DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) $838,920,000 -$96,280,000 / -10.3%

CISE Funding

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Percent
Office of Advanced Cyberinfrastructure (OAC)	$222.19	-	$199.31	-$22.88	-10.3%
Computing and Communication Foundations (CCF)	194.13	-	174.14	-19.99	-10.3%
Computer and Network Systems (CNS)	230.99	-	207.21	-23.78	-10.3%
Information and Intelligent Systems (IIS)	194.80	-	174.75	-20.05	-10.3%
Information Technology Research (ITR)	93.09	-	83.51	-9.58	-10.3%
Total	**$935.20**	**-**	**$838.92**	**-$96.28**	**-10.3%**

About CISE

Advances in information technology (IT) over the past two decades have proven to be key drivers of U.S. economic competitiveness. Essentially all practical applications of today's IT are based on ideas and concepts that emerged from investments in fundamental computing research, many of them funded by NSF and CISE.[1] Fundamental ideas and concepts advanced through computing research have enabled innovative products and applications that now permeate many aspects of daily life, including personal communications, 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 U.S. leadership in IT and its applications, including in intelligent infrastructure, augmented and virtual reality, quantum computing, and research cyberinfrastructure for all domains, will require sustained investment. Indeed, NSF and CISE must continue to play a central and leadership role in improving the Nation's economic outlook and advancing a highly-trained, technologically astute workforce.

Specifically, 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 cyberinfrastructure 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 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 cyberinfrastructure for all areas of science and engineering; contributes to the education and training of computing professionals; and more broadly, informs the preparation of a U.S. workforce with computing and computational competencies essential to success in an increasingly competitive global market. CISE executes its mission through its Divisions of Computing and Communication Foundations (CCF), Computer and Network Systems (CNS), Information and Intelligent Systems (IIS), and Information and Technology Research (ITR), and the Office of Advanced Cyberinfrastructure (OAC).

CISE's FY 2018 Budget Request is shaped by the following NSF-wide priorities: Cyber-Enabled Materials, Manufacturing, and Smart Systems (CEMMSS); Harnessing the Data Revolution (HDR) Big Idea; National

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

Strategic Computing Initiative (NSCI); NSF Innovation Corps (NSF I-Corps™); NSF Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES); Secure and Trustworthy Cyberspace (SaTC); Smart and Connected Communities (S&CC); and Understanding the Brain (UtB). In addition to the HDR Big Idea, CISE will also actively participate in several other Big Ideas in collaboration with all NSF directorates and offices, particularly Work at the Human-Technology Frontier (W-HTF), Quantum Leap, Navigating the New Arctic, Rules of Life, Convergence, and Mid-Scale Research Infrastructure. Progress in foundational research, research infrastructure, and education in these areas is vital to address key national challenges, spur innovation, increase productivity, secure critical infrastructure, improve data analysis and sharing, and develop the next generation of computing and computational scientists and engineers.

In addition, CISE continues to provide leadership for the multi-agency National Science and Technology Council (NSTC) Committee on Technology (COT) Subcommittee on Networking and Information Technology Research and Development (NITRD). The NITRD Subcommittee is co-chaired by the CISE Assistant Director. All research, education, and research infrastructure projects supported by CISE enrich the agency's NITRD portfolio.

CISE provides about 83 percent of the federal funding for basic research at U.S. academic institutions in computer science.

Major Investments

CISE Major Investments

(Dollars in Millions)

Area of Investment	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
CAREER	$45.20	-	$37.30	-$7.90	-17.5%
CEMMSS	91.93	-	72.70	-19.23	-20.9%
Advanced Manufacturing	*43.25*	-	*37.00*	*-6.25*	*-14.5%*
CIF21	87.50	-	-	-87.50	-100.0%
HDR	-	-	50.00	50.00	N/A
INFEWS	8.00	-	-	-8.00	-100.0%
IUSE	1.98	-	2.00	0.02	1.0%
NRT	7.69	-	3.00	-4.69	-61.0%
NSCI*	-	-	97.00	97.00	N/A
NSF I-Corps™	11.71	-	9.65	-2.06	-17.6%
NSF INCLUDES	1.72	-	1.78	0.06	3.5%
R&R	5.98	-	-	-5.98	-100.0%
SaTC	70.90	-	65.50	-5.40	-7.6%
S&CC	13.50	-	16.50	3.00	22.2%
Understanding the Brain	30.60	-	22.15	-8.45	-27.6%
BRAIN Initiative	9.80	-	9.50	-0.30	-3.1%

