6.6**	**10.7**	**9.0**	**17.6**	**32.5**	**1.0**	**246.0**

Table 1. Agency Budgets by PCA, FYs 2019–2021 (p. 2 of 2)

FY2019 Budget Actuals, FY2020 Budgets Enacted & Supplemental,[a] and FY2021 Budget Request ($ in millions)

Agency[b]	Fiscal Year[a]	11 NITRD Program Component Areas											Totals[d]
		AI[c]	CHuman	CNPS	CSP	EdW	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
NOAA	FY19 Actual	0.8	0.2	0.0	0.0	0.0	0.0	50.7	0.0	0.0	3.3	3.7	58.6
	FY20 Enacted	*0.8*	*0.2*	*0.0*	*0.0*	*0.0*	*0.0*	*58.0*	*0.0*	*0.0*	*4.3*	*3.7*	*66.9*
	FY20 Suppl.	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.7**	**0.9**
	FY21 Request	**0.8**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**41.0**	**0.0**	**0.0**	**4.3**	**3.7**	**49.9**
NSF	FY19 Actual	235.0	94.6	77.1	110.3	81.5	178.8	196.2	45.9	194.2	131.3	72.1	1,416.9
NSF	*FY20 Enacted*	*264.9*	*98.5*	*79.6*	*113.1*	*78.3*	*164.9*	*187.5*	*47.6*	*193.4*	*150.9*	*72.8*	*1,451.7*
NSF	**FY20 Suppl.**	**5.6**	**1.8**	**4.1**	**2.2**	**1.7**	**0.4**	**0.6**	**0.3**	**5.4**	**1.8**	**0.7**	**24.8**
NSF	**FY21 Request**	**456.8**	**92.4**	**82.9**	**106.3**	**68.6**	**159.4**	**168.4**	**57.6**	**212.9**	**131.0**	**64.9**	**1,601.1**
NTIA	FY19 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	5.9
	FY20 Enacted	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*6.2*	*0.0*	*6.2*
	FY21 Request	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**9.7**	**0.0**	**9.7**
Treas/FCEN	FY19 Actual	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
	FY20 Enacted	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.6*
	FY21 Request	**0.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.6**
USDA	FY19 Actual	45.1	0.7	3.9	0.0	1.3	0.0	0.0	4.6	1.3	0.0	0.0	56.9
	FY20 Enacted	*53.2*	*0.7*	*3.9*	*0.0*	*1.3*	*0.0*	*0.0*	*4.6*	*1.3*	*0.0*	*0.0*	*65.0*
	FY21 Request	**127.9**	**0.7**	**3.9**	**0.0**	**1.3**	**0.0**	**0.0**	**4.6**	**1.3**	**0.0**	**0.0**	**139.7**
VA	FY19 Actual	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8
	FY20 Enacted	*14.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*14.1*
	FY21 Request	**14.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**14.1**
TOTALS[d]	FY19 Actual	627.7	663.4	185.4	783.4	191.8	355.7	1,464.1	334.4	949.4	629.6	287.2	6,472.1
TOTALS[d]	*FY20 Enacted*	*654.9*	*721.7*	*187.6*	*790.4*	*243.9*	*427.5*	*1,532.5*	*298.8*	*900.7*	*604.2*	*304.3*	*6,666.5*
TOTALS[d]	**FY20 Suppl.**	**5.6**	**2.0**	**4.1**	**2.2**	**1.7**	**0.4**	**0.6**	**0.3**	**5.4**	**1.8**	**1.4**	**25.7**
TOTALS[d]	**FY21 Request**	**912.0[c]**	**650.3**	**173.6**	**732.9**	**230.7**	**434.3**	**1,454.3**	**241.5**	**869.9**	**521.9**	**283.6**	**6,505.0**

Budget Table 1 Notes

a. FY2020 Budget Supplemental (Suppl.) figures have *not* been included in calculating any changes between the FY2020 and FY2021 budget numbers. See also footnote 13 on p. 7.

b. Agency subcomponents (departments and offices) that reported budgets are as noted below (*see Abbreviations pp. 35-36*): **DHS:** CISA, CG, CWMD, and TSA; **DOD:** OSD and DOD Military Services' research organizations, C5ISR, DREN, GVSC, and HPCMP; **DOE:** DOE/AITO, DOE/ARPA-E, DOE/CESER, DOE/EERE, DOE/FE, and DOE/SC; **DOI:** USBR and USGS; **DOT:** FAA, FHWA, FMCSA, FRA, FTA, and PHMSA; **USDA:** ARS and NIFA.

c. The AI budget reported under the AI PCA is not the complete AI budget; refer also to Table 2 and the Budget Analysis section.

d. Totals might not sum exactly due to rounding.

e. DARPA is a DOD research organization, but it reports its budgets separately from the DOD Services research organizations.

f. DOD and DARPA budget figures for AI R&D are not publicly available.

g. DOE/NNSA budget is listed separately.

h. NARA's NITRD budgets are $0.02 million in the LSDMA PCA in the years covered here; this table represents numbers to only one decimal place; however, NARA budgets are accounted for in the table totals.

Table 2. Agency Budgets by PCA for AI R&D,[a] FYs 2019–2021 (p. 1 of 2)

FY2019 Budget Actuals, FY2020 Budgets Enacted & Supplemental,[b] and FY2021 Budget Request ($ in millions)

Agency[a, c]	Fiscal Year[b]	11 NITRD Program Component Areas											Totals[e]
		AI[d]	CHuman	CNPS	CSP	EdW	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
DHS/CWMD	FY19 Actual	1.9	0.0	3.3	0.0	0.0	0.0	0.0	1.0	5.0	0.5	0.0	11.6
	FY20 Enacted	*2.4*	*0.0*	*1.7*	*0.0*	*0.0*	*0.0*	*0.0*	*1.0*	*6.1*	*0.5*	*0.0*	*11.7*
	FY21 Request	**1.9**	**0.0**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	**1.0**	**1.0**	**0.0**	**0.0**	**4.8**
DHS/S&T	FY19 Actual	22.4	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.6
	FY20 Enacted	*25.1*	*0.0*	*0.0*	*6.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*31.7*
	FY21 Request	**17.7**	**0.0**	**0.0**	**1.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**19.5**
DHS/TSA	FY19 Actual	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
	FY20 Enacted	*7.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*7.0*
	FY21 Request	**7.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**7.0**
DOE/AITO	FY19 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FY20 Enacted	*2.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.5*
	FY21 Request	**4.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4.9**
DOE/ARPA-E	FY19 Actual	85.0	0.0	0.0	0.0	0.0	0.0	0.0	55.0	30.2	0.0	0.0	170.2
	FY20 Enacted	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	FY21 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**
DOE/EERE	FY19 Actual	34.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.5
	FY20 Enacted	*63.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*63.2*
	FY21 Request	**4.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4.3**
DOE/FE	FY19 Actual	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9
	FY20 Enacted	*14.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*14.5*
	FY21 Request	**15.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**15.1**
DOE/NNSA	FY19 Actual	21.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.8
	FY20 Enacted	*20.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*20.6*
	FY21 Request	**25.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**25.6**
DOE/SC	FY19 Actual	2.1	0.0	0.0	0.0	0.0	1.0	15.2	0.0	0.0	0.0	0.0	18.3
	FY20 Enacted	*26.0*	*0.0*	*0.0*	*0.0*	*0.0*	*9.7*	*35.3*	*0.0*	*0.0*	*0.0*	*0.0*	*71.0*
	FY21 Request	**59.4**	**0.0**	**0.0**	**0.0**	**0.0**	**14.9**	**50.2**	**0.0**	**0.0**	**0.0**	**0.0**	**124.5**
DOI/USBR	FY19 Actual	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	FY20 Enacted	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.6*
	FY21 Request	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**
DOI/USGS	FY19 Actual	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
	FY20 Enacted	*5.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.3*
	FY21 Request	**4.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4.1**
DOT/FAA	FY19 Actual	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	FY20 Enacted	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.6*
	FY21 Request	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.5**
DOT/FHWA	FY19 Actual	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
	FY20 Enacted	*3.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.1*
	FY21 Request	**1.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.5**
DOT/FMCSA	FY19 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FY20 Enacted	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.4*
	FY21 Request	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.4**
DOT/FRA	FY19 Actual	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	FY20 Enacted	*3.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.6*
	FY21 Request	**3.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.5**
DOT/FTA	FY19 Actual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
	FY20 Enacted	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*7.0*	*0.0*	*0.0*	*0.0*	*7.0*
	FY21 Request	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**8.0**	**0.0**	**0.0**	**0.0**	**8.0**

Table 2. Agency Budgets by PCA for AI R&D,[a] FYs 2019–2021 (p. 2 of 2)

FY2019 Budget Actuals, FY2020 Budgets Enacted & Supplemental,[b] and FY2021 Budget Request ($ in millions)

