DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) **$883,040,000**
-$77,760,000 / -8.1%

CISE Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Percent
Office of Advanced Cyberinfrastructure (OAC)	$224.24	-	$199.02	-$25.22	-11.2%
Computing and Communication Foundations (CCF)	195.63	-	172.93	-22.70	-11.6%
Computer and Network Systems (CNS)	231.88	-	205.73	-26.15	-11.3%
Information and Intelligent Systems (IIS)	210.69	-	189.51	-21.18	-10.1%
Information Technology Research (ITR)	98.36	-	115.85	17.49	17.8%
Total	**$960.80**	**-**	**$883.04**	**-$77.76**	**-8.1%**

About CISE

Advances in information technology (IT) over the past two decades have proven to be key drivers of the American economy. Essentially all practical applications of today's IT are based on ideas and concepts that emerged from investments in fundamental computing research.[1] CISE funded basic research in computing has enabled innovative products and applications that permeate many aspects of daily life, including personal communication, energy, transportation, health care, advanced manufacturing, national and homeland security, disaster preparedness and response, education and workforce development, public and private organizational effectiveness and efficiency, and discovery and innovation at the frontiers of all areas of scientific and engineering research. Maintaining American leadership in IT and its applications, including in artificial intelligence (AI) and machine learning (ML), augmented and virtual reality, data science, intelligent civil infrastructure, quantum computing and communication, and advanced research cyberinfrastructure (CI) for all domains, will require sustained investment. CISE will continue to play a major role in funding computing research and training that serve to improve America's economic outlook and advance a highly-trained, technologically astute, and diverse American workforce.

CISE's mission is to promote the progress of computer and information science and engineering research and education, and advance the development and use of CI across the science and engineering research enterprise; to promote understanding of the principles and uses of advanced computer, communication, and information systems in advancing science and engineering and in service to society; and to contribute to universal, transparent, and affordable participation in a knowledge-based society. CISE supports ambitious, long-term research and research infrastructure projects within and across the many subfields of computing, as well as advanced research CI for all areas of science and engineering; contributes to the education and training of computing professionals; and more broadly, informs the preparation of an American workforce with computing and computational competencies essential for success in an increasingly competitive global and digital market. CISE executes its mission through its CCF, CNS, IIS, and ITR, and through OAC, which has a Foundation-wide role supporting advanced research CI for all areas of science and engineering—and in close partnership with other NSF units, federal agencies, international funders, and the private sector.

CISE investments in FY 2020 will provide continued support for Administration priorities, including basic research in AI, quantum information sciences (QIS), and strategic computing, which are critically important for national security, economic competitiveness, and the broad advancement of all fields of science and engineering. CISE will also continue to invest in advanced manufacturing, and in microelectronics and

[1] www.nap.edu/catalog.php?record_id=13427

semiconductor research, promoting continued U.S. leadership in these areas. For example, investments in next-generation manufacturing technologies enabled by AI and ML will help keep jobs in America, ensure products are made in America, and strengthen our national manufacturing industrial base.

CISE's FY 2020 Budget Request is also shaped by continued support for NSF's 10 Big Ideas, including co-leadership of HDR, FW-HTF, and QL. Advances in AI and ML are major components of both HDR and FW-HTF. CISE's FY 2020 Budget Request also comprises support for other ongoing NSF-wide priorities, including IUSE; I-Corps™; and SaTC. In partnership with other NSF directorates and offices, CISE will also participate in the NNA and URoL Big Ideas.

CISE, through OAC and in partnership with other NSF directorates and offices, will lead the all-of-government strategic computing activities previously initiated under the National Strategic Computing Initiative. This activity is described in more detail in the OAC section.

In addition, CISE will continue to provide leadership for the federal government's Networking and Information Technology Research and Development (NITRD) program. The NITRD Subcommittee of the National Science and Technology Council (NSTC), which coordinates investments in networking and information technology research and development across more than 20 federal departments, agencies, and offices, is co-chaired by the NSF assistant director for CISE. All research, education, and research infrastructure projects supported by CISE contribute to NSF's NITRD portfolio. CISE will also continue to co-chair the NSTC Machine Learning and Artificial Intelligence (MLAI) and Open Science Subcommittees.

Finally, CISE will continue to place a priority on developing partnerships with other NSF units, federal agencies, and international funders, and especially with the private sector, including private industry, foundations, and nonprofits, as an increasingly important means to maximize the scientific, economic, and societal impacts of its investments. These external partnerships leverage resources, inform use-inspired research, accelerate the transition of research innovations to practice, and enhance workforce development.

CISE provides about 85 percent of the federal funding for fundamental computer science research at U.S. academic institutions.

Major Investments

CISE Major Investments
(Dollars in Millions)

Area of Investment	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Advanced Manufacturing	$41.27	-	$41.27	-	-
Artificial Intelligence (AI)	284.67	-	309.12	24.45	8.6%
I-Corps™	11.64	-	13.80	2.16	18.6%
IUSE	-	-	2.00	2.00	N/A
Microelectronics and Semiconductors	17.20	-	17.20	-	-
Quantum Information Sciences (QIS)	10.00	-	15.28	5.28	52.8%
SaTC	70.50	-	65.00	-5.50	-7.8%
NSF's Big Ideas					
HDR Stewardship	*-*	*-*	*30.00*	*30.00*	*N/A*

Major investments may have funding overlap and thus should not be summed.

- Advanced Manufacturing: CISE will invest in research that integrates ubiquitous sensors, computational tools, and highly connected cyber-physical systems in smart processing and cyber-manufacturing systems. This investment will enable new functionalities that will increase the efficiency and sustainability of the production of the next generation of products and services. CISE's investment will also continue support for research on collaborative robotics, i.e., robots that work alongside or cooperatively with people in manufacturing environments to increase their productivity, performance, and safety.

- AI: CISE, together with other NSF directorates/offices, will increase support for AI research and development. A key focal point will be support for *AI Frontiers*, a new center-scale activity that will span (a) foundational areas of ML, computer vision, natural language processing, and autonomy, along with safety, security, robustness, and explainability of AI systems; (b) translational research at the intersection of AI and various science and engineering domains supported by NSF as well as sectors such as agriculture, transportation, and personalized medicine; (c) workforce development, including growing human capital and institutional capacity to nurture a next generation of AI researchers and practitioners; and (d) advanced computing infrastructure, including access to data and compute capabilities enabling AI innovations.