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

*This includes $60 million in FY 2018 as part of OAC's HPC investment for a leadership-class computing resource (see HPC Appendix for more information).

All funding decreases/increases represent changes over the FY 2016 Actual.

- Faculty Early-Career Development Program (CAREER) (-$7.90 million to a total of $37.30 million): CISE will continue to invest in CAREER, which supports the integration of research and education of early career researchers, and contributes to the development of future generations of computer and information scientists and engineers, as well as computational scientists across all areas of science and engineering.

- CEMMSS (-$19.23 million to a total of $72.70 million): CISE will continue to lead CEMMSS, in partnership with the Directorate for Biological Sciences (BIO), Directorate for Education and Human Resources (EHR), Directorate for Engineering (ENG), and Directorate for Mathematical and Physical Sciences (MPS), aiming to establish a scientific basis for engineered systems interdependent with the physical world and with humans in the loop; synthesize multi-disciplinary knowledge to model and simulate such systems in their full complexity and dynamics; and develop a smart systems technology framework spanning robotic and cyber-physical systems. As part of CEMMSS, CISE will continue to lead the Cyber-Physical Systems (CPS) and National Robotics Initiative (NRI) programs. These investments will focus on fundamental science and engineering addressing how intelligent physical systems sense, perceive, and operate in environments that are dynamic, uncertain, and unanticipated.

- Advanced Manufacturing (-$6.25 million to a total of $37.0 million): As part of CEMMSS, CISE, in partnership with ENG and MPS, will continue to 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 and provide the next generation of products and services in various industries, including higher-quality products with greater efficiency and sustainability produced by the factories of the future. In addition, CISE will continue to support research on co-robots that work alongside or cooperatively with people in manufacturing environments to increase their productivity, performance, and safety as part of its support for NRI.

- Cyberinfrastructure Framework for 21st Century Science, Engineering, and Education (CIF21) (-$87.50 million to a total of zero): CISE investments in CIF21 will transition to HDR and NSCI in FY 2018.

- HDR (+$50.0 million to a total of $50.0 million): CISE will lead HDR in partnership with all other NSF directorates and offices, continuing the visioning and planning activities that have already begun.[2] HDR will engage NSF's research and education community in the 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. CISE, together with MPS, will continue the initial HDR investment in Transdisciplinary Research in Principles of Data Science (TRIPODS), bringing together the statistics, mathematics, and theoretical computer science communities to develop the theoretical foundations of data science through integrated research and training activities. In addition to these forward-looking investments aimed at building the foundation for future HDR activities, HDR will also encompass NSF's existing data-related research, research infrastructure, and education portfolio that is transitioning from CIF21, including Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Science (BIGDATA); Data Infrastructure Building Blocks (DIBBs); EarthCube; and Resource Implementations for Data Intensive Research in Social, Behavioral, and Economic Sciences (RIDIR). As part of HDR, CISE will also collaborate with other NSF directorates and offices on new approaches to community data governance and research data lifecycles in alignment with NSF's *Public Access Plan*.

[2] Dear Colleague Letter: Growing Convergence Research at NSF (NSF 17-065), www.nsf.gov/pubs/2017/nsf17065/nsf17065.jsp.

- Innovations at the Nexus of Food, Energy and Water Systems (INFEWS) (-$8.0 million to a total of zero): CISE will continue to support research related to this area through investments in CEMMSS, notably CPS, and S&CC.