Agency [a, c]	Fiscal Year[b]	11 NITRD Program Component Areas											Totals[e]
		AI[d]	CHuman	CNPS	CSP	EdW	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
DOT/PHMSA	FY19 Actual	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4
	FY20 Enacted	*2.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.4*
	FY21 Request	**2.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2.4**
FDA	FY19 Actual	39.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0
	FY20 Enacted	*39.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*39.0*
	FY21 Request	**38.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**38.0**
NASA	FY19 Actual	26.3	0.0	1.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	1.0	31.3
	FY20 Enacted	*26.3*	*0.0*	*0.9*	*0.0*	*0.0*	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.9*	*28.5*
	FY21 Request	**26.3**	**0.0**	**1.1**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**1.1**	**28.8**
NIH	FY19 Actual	52.0	45.8	3.3	0.0	7.4	20.9	12.5	2.2	33.5	0.6	8.7	187.0
	FY20 Enacted	*53.9*	*48.6*	*3.2*	*0.0*	*7.9*	*22.1*	*13.7*	*2.3*	*32.7*	*0.5*	*9.1*	*193.9*
	FY21 Request	**49.4**	**43.8**	**3.0**	**0.0**	**7.2**	**20.2**	**12.2**	**2.1**	**30.1**	**0.5**	**8.4**	**176.8**
NIJ	FY19 Actual	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
	FY20 Enacted	*3.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.0*
	FY21 Request	**3.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.0**
NIST	FY19 Actual	12.7	0.0	0.0	0.0	0.0	1.0	0.0	2.3	0.0	0.6	0.0	16.6
	FY20 Enacted	*22.1*	*0.0*	*0.0*	*0.0*	*0.0*	*1.7*	*0.0*	*3.1*	*0.0*	*0.7*	*0.0*	*27.6*
	FY21 Request	**47.1**	**0.0**	**0.0**	**0.0**	**0.0**	**1.7**	**0.0**	**3.1**	**0.0**	**0.7**	**0.0**	**52.7**
NOAA	FY19 Actual	0.8	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.1	1.5
	FY20 Enacted	*0.8*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.7*	*0.0*	*0.0*	*0.0*	*0.1*	*1.6*
	FY21 Request	**0.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.7**	**0.0**	**0.0**	**0.0**	**0.1**	**1.6**
NSF	FY19 Actual	235.0	32.6	28.8	21.6	9.1	11.3	21.0	45.9	42.0	7.2	3.7	458.1
	FY20 Enacted	*264.9*	*36.4*	*32.2*	*22.6*	*10.3*	*16.2*	*21.7*	*47.6*	*46.6*	*7.4*	*3.8*	*509.7*
	FY20 Suppl.	**5.6**	**0.5**	**0.3**	**0.3**	**0.0**	**0.0**	**0.1**	**0.3**	**1.3**	**0.1**	**0.0**	**8.6**
	FY21 Request	**456.8**	**40.0**	**37.3**	**41.5**	**22.2**	**26.8**	**36.7**	**57.6**	**84.1**	**17.7**	**10.7**	**831.2**
Treas/FCEN	FY19 Actual	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
	FY20 Enacted	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.6*
	FY21 Request	**0.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.6**
USDA/ARS	FY19 Actual	18.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.1
	FY20 Enacted	*18.7*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*18.7*
	FY21 Request	**17.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**17.9**
USDA/NIFA	FY19 Actual	27.0	0.0	1.2	0.0	0.1	0.0	0.0	0.2	0.1	0.0	0.0	28.7
	FY20 Enacted	*34.5*	*0.0*	*1.2*	*0.0*	*0.1*	*0.0*	*0.0*	*0.2*	*0.1*	*0.0*	*0.0*	*36.2*
	FY21 Request	**110.0**	**0.0**	**1.2**	**0.0**	**0.1**	**0.0**	**0.0**	**0.2**	**0.1**	**0.0**	**0.0**	**111.7**
VA	FY19 Actual	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8
	FY20 Enacted	*14.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*14.1*
	FY21 Request	**14.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**14.1**
TOTALS[e]	FY19 Actual	627.7	78.5	37.6	26.8	16.7	37.2	49.4	107.6	110.8	8.9	13.5	1,114.6
TOTALS[e]	*FY20 Enacted*	*654.9*	*85.0*	*39.1*	*29.2*	*18.3*	*50.4*	*71.4*	*61.2*	*85.5*	*9.1*	*13.9*	*1,118.3*
TOTALS[e]	**FY20 Suppl.**	**5.6**	**0.5**	**0.3**	**0.3**	**0.0**	**0.0**	**0.1**	**0.3**	**1.3**	**0.1**	**0.0**	**8.6**
TOTALS[e]	**FY21 Request**	**912.0**	**83.8**	**43.4**	**43.2**	**29.5**	**64.4**	**99.9**	**72.0**	**115.4**	**18.9**	**20.1**	**1,502.5**

AI Budget Table 2 Notes

a. DOD and DARPA AI R&D investments are not publicly available.
b. FY2020 Supplemental (Suppl.) Budgets: See footnote 13 on p. 7.
c. For full names of agency subcomponents (departments and offices), see the Abbreviations list on pp. 35-36.
d. (1) Examples of AI R&D investments reported under the AI PCA are R&D on general methods for machine vision; (primarily) machine learning; cybersecurity challenges unique to AI, e.g., ability to exploit flaws in an AI system's goals; algorithms for computational linguistics; and neuromorphic computing architectures or chips optimized for neural nets.

Table 2 notes are continued on the next page.

AI Budget Table 2 Notes (cont.)

d. (2) Examples of AI investments reported in other PCAs are R&D on robots (*reported for IRAS*); the data analysis and management ecosystem (*reported for LSDMA*); broad issues of human-machine interaction (*reported for CHuman*) and cybersecurity research (*reported for CSP*); and general neuromorphic computing (*reported for EHCS*).

e. Totals might not sum exactly due to rounding.

Table 3. Agency Budgets for ACN R&D,[a,b] FY2019–FY2021 ($ in millions)

Agencies / Fiscal Year	DARPA	DHS S&T	DOD/Air Force	DOD /Army	DOD /Navy	NIST	NSF	NTIA	TOTALS[c]
FY19 Actual	40.9	15.2	0.0	0.0	0.9	12.2	80.0	5.9	155.0
FY20 Enacted	*40.0*	*8.2*	*3.5*	*28.2*	*2.6*	*18.8*	*100.7*	*6.2*	*208.2*
FY20 Supplemental[d]	0.0	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.8**	**0.0**	*0.8*
FY21 Request	**29.2**	**1.2**	**8.6**	**25.6**	**2.4**	**18.9**	**93.4**	**9.7**	**189.0**

ACN Budget Table 3 Notes

a. Figures in the table break out those portions of NITRD member agencies' R&D investments in the LSN PCA that are primarily dedicated to advanced communications networks. ACN R&D investments are primarily coordinated through NITRD's Wireless Spectrum R&D Interagency Working Group. They include Federal spectrum-related R&D investments that promote efficient use of wireless spectrum through advanced technologies and systems.

b. This is the first year NITRD has collected ACN R&D numbers; as such, this table may not fully cover the agency investments in ACN R&D, and the numbers are not comparable to any previous NITRD budget reporting.

c. Totals might not sum exactly due to rounding.

d. See footnote 13 on p. 7.

Budget Analysis

Agency Budgets for Artificial Intelligence

In support of Executive Order 13859, "Maintaining American Leadership in Artificial Intelligence," and *The National Artificial Intelligence Research and Development Strategic Plan: 2019 Update*,[15] NITRD worked with Federal agencies to establish a process to accurately account for AI R&D investments, given that R&D in AI intersects with multiple PCAs. (Table 2, footnote d, gives examples of distinctions between AI and other PCAs.) The FY2020 budget request set a baseline 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 last year, the AI investments reported in this budget supplement are only comparable to other NITRD-reported 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. The FY2021 funding level shown for AI in Table 2 indicates both the nondefense Federal programs directly related to AI ($912 million) and the AI-related efforts reported in the other PCAs ($590.5 million). Together, these total a Federal FY2021 nondefense budget request in AI of $1.5 billion, a 34.4 percent increase over the FY2020 enacted investments and a 54.3 percent increase over the FY2020 budget request.[16]

Agency Budgets for Advanced Communications Networks

In support of the Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future[17] NITRD requested that agencies report investments in ACN, as a portion of the investment reported in the LSN PCA (see Table 3).

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

[16] See https://www.nitrd.gov/pubs/FY2020-NITRD-Supplement.pdf for the FY2020 NITRD budget request.

[17] https://www.whitehouse.gov/presidential-actions/presidential-memorandum-developing-sustainable-spectrum-strategy-americas-future/

Changes in Overall Agency Budgets, FY2020 to FY2021

The following paragraphs note changes of investment greater than $10 million, by agency, between the FY2020 enacted budgets and the FY2021 budget request.[18]

AHRQ: The decrease of $16.5 million is due to AHRQ reporting no CHuman-related or other NITRD-related program for FY2021.

DARPA: The decrease of $47.9 million is due to a decrease of $35.2 million in LSN following the ramping down of several information integration systems programs—including Secure Handhelds on Assured Resilient networks at the tactical Edge, Dynamic Network Adaptation for Mission Optimization, and Network Universal Persistence—and a decrease of $14.9 million in CSP following the completion of several applied cyber research programs in FY2020, with smaller increases and decreases in other PCAs. DARPA's AI R&D investments are not publicly available.

DHS: The decrease of $24.8 million is due to small decreases across PCAs.

DOD: The decrease of $111.5 million is due to decreases of $65.3 million in IRAS, $27.8 million in CSP, $14.9 million in LSN, $10.9 million in CNPS, $10.2 million in CHuman, and a smaller decrease in HCIA; these decreases are partially offset by an increase of $12.6 million in EHCS and smaller increases in other PCAs. DOD AI R&D investments are not publicly available.

DOE: The decrease of $15.2 million reflects a decrease of 75% in DOE/EERE's overall budget; decreases of $17.2 million in LSDMA at DOE/ARPA-E due to sunsetting the Systems for Monitoring and Analytics for Renewable Transportation Fuel from Agricultural Resources and Management program; $10 million in LSN at DOE/SC for supporting the ESnet-6 upgrade and operation of ESnet-5; and smaller decreases in other programs and PCAs. These are partially offset by increases of $33.4 million in AI at DOE/SC to address the challenges of data-intensive science at its scientific user facilities and in critical applications, and smaller increases in AI at DOE/AITO and DOE/FE; and $47.9 million in EHCS at DOE/SC for increased investments in new algorithms, applications, and data infrastructure for AI and future computing technologies.

DOE/NNSA: The decrease of $29.0 million is due to a $34 million decrease in EHCS following the conclusion of the DOE Exascale Computing Project PathForward program in FY2020, partially offset by an increase in AI.

NIH: The decrease of $141.7 million is due to a decrease of $38.3 in LSDMA, which reflects completion of Big Data to Knowledge efforts, decreases of $36.8 in CHuman, $30.8 in HCIA, and $13.8 in SPSQ, and smaller decreases in all other PCAs to reflect agency reprioritization in support of AI.

NIST: The increase of $25.5 million is due to an increase of $25 million in the AI PCA, based on the increase proposed in the FY2021 President's Budget, and a smaller increase in LSN.

NOAA: The decrease of $17 million is due to reduction in NOAA initiatives in the HCIA PCA.

NSF: The increase of $149.4 million is due to increases of $191.9 million in the AI PCA for research and education investments including additional AI Institutes, $19.5 million in LSDMA for Harnessing the Data Revolution and other data-related programs, $10 million in IRAS, and a smaller increase in CNPS; these increases are partially offset by decreases of $19.9 million in LSN, $19.1 million in HCIA, and smaller decreases in other PCAs.

USDA: The increase of $74.7 million is due to an increase of $75.5 in the AI PCA at NIFA for FY2021 contributions to the NSF AI Research Institutes and for grants to study application of AI predictive decision-making in the food and agricultural sector and to support development of an AI-savvy workforce for agricultural applications; this increase is partially offset by a small decrease in the AI PCA at ARS.

[18] No FY2020 budget supplemental figures were included in calculating changes between the FY2020 and FY2021 budgets.

3. Key Activities of the NITRD PCAs and IWGs

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, natural language processing/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.[19]

Artificial Intelligence IWG

Participating Agencies: Air Force, Army, DARPA, DHS, DOD, DOE, DOJ, DOT, FAA, FBI, FDA, GSA, IARPA, NARA, NASA, Navy, NIFA, NIH, NIJ, NIST, NMIO, NOAA, NSA, NSF, NTIA, ODNI, ONC, OSD, OSTP, State, USPTO, VA

Guided by the eight strategic priorities of the 2019 *National AI R&D Strategic Plan,*[20] the AI IWG coordinates Federal AI R&D and supports activities tasked by both the NSTC Select Committee on AI and the Subcommittee on Machine Learning and Artificial Intelligence. This vital work promotes U.S. leadership and global competitiveness in AI R&D and in its applications. Details of many recent and ongoing Federal AI R&D programs and applications are available in the *2016-2019 AI R&D Progress Report.*[21]

Strategic Priorities and Associated Key Programs

Make long-term investments in AI research: Coordinate long-term Federal investments in AI R&D that could lead to transformative AI technologies and breakthroughs across all sectors of society.