- I-Corps™: CISE, in partnership with the other directorates, will continue to support the I-Corps™ program that connects NSF-funded science and engineering research with the technological, entrepreneurial, and business communities, and fosters a national innovation ecosystem that links scientific discovery with technology development, societal needs, and economic opportunities.

- IUSE: Given the increasing centrality of computing to innovation across a wide range of disciplinary and interdisciplinary domains, undergraduate computer science (CS) programs are being called upon to prepare larger and more diverse student populations for careers in both CS and non-CS fields.Many of these students aim to acquire the understandings and competencies needed to learn how to use computation collaboratively across different contexts and challenging problems. Through IUSE: Computing in Undergraduate Education, and together with EHR, CISE will continue to support efforts to re-envision the role of computing in interdisciplinary collaboration within American institutions of higher education.

- Microelectronics and Semiconductors: CISE, together with ENG and MPS, will support research to address fundamental science and engineering questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor and microelectronic technologies. Such progress is critical for emerging technologies such as AI and quantum computing, and will in turn contribute to advances across all sectors of the economy, including energy, transportation, health care, and advanced manufacturing.

- QIS: CISE investments will support research leading to the development of next-generation quantum technologies for sensing, communication, and computing that exploit interactions among particles in quantum systems, offering the promise of dramatic increases in accuracy and efficiency. Developments in QIS could lead to novel algorithms for ML and optimization, along with transformative cybersecurity systems including quantum-resistant cryptography. A key component of CISE's investment in QIS will be to increase capacity in quantum computing and information science within American institutions of higher education

- SaTC: CISE will continue to lead SaTC in partnership with EHR, ENG, MPS, and SBE, investing in current and emerging areas of importance for security and privacy. These areas include the application of AI to security, security and resilience of AI systems, security implications of quantum computation

and communication, and critical infrastructure security. These investments will also address education and workforce issues related to cybersecurity and privacy.

- HDR: CISE, as the steward for HDR, will support fundamental research in data science and engineering; development of a cohesive, federated approach to the research data infrastructure; and development of a 21st-century data-capable workforce. Through HDR, CISE will continue to support key foundational programs, including Cyberinfrastructure for Sustained Scientific Innovation (CSSI) and EarthCube, as well as conceptualization activities leading to HDR institutes that will harness diverse data sources and develop new methodologies, technologies, and infrastructure for data management and analysis in national priority areas.

- NSF-wide Education Programs: While CISE will continue to participate in ADVANCE: Organizational Change for Gender Equity in STEM Academic Professions, NSF INCLUDES, and NRT programs in FY 2020, the funds for these NSF-wide education-related programs will be centrally located in EHR.

CISE Funding for Centers Programs and Facilities

CISE Funding for Centers Programs
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$9.94**	**-**	**$6.30**	**-$3.64**	**-36.6%**
STC: Center for the Science of Information (CCF)	4.94	-	1.30	-3.64	-73.7%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR)	5.00	-	5.00	-	-

For detailed information about NSF Centers programs, please see the NSF-Wide Investments chapter.

Funding Profile

CISE Funding Profile

	FY 2018 Actual Estimate	FY 2019 (TBD)	FY 2020 Estimate
Statistics for Competitive Awards:			
Number of Proposals	9,151	-	9,600
Number of New Awards	2,099	-	1,900
Funding Rate	23%	N/A	20%
Statistics for Research Grants:			
Number of Research Grant Proposals	8,749	-	9,180
Number of Research Grants	1,823	-	1,650
Funding Rate	21%	N/A	18%
Median Annualized Award Size	$166,309	-	$165,000
Average Annualized Award Size	$199,292	-	$200,000
Average Award Duration, in years	2.9	-	3.0

Program Monitoring and Evaluation

Committees of Visitors (COVs):

- In early FY 2018, OAC convened a COV to examine and assess the quality of the merit review process across OAC. The report from that COV was accepted by the Advisory Committee for Cyberinfrastructure (ACCI) at its Spring 2018 meeting.[2]
- In late 2019, CISE will convene a COV to review FY 2014-FY 2018 programs in its CCF, CNS, and IIS divisions.

Program Evaluations:

- In FY 2012, the Science and Technology Policy Institute (STPI) conducted a program evaluation feasibility study for SaTC. This feasibility study provided methods for examining baseline portfolio investments and identifying metrics to measure progress toward program goals. The study was part of a broader effort to develop a plan for a future impact assessment. STPI identified baseline evaluation metrics in FY 2013-FY 2015 and completed the evaluation feasibility study in FY 2016. CISE, together with the NSF Evaluation and Assessment Capability, funded a program evaluation of SaTC in FY 2016; that program evaluation is anticipated to be completed by the end of FY 2019.
- Evaluation is a key part of all of CISE's education programs. K-12 computer science education projects managed by CISE include rigorous research and evaluation plans designed to guide project progress and measure project impacts. CISE has also funded a third-party evaluation across individual teacher professional development projects at the high school level. The evaluators for these activities meet regularly, discuss evaluation issues, and contribute statistics to a common dataset in order to track program-level progress. CISE expects to continue these evaluation activities in FY 2020.

With BIO, CISE is co-leading NSF's Agency Priority Goal (APG) to expand public and private partnerships agency-wide in order to enhance the impact of NSF's investments and contribute to American economic competitiveness and security. As part of this APG, NSF is conducting an inventory and analysis of NSF public and private partnerships that will help inform the strategy for partnerships in the future.