- Improving Undergraduate STEM Education (IUSE) (+$20,000 to a total of $2.0 million): CISE will continue to invest in IUSE, with a focus on novel approaches for CS+X, enabling the diffusion of the fundamentals of computational thinking and computer science across a broad array of other disciplines at the undergraduate level.

- NSF Research Traineeships (NRT) (-$4.69 million to a total of $3.0 million: CISE will continue to invest in NRT, supporting STEM graduate students in interdisciplinary areas of national priority, as well as the development of bold, new, potentially transformative, and scalable models for STEM graduate training.

- NSCI (+$97.0 million to a total of $97.0 million): CISE, through OAC, will co-lead NSCI with MPS and in partnership with other NSF directorates and will represent NSF in its leadership role for NSCI across the federal government. The goal of NSCI is to advance national leadership in High-Performance Computing (HPC) and maximize the benefits of HPC for scientific discovery and economic competitiveness. Under NSCI, CISE will support research advances in new computing technologies, architectures, and platforms for the future, as well as the development and deployment of advanced HPC systems, including maximizing their benefits through deep integration of HPC cyberinfrastructure with science and engineering research. This deep and agile engagement will be pursued along a number of key fronts: increasing coherence between the technology base used for modeling and simulation and that used for data analytics; establishing a viable path forward for HPC systems in the post-Moore's Law device and hardware era; and increasing the capacity, capability, and sustainability of an enduring national HPC ecosystem, including addressing foundational algorithms and software, programmability, networking technology, accessibility, workflow, and workforce development.

- NSF I-Corps™ (-$2.06 million to a total of $9.65 million): CISE will continue to invest in I-Corps™ Nodes, Sites, and Teams to further build, utilize, and sustain a national innovation ecosystem that continues to augment the development of technologies, products, and processes that benefit the Nation. CISE investments in NSF I-Corps™ will seek to identify NSF-funded researchers who will receive additional support, in the form of entrepreneurial training and mentoring, to accelerate innovation and knowledge transfer that can attract subsequent third-party investment.

- NSF INCLUDES (+$60,000 to a total of $1.78 million): CISE will continue to invest in NSF INCLUDES, the NSF-wide effort to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved and/or underrepresented in STEM fields.

- Risk and Resilience (R&R) (-$5.98 million to a total of zero): CISE will continue to support research related to this area through investments in CEMMSS, notably CPS, and S&CC.

- SaTC (-$5.40 million to a total of $65.50 million): CISE will continue to lead SaTC, in partnership with EHR, ENG, MPS, and the Directorate for Social, Behavioral, and Economic Sciences (SBE), aligning cybersecurity investments with the federal cybersecurity R&D strategy. SaTC aims to support the foundational research necessary to ensure society's ubiquitous computing and communication systems are resistant to cyber-attacks and associated vulnerabilities, while enabling and preserving privacy and trust. As part of this investment, CISE will continue collaborating with EHR to support a growing

pipeline of cybersecurity researchers and educators, and to develop a citizenry that understands the security and privacy of the digital systems on which it increasingly depends.

- S&CC (+$3.0 million to a total of $16.50 million): CISE will continue to lead S&CC, in partnership with EHR, ENG, the Directorate for Geosciences (GEO), and SBE, pursuing interdisciplinary, integrative research and research capacity-building activities that improve understanding and design of intelligent infrastructure for communities and that lead to enhanced quality of life for residents. CISE investments in S&CC will consider the broad context of communities, not just large urban areas, and multiple dimensions and domains, including health and wellness, energy efficiency, transportation, education and learning, and public safety/disaster preparedness and response.

- UtB (-$8.45 million to a total of $22.15 million): CISE will continue to invest in core and interdisciplinary projects focused on understanding the brain. In particular, CISE will support projects that develop novel computational approaches for performing multi-scale analysis of physiological, cognitive, and behavioral data; innovative models that accelerate the integration of brain knowledge across scales and disciplines; and innovative neurotechnologies to monitor and further brain function. This research will aim to accelerate the formulation of an integrative, quantitative, and predictive theory of brain function.