Key programs: National AI Research Institutes—*DHS, DOT, NIFA, NSF, VA*; Emerging Technology Risk Assessment—*DHS*; Connected and Automated Vehicles—*DOT*; Assisting Vulnerable Travelers—*DOT*; Computer Vision—*DOT, NIH*; Joint AI Center—*DOD*; Joint Design of Advanced Computing Solutions for Cancer—*DOE, NIH*; Air Traffic Management–eXploration—*NASA*; UAS integration in the National Airspace System—*NASA*; Agriculture and Food Research Initiative—*NIFA*; Novel Computational Paradigms for AI—*NIST*; Center for Artificial Intelligence—*NOAA*; Earth Prediction Innovation Center—*NOAA*; Integrated Ocean Observing System—*NOAA*; Coastal Change Analysis—*NOAA*; Information Integration and Informatics—*NSF*; Real-Time Machine Learning—*NSF*; Robust Intelligence—*NSF*; Spectrum monitoring—*NTIA*; AI R&D for Veteran Priorities—*VA*

Develop effective methods for human–AI collaboration: Promote safe and effective methods for human–AI collaboration to achieve optimal efficiency and performance by developing advanced AI techniques for human augmentation, improved visualization, and AI–human interfaces.

Key programs: Center for Advanced Mathematics for Energy Research Applications—*DOE*; National Robotics Initiative (NRI)-2.0—*NASA, NIOSH, NSF, USDA*; Real or near-real-time decision-making—*DHS, NSF, NIJ*; AI Usability—*NIST*; Satellite Based Products for Weather Forecasting—*NOAA*; Cyber-Human Systems—*NSF*; Veteran-embedded AI R&D—*VA*

Understand and address the ethical, legal, and societal implications of AI: Develop design methods for trustworthy AI that align with ethical-legal-societal goals and expectations.

Key programs: Agriculture and Food Research Initiative—*NIFA*; Electronic monitoring of fish landings aboard fishing vessels—*NOAA*; Exploration of the value of oceans to society—*NOAA*; Future of Work at the Human-Technology Frontier (FW-HTF)—*NSF*; Driver facial privacy—*DOT, NSF*

[19] Budget Table 2, note c (p. 10), describes how NITRD agencies distinguish between PCA investments related to AI.

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

[21] https://www.nitrd.gov/pubs/AI-Research-and-Development-Progress-Report-2016-2019.pdf

Ensure the safety and security of AI systems: Improve the safety and security of AI systems so that they operate in a controlled, well-defined, and well-understood manner.

Key programs: Exploratory Research on Artificial Intelligence and Society—*NSF*; Secure AI—*NIST*; Secure, Assured, Intelligent Learning Systems—*IARPA*; Autonomous systems policies—*DHS*; Trojans in Artificial Intelligence—*IARPA, NIST*; Cybersecurity—*NASA*; Software Verification and Validation—*NASA*

Develop shared public datasets and environments for AI training and testing to enable discovery, access, and use.

Key programs: Applied AI/ML/DL (deep learning)—*DHS*; Simulated and Synthetic Data for Infrastructure Modeling—*NSF*; Spectrum Monitoring—*NTIA*; Quality of Experience—*NTIA*; Evaluation of AI/ML techniques against current approaches—*NOAA*; ML training on high-resolution global earth system models—*NOAA*; Advanced Information Systems Technology—*NASA*; Advancing Collaborative Connections for Earth System Science—*NASA*; VA Data Commons—*VA*; AI Tech Sprints—*NCI, VA*

Measure and evaluate AI technologies through standards and benchmarks to address safety, reliability, accuracy, usability, interoperability, robustness, and security.

Key programs: Fundamental and Applied Research and Standards for AI Technologies—*NIST*; Applied AI/ML/DL—*DHS*; Participate in and contribute to development of AI standards—*NIST, all AI IWG agencies*; AI validation and evaluation—*NIST*

Better understand the national AI R&D workforce needs: Grow the AI R&D workforce to ensure America leads the AI innovation of the future.

Key programs: Empower partnerships with industry and government—*DHS*; FW-HTF—*NSF*; Big Data Scientist Training Enhancement Program—*VA*; Graduate Research Fellowships—*NIJ*

Expand PPPs to accelerate advances in AI and strengthen the Nation's R&D ecosystem.

Key programs: Fairness in AI—*NSF, industry partner*; Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability—*NIH*; National Cybersecurity Center of Excellence—*NIST*; AI/ML/DL methods to exploit satellite data—*NOAA*

Key Coordination Activities

- *National Artificial Intelligence R&D Strategic Plan 2019 Update*. *All AI IWG agencies*
- *AI R&D Progress Report*. *All AI IWG agencies*
- *Advanced Information Systems Technology:* Develop and apply AI and ML to Earth Science. *NASA*
- *Principal Investigator meetings:* Review research, identify new applications, and discuss S&T gaps and barriers. *DARPA, DOD, DOE, DHS, DOT, NASA, NIFA, NIH, NIJ, NIOSH, NIST, NSA, NSF*
- *Joint Artificial Intelligence Center:* Coordinate military service and defense agency AI efforts. *DOD, OSD*
- *Aviation Safety Information Analysis and Sharing:* Actively archive and use ML to analyze commercial flight-recorded data and safety reports for safety incidents. *FAA, NASA, NTSB, public partners*
- *Research at the Intersection of Agricultural Science, Big Data, Informatics, and Smart Communities:* Conduct convergent research and engineering to exploit opportunities in digital agriculture. *NIFA, NSF*
- *Million Veteran Program:* Use ML on veteran data to learn how genes, military exposures, and lifestyle affect health and illness to improve the lives of veterans. *DOE, VA*
- *NOAA Workshops, Leveraging AI in Environmental Science* and *Emerging Technologies:* Use these events to promote development of AI tools and applications, support knowledge exchange, and showcase AI innovations for collecting, analyzing, and/or synthesizing environmental data. *NOAA*
- *Video and Image Analytics (VIA) Team of the AI IWG*: Publish an action plan for advancing VIA R&D. *DARPA, DHS, DOJ, FBI, FHWA, IARPA, NIJ, NIST, NRL, NSF*

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.[22]

Reporting Agencies: AHRQ, Air Force, DARPA, DOD, Navy, NIH, NIJ, NIST, NOAA, NSF, ONC, USDA

Strategic Priorities and Associated Key Programs

Develop cohesive sociotechnical systems that support collaboration and innovation, including systems that can manage, verify, and disseminate information online. Integrate diverse human teams having knowledge of both constructive and malicious human behavior with ubiquitous computing, networking, data analytic, and knowledge representation systems.

Key programs: Clinical Decision Support: Advance the science of CDS by supporting clinicians, vendors, and implementers in developing shareable, standards-based, patient-centered tools, and Patient Reported Outcomes Initiative: Develop and pilot test applications that incorporate Fast Healthcare Interoperability Resource standards—*AHRQ*; Smart and Connected Health: Integrate technical computing advances with new sociobehavioral, cognitive, and system/process models around healthcare and quality of life—*NIH, NSF*; Mobile Health: Support exploratory and developmental R&D to develop or adapt novel mHealth technology for low-/middle-income countries, and measure health outcomes—*NIH*; Safe Use of Robotics in the Workplace: Evaluate potential benefits and risks of robots in the workplace and develop interventions and guidance for safe, effective interactions between humans and robots—*NIOSH*

Improve interfaces between humans and intelligent systems—including robots, intelligent agents, autonomous vehicles, and machine learning systems—to accomplish complex missions.

Key programs: Future of Work at the Human-Technology Frontier—*NSF*; Human Systems Integration Architecture for Increasingly Earth-Independent Mission Operations: Enable small crews to address mission anomalies using intelligent systems on next-generation spacecraft, and Unmanned Aerial Systems in the National Air Space: Enable UAS operations with human-in-the-loop planning and coordination but minimal direct human control of vehicles—*NASA*; Collaborative Research in Computational Neuroscience: Explore modeling/use of neurobiological systems with application to ML and brain–computer interfaces—*NIH, NSF*; BRAIN Initiative: Revolutionize understanding of the human brain, including in clinical studies, to advance recording and modulating the human central nervous system—*FDA, IARPA, NIH, NSF*; Stimulating Peripheral Activity to Relieve Conditions: Accelerate development of therapeutic devices that modulate electrical activity in nerves to improve organ function, and generate tools to identify and influence therapeutic targets in organ and tissue neural circuitry—*NIH*; Usability research grants: Apply cognitive science, user-centered design, and usability principles to improve measurement/evaluation methods, guidelines, and standards; human-system interactions; workflow-friendly EHRs; and virtual coaching—*AHRQ, NIST, NIH*

Promote education and workforce development in understanding human-IT interactions: Develop new curricula based on evolving educational and technological models. (*See the EdW PCA.*)

Key Coordination Activities

- *NRI-2.0:* Integrate ubiquitous and collaborative robots that work cooperatively with people to assist humans in every aspect of life. *NASA, NIOSH, NSF, USDA*
- *Integrating scientific, computational, and socioeconomic R&D in AI:* Pursue safe, robust, trustworthy AI; fairness, bias, and transparency; human-AI interaction; and social and ethical impacts. *NIH, NSF*
- *Cyber-Physical Systems:* Advance integration of computation and physical systems; expand capability, adaptability, scalability, resiliency, safety, security, usability, and participation. *DHS, DOT, NIH, NSF, USDA*

[22] There is no IWG for this PCA; the NITRD Subcommittee and other IWGs coordinate CHuman activities directly.

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, real-time, networked, and hybrid computing and engineered systems.

Computing-Enabled Networked Physical Systems IWG

Participating Agencies: Air Force, Army, BLS, DARPA, DHS, DOE, FAA, FDA, FHWA, ITA, ITS JPO, NASA, Navy, NIFA, NIH, NIOSH, NIST, NRC, NSA, NSF, NTIA, OSD

The CNPS IWG coordinates Federal R&D to advance and assure integrated IT-enabled cyber, physical, and human systems. This spans complex, high-reliability, safety-/security-critical, real-time computing and engineered systems with varying degrees of autonomy and human–system interaction in such uses as automated vehicles, smart grids, manufacturing, intelligent defense systems, and smart cities.

Strategic Priorities and Associated Key Programs

Develop core science and engineering for complex CNPS technologies: Create unified foundations, models and analysis tools, system capabilities, interoperability standards, assurance approaches, and architectures that support innovation and integration within both natural and social systems.