Reports:

- CISE has funded several studies led by the Computer Science and Telecommunications Board (CSTB) within the National Academies of Sciences, Engineering, and Medicine that resonate with the directorate's FY 2020 investments:
  - Over the last decade, CISE has funded the CSTB to study the IT innovation ecosystem and assess the long-term economic impacts of CISE investments. For example, a 2009 report, *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem*,[3] provides an in-depth articulation of the creation of almost 20 IT industries since 1965 valued at a minimum of $1 billion each. A 2012 report, *Continuing Innovation in Information Technology*,[4] identified additional IT industries that had reached the billion-dollar mark, and noted the nature and successes of U.S. research partnerships among government, industry, and universities, and the economic payoffs of these research investments. In FY 2017, CISE funded CSTB to update the so-called "tire-tracks" diagram[5] from the 2012 report, depicting the interconnections across research areas and with the creation and evolution of IT industry sectors.[6]

[2] www.nsf.gov/od/oia/activities/cov/covs.jsp#cise
[3] www.nap.edu/catalog.php?record_id=12174
[4] www.nap.edu/catalog.php?record_id=13427
[5] http://sites.nationalacademies.org/CSTB/CSTB_181872
[6] www.nsf.gov/awardsearch/showAward?AWD_ID=1748756&HistoricalAwards=false

- *Toward 21st-Century Cyber-Physical Systems Education:* a 2016 report on the current and future needs in education for cyber-physical systems (CPS), articulating a vision for a 2l[st]-century CPS-capable U.S. workforce.[7]
- *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science in 2017-2020:* a 2016 report on anticipated priorities and associated tradeoffs for advanced computing in support of NSF-sponsored science and engineering research, yielding recommendations in support of four broad goals: (1) position the U.S. for continued leadership in science and engineering, (2) ensure that resources meet community needs, (3) aid the scientific community in keeping up with the revolution in computing, and (4) sustain the infrastructure for advanced computing.[8] Recommendations from the report have led to new programs, including a solicitation for the initial phase of a leadership-class computing facility in FY 2018 (see the Advanced Computing Appendix in this narrative for more information).
- *Information Technology and the U.S. Workforce: Where Are We and Where Do We Go from Here?:* a 2017 report on the interactions between technological, economic, and societal trends, notably how significant advances in IT and automation have profoundly impacted the way work is conducted, and identified open questions and promising research pathways.[9]
- *Growth of Computer Science Undergraduate Enrollments:* a 2017 report recommending responses to growing undergraduate computer science enrollments, including: (1) bringing computer science faculty and institutional leaders together to identify best practices and innovation in computer science education across the entire student body; (2) conducting research on how best to use technology in teaching large classes, and on best practices for supporting diversity in computing; and (3) expanding instructional resources for undergraduate computer science education.[10]
- *Envisioning the Data Science Discipline: The Undergraduate Perspective:* a 2018 report offering a vision for the emerging discipline of data science at the undergraduate level along with considerations and approaches for academic institutions and others to help guide the ongoing transformation of the field.[11]
- *Quantum Computing:* a 2018 report assessing the current progress and possible future pathways toward developing a general-purpose quantum computer as well as its potential implications.[12]

- The Computing Community Consortium (CCC) has led several community visioning efforts that resonate with the directorate's FY 2020 investments:
  - *Computing Visions 2025:* inspired the CISE research community to envision future trends and opportunities in computer and information science and engineering research. Two workshops were held under this activity: *Interacting with Computers All Around Us*, and *The New Making Renaissance: Programmable Matter and Things.*[13]
  - *Intelligent Infrastructure:* jointly with the Electrical and Computer Engineering Department Heads Association, presented a national research agenda for intelligent infrastructure, or the deep embedding of sensing, computation, and communication capabilities into traditional physical infrastructure such as roads, bridges, railways, and buildings, for enhancing efficiency, resiliency, and safety.[14]
  - *Next Steps in Quantum Computing: Computer Science's Role:* brought together researchers from quantum computing, computer architecture, electronic design automation, compiler construction,

[7] www.nap.edu/catalog/23686/a-21st-century-cyber-physical-systems-education
[8] www.nap.edu/catalog/21886/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-and-engineering-in-2017-2020
[9] www.nap.edu/catalog/24649/information-technology-and-the-us-workforce-where-are-we-and
[10] www.nap.edu/catalog/24926/assessing-and-responding-to-the-growth-of-computer-science-undergraduate-enrollments
[11] www.nap.edu/catalog/25104/data-science-for-undergraduates-opportunities-and-options
[12] www.nap.edu/catalog/25196/quantum-computing-progress-and-prospects
[13] https://cra.org/ccc/visioning/computing-visions-2025/
[14] https://cra.org/ccc/resources/ccc-led-whitepapers/#infrastructure

and classical programming languages to articulate the central role that various CISE subfields play to close the gap between the problems for which a quantum computer might be useful and what we can currently build, program, and run.[15]

- *Fair Representations and Fair Interactive Learning:* brought together researchers from academia, industry, and government to identify key challenges underlying the science of fairness in ML, with a particular focus on theoretical work aimed at providing a scientific foundation for understanding algorithmic bias.[16]
- *Artificial Intelligence Roadmap:* developing a roadmap for AI research priorities over the next 20 years, including key challenges, opportunities, and pitfalls.[17]

- CISE-funded community workshops also resonate with the directorate's FY 2020 investments. For example, a January 2018 workshop on *Enabling Computer and Information Science and Engineering Research and Education in the Cloud* brought together researchers from academia, industry, and government to discuss ways to enable the CISE community to effectively utilize cloud computing resources.[18]

The Performance chapter provides details regarding the periodic reviews of programs and portfolios of programs by external COVs and directorate Advisory Committees. Please refer to this chapter for additional information.

People Involved in CISE Activities

Number of People Involved in CISE Activities

	FY 2018 Actual Estimate	FY 2019 (TBD)	FY 2020 Estimate
Senior Researchers	7,837	-	7,200
Other Professionals	1,158	-	1,000
Postdoctoral Associates	455	-	400
Graduate Students	6,598	-	6,100
Undergraduate Students	2,741	-	2,500
Total Number of People	**18,789**	**-**	**17,200**

[15] https://cra.org/ccc/events/quantum-computing/
[16] https://cra.org/ccc/events/fair-representations-fair-interactive-learning/
[17] https://cra.org/ccc/visioning/visioning-activities/2018-activities/artificial-intelligence-roadmap/
[18] https://dl.acm.org/citation.cfm?id=3233928

OFFICE OF ADVANCED CYBERINFRASTRUCTURE (OAC) **$199,020,000**
-$25,220,000 / -11.2%

OAC Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$224.24**	**-**	**$199.02**	**-$25.22**	**-11.2%**
Research	**96.22**	**-**	**74.82**	**-21.40**	**-22.2%**
CAREER	1.80	-	1.60	-0.20	-11.1%
Education	**9.64**	**-**	**6.70**	**-2.94**	**-30.5%**
Infrastructure	**118.39**	**-**	**117.50**	**-0.89**	**-0.8%**
Networking and Computational Resources Infrastructure and Services	118.39	-	117.50	-0.89	-0.8%