CISE Funding for Centers Programs and Facilities

CISE Funding for Centers Programs

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
Total, Centers Programs	**$10.00**	**-**	**$10.00**	**-**	**-**
STC: Center for the Science of Information	5.00	-	5.00	-	-
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	5.00	-	5.00	-	-

For detailed information on individual centers programs, see the NSF-Wide Investments chapter.

CISE Funding for Facilities

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
Total, Facilities	**$0.60**	**-**	**$0.60**	**-**	**-**
National Nanotechnology Coordinated Infrastructure (NNCI) Program (CCF)	0.60	-	0.60	-	-

For detailed information on individual facilities, see the Facilities and the Major Research Equipment and Facilities Construction chapters.

Funding Profile

CISE supports investments in core and interdisciplinary research and education, as well as in computing research infrastructure.

In FY 2018, the number of research grant proposals is expected to increase by 3.0 percent compared to the FY 2016 Actual Estimate, with CISE anticipating awarding approximately 1,450 research grants in FY 2018. Average annualized award size and average award duration are expected to remain relatively stable between the FY 2016 Actual Estimate and FY 2018 Estimate.

Funding for research infrastructure represents 18.8 percent of the CISE Request. Most of CISE's research infrastructure support is for HPC (see Appendix A for more information on the HPC portfolio).

CISE Funding Profile

	FY 2016 Actual Estimate	FY 2017 (TBD)	FY 2018 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,301	-	8,550
Number of New Awards	1,919	-	1,720
Funding Rate	23%	-	20%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,909	-	8,150
Number of Research Grants	1,622	-	1,450
Funding Rate	21%	-	18%
Median Annualized Award Size	$156,309	-	$160,000
Average Annualized Award Size	$203,144	-	$200,000
Average Award Duration, in years	2.8	-	3.0

Program Monitoring and Evaluation

Committees of Visitors (COV):

- In early FY 2015, CISE convened a Committee of Visitors (COV) to examine and assess the quality of the merit review process across three of its divisions: CCF, CNS, and IIS. The CISE Advisory Committee subsequently accepted the COV report.
- OAC plans to hold a COV in FY 2018.

Program Evaluations:

- In FY 2012, the Science and Technology Policy Institute (STPI) conducted program evaluation feasibility studies for the CEMMSS and SaTC investments. These feasibility studies provided methods for examining baseline portfolio investments and identifying metrics to measure progress toward program goals. They were part of a broader effort to develop a plan for impact assessments, particularly for the SaTC investment. STPI identified baseline evaluation metrics in FY 2013-FY 2015, and completed the evaluation feasibility studies for CEMMSS and SaTC in FY 2016.
- Evaluation is a key part of CISE's education programs. Both STEM + Computing Partnerships (STEM+C) and Computer Science for All (CSforAll) projects managed by CISE include rigorous research and evaluation plans designed to guide project progress and measure project impacts. Additionally, CISE tasked STPI to conduct an evaluation feasibility study for STEM+C, and the

Education Development Center, Inc. (EDC) to develop a program evaluation instrument for legacy CSforAll (CS 10K) projects. The first program evaluation of the CS 10K projects is currently under way.

Reports:

- In 2008, CISE funded the Computer Science and Telecommunications Board (CSTB) within the National Academy of Sciences, Engineering, and Medicine to study the IT innovation ecosystem and to assess the long-term economic impacts of CISE investments. The resulting report, *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem*,[3] published in 2009, includes an in-depth articulation of the creation of almost 20 IT industries since 1965 valued at a minimum of a billion dollars each. To update this study, CISE funded CSTB to identify recent IT industries that have reached the billion-dollar mark; develop a brief report that highlights the updated figures; and summarize results-to-date of IT research, including the nature and successes of U.S. research partnerships among government, industry, and universities, and the economic payoffs of these research investments. The resulting report, *Continuing Innovation in Information Technology*, was published in 2012.[4] A more recent CSTB study, *Continuing Innovation in Information Technology: A Workshop* (described below), employed this report's framework.
- In FY 2012, a CSTB study, *The Future of Computing Performance: Game Over or Next Level?*,[5] together with a white paper from the CISE-funded Computing Community Consortium (CCC), *21st Century Computer Architecture*,[6] outlined the need for advances in computer architecture research, leading to the development of the Exploiting Parallelism and Scalability (XPS) program in FY 2013. In FY 2018, CISE will continue to invest in advanced computer architecture research through the Scalable Parallelism in the Extreme (SPX) program, leveraging past investments in XPS.
- In FY 2013, the CCC collected community white papers articulating the potential needs and payoff for additional investments in mid-scale infrastructure for computing research;[7] this led to the development of the NSFFutureCloud program started in FY 2014. In FY 2018, CISE will continue to invest in NSFFutureCloud.
- Since FY 2014, the CCC has led several additional community visioning efforts that have the potential to influence CISE programs in FY 2018:
  - *Computing Visions 2025:*[8] inspired the computing community to envision future trends and opportunities in computing research. Two workshops were held under this initiative: *Interacting with Computers All Around Us*, and *The New Making Renaissance: Programmable Matter and Things.*
  - *Toward a Science of Autonomy for Physical Systems:*[9] offered a series of white papers framing the challenges and opportunities associated with a future of autonomous physical systems across a range of domains including health care, transportation, and disaster response. These white papers have the potential to influence CISE investments in CEMMSS, including in CPS and NRI.
  - *A New Age of Computing and the Brain:* brought together computer and information scientists and engineers and brain scientists to explore opportunities and connections at the intersection of computer and information science and brain science. The resultant workshop report summarizing the key findings has the potential to influence CISE and NSF investments in UtB.[10]
  - *Artificial Intelligence (AI) for Social Good:*[11] furthered the discussion of the benefits of AI to

[3] www.nap.edu/catalog.php?record_id=12174
[4] www.nap.edu/catalog.php?record_id=13427
[5] www.nap.edu/openbook.php?record_id=12980
[6] http://cra.org/ccc/docs/init/21stcenturyarchitecturewhitepaper.pdf
[7] http://cra.org/ccc/visioning/visioning-activities/mid-scale-infrastructure-investments-for-computing-research
[8] http://cra.org/ccc/visioning/computing-visions-2025/
[9] http://cra.org/ccc/resources/ccc-led-whitepapers/#toward-a-science-of-autonomy-for-physical-systems
[10] http://cra.org/ccc/wp-content/uploads/sites/2/2014/12/BRAIN-Report.pdf
[11] http://cra.org/ccc/events/symposium-ai-social-good/

society. Two workshops were held jointly with the Association for the Advancement of Artificial Intelligence (AAAI), exploring the potential use of AI in various areas, including smart and connected communities, health and wellness, and security. The CCC also published a white paper about advances in AI.[12] These efforts have the potential to influence CISE investments in AI.

- *Intelligent Infrastructure:*[13] 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 the purpose of enhancing efficiency, resiliency, and safety. These white papers, which the CCC produced jointly with the Electrical and Computer Engineering Department Heads Association (ECEDHA), have the potential to influence CISE investments in S&CC.

- Similarly, since FY 2014, CISE has funded several CSTB studies that have the potential to influence CISE programs in FY 2018:
  - *Continuing Innovation in Information Technology: A Workshop:* conducted a public workshop to highlight additional examples of the impacts of computing research using the framework established in the "tiretracks" figure published in CSTB's 2012 report *Continuing Innovation in Information Technology*. The resultant workshop report was published in 2016.[14]
  - *Toward 21st-Century Cyber-Physical Systems Education:* published a report in 2016 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.[15]
  - *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science in 2017-2020:* published a report in 2016 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 United States 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.[16]
  - *Information Technology and the U.S. Workforce: Where Are We and Where Do We Go from Here?:* published a report in 2017 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.[17]
  - *Envisioning the Data Science Discipline: The Undergraduate Perspective:*[18] is developing a vision for the emerging discipline of data science at the undergraduate level.
  - *Growth of Computer Science Undergraduate Enrollments:*[19] is examining potential responses to the current large influx of undergraduate students enrolling in computing and computer science courses.