Key programs: Enable engineering of complex cyber-physical systems (CPS) through research in control, data analytics, autonomy, design, information management, IoT, human-in- or on-the-loop, networking, privacy, real-time systems, safety, security, and verification—*DHS, FHWA, NIFA, NIH, NSF, NTIA*; Develop an open-source software platform for an integrative, reconfigurable, reproducible, scalable, usable CPS and IoT testbed—*NIST*; Pursue foundational research in the Cyber-Physical Systems program, including in control, verification, networking, data analytics, IoT, privacy, and real-time systems—*NSF*; Develop technologies that leverage properties of CPS to ensure resilience of Navy physical systems to cyber-attack—*NRL, ONR*

Support and enable safety- and security-critical and high-dependability applications, especially in applications of assured autonomy and AI technologies.

Key programs: Research the design, verification, validation, and certification of novel air vehicles with increasingly autonomous functions—*DOD, FAA, NASA, NTSB, industrial partners*; Mitigate adversarial machine learning by leveraging the development of lightweight simulation language, metrics to measure the quality of an adversarial influence strategy, and models to simulate attacker and defender uses of ML—*ARL, NSA, OUSD R&E*

Support advances in smart cities and communities: Invest in multidisciplinary, multisector collaborations that leverage CNPS applications and engagement of local cities and communities in research- and technology-enabled approaches, including infrastructure integration and integrative research addressing sociotechnological dimensions.

Key programs: Promote formation, growth, and advancement of project teams, community leaders, and private-sector innovators for replicable smart city solutions and teams-of-teams for smart city technology blueprints in transportation, public safety, data, and other application areas—*DHS, ITA, NIST, NSF, NTIA*; Accelerate creation of S&E foundations in Smart and Connected Communities programs to generate new levels of economic opportunity, safety and security, health and wellness, and overall quality of life—*NSF*

Facilitate the transition of new CNPS technologies and tools from laboratories and academia to public and private systems, and prioritize cyber-physical security by minimizing vulnerabilities, protecting privacy, and promoting health and well-being in CNPS and IoT technologies.

Key programs: Explore emerging technologies to enable fully accessible transportation for mobility-impaired persons—*DOD, DOL, DOT, FHWA, HHS, ITS JPO*; Support high-impact transition-to-practice activities in CPS and SCC programs—*NSF*; Advance food and nutritional security through development of

high-output, efficient, controlled-environment urban agriculture systems—*NIFA, NSF*; Develop and integrate computer and information S&E approaches to support the advancement of health and medicine to better support the wide-ranging healthcare needs of the American people—*NIH, NSF*

Promote inclusive education and workforce development by developing new curricula that integrate CNPS theory and methodology. (*See the EdW PCA.*)

Key Coordination Activities

- *CPS Principal Investigator meetings:* Meet annually to bring together CPS researchers and multiple agency partners to review CPS research results. *DOD, DOE, DHS, DOT, NASA, NIFA, NIH, NIST, NSA, NSF*
- *Cyber-Physical Systems:* Collaborate on the annual NSF solicitation to explore new research ideas spanning multiple technology spaces and priorities. *DHS, FHWA, NIFA, NIH, NSF*
- *Computing Community Consortium Workshops on Assured Autonomy:* Identify challenges to the assurance of autonomy, including the R&D needed to overcome these challenges and the gaps in support for the needed R&D. *AFRL, DHS, FHWA, NASA, NIST, NSA, NSF*
- *Global Cities Team Challenge Smart Buildings Action Cluster:* Engage relevant stakeholders to develop best practices and projects for smart buildings as a foundational component of the smart cities ecosystem. *DHS S&T, NASA, NIST, NTIA*

Cyber Security and Privacy (CSP) PCA

CSP R&D advances protection of information, information systems, and people from cyber threats and prevention of adverse privacy effects arising from information processing; this includes R&D to deter, detect, prevent, counter, respond to, recover from, and adapt to threats to the availability, integrity, and confidentiality of information and information systems, along with R&D to address privacy goals of individuals and society related to direct and indirect effects of information processing.[23]

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 and Associated Key Programs[24]

Defensive Areas

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 programs: Cyber deception—*ARL, C5ISR, ONR*; Cyber attribution—*DARPA*; Social engineering defense— *DARPA*; Autonomous and proactive cyber defense—*AFRL, ARL, C5ISR, NSF, ONR, OSD*

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

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[23] Both the CSIA and Privacy IWGs report under the CSP PCA.

[24] See Federal cybersecurity R&D priorities in https://www.nitrd.gov/pubs/Federal-Cybersecurity-RD-Strategic-Plan-2019.pdf.

Key programs: Automated and autonomous cyber defense and operations—*AFRL, ARL, C5ISR, NSA, NSF, ONR, OSD*; Assured AI and systems engineering—*AFRL, DARPA, NIST, NSA, NSF*; Resilient cyber, cyber-physical, and IoT systems—*AFRL, ARL, C5ISR, DARPA, DHS, DOE/CESER, HPCMP, 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—*DARPA, NIST, NSA*

Detect: Develop technologies to ensure that system owners and users have situational awareness and understanding of ongoing activities and can reliably detect malicious cyber activities.

Key programs: Cyber situational awareness—*AFRL, ARL, C5ISR, DARPA, DOE/CESER, HPCMP, NSA, OSD*; Malware detection and mitigation—*DHS, NIST, NSF, ONR*; Machine learning for security—*DARPA, NIST, NSA, NSF, OSD*

Respond: Develop technologies to provide real-time assessment of system anomalies, provide adaptive response to disruptions, sustain critical functions, and enable automated recovery.

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

Priority Areas

Artificial Intelligence: Develop solutions that enable automated cyber defense, minimize susceptibility of AI systems to attacks, and ensure that AI systems are explainable.

Key programs: AI for cybersecurity—*ARL, C5ISR, DOE/CESER, HPCMP, NIST, NSA, NSF, ONR, OSD*; Cybersecurity of AI—*ARL, C5ISR, NIST, NSA, NSF, OSD*; Standards for AI—*NIST, all AI IWG agencies*

Quantum Information Science: Develop technologies for securing quantum software and hardware and for developing countermeasures against quantum-based attacks.

Key programs: Quantum programming and protocols—*AFRL, DOE/CESER, NSF*; Quantum-resistant cryptography—*NIST, NSF*

Trustworthy Distributed Digital Infrastructure: Develop technologies to provide secure and resilient communication and computing infrastructures that incorporate advanced communications networks, cloud computing, IoT, and CPS resources.

Key programs: Wireless and network security—*ARL, C5ISR, DHS, DOE/CESER, NIST, NSF, NSA, ONR, OSD*; Protection of cyber-physical and IoT systems—*DHS, DOE/CESER, NSA, NSF, ONR*

Privacy: Develop solutions to enable privacy-protecting data processing and analytics and to provide for recovery from privacy violations.

Key programs: Cryptography for privacy—*NSA, NSF, ONR*; Privacy Framework—*NIST;* See also Privacy R&D IWG below.

Secure Hardware and Software: Develop technologies to assure that the design and operation of IT hardware and software can be verifiably trusted and cannot be maliciously compromised.

Key programs: Software assurance—*AFRL, DARPA, DHS, DOE/CESER, NIST, NSA, NSF, ONR, OSD*; Formal verification of software and hardware—*AFRL, NSF, ONR*; Secure microprocessors and IoT—*AFRL, NSA, NSF*

Education and Workforce Development: Develop and accelerate adoption of effective educational programs to prepare the Nation, at all education levels and in all sectors of society, for possible careers in cybersecurity and for safe and secure use of the cyberspace.

Key programs: Education and workforce development—*AFRL, DOE/CESER, NIST, NSA, NSF*; Behavioral cyber science—*OSD;* See also EdW PCA (pp. 21-22)

Key Coordination Activities

- *Federal Cybersecurity R&D Strategic Plan Implementation Roadmap:*[25] Update as directed by the Cybersecurity Enhancement Act of 2014. *All CSIA IWG agencies*
- *Technical standards:* Cryptographic standards development. *NIST, NSA*; Internet Engineering Task Force public working groups. *NIST, NSA, OSD*
- *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:* Organize annual cyber technology demonstrations. *DARPA, NIST, NSA, OSD*; Cyber/cyber-physical security public working groups. *NIST*; National Initiative for Cybersecurity Education Conference/Expo. *NIST, NSA, NSF*; Cybersecurity research workshops. *NSF*
- *DOD Cyber Community of Interest*: Provide oversight and coordination among DOD cyber S&T programs. *AFRL, ARL, C5ISR, DARPA, NSA, ONR, OSD*
- *Cyber education:* Support the Centers of Academic Excellence. *NSA*; CyberCorps, Scholarship for Service, Advanced Technological Education. *NSF*; National Initiative for Cybersecurity Education. *NIST, NSA, NSF, OSD*
- *International:* Collaborate in science programs with Israel, Netherlands, and Brazil. *NSF*; The Technical Cooperation Program Command, Control, Communications, Information Systems Group 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 R&D 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 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.

Strategic Priorities and Associated Key Programs

Understand privacy desires and impacts.

Key programs: Develop models and conduct studies to understand peoples' privacy needs in different contexts—*Census, NIH, NIST, NSA, NSF*

Develop system design methods that incorporate privacy requirements and controls.

Key programs: Apply formal privacy safeguards to the 2020 Census and American Community Survey—*Census*; Develop practical approaches for implementing privacy protections in data analytics systems—*Census, NIH, NIST, NSA, NSF*; Provide methods for secure, privacy-preserving access to precision medicine data—*NIH*; Develop privacy framework and standards-based tools and privacy engineering practices—*NIST*

Develop techniques to assure that information use is consistent with privacy rules.

Key programs: Build encryption for privacy protections—*NIH, NSF, NSA*; Determine privacy engineering and technical standards for privacy—*NIST, NSA*

Develop solutions to enable user-driven controls and actions over data collection, use, and deletion.

Key programs: Protect privacy in networking, mobile computing, and the IoT—*NSA, NSF*

[25] https://www.nitrd.gov/pubs/FY2021-Cybersecurity-RD-Roadmap.pdf

Develop solutions for minimizing reidentification risks while maximizing utility of data analytics.

Key programs: Adopt differential privacy for the 2020 Census—*Census*; Develop techniques to assure privacy protections in analytical and ML systems—*NIH, NSA, NSF*; Develop secure and private collaboration environments—*Census, NIH*

Develop solutions for recovery from privacy violations.

Key programs: Develop techniques to mitigate privacy violations and support privacy recovery—*NIST, NSF*

Key Coordination Activities

- *NIST Privacy Engineering Collaboration Space:* Actively support this online forum for sharing use cases and tools to advance privacy engineering. *All Privacy R&D IWG agencies*
- *Workshops:* Continue the annual workshops on privacy research topics such as privacy controls, privacy framework, algorithmic transparency, and consumer privacy protections. *FTC, NIST, NSF*
- *Federal Privacy Council:* Participate actively in this interagency forum organized to improve the privacy practices of Federal agencies. *FTC, NIST*
- *Technical privacy guidelines:* Develop and coordinate recommendations, guidelines, and standards for privacy-preserving technologies and privacy risk assessment methodologies. *Census, NIST*
- *International collaborations:* Engage in international privacy standards development. *NIST*; Co-fund United States–Netherlands research activities in privacy. *NSF*

Education and Workforce (EdW) PCA[26]

EdW R&D advances the 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. 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*.[27]

Reporting Agencies: DHS, DOC, DOD, DOE/NNSA, DOE, NASA, Navy, NIFA, NIH, NIST, NSA, NSF, ODNI, VA

Strategic Priorities and Associated Key Programs

Ensure a consistent flow of skilled workers capable of using the tools and methods of the future by creating opportunities to teach and learn IT and AI at all educational levels. These experiences must reach across multiple STEM and IT domains, support diversity and inclusion, and include internships, fellowships, and early research opportunities.