About OAC

OAC supports the conceptualization, design, and implementation of the advanced research CI ecosystem that is critical to advances in all areas of science and engineering research and education in the 21st century, and in this way, serves to sustain U.S. economic competitiveness and national security. Given its role across all of science and engineering, OAC works in partnership with all NSF directorates and offices as well as other CISE divisions, to provide support to academic institutions encourages a rich and vibrant ecosystem that blends translational computer and computational research and research-specific CI with innovations from the private sector. Specifically, OAC investments include acquisition, integration, coordination, and operations associated with shared data, secure networking, advanced computation, scientific software and data services, and the design and development of computational and data-enabled science and engineering tools and expertise. OAC also nurtures the computational and data skills and expertise needed to conduct next-generation science and engineering. Collectively, OAC enables more than 8,000 faculty and researchers to address complex and multidisciplinary discovery, prediction, and innovation challenges by providing access to CI resources and services, along with secure connectivity to major international facilities and scientific instruments. OAC promotes innovative, robust, secure, and interoperable CI, as well as sharing and collaboration among academic research infrastructure groups, other federal agencies and international research funders, and the private sector.

OAC, in partnership with other NSF directorates and offices, will lead the all-of-government strategic computing activities previously initiated under the National Strategic Computing Initiative. This activity will support research advances in new computing technologies, architectures, and platforms for the future, as well as the development and deployment of advanced computing systems and services, including maximizing the benefits of these systems and services through the deep integration with science and engineering research. These investments will enable shared resources and improved capabilities across a range of disciplines and will enable a broad set of users within a large number of academic institutions.

In general, about 51 percent of the OAC portfolio is available to support new grants. The remaining 49 percent supports grants made in prior years.

DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) **$172,930,000**
-$22,700,000 / -11.6%

CCF Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$195.63**	**-**	**$172.93**	**-$22.70**	**-11.6%**
Research	**183.93**	**-**	**164.33**	**-19.60**	**-10.7%**
CAREER	18.06	-	15.96	-2.10	-11.6%
Centers Funding (total)	7.94	-	4.30	-3.64	-45.8%
STC: Center for the Science of Information	4.94	-	1.30	-3.64	-73.7%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	3.00	-	3.00	-	-
Education	**11.10**	**-**	**8.00**	**-3.10**	**-27.9%**
Infrastructure	**0.60**	**-**	**0.60**	**-**	**-**
National Nanotechnology Coordinated Infrastructure (NNCI)	0.60	-	0.60	-	-

About CCF

CCF supports research and educational activities that study the theoretical foundations of computing, communication, and information. CCF supports exploring the fundamental limits of computation, communication, and information across analog, digital, quantum, and biological domains; advancing algorithmic knowledge for research areas within and outside computer science; and furthering software and hardware design. CCF's research investments enable advances in the design and analysis of algorithms, computational complexity, theoretical and experimental studies of algorithms and their resource requirements, and mathematical models of computation, including approaches for parallel, distributed, and heterogeneous multi-core machines. CCF also invests in foundational research on the theoretical underpinnings and enabling technologies for information acquisition, transmission, and processing in communication and information networks, such as sensor, wireless, multimedia, quantum, and biological networks. CCF investments advance the design, verification, evaluation, and utilization of computing hardware and software through new theories, programming languages, and formal methods that focus on improving performance, correctness, usability, reliability, and scalability. CCF research also explores the potential impact of emerging technologies on computation, communication, and information, including quantum devices and systems, neuromorphic computation, nanotechnology, and biocomputing.

In general, about 72 percent of the CCF portfolio is available to support new grants. The remaining 28 percent supports grants made in prior years.

DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS) **$205,730,000**
-$26,150,000 / -11.3%

CNS Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$231.88**	**-**	**$205.73**	**-$26.15**	**-11.3%**
Research	**189.83**	**-**	**168.63**	**-21.20**	**-11.2%**
CAREER	10.05	-	8.91	-1.14	-11.3%
Education	**15.97**	**-**	**11.10**	**-4.87**	**-30.5%**
Infrastructure	**26.09**	**-**	**26.00**	**-0.09**	**-0.3%**
Research Resources	26.09	-	26.00	-0.09	-0.3%

About CNS

CNS supports research and education activities that advance understanding of the fundamental properties of computer systems and networks. CNS investments produce new insights into the dynamics of complex hardware and software systems and explore new architectures for future-generation computing and communication infrastructures and services, thereby lowering barriers to innovation and enhancing economic competitiveness. CNS-enabled systems include, but are not limited to, cyber-physical, embedded, distributed, centralized, virtualized, cloud, wireless, and mobile systems. CNS also supports research and education activities in cybersecurity to ensure that society's ubiquitous computing and communication infrastructures deliver the quality of service they are designed to achieve without disruption, while enabling and preserving privacy, security, and trust. CNS also plays a leadership role in coordinating CISE investments in systems research infrastructure and in the development of the computing workforce of the future.

In general, about 75 percent of the CNS portfolio is available to support new grants. The remaining 25 percent supports grants made in prior years.

DIVISION OF INFORMATION AND INTELLIGENT SYSTEMS (IIS) **$189,510,000**
-$21,180,000 / -10.1%

IIS Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$210.69**	**-**	**$189.51**	**-$21.18**	**-10.1%**
Research	**199.73**	**-**	**181.51**	**-18.22**	**-9.1%**
CAREER	21.24	-	19.10	-2.14	-10.1%
Centers Funding (total)	1.00	-	1.00	-	-
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	1.00	-	1.00	-	-
Education	**10.96**	**-**	**8.00**	**-2.96**	**-27.0%**

About IIS

IIS supports research that studies the interrelated roles of people, computers, and information. Specifically, IIS supports research and education in AI, data science, and human-computer interaction. Research in AI includes machine learning, knowledge representation, computer vision, and natural language processing. Research in data science includes data management, data collection, data analytics, and data integration. Research in human-computer interaction includes work on computer system usability, new kinds of user interfaces, and computer systems to augment human capabilities. Research supported by IIS addresses fundamental questions about machine intelligence, helps us understand how data can improve our lives, and lays the foundation for innovations in a myriad sectors including energy, transportation, healthcare, manufacturing, and defense.

In general, about 81 percent of the IIS portfolio is available to support new grants. The remaining 19 percent supports grants made in prior years.

DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR) **$115,850,000**
+$17,490,000 / 17.8%

ITR Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$98.36**	**-**	**$115.85**	**$17.49**	**17.8%**
Research	**85.37**	**-**	**105.85**	**20.48**	**24.0%**
Big Idea: HDR	-	-	30.00	30.00	N/A
CAREER	1.53	-	-	-1.53	-100.0%
Centers Funding (total)	1.00	-	1.00	-	-
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	1.00	-	1.00	-	-
Education	**2.81**	**-**	**-**	**-2.81**	**-100.0%**
Infrastructure	**10.18**	**-**	**10.00**	**-0.18**	**-1.8%**
Research Resources	10.18	-	10.00	-0.18	-1.8%

About ITR

ITR provides support for transformative explorations in computer and information science and engineering research, infrastructure, and education, emphasizing the funding of innovative, high-risk/high-reward, multi-investigator projects. ITR investments support emerging and urgent high-priority areas of potentially transformative research that cut across traditional disciplinary boundaries and promise to accelerate discovery at the frontiers of computer and information science and engineering. This includes support for fundamental research on advanced networking, physical sensors/devices and large-scale data management, analysis and decision making; innovative partnerships and collaborations between academia and industry; as well as the development of world-class research infrastructure. This is done in partnership with all of the CISE divisions as well as through cross-NSF and interagency activities.

ITR, in partnership with all of the NSF directorates and research offices, will advance the HDR Big Idea by investing funds to support convergent activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. These activities will enable pursuit of fundamental research in data science and engineering; the development of a cohesive, federated, national-scale approach to research data infrastructure; and the development of a 21st-century data-capable workforce. While budget management and reporting for this investment will be the responsibility of CISE, the convergent activities will be overseen and managed collaboratively by the multi-directorate/office HDR leadership team.

In general, about 53 percent of the ITR portfolio is available to support new grants. The remaining 47 percent supports grants made in prior years.

APPENDIX A – ADVANCED COMPUTING PORTFOLIO

Advanced Computing Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request
Leadership-Class Computing	$60.12	-	$20.00
Advanced/Innovative Computing Systems and Services	13.81	-	40.00
Coordination and Support Services	8.00	-	22.00
Total	**$81.93**	**-**	**$82.00**

For nearly four decades, NSF has been a recognized leader in enabling the innovative use and broad availability of a cohesive, powerful, and advanced computing ecosystem to accelerate fundamental science and engineering. NSF aims to sustain America's leadership in the research, development, and broad deployment of existing as well as new advanced computing technologies, services, and skills—and aims to do so in part through leadership of the all-of-government strategic computing activities previously initiated under the National Strategic Computing Initiative[19] jointly with the Department of Defense and Department of Energy, and in concert with other participating federal agencies as well as the private sector. Within the broad goals set for the all-of-government strategic computing activities, key NSF foci include fundamental discoveries to support future generations of advanced computing; research and cyberinfrastructure promoting cohesive platforms and interoperability for large-scale data analytics as well as modeling and simulation applications; and support for a comprehensive advanced computing ecosystem for science and engineering research.[20] These foci include an emphasis on a holistic approach to America's computational infrastructure for science and engineering research, spanning both human and technical dimensions.

The overall NSF advanced computing strategy and program portfolio receives guidance and input from the Advisory Committee for Cyberinfrastructure (ACCI); Assistant Directors (AD) Council, which includes ADs and Office Heads from the various NSF research and education directorates and offices; cross-directorate working group for strategic computing; and directly from the research community through Principal Investigators' meetings, workshops, and sessions at professional conferences.[21] In 2013, OAC supported a National Academies of Sciences, Engineering, and Medicine study to further inform the implementation of its advanced computing strategy in the 2017 to 2020 timeframe; the final report, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017-2020*, was published in 2016.[22] In 2017, OAC launched an effort to refresh the vision, strategy, and investment approaches for cyberinfrastructure, including advanced computing, to support the evolving needs of the science and engineering community,[23] and also funded a study seeking to identify and catalog best practices for collaborations between academic or federally-funded High-Performance Computing (HPC) centers and industry.[24] In 2018, NSF funded a workshop focused on "Future Cyberinfrastructure: Rethinking NSF's Computational Ecosystem for 21st-Century Science and Engineering."[25] International activities to accelerate investments in leadership-class computing, particularly in Europe and Asia, are

[19] www.nitrd.gov/nsci/
[20] www.nsf.gov/cise/nsci/
[21] See, for example, https://sc18.supercomputing.org/presentation/?id=bof154&sess=sess417
[22] www.nap.edu/catalog/21886/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-6
[23] www.nsf.gov/cise/oac/ci2030/
[24] www.ncsa.illinois.edu/assets/pdf/industry/Industry_Report_2017.pdf
[25] https://uiowa.edu/nsfcyberinfrastructure/article/workshop-report

providing additional urgency and importance for this investment strategy to ensure the U.S. maintains its global leadership role in science and engineering.

Technological advances come rapidly, and the capabilities and services offered by commercial interests (e.g., cloud) also change rapidly. The requirements of the science and engineering research communities are both heterogeneous and dynamic. To meet these continually evolving needs in an agile yet predictable way, NSF currently invests in three broad and complementary advanced computing areas: Leadership-Class Computing; Advanced/Innovative Computing Systems and Services; and Coordination and Support Services. These resources and services complement each other as well as discipline-specific investments by NSF's directorates, mission-specific investments by other agencies, and cumulatively extensive but individually smaller investments by academic institutions at the regional and campus levels. Specifically:

- **Leadership-Class Computing** (formerly Petascale Computing) aims to provide unique services and resources to advance the largest and most computationally-intensive science and engineering research frontiers not otherwise possible;
- **Advanced/Innovative Computing Systems and Services** (formerly Innovative HPC Program) aims to provide a technically diverse and potentially future-looking advanced computing portfolio, reflecting the growing and changing use of computation and data in both the research and education processes, and capable of supporting hundreds to thousands of investigators conducting cutting-edge science and engineering research; and
- **Coordination and Support Services** (formerly Extreme Digital) aims to coordinate the provisioning, allocation, and operations of NSF's advanced computing resources, providing advanced assistance to the user community, supporting aggregation and federation capabilities, and broadening participation.

Leadership-Class Computing

Description

Leadership-class computing systems have represented a key component of NSF's computational portfolio for decades. NSF's current leadership-class computing resource is Blue Waters, which is deployed at the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (UIUC). Since it became operational in FY 2013, Blue Waters has allowed researchers to tackle much larger and more complex challenges than ever before, within and across disciplines as diverse as biology, astronomy, engineering, materials science, and the geosciences.

Despite the success of Blue Waters, this computing resource is reaching its natural end of life and will complete its operational cycle in December 2019. NSF's next leadership-class computing system will be the recently-funded Frontera system. Frontera will be deployed by the Texas Advanced Computing Center (TACC) at the University of Texas at Austin (UT Austin) and is expected to be among the largest central processing unit (CPU)-based systems in the world and among the most powerful supercomputers ever deployed on a U.S. academic campus when it becomes operational. The system is expected to begin accepting early science and engineering research users in May 2019 and to be fully operational by July 2019.

Current Status

As noted above, the Blue Waters system is nearing its natural end of life. Following system testing and acceptance in December 2012, and acceptance of the NCSA archival system in March 2013, the Blue Waters project entered a five-year operations phase. The award was granted a no-cost extension in FY 2016 that runs through mid-FY 2019. A second extension granted at the end of calendar year 2018 will allow the system to operate through December 2019, enabling a seamless transition from Blue Waters to the recently-awarded Frontera system at TACC. With the extension of the operational end date of Blue Waters through 2019, the system will have run for roughly three years longer than the typical lifetime for a system of this type, providing excellent return on federal investment.

In anticipation of the operational end date of Blue Waters in FY 2016, NSF developed a plan for a phased approach to support a next-generation, leadership-class computing system. This plan was discussed with the National Science Board (NSB) in FY 2017, and in May 2017, NSF issued a competitive solicitation[26] for the first phase (Phase 1) of a two-phase plan to deploy a new leadership-class computing facility. The solicitation called for a Phase 1 system that would be two to three times more powerful in application performance than Blue Waters. The system acquisition was awarded in FY 2018, and will be followed by a separate award for an operations and maintenance (O&M) phase, anticipated to commence in FY 2019 and last for five years.

Following the Phase 1 solicitation and associated review process of the submitted proposals, NSB at its July 2018 meeting authorized the Director at her discretion to make an award to the TACC for the acquisition of the Frontera system in an amount not to exceed $60.0 million over a period of five years. The resolution also authorized that, pending appropriate approval associated with NSF's Major Research Equipment and Facilities Construction (MREFC) policies, an additional amount not to exceed $8.0 million may be made available to TACC in the form of supplemental funding to this award to advance the design of the Phase 2 leadership-class computing system. NSF issued an award to the University of Texas at Austin for the acquisition of Frontera in September 2018.

When deployed, the Frontera system will offer the highest scale, throughput, and data analysis capabilities ever deployed on a university campus in the U.S. TACC is building the supercomputer, with the primary computing system provided by Dell EMC and powered by Intel processors. Through its primary CPU subsystem, Frontera will offer more than five times greater capacity than the previous leadership-class NSF-funded computing system. In addition, Frontera's graphics processing unit (GPU) will accelerate discoveries in dynamic research areas such as deep learning and molecular dynamics. The system will also allow science and engineering evaluation to inform the design of a future leadership-class computing facility.

Science and engineering research and education activities enabled by Leadership-Class Computing

Leadership-class computing systems enable investigators across the country to conduct innovative research that is not otherwise possible due to demanding technical requirements. Over its lifetime, the Blue Waters project has supported more than 700 project teams, the majority of them through the highly competitive NSF Petascale Computing Resource Allocations (PRAC) program. The research topics that the PRAC program supports include: complex biological behavior in fluctuating environments; electronic properties of strongly correlated systems; properties of hydrogen and hydrogen-helium mixtures in astrophysically-relevant conditions; electronic and magnetic structures of transition metal compounds; molecular dynamics responsible for the properties of liquid water; and propagation of seismic energy through a detailed structural model of Southern California together with prediction of ground motion and modeling of the response of buildings and other structures. Other allocations address testing hypotheses about the role of cloud processes and ocean mesoscale eddy mixing; formation of the first galaxies; turbulent stellar hydrodynamics; binary black hole and neutron star systems as sources of gamma ray bursts; and other intense radiation phenomena, contagion, and particle physics. For the transition period between Blue Waters and Frontera, NSF has issued a Dear Colleague Letter[27] accepting applications for supplements to active NSF research awards for time on both systems.

Education and outreach projects are ongoing; they target pre-college, undergraduate, graduate, and post-graduate students. The Blue Waters project also sponsors workshops, conferences, summer schools, and seminars. The project includes industry partnership activities as well. The Industry Partners in Petascale Engagement program provides industry partners across a wide range of market sectors (e.g., health, energy,

[26] www.nsf.gov/pubs/2017/nsf17558/nsf17558.htm
[27] www.nsf.gov/pubs/2019/nsf19030/nsf19030.jsp

advanced manufacturing) with expertise as well as a first look at the technological and scientific developments that flow from the petascale program. To date, there have been more than 200 education, outreach, and training projects engaging over 3,700 individuals at over 160 institutions, including 41 institutions in Established Program to Stimulate Competitive Research (EPSCoR) jurisdictions and 14 Minority-Serving Institutions.

Management and Oversight
The Blue Waters and Frontera projects are overseen by OAC's program directors and BFA's Division of Grants and Agreements staff, who receive strategic advice from the AD Council. Advice from the NSF Office of General Counsel is also sought, as necessary.

The NSB receives updates on any major changes in risk assessments, which are reviewed annually by an external panel. Risks identified during the operational phase of a project include system security, power costs, and performance/reliability/usability due to large system scale.

Advanced/Innovative Computing Systems and Services

Description
NSF funds the acquisition and operation of nationally-available Advanced/Innovative Computing Systems and Services that, in aggregate, are forward-looking and technically diverse, and reflect changing and growing use of data-intensive computation in both the research and education processes. At the same time, they are intended to enable discoveries at a computational scale beyond the reach of an individual or regional academic institution.

Deployed systems serve as a cohesive set of allocable resources within the eXtreme Digital (XD) integrated services infrastructure, which is described in the following section. Advanced/innovative computing systems and services awards are generally made as two parts: an acquisition and deployment award that may be the result of a competitive or a renewal proposal; and a separate award for operations and maintenance following deployment. When an award is made, the awardee institution issues sub-awards to vendors and/or other organizations for acquisitions and services as necessary. Expenditures are contingent on successful completion of deployment milestones.