Key programs: Big Data Scientist Training Enhancement Program—*VA*; Centers of Academic Excellence—*NSA*; CyberCorps, Scholarship for Service, Advanced Technological Education—*NSF*; Computational Science Graduate Fellowship—*DOE/NNSA, DOE/SC*; High Performance Computing Internships—*HPCMP*; Research opportunities in quantum information theory—*NIST*; Quantum Computing and Information Science Faculty Fellows Program—*NSF*; Research Education for Undergraduates Program—*NSF*; Space Technology Research Fellowships—*NASA*; Computational Sciences Graduate Fellowship—*DOE/SC*; S&T Technology Fellowship—*DHS*; AFRI Education and Workforce Development Program—*NIFA*

Prepare all Americans, through IT and AI life-long learning programs in the workplace and community, to successfully participate in the economy and society of the future.

Key programs: FW-HTF, Training-based Workforce Development for Advanced Cyber-infrastructure, Data Science Corps, and CISE Education and Workforce Program—*NSF*

[26] There is no IWG for this PCA; the NITRD Subcommittee and other IWGs coordinate EdW activities directly.

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

Promote coordination and collaboration among Federal agencies and business, educational, and nonprofit communities to develop a persistent and robust U.S. IT education ecosystem including educational programs, tools, and technologies, consistent with the cross-agency strategies and work of the *NSTC STEM Education Subcommittee, Convergence IWG* and *Computational Literacy IWG*; the *DOD STEM strategy*; the *NICE Strategic Plan* and *Interagency Coordinating Council*; and workforce provisions of the *Cybersecurity Executive Order.*

Key programs: Program to Empower Partnerships with Industry and Government—*DHS*; University-based Engineering Research Center—*DOE/OE, NSF*; OnRamp II—*NSA*; National Initiative for Cybersecurity Education—*NIST, NSA, NSF, OSD*; NIST Privacy Engineering Collaboration Space—*NIST*

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.

High End Computing (HEC) IWG

Participating Agencies: Air Force, Army, DARPA, DOE/NNSA, DOE/SC, IARPA, NASA, Navy, NIH, NIST, NOAA, NRO, NSA, NSF, OSD, USGS

The HEC IWG coordinates Federal R&D of innovative technologies to extend U.S. leadership in advanced computing and enable transformative research that support the Nation's economic competitiveness, security, and leadership in science and engineering. EHCS research ensures the development of technologies critical to preparing for the next computing revolution and to overcoming challenges such as the slowdown of Moore's Law, the growing deluge of data, and the rapid changes in the technological landscape, while ensuring that these technology advancements support endeavors vital to the Nation. High-capability computing (HCC) impacts the full spectrum of computing devices and open innovation prospects in areas like precision medicine, smart and connected communities, and autonomous machines.

Strategic Priorities and Associated Key Programs

Research and develop innovative approaches and technologies critical to the delivery of extreme-scale computing systems.

Key programs: Continue joint execution of the Exascale Computing Project to develop applications and related infrastructure, and support application and software technology testing on hardware to prepare for capable exascale systems—*DOE/NNSA, DOE/SC*; Develop programming tools and runtime environments to support domain-aware AI workflows—*DOE/SC*; Invest in new computational platforms for data-intensive HCC and machine learning—*HPCMP*; Enhance testbed computing programs to test various architecture options, and continue to modernize applications by developing algorithms and preparing scientific applications to ensure software performance and portability on new architectures—*NASA*; Develop extreme-scale computational approaches/techniques under the Precision Medicine Initiative–Oncology and Microscopy for Enhanced Drug Development Program—*NIH*; Develop methods for quantifying reproducibility and uncertainty in scientific computing and develop algorithms and software innovations to process extreme data—*NIST*; Continue the Software Engineering for Novel Architectures project to develop new software approaches for an application portfolio that operates efficiently on nontraditional architectures—*NOAA*; Continue R&D to increase performance in massively parallel computing systems and to develop new algorithms and techniques to enable major S&E breakthroughs; and invest in pioneering S&E methods, applications, and paradigms by exploring and deploying novel technologies, architectures, and usage modes within the Advanced Computing Systems and Services Program—*NSF*

Research and develop technologies to make breakthroughs in HCC's most pressing challenges, pioneer new digital and nondigital computing frontiers, and take computing beyond Moore's Law, including advancing quantum computing.

Key programs: Continue research to advance quantum information science—*DOE/SC, NIST, NSF*; Continue work on quantum computing simulators and partner with industry to broaden the scope of research areas to test and evaluate new experimental devices and systems, and partner with industry on fabrication processes for noise reduction in quantum devices—*NASA*; Develop measurement science for computing and communication devices based on quantum phenomena—*NIST*; Establish foundries for rapid prototyping of quantum devices and materials, support interdisciplinary teams to explore innovative ideas for developing/applying quantum technologies, and continue the Foundational Microarchitecture Research partnership with industry to deliver future CPU performance growth beyond Moore's Law—*NSF*; Develop software tools or bio-inspired devices for reconfigurable neuromorphic computing—*DOE/SC, NIST*

Research and develop new approaches and techniques to improve programmability, portability, and usability of high capability computing to boost the productivity of HCC systems.

Key programs: Develop compilers, languages, tools, environments, and methodologies for highly heterogeneous high-performance computing (HPC) systems—*DOE/SC*; 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 software and data services that address all aspects of the NSF umbrella program Cyberinfrastructure for Sustained Scientific Innovation—*NSF*

Conduct crosscutting activities that serve to extend the breadth and impact of HCC.

Key programs: Assimilate HPC into NASA's Aeronautics, Exploration, Science, and Space Technology missions—*NASA*; Investigate use of ML in data assimilation for forecast simulation and analysis—*NOAA*; Enable HPC to use AI to fuse data from hundreds of video feeds—*OSD*

Develop the future HEC workforce. (*See the EdW PCA.*)

Key Coordination Activities

- *Earth System Prediction Capability:* Participate in monthly meetings to discuss HCC issues and challenges. *DOD, DOE, NASA, NOAA, NSF*
- *Enhance research in cancer and drug discovery with HCC capabilities:* Continue collaborations in analytics, and tools and support projects. *DOE/NNSA, DOE/SC, NIH*
- *Project 38:* Explore architectural innovations and quantify their value. *DOE/NNSA, DOE/SC, NSA*
- *Explore software sustainability and usability in the era of extreme heterogeneity*. *HEC IWG agencies*
- *Joint Center for Quantum Information and Computer Science*. *NIST, NSA*

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.

High End Computing IWG

Participating Agencies: Air Force, Army, DOE/NNSA, DOE/SC, IARPA, NASA, Navy, NIH, NIST, NOAA, NRO, NSA, NSF, OSD, USGS

In addition to coordinating EHCS R&D, the HEC IWG coordinates Federal activities to provide HCC systems and infrastructure and develop 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 S&E applications of national interest.

Strategic Priorities and Associated Key Programs

Acquire, operate, and provide to researchers HCC systems with the varying capabilities required to meet critical national needs and support research and education across all S&E areas.

Key programs: Provide leadership-class HCC at Leadership Computing Facilities Argonne (Aurora, Summit) and Oak Ridge (Frontier); and deploy the Perlmutter (NERSC-9) upgrade at the National Energy Research Scientific Computing Center—*DOE/SC*; Support DOD Supercomputing Resource Centers and provide HCC capability in a container for at-the-edge use cases—*HPCMP*; Provide HCC capability to NASA S&E communities and support NASA's digital transformation through the NASA Center for Climate Simulation and NASA Ames Research Center—*NASA*; Provide HCC resources Anton 2 and Biowulf for biomedical research—*NIH*; Deploy new architecture for Weather and Climate Operational Supercomputing Systems—*NOAA*; Provide and support HCC through the Leadership-Class Computing program, HCC resources through the National Center for Atmospheric Research–Wyoming Supercomputing Center program and Advanced Computing Systems & Services program, and campus HCC clusters through the Major Research Instrumentation program—*NSF*; Provide computational platforms for development and exploration of scientific codes—*USGS*

Develop algorithms and applications software for current and next-generation HCC platforms to maintain and improve the performance of existing codes to support and advance applications vital to the Nation's security and economy and individual well-being.

Key programs: Support SciDAC application partnerships to maximize effective use of exascale platforms; and prepare algorithms, applications, and workflows for next-generation HCC platforms—*DOE/SC*; Develop and optimize DOD multiphysics software applications—*HPCMP*; Determine appropriate programming methods for scalability, performance, and portability—*NOAA*; Support the Modeling, Analysis, and Prediction Program to modernize models, port codes, and refactor major applications—*NASA*; Develop analytics and support multiscale modeling of biomedical processes for improved disease treatment and advancing understanding of the human body, including the brain—*NIH*; Develop the algorithms, tools for modeling, large-scale high-performance image processing techniques, and computation methods required for applications in measurement science—*NIST*; Support a community of researchers in the Principles and Practice of Scalable Systems program who will work across disciplines to foster development of principles for design and implementation of large-scale systems and applications across the full hardware/software stack—*NSF*; Enable porting and development of applications to and on HCC systems for higher-fidelity, higher-resolution models, simulations, and analyses—*USGS*

Provide a diverse user community access to the HCC ecosystem, including facilities and resources, and enhance the infrastructure and ecosystem needed to support U.S. leadership in S&E.

Key programs: Provide researchers access to and support in using leadership computing facility resources through DOE allocation programs—*DOE/SC*; Provide DOD users computational tools and techniques, enterprise administration and user support, computational expertise, and HCC systems and networking—*HPCMP*; Develop and provide computing and data services in the cloud to NASA S&E projects—*NASA*; Broaden partnerships with industry to provide access to services and tools for high-throughput biomedical research—*NIH*; Support a collaborative partnership of 19 academic institutions to provide support for HCC, storage, visualization, and data services—*NSF*; Provide on-premises/cloud hybrid HCC systems, data management services, and file systems—*USGS*

Develop resources and tools to lower barriers to HCC access, improve usability, and support collaborations as means to increase productivity and impact.