Current Status
Four resources, Wrangler, Comet, Bridges, and Jetsream, commenced operations in FY 2015 and FY 2016, and the capabilities of Comet, Bridges, and Jetstream have been augmented since initial deployment. In FY 2018, the period of operation for these four systems was extended, as noted below, allowing for increased return on investment and ensuring continuity of operations for the research community. Stampede 2, the largest of the currently active HPC resources within this portfolio, commenced operation in FY 2017. NSF will continue to diversify its portfolio of advanced/innovative computing systems and services to address the evolving and broadening needs of the research community.

Deployed in FY 2015, Wrangler is the most powerful data analysis system allocated in XD, with 10 petabytes of replicated, secure, high-performance data storage. This innovative system consists of 3,000 embedded processing cores for data analysis; 120 Intel Haswell-based servers for data access and embedded analytics; and a large-scale flash storage tier for analytics, with bandwidth of one terabyte per second and 275 million Input/Output Operations Per Second (IOPS). Wrangler provides flexible support for a wide range of software stacks, including Hadoop and relational data. Support for ongoing Wrangler operations and maintenance continues through October 2019, and is provided to UT Austin at a level of approximately 20 percent of the initial acquisition cost per annum, consistent with the level specified in the FY 2013

Innovative HPC program solicitation.[28] Wrangler's 275 million IOPS capabilities remain at the leading edge of currently deployed systems in production operations; the extension provides for continuing operations at that performance level.

Comet also came online in FY 2015 at the University of California, San Diego (UCSD). It supports research interests and priorities requiring large, high-throughput workloads, which in turn prompt massive amounts of computation but at moderate scalability. Notably, as a resource responsive to the "long tail of science," Comet is particularly well-suited for the large-scale computational needs of research community portals such as Cyberinfrastructure for Phylogenetic Research as well as distributed workflows such as those required by the Laser Interferometer Gravitational-Wave Observatory. Comet's heterogeneous configuration supports not only complex simulations but also advanced analytics and visualization of outputs. As a result of its role in machine learning, visualization, and advanced analytics, supplemental funding was provided to increase the GPU component of Comet in FY 2017. Comet is planned to remain operational through March 2021.

Bridges came online in FY 2016 at the Pittsburgh Supercomputing Center on the campus of Carnegie Mellon University (CMU). Bridges provides an innovative and groundbreaking HPC and data analytics system integrating advanced memory technologies to empower new communities. It brings desktop convenience to HPC, connecting to campuses, and intuitively integrating data-intensive workflows to increase the output of a large community of scientific and engineering researchers that has not traditionally used HPC resources. Bridges extends the impact of HPC to EPSCoR jurisdictions and Minority-Serving Institutions, raising the level of computational awareness at four-year colleges, and promoting computational thinking in high-schools. Bridges was augmented with GPU nodes in FY 2018 and will remain operational through November 2020.

Jetstream also came online in FY 2016 at Indiana University. Jetstream is a cloud-based platform that incorporates the best elements of commercial cloud computing resources with some of the best software for solving important scientific problems. Jetstream enables new modes of sharing data and computational analysis, allowing for increased scientific reproducibility and enabling American scientists and engineers to make new discoveries that are important to understanding the world around us, thereby improving the quality of life for all Americans and promoting the nation's competitive standing in the world. Jetstream's system operation was augmented in FY 2017 to provide additional focused staff expertise to accelerate effective researcher utilizations of the programmable cyberinfrastructure/virtual machine-enabled architecture. The system will continue operations through November 2020.

In FY 2016, NSF awarded *Stampede 2: The Next Generation of Petascale Computing for Science and Engineering* to UT Austin following a rigorous merit review, enabling the acquisition, development, and deployment of Stampede 2 as a successor resource to the highly successful Stampede system. Stampede operated from 2013 through 2017 and was considered the "backbone" for the XD environment, annually supporting more than 5,000 researchers and more than 1,000 computationally-intensive projects across the Nation. Stampede 2 similarly serves as the primary national resource (i.e., the "workhorse") for thousands of American academic researchers, complements other national advanced computing systems and services, and provides capabilities beyond the reach of individual campuses and regional resources, including support for multiscale modeling, simulation, and data-intensive research. Stampede 2 has been deployed into production operation through three phases: (1) the Intel Knights Landing many-core nodes were deployed in 2017, demonstrating increased performance at lower power rates; (2) the highly complementary Intel SkyLake processors, which are responsive to data-intensive computing, were in early operations in 2017 and fully deployed as a peak 18-petaflop system in 2018; and (3) the final deployment phase, also in 2018, introduced persistent memory to the previously-deployed Skylake processors to significantly enhance

[28] www.nsf.gov/pubs/2013/nsf13528/nsf13528.htm

overall system performance. Stampede 2 will serve the high-end, open science community through November 2022.

As noted above, Wrangler, Comet, Bridges, and Jetstream are all scheduled to ramp down operations during FY 2020 through FY 2021. During the same period, Stampede 2 will continue at full operation and the new leadership-class computing system, Frontera, will ramp up to full operations to ensure continued support for the science and engineering research community. Moving forward, NSF envisions that investments in advanced/innovative computing systems and services will foster an integrated cyberinfrastructure ecosystem that addresses the growing scale and diversity of the science and engineering community, the changing nature of science and engineering research requirements, and the rapidly evolving technology and services landscape, with the overarching goal of supporting the full range of computational- and data-intensive research across all science and engineering domains. To further this goal, NSF issued a solicitation for advanced computing systems and services in FY 2019 with anticipated awards spanning FY 2019-FY 2024.[29] This solicitation calls for investments in two categories:

- Category I, Capacity Systems: production computational resources maximizing the capacity provided to support the broad range of computation and data analytics needs in science and engineering research; and
- Category II, Innovative Prototypes/Testbeds: innovative forward-looking capabilities deploying novel technologies, architectures, usage modes, etc., and exploring new target applications, methods, and paradigms for science and engineering discoveries.

The solicitation will remain in effect through FY 2020, allowing for two cycles of submissions and awards.

Science and engineering research and education activities enabled by Advanced/Innovative Computing Systems and Services

The ecosystem of advanced/innovative computing systems and services is enabling new, world-leading, and transformative advances across the breadth of science and engineering research, in the integration of research and education, and in broadening participation in science and engineering by underrepresented groups. It is enabling new collaborations across public and private sectors to advance American security and economic competitiveness. These advances are made possible by providing researchers and educators with usable access to world-leading computational systems and services, together with expertise, beyond that typically available on most campuses, including the interfaces, consulting support, and training necessary to facilitate use of the systems and services. This activity is central to America achieving the full potential of complementary investments by NSF, other federal agencies, and academic institutions.

Management and Oversight

OAC's program directors provide direct oversight during both the acquisition and operations and maintenance awards. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors.

Awards for advanced/innovative computing system and services are managed under cooperative agreements that include the management structures, milestones, spending authorization levels, and review schedules. Each awardee is responsible for the satisfactory completion of milestones prior to NSF authorization of spending. Progress is assessed with the aid of annual external reviews. In addition, each project is required to have a project management plan.

Any activity of this nature, and at this scale, comes with a certain element of risk. The review process, conducted prior to award, analyzes the risks as presented in the proposal and identifies any additional risks that should be considered. During the award process, risks are identified and analyzed, and a mitigation

[29] www.nsf.gov/pubs/2019/nsf19534/nsf19534.htm

plan is created and followed. One of the activities of the periodic NSF external reviews, conducted by an external panel of experts, is to revisit and reassess the risk situation and make recommendations as deemed necessary. In the case of projects that involve an acquisition, typically, project risks are substantially reduced subsequent to deployment. Thus, the pacing of the acquisitions and deployments for such projects provides balance in the overall risk portfolio for the program.

Milestone-driven reviews occur during the acquisition award, typically with an external review prior to deployment. Annual reviews, conducted by an external panel of expert reviewers and managed by OAC program directors, are performed during the operational phase of each project.

Coordination and Support Services

Description

NSF's investments in coordinaton and support services, as exemplified by the XD integrated services infrastructure, add value to the NSF advanced/innovative computing systems and services by coordinating the systems and services, providing advanced assistance to the user community, and broadening participation. The XD program's shared services model for coherently and efficiently delivering to researchers both access and expertise to diverse, dynamic, and distributed resources is a cornerstone of the American advanced computing, including HPC, ecosystem. Enabling the connection between individual campuses and national resources is an essential aspect of the advanced computing ecosystem.

XD enables and supports leading-edge scientific discovery and promotes science and technology education. The program encourages innovation in the design and implementation of an effective, efficient, increasingly virtualized approach to the provision of high-end digital services, while ensuring that the infrastructure continues to deliver high-quality access for the many researchers and educators who use it in their work.

XD shared services consist of several interrelated parts: allocation of resources to computational and data research projects; advanced user assistance; training, education, and outreach; architecture and operation of an integrated digital services infrastructure; metrics services; and overall coordination. These elements are designed and implemented in a way that is clearly tied to the requirements of the science and engineering research community, using a flexible methodology that permits the architecture to evolve in response to changing community needs and that presents individual users with a common environment regardless of where the resources or researchers are located.

Current Status

Two awards are currently active within the XD program: XD Metrics Service (XMS) and the eXtreme Science and Engineering Discovery Environment (XSEDE). The smaller XMS award was made in FY 2015 to The State University of New York at Buffalo. This award provides metrics services allowing measurement of key operational data for both resources and services. All other services are provided by XSEDE. The XSEDE award to UIUC was renewed in September 2016, continuing the prior XSEDE award for another five-year period. The award will conclude at the end of August 2021, and in anticipation of that date, NSF has initiated engagements with the community about the structure and composition of future coordination efforts.

Within the current XSEDE project, there are 18 partners engaged via subawards to the University of Tennessee at Knoxville (National Institute for Computational Sciences), CMU and University of Pittsburgh (Pittsburgh Supercomputing Center), UT Austin (TACC), UCSD (San Diego Supercomputing Center), University of Chicago, Indiana University, Purdue University, Shodor Education Foundation, Ohio Supercomputer Center, Southeastern Universities Research Association, Cornell University, National Center for Atmospheric Research, Georgia Institute of Technology, Oklahoma State University, University of Georgia, Oklahoma University, University of Southern California, and University of Arkansas.

The mid-project external site review of the XMS project took place in June 2018 and continued operations were authorized based on the successful outcome of that review. XSEDE has annual external reviews at NSF. The first external review of the renewed XSEDE project took place in June 2017; subsequent external milestone reviews have taken place in January and June 2018. On the basis of these successful reviews, funds have been authorized for operations through the third year of the five-year award.

Science and engineering research and education activities enabled by Coordination and Support Services
Coordination and support services, as exemplified by XD, enable transformative advances in science and engineering research, in the integration of research and education, and in broadening the participation of underrepresented groups in science and engineering. These advances are accomplished by providing researchers and educators with coherent and highly usable access to extreme-scale digital resources beyond those typically available on most campuses, together with the interfaces, consulting, advanced user support, and training necessary to facilitate their use.

XD coordinates access to advanced/innovative computing systems and services and enables researchers to efficiently manipulate, analyze, visualize, and share extremely large amounts of distributed digital information from simulations, sensors, and experiments.

XD's XSEDE project delivers tools and services that not only link users to national facilities, but also enable scientific collaborations of geographically distributed teams. In doing so, it facilitates dynamic access to digital resources and experimental testbeds within and across university campuses, as well as government laboratories.

The XSEDE project includes outreach and training critical to reducing barriers to the use of advanced digital systems by the research and education communities, thereby promoting enhanced productivity.

XD's XMS project develops analysis tools and collects operational data from XD projects such as XSEDE and the advanced computing/innovative systems and services. The immediate users of these methods and tools are the providers of NSF-supported advanced computing systems and services. However, both tools and data are publicly available and used by other projects such as Blue Waters, Frontera, and individual universities.

Management and Oversight
OAC's program directors oversee the XD projects. XSEDE has an external advisory board, a user board, and a service provider forum to ensure that all stakeholders can provide project input. OAC oversight of the XSEDE project includes participation in weekly teleconferences with senior XSEDE personnel and in quarterly project-wide staff meetings. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors.

Each XD award is managed under a cooperative agreement that includes requirements for a specific management structure, milestones, reporting of spending levels over time, and a review schedule. Each awardee is responsible for the satisfactory completion of milestones prior to NSF authorization of spending. In addition, each project is required to have a detailed management plan in place.

While XD is operational in nature, the virtual organizations of the XSEDE project and the services of all XD projects are innovative and thus bear inherent risks. The projects maintain risk registers that are reviewed periodically by external panels and by the cognizant program directors.

Annual reviews for XSEDE and mid-project reviews for XMS are conducted by external panels of expert reviewers and managed by OAC program directors.