Key programs: Provide Exascale Computing Project software development kits to the community; and continue support for the DOE/NERSC and the Oak Ridge and Argonne Leadership Computing Facilities, including training, outreach, and application readiness for future system upgrades—*DOE/SC*; Develop a web browser portal to provide users secure access to DOD HCC environments—*HPCMP*; Consolidate code repositories and support open source code development and use of GitHub to enhance collaboration and enable community development—*NASA*; Support Science Gateway Community Institute's provision of services, resources, support, and education for creating and sustaining science gateways—*NSF*

Key Coordination Activities

- *Provide and support HCC and/or HCC resources:* The Leadership-Class Computing Program, National Center for Atmospheric Research/Wyoming Supercomputing Center Program, and the Advanced Computing Systems and Services Program. *NSF*
- *Major Research Instrumentation Program:* Provide and support campus HCC clusters. *NSF*
- *Provide HCC compute core hours*[28] *for applications vital to the Nation*. *DOE/SC, HPCMP, NASA, NIH, NSF*

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.

Intelligent Robotics and Autonomous Systems IWG

Participating Agencies: Air Force, Army, DHS, , DOD, DOE/ARPA-E, DOE/EM, DOI, DOJ, DOT, FAA, NASA, Navy, NIFA, NIH, NIJ, NIOSH, NIST, NRC, NRO, NSA, NSF, ODNI, OSD, USDA

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.

Strategic Priorities and Associated Key Programs

Promote safe, efficient human-robot teaming, including evaluating human-robotic interaction systems for safe, trustworthy, transparent collaboration to increase quality of work and life.

Key programs: Human/Autonomous System Interaction and Collaboration, and Scalable Teaming of Autonomous Systems—*DOD*; Center for Occupational Robotics Research—*NIOSH*; Mind, Machine, and Motor Nexus and Robust Intelligence—*NSF*; Measurement Science for Manufacturing Robotics, Performance of Human–Robot Interaction—*NIST, NRL*; Human Robotic Systems—*NASA*; NRI-2.0—*NASA, NIOSH, NSF, USDA;* Improve validation and verification of robotic and autonomous systems, including developing metrics, information models, methods, protocols, and tools.

Key programs: Automated Driving Systems—*DOD, DOT*; Multi-segmented magnetic robot—*DOD, NIST*; Testing, Evaluation, Verification, and Validation—*DOD*; Performance Standards for Response Robots—*DHS, NIST*; Development of Methods for Verification of Autonomous Systems—*NRL*

Advance intelligent physical systems to improve their abilities to robustly sense, model, act, plan, learn, and behave ethically in complex and uncertain situations.

Key programs: Dynamical Systems and Control Theory—*Air Force, AFOSR*; Science of Autonomy—*Navy, ONR*; FW-HTF—*NSF*; Machine Perception, Reasoning, and Intelligence—*DOD*; Game Changing Development,

[28] Term for the number of processor units (cores) used to run a simulation multiplied by the duration of the job in hours.

Smart and Autonomous Systems for Space, and Innovative Advanced Concepts programs: Develop autonomous systems technologies for space missions, including multirobot teaming and medical decision-support software, and develop new space robots to explore extreme deep space environments—*NASA*; Scalable Robotic Technologies for Agriculture—*NIFA*; Behavior-Based Control for Teams and Swarms of Autonomous Systems, Space Robotics for Satellite Servicing, and Intelligent Control of Autonomous Underwater Vehicles—*NRL*; Foundational Research in Robotics—*NSF*

Improve wearable robotic systems, including exoskeletons and exosuits.

Key programs: Compliant and Configurable Soft Robotics Engineering—*DOD, NSF*; Interoperability: Investigate open/common architectures, modular systems, interchangeable parts, composable systems, and synergized capabilities as strong foundations for future systems—*DOD*; Designing Materials to Navigation for the Blind—*NIH*; NASA Space and Technology Research Grant: Develop an improved model of human shoulders to inform future spacesuit designs that incorporate strength augmentation—*NASA*; Exoskeletons in the Workplace: Assess safety, usability, and productivity—*NIOSH*; Develop metrics, test artifacts, and evaluation methodologies for measuring the effect of exoskeletons on performance of industrial tasks—*NIST*; Revolutionize and Engineer our Future—*NSF*

Key Coordination Activities

- *Principal Investigator meetings:* Review research, identify new applications, and discuss S&T gaps and barriers. *AFOSR, DHS, DOD, DOE, DOT, NASA, Navy, NIFA, NIH, NIOSH, NIST, NSA, NSF, ONR, USDA*
- *Advanced Robotics for Manufacturing Institute:* Develop open-source, interoperable performance metrics and test methods with academic and industry partners. *Air Force, Army, NASA, Navy, NIOSH, NIST*
- *Safety and other standards development:* Work in PPPs to set standards for vehicles, collaborative robots, mobile manipulators, exoskeletons. *DHS, DOD, DOE, DOI, FAA, NIH, NIOSH, NIST, NRC, NRL*
- *Trusted Autonomy:* Identify and prioritize development of self-sustaining and reliable technologies that are certified for mission use. *Air Force, DOD, NASA, NRL, NRO*
- *OSHA–NIOSH Alliance Program:* Work with industry and other partners to increase workplace safety related to intelligent and autonomous systems, share technical knowledge, improve awareness about workplace hazards and appropriate safeguards, promote best practices, and identify needed research on use of traditional industrial and emerging collaborative robot technologies and systems. *NIOSH, OSHA*
- *ASTM Committee E54 on Homeland Security Applications:* Develop performance standards for response robots. *DHS, DOD, DOJ, FAA, NIOSH, NIST, State*

Large Scale Data Management and Analysis (LSDMA) PCA

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

Big Data (BD) IWG

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

The BD 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 BD will accelerate scientific discovery and innovation, provide the foundation for algorithm-driven businesses, and create new capabilities critical to the Nation.

Strategic Priorities and Associated Key Programs

Maximize use of large-scale data resources through foundational research into innovative tools and methodologies to solve problems of national and societal importance.

Key programs: Cybersecurity and Critical Infrastructure—*DHS*; Advanced Scientific Computing Research—*DOE/SC*; Technologies to utilize Earth observations—*NASA*; Data, Modeling, and Coordination Centers; and Cryo-Electron Microscopy—*NIH*; Transdisciplinary Research in Principles of Data Science, Phase II, and Harnessing the Data Revolution institutes and research networks—*NSF*

Establish the trustworthiness of data-driven discovery and decision-making to ensure reliability, accuracy, generalizability, and performance in solutions to drive S&T and the IotF.

Key programs: Semantic Forensics—*DARPA*; Open-Source and Social Media Analytics—*DHS*; Uncertainty quantification for simulation and machine learning—*DOE/SC*; Computing and Communication Foundations, Information and Intelligent Systems Core—*NSF*

Enable the interoperability of diverse data types and sources that is scalable and enables data integration among heterogeneous datasets to support innovative solutions.

Key programs: Secure Multiparty Computation Architectures, and Information Analytics for Border Security—*DHS*; Develop FAIR (findable, accessible, interoperable, and reusable) frameworks for data and models to address open questions in AI—*DOE/SC*; Big Data Governance and Metadata Management—*NARA, NIST*; Genomic Data Science Analysis, Visualization, and Informatics Lab-space; and Changing the Course of Childhood Cancer—*NIH*; Big Data Quality Framework—*NIST*

Support real-time analytics by reducing latency between data ingest, analysis, and decision-making.

Key programs: Dynamic Data Driven Application Systems—*Air Force*; Warfighter Analytics using Smartphones for Health—*DARPA*; Real-time Analytics for Multi-latency, Multi-party, Metro-scale Networks—*DHS*; Conduct research to address management and analysis of experimental and observational data for real-time feedback—*DOE/SC*; Real-Time Learning—*NSF*

Develop and retain a data-literate workforce via R&D and training opportunities. (*See the EdW PCA*.)

Transition research to practice by translating R&D into operational tools and technologies that enhance U.S. economy, security, and well-being.

Key programs: Rapid Deployment Research and Development Capabilities—*DHS*; Support small business solutions for data analysis and management—*Air Force, DOE/SC*; Helping to End Addiction Long-term—*NIH*; Convergence Accelerator Pilot: Open Knowledge Network—*NSF*

Key Coordination Activities

- *National AI Research Institutes:* Research trustworthy AI and foundations of ML. *DHS, NSF, USDA*
- *Data Science and AI:* Coordinate on basic research in BD and AI. *DOE/SC, NIH*
- *Chios:* Enable segmented data sharing without exposing the whole. *DHS, FDA, NIST, NSF*

Large Scale Networking (LSN) PCA

LSN R&D advances networking technologies and services; this includes R&D in networking architectures, wireless networks, software-defined networks, heterogeneous multimedia networks, testbeds, grid and cloud research and infrastructure, network service and cloud computing middleware, identity management, and end-to-end performance enhancement and performance measurement.[29]

[29] Both the LSN and WSRD IWGs report under the LSN PCA.

Large Scale Networking IWG

Participating Agencies: Air Force, Army, DARPA, DOD, DOE/SC, DREN, FCC, NASA, Navy, NIH, NIST, NOAA, NSA, NSF, ODNI, OSD, USDA, 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 and Associated Key Programs

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

Key programs: Provide connectivity/communications in contested/congested environments—*AFRL, C5ISR*; Advance quantum communications and networking—*AFRL, DOE/SC, NIST, NSF*; Provide fourth-generation (4G) commercial services in high-performance wide area networks—*DREN*; Advance communications as a service and convergent networks—*ONR*; Develop new technologies, measurement techniques, methodologies, next-generation network research, testbeds, and demonstrations (e.g., 5G, ML, networking)—*DOE/SC, DREN, NIST, NOAA, NSA, NSF*

Develop cloud infrastructure enhancements.

Key programs: Enable mission-responsive information exchange from enterprise to tactical edge—*AFRL*; Operationalize N-Wave cloud broker services and start operationalizing cloud-based international satellite data ingestion and security validation—*DREN, NOAA*; Develop standards, metrics, and guidance for adoption of cloud computing technologies—*NIST*; Deploy federated distributed computing infrastructure—*DOE/SC*; Conduct network technology and systems R&D, develop new hardware for future cloud systems, advance reproducibility research for cloud systems, and examine edge devices—*DOE/SC, NSA, NSF*

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

Key programs: Expand workload management system access to leadership-class supercomputers—*DOE/SC, DREN*; Develop programmable frameworks for network management—*ONR*; Advance the design of edge computing and edge networking infrastructure, and develop scalable platforms for data analytics for emerging IoT devices—*NSF*; Provide services for applications in precision medicine, mobile health, and telemedicine—*DOE/SC, NIH*; Develop and deploy advanced network infrastructure to enable data-intensive workflows and automated provisioning and monitoring of network operations and services—*DOE/SC*; Enhance the efficiency of big data transfers over high-bandwidth connections—*DOE/SC, DREN*; 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 information-centric networking—*NIST, NSF*; Develop distributed network security analytics for a wide range of 5G environments—*NSA*

Develop, evaluate, and standardize technologies to achieve security and resilience in emerging wireless networks and multidomain internets and to protect core network infrastructure.

Key programs: Enhance cybersecurity awareness and capabilities through developing new services and/or tools (e.g., AI tools)—*AFRL, C5ISR, DOE/SC, DREN, NIST, NOAA*; Support cyber technology innovations for trustworthy networks, data and supply chain security, and infrastructure monitoring—*C5ISR, DOE/SC, NIST, NSA, NSF, ONR*

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

Key programs: Develop nontraditional waveforms and technologies for resilient communications—*C5ISR*; Deploy and operate nationwide testbeds supporting performance monitoring and protocol development—*DOE/SC, NSF*; Share multilevel information across tactical wireless networks—*DARPA*; Increase deployment of Industrial IoT and future wireless networks—*NIST, NOAA*; Enable the investigation of platforms for advanced wireless systems and technologies—*NSF, private partners*

Key Coordination Activities

- *AI for Science:* Coordinate with other agencies in Federal AI/ML initiatives. *DOE/SC*
- *Networking for disaster recovery and crisis management:* Promulgate the resources of the Disaster Information Management Research Center. *NIH, NLM*
- *Broadband Research and Development Team:* Coordinate strategies to address disparities in nation-wide broadband access, adoption, and usage. *Census, DOE, DOL, FCC, NIJ, NIST, NSF, NTIA, OSD, USDA*
- *Joint Engineering Team (JET):*[30] Coordinate R&D activities in networking, advanced technologies, end-user requirements, user interfaces, research and storage networks, end-to-end big data testbeds and metrics, trusted Internet connections, and tools. *DOE/SC, DREN, FCC, NASA, NIH, NIST, NOAA, NRL, NSF*
- *Middleware and Grid Interagency Coordination Team (MAGIC):*[30] Coordinate activities in identity management, distributed computing, middleware, cloud, and grid computing services and information exchanges; standards and implementation; resource architecture, access, and management best practices; and security and privacy. *DOE/SC, FCC, NIST, NRL, NSF*

Wireless Spectrum R&D (WSRD) IWG

Participating Agencies: Air Force, Army, DARPA, DEA, DHS, DOD, DOE/NNSA, DOE/SC, DOJ, FAA, FCC, 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 and Associated Key Programs

Increase spectrum efficiency, flexibility, and adaptability.

Key programs: 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—*DHS, DOE/NE, NIST, NSF*; Develop signal processing techniques for passive and active RF sensors, and deliver adaptable waveforms that are tailored to the mission and spectral environment—*AFRL, DOE/NE, NASA*; Define and improve spectrum efficiency within space, frequency, and time to establish meaningful, quantifiable, actionable metrics, and develop new spectrum-sharing methods, models, platforms, and measurement means—*DARPA, DEA, DOD, FCC, NIST, NSF, NTIA*; Develop ML techniques for spectrum access systems and environmental sensing capability sensors and systems for signal classification—*DARPA, DOD, DEA, FCC, DOE/NE, NIST, NSF, NTIA*

Design robust, secure, and dependable systems and networks that rely on use of wireless spectrum.

Key programs: Provide secure tactical intranetworking for military communications through multibeam directional connectivity and airborne data exchange between security domains, and improve unmanned aircraft system security measures—*AFRL, DOE/NE, Navy, NSA*; Deploy experimental networks and explore trust and coexistence between different types of wireless networks, expand to 5G wideband encryption and optimized massive-MIMO security, and enable anti-jamming low probability of detection, interception, and exploitation—*DEA, DHS, DOE/NE, NSF*; Explore new approaches using AI/ML to enable an autonomous communication infrastructure—*NIST, NSF*

[30] Both the JET and MAGIC teams hold information-sharing meetings among Federal and non-Federal participants.

Provide capabilities for devices to monitor their spectrum environments and adapt in real time.

Key programs: Electromagnetic Spectrum Monitoring: Share spectrum situational awareness using ML, visualization, and network-based techniques for collaborative planning and decentralized decision-making, and develop infrastructure and best practices to acquire data and facilitate data sharing—*AFRL, DARPA, DOE/NE, FCC, NSF, NTIA, OSD*

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

Key programs: Develop air-to-air capability for long-range ultra-broadband terahertz communications; understand mmWave channel characteristics in real-life deployments; and demonstrate effective, secure unmanned aircraft system and wideband communications in mmWave bands—*AFRL, DOE/NE, NIST, NSF, NTIA*; Develop laser airborne terminals with RF networking for increased capacity and robustness and capabilities to move data into and out of space, expand communication capabilities of CubeSats, characterize channel effects, and improve beacon transmission and data collection—*AFRL, Air Force, NASA, NIST, NRL, NSF*

Accelerate deployment of spectrum R&D into usable tools via testing, modeling, and simulation.

Key programs: Hybrid RF-Optical Link Adaptation Risk-reduction and Stockbridge Controllable Contested Environment—*AFRL, FAA, NASA, NRL*; National Advanced Spectrum and Communications Test Network—*DOD, NASA, NIST, NOAA, NSF, NTIA*; Platforms for Advanced Wireless Research: Fund and operate four city-scale test platforms to design, develop, and validate research in advanced wireless technologies in real-life environments—*NSF*; Establish accurate measurements, system calibrations, technology, and models to address challenges in next-generation wireless communications, spectrum sharing, and wireless coexistence; develop testing methods in measurement science; and maintain publicly available web-based tools—*DOE/NE, NIST, NTIA*; Enhance DOE National Laboratory test facilities, e.g., Next Generation Wireless Test Bed—*DOE/NE*; Future Cities Testing—*DOE/NE*; Extreme Environments Testing—*DOE/NNSA*

Key Coordination Activities

- *5G Millimeter-Wave Channel Model Alliance:* Facilitate global efforts to define the radio channels where next-generation 5G wireless will operate. *NIST, NSF, NTIA*
- *Spectrum Innovation Zones:* Enable testing of new wireless devices, communication techniques, networks, systems, and services in real environments. *FCC, NSF*

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, and understanding of the economics of software and its development, sustainability, measurement, assurance, and adaptability; and guarantees of essential requirements such as security, privacy, usability, reliability, and autonomy.

Software Productivity, Sustainability, and Quality IWG

Participating Agencies: Air Force, BEA, BLS, CDC, DARPA, DHS, GSA, NASA, Navy, NIH, NIJ, NIST, NOAA, NRC, NSA, NSF, OSD

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

Strategic Priorities and Associated Key Programs

Advance timely, affordable development and sustainment of low-defect, low-vulnerability software.

Key programs: Support transformative research in design, verification, operation, utilization, and evaluation of computer software, including research focused on S&E of software to transform relationships between requirements, design, and evolution; formal methods for specification, development, and verification of software systems; and design and implementation of programming languages and compilers—*DOD, NSF*; Employ existing techniques and develop and deploy new ones, with academic partners, to productively rewrite and refactor software models for nontraditional architectures and future exascale computers—*DOD, DOE, NOAA*; Employ a category theory approach to integration and interoperability of application software and associated workflow tools to enable solving complex scientific and engineering problems—*NIST*; Create novel software engineering technologies that enable automated adaptation of software to changes in the system requirements and/or the computational environment—*DARPA*

Enhance critical software quality and productivity to maximize positive economic impact by increasing execution efficiency and trustworthiness and reducing vulnerability.

Key programs: 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—*DOD, ONR*; 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 despite an attack, including techniques for automated, real-time repair, software diversity, dynamic assurance cases, and formal methods for software sustainment—*AFRL, DOD*; Develop, deploy, and transfer technology to support software assurance and productivity in aerospace systems that are software-intensive and increasingly autonomous—*AFRL, DOD, FAA, NASA, industry partners*; Provide standard reference data for flawed and fixed code through the Software Assurance Reference Dataset and run a periodic evaluation of static analysis tools—*IARPA, NIST, NSA, DARPA*

Modernize and manage research and regulatory infrastructures to improve the safety, security, trustworthiness, and resilience of digital systems.

Key programs: Support research that addresses emerging needs in scientific software cyberinfrastructure and serves large, multidisciplinary research communities—*DOD, NSF*; 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*; Develop and sustain software for biomedical and public health research, including novel applications of machine learning, artificial intelligence, clinical informatics, and high-performance computing modeling and simulation—*CDC, NIH*

Support software-related STEM education and training to develop the future workforce.

Key programs: CISE Community Research Infrastructure: Build resources such as software libraries, tools, and platforms to support computer/information science/engineering research and education—*NSF*

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. *DOD*

4. Other NITRD Interagency Coordination Activities

Health Information Technology R&D (HITRD) IWG [31]

Participating agencies: Army, AHRQ, CDC, CMS, DARPA, DHA, FDA, HHS, HRSA, IARPA, NIH, NIST, NSF, ONC, VA

The HITRD IWG coordinates R&D aimed at improving the health of Americans by advancing technologies that support personalized health screening, monitoring, diagnosis, and treatment; disease prevention; emergency response; broad access to healthcare information and resources; and building and sustaining a diverse and highly skilled health IT workforce.

Strategic Priorities and Key Areas of Research

Support R&D of health IT tools and services to reduce administrative burdens, enable a new bio-economy, and serve the full community of users.

Key programs: Advance fundamental computer science, networks, data science, and engineering to support new knowledge and services for substantive improvements in health—*NIH, NSF, VA*; Design intelligent devices to monitor, assess, and assist users—*DOD, NIH, NIST, NSF, VA*; Develop tools to make clinical decision support systems extensible and shareable—*AHRQ, CDC, CMS, VA*

Leverage the power of data, computing, and AI to promote infrastructure and standards for accessible, interoperable, reusable health data, devices, and related applications.

Key programs: Create platforms to securely share data, documents, applications, standards, testing, and terminology—*FDA, NIDILRR, NIST*; Foster R&D collaborations via secure access methods that enable scientific advances and development of valid, clinical applications of AI—*FDA, NIDILRR, NIH, ONC, VA*; Enable interoperability of data from diverse sources—*AHRQ, DOD, FDA, NIH, NIST, NSF, ONC, VA*; Improve data and metadata management strategies—*DHA, FDA, NIH, NIST, NSF, ONC, VA*

Support the development of robust health IT R&D that focuses on cybersecurity and privacy.

Key programs: Develop privacy-preserving and secure methods, standards, testing, certification, and data transfer strategies to make systems and repositories more robust and accessible for research collaboration and provision of services—*AHRQ, NIH, NIST, NSF, ONC*

Build and leverage a diverse, highly skilled American health IT workforce of the future.

Key programs: Build and scale expertise in health IT, data science and AI/ML applications through multidisciplinary research collaborations—*NIH, NSF, ONC, VA*; Train and mentor students at every stage of education and career—*AHRQ, FDA, NIH, NSF*; Support cross-disciplinary research in Health IT to understand the impact of technologies, including AI, on workers—*NSF*

Key Coordination Activities

- *Federal Initiatives:* 21st Century Cures Act implementation, Brain Research through Advancing Innovative Neuro-technologies, Cancer Moonshot, Precision Medicine Initiative. *DARPA, FDA, IARPA, NIH, ONC*
- *Health data collection, management, interoperability, and use:* Provide access, privacy, and security of data from diverse sources and for diverse uses. *All HITRD agencies*
- *Artificial intelligence and healthcare:* Advance ML, data mining, and deep learning to enable AI-enabled decision-making. *All HITRD agencies*

[31] Distinct from other IWGs, HITRD IWG agencies report funding to various PCAs—including CHuman, CNPS, EdW, and IRAS—depending on the focus areas of the agencies.

National Science and Technology Council

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Director, OSTP

Staff: Tracie Lattimore
Executive Director, NSTC

Committee on Science and Technology Enterprise
Subcommittee on Networking and Information Technology Research and Development

Co-Chair: Kathleen (Kamie) Roberts (NCO) **Co-Chair: Margaret Martonosi (NSF)**
Executive Secretary: Nekeia Butler (NCO)

National Coordination Office for Networking and Information Technology Research and Development

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* **Principal representatives are shown in bold text;** alternates are shown in normal text.

Other Participating Departments and Agencies

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

Department of Commerce (DOC)
- Bureau of Economic Analysis (BEA)
- International Trade Administration (ITA)
- National Telecommunications and Information Administration (NTIA)
- United States Census Bureau (Census)

Department of Defense (DOD)
- Command, Control, Communications, Computers, Combat Systems, Intelligence, Surveillance, and Reconnaissance Center (C5ISR)
- Defense Health Agency (DHA)
- Defense Threat Reduction Agency (DTRA)
- Defense Research and Engineering Network (DREN)
- Military Services:
  - Air Force Office of Scientific Research (AFOSR)
  - Air Force Research Laboratory (AFRL)
  - Army Research Laboratory (ARL)
  - High-Performance Computing Modernization Program (HPCMP)
  - National Maritime Intelligence-Integration Office (NMIO)
  - Naval Research Laboratory (NRL)
  - Office of Naval Research (ONR)
- Office of the Under Secretary of Defense, Research and Engineering (OUSD R&E)
- United States Army Futures Command Ground Vehicle Systems Center (GVSC)

Department of Energy (DOE)
- Office of Environmental Management (DOE/EM)
- Office of Electricity (DOE/OE)
- Office of Nuclear Energy (DOE/NE)

Department of Health and Human Services (HHS)
- Centers for Disease Control and Prevention (CDC)
- Centers for Medicare and Medicaid Services (CMS)
- Health Resources and Services Administration (HRSA)
- National Cancer Institute (NCI)
- National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR)
- National Library of Medicine (NLM)

U.S. Food and Drug Administration (FDA)

Department of Justice (DOJ)
- Drug Enforcement Administration (DEA)
- Federal Bureau of Investigation (FBI)

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)
- Financial Crimes Enforcement Network (FCEN)

Federal Communications Commission (FCC)

Federal Trade Commission (FTC)

General Services Administration (GSA)

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

National Transportation Safety Board (NTSB)

Nuclear Regulatory Commission (NRC)

United States Patent and Trade Office (USPTO)

U.S. Agency for International Development (USAID)

U.S. Bureau of Labor Statistics (BLS)

U.S. Department of Agriculture (USDA)
- Agricultural Research Service (ARS)
- National Institute of Food and Agriculture (NIFA)

U.S. Department of Veterans Affairs (VA)

Abbreviations

5G	fifth-generation cellular wireless technology
ACN	advanced communications networks
AFOSR	Air Force Office of Scientific Research (DOD)
AFRI	Agriculture and Food Resource Initiative (USDA)
AFRL	Air Force Research Laboratory (DOD)
AHRQ	Agency for Healthcare Research and Quality (HHS)
AI	artificial intelligence (and NITRD PCA and IWG)
ARL	Army Research Laboratory (DOD)
ARS	Agricultural Research Service (USDA)
BD	Big Data (NITRD IWG)
BEA	Bureau of Economic Analysis
BLS	U.S. Bureau of Labor Statistics (DOL)
BRAIN	Brain Research through Advancing Innovative Neurotechnologies Initiative
C5ISR	Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance & Reconnaissance Center (DOD)
CDC	Centers for Disease Control and Prevention (HHS)
CHuman	Computing-Enabled Human Interaction, Communication, and Augmentation (NITRD PCA)
CISE	Computer and Information Science and Engineering Directorate (NSF)
CMS	Centers for Medicare and Medicaid Services (HHS)
CNPS	Computing-enabled Networked Physical Systems (NITRD PCA)
CPS	cyber-physical systems
CPU	central processing unit
CSIA	Cybersecurity and Information Assurance (NITRD IWG)
CSP	Cyber Security and Privacy (NITRD PCA)
DARPA	Defense Advanced Research Projects Agency (DOD)
DEA	Drug Enforcement Administration
DHA	Defense Health Agency (DOD)
DHS	Department of Homeland Security
DHS S&T	DHS Science and Technology Directorate
DL	deep learning
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOE/AITO	Artificial Intelligence and Technology Office
DOE/ARPA-E	Advanced Research Projects Agency–Energy
DOE/CESER	Office of Cybersecurity, Energy Security, and Emergency Response
DOE/EERE	Office of Energy Efficiency and Renewable Energy
DOE/EM	Office of Environmental Management
DOE/FE	DOE Office of Fossil Energy
DOE/NE	DOE Office of Nuclear Energy
DOE/NERSC	National Energy Research Scientific Computing Center
DOE/NNSA	National Nuclear Security Administration
DOE/OE	Office of Electricity
DOE/SC	DOE Office of Science
DOI	Department of the Interior
DOJ	Department of Justice
DOL	Department of Labor
DOT	Department of Transportation
DREN	Defense Research and Engineering Network (DOD)
DTRA	Defense Threat Reduction Agency (DOD)
EdW	Education and Workforce (NITRD PCA)
EHCS	Enabling R&D for High-Capability Computing Systems (NITRD PCA)
EHR	electronic health record
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration (DOT)
FBI	Federal Bureau of Investigation (DOJ)
FCC	Federal Communications Commission
FCEN	Financial Crimes Enforcement Network (Treasury)
FDA	Food and Drug Administration
FMCSA	Federal Motor Carrier Safety Administration (DOT)
FW-HTF	Future of Work at the Human Technology Frontier
FHWA	Federal Highway Administration (DOT)
FRA	Federal Railroad Administration (DOT)
FTA	Federal Transit Administration (DOT)
FTC	Federal Trade Commission
FY	fiscal year
GSA	General Services Administration
HCC	high-capability computing
HCIA	High-Capability Computing Infrastructure and Applications (NITRD PCA)
HEC	High End Computing (and NITRD IWG)
HHS	Department of Health and Human Services
HITRD	Health Information Technology Research and Development (NITRD IWG)

HPC	high-performance computing
HPCMP	High-Performance Computing Modernization Program (DOD/Army)
HRSA	Health Resources and Services Administration (HHS)
IARPA	Intelligence Advanced Research Projects Activity (ODNI)
IoT	Internet of Things
IotF	Industries of the Future
IRAS	Intelligent Robotics and Autonomous Systems (NITRD PCA and IWG)
IT	information technology
ITA	International Trade Administration (DOC)
ITS JPO	Intelligent Transportation Systems Joint Program Office (DOT)
IWG	Interagency Working Group
JFAC	Joint Federated Assurance Center (DOD, OUSD/R&E)
LSDMA	Large Scale Data Management and Analysis (NITRD PCA)
LSN	Large Scale Networking (NITRD PCA and IWG)
MIMO	multiple-input multiple-output
ML	machine learning
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NCO	National Coordination Office (NITRD Program)
NCI	National Cancer Institute (NIH)
NICE	National Initiative for Cybersecurity Education
NIDILRR	National Institute on Disability, Independent Living, and Rehabilitation Research
NIFA	National Institute of Food and Agriculture (USDA)
NIH	National Institutes of Health (HHS)
NIJ	National Institute of Justice (DOJ)
NIOSH	National Institute for Occupational Safety and Health (HHS/CDC)
NIST	National Institute of Standards and Technology (DOC)
NMIO	National Maritime Intelligence-Integration Office (DOD)
NITRD	Networking and Information Technology Research and Development (Program and NSTC Subcommittee
NLM	National Library of Medicine (NIH)
NOAA	National Oceanic and Atmospheric Administration (DOC)
NRC	Nuclear Regulatory Commission
NRI-2.0	National Robotics Initiative (2nd generation)
NRL	Naval Research Laboratory (DOD)
NRO	National Reconnaissance Office
NSA	National Security Agency (DOD)
NSF	National Science Foundation
NSTC	National Science and Technology Council
NTIA	National Telecommuni-cations and Information Administration (DOC)
NTSB	National Transportation Safety Board
ODNI	Office of the Director of National Intelligence
ONC	Office of the National Coordinator for Health Information Technology (HHS)
ONR	Office of Naval Research (DOD)
OSD	Office of the Secretary of Defense (DOD)
OSHA	Occupational Safety and Health Administration (DOL)
OSTP	White House Office of Science and Technology Policy
OUSD/R&E	Office of the Undersecretary of Defense for Research and Engineering
PCA	Program Component Area
PHMSA	Pipeline and Hazardous Materials Safety Administration (DOT)
PPP	public-private partnership
R&D	research and development
RF	radio frequency
S&E	science and engineering
S&T	science and technology
SciDAC	Scientific Discovery through Advanced Computing (DOE)
SPSQ	Software Productivity, Sustainability, and Quality (NITRD PCA and IWG)
State	Department of State
STEM	science, technology, engineering, and mathematics
Treasury	Department of the Treasury
UAS	unmanned aircraft systems
USAID	U.S. Agency for International Development
USBR	Bureau of Reclamation (DOI)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey (DOI)
USPTO	U.S. Patent and Trade Office
VA	Department of Veterans Affairs
VIA	Video and Image Analytics (NITRD AI IWG task force)
WSRD	Wireless Spectrum Research & Development (NITRD IWG)

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 Interagency Working Groups

Through annual workplans, workshops, monthly coordination meetings, provision of public online resources, and broad engagement with stakeholders, the NITRD IWGs work to align Federal agency R&D with Administration priorities, increase efficiency in agency investments in high-impact basic research, help transfer discoveries to the marketplace, advance the Nation's IT R&D infrastructure, and strengthen community R&D alliances.

About This Document

This document is a supplement to the President's FY2021 Budget Request to Congress. This Supplement reports actual investments for FY2019, enacted and supplemental investments for FY2020, and requested funding levels for FY2021 by agency and Program Component Area (PCA) for all NITRD R&D programs. It also reports specific agency investments for artificial intelligence and advanced wireless communications. Following Congressional mandate, the Supplement also describes key R&D programs and coordination activities planned for FY2021 by the Federal agencies participating in the NITRD Program. An appendix to the Supplement, the *FY2021 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; it is available at https://www.nitrd.gov/pubs/FY2021-Cybersecurity-RD-Roadmap.pdf.

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