[12] http://cra.org/ccc/wp-content/uploads/sites/2/2015/01/CCC-AI-Systems-2017-FINAL.pdf
[13] http://cra.org/ccc/resources/ccc-led-whitepapers/#infrastructure
[14] https://www.nap.edu/catalog/23393/continuing-innovation-in-information-technology-workshop-report
[15] www.nap.edu/catalog/23686/a-21st-century-cyber-physical-systems-education
[16] www.nap.edu/catalog/21886/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-and-engineering-in-2017-2020
[17] www.nap.edu/catalog/24649/information-technology-and-the-us-workforce-where-are-we-and
[18] http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_175246
[19] http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_171607

Number of People Involved in CISE Activities

	FY 2016 Actual Estimate	FY 2017 (TBD)	FY 2018 Estimate
Senior Researchers	7,288	-	6,500
Other Professionals	1,238	-	1,100
Postdoctoral Associates	490	-	400
Graduate Students	6,565	-	5,900
Undergraduate Students	2,660	-	2,400
K-12 Teachers	-	-	-
K-12 Students	-	-	-
Total Number of People	18,241	-	16,300

OFFICE OF ADVANCED CYBERINFRASTRUCTURE (OAC) $199,310,000
-$22,880,000 / -10.3%

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
Total	**$222.19**	**-**	**$199.31**	**-$22.88**	**-10.3%**
Research	**86.39**	**-**	**76.61**	**-9.78**	**-11.3%**
CAREER	2.04	-	1.80	-0.24	-11.6%
Education	**6.44**	**-**	**5.20**	**-1.24**	**-19.3%**
Infrastructure	**129.35**	**-**	**117.50**	**-11.85**	**-9.2%**
Networking and Computational Resources Infrastructure and Services	129.35	-	117.50	-11.85	-9.2%

OAC supports the exploration, development, deployment, and expert services necessary for world-leading research cyberinfrastructure (CI), which is critical to the advancement of all areas of science and engineering research and education in the 21st century and therefore essential to sustaining U.S. economic competitiveness and national security. In partnership with all NSF directorates and offices as well as other CISE divisions, OAC support to academic institutions encourages a rich and vibrant ecosystem that blends research-specific infrastructure 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 the 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. In order to address complex and multidisciplinary discovery, prediction, and innovation, OAC enables more than 8,000 faculty and researchers to access computational resources and services, along with secure connectivity to major international facilities and scientific instruments. Ultimately, OAC promotes secure CI interoperability, sharing, and collaborations among academic research infrastructure groups, other federal agencies and international research funding agencies, and the private sector.

In general, about 42 percent of the OAC portfolio is available for new grants and 58 percent is available for continuing grants.

Approximately 55 percent of OAC's budget is used to support individuals and small groups of researchers in pilot, prototype, and innovative multidisciplinary projects. The remaining 45 percent of the budget goes toward the support of larger cyberinfrastructure consortia, including Petascale Computing, Innovative High-Performance Computing (HPC), and eXtreme Digital (XD) shared services. Collectively, these larger-scale programs complement and connect both smaller NSF-supported as well as university-supported CI as part of an integrated, national research infrastructure ecosystem.

FY 2018 Summary

All funding decreases/increases represent changes over the FY 2016 Actual.

Research

- OAC will continue to invest in early-career researchers through CAREER (-$240,000 to a total of $1.80 million).
- OAC will transition support for CIF21 (-$62.0 million to a total of zero), investing in NSCI (+$26.50

million to a total of $26.50 million) and HDR (+$30.0 million to a total of $30.0 million). Together with MPS, OAC will co-lead the NSF-wide NSCI activity and will represent NSF in its leadership role for NSCI across the federal government. OAC research investments in NSCI will emphasize future HPC systems beyond the limits of current semiconductor technology, as well as emerging infrastructure, including quantum technologies, for all areas of science and engineering. In concert with investments by other NSF directorates/offices, OAC investments in NSCI will also support novel scientific software architectures that are resilient, reusable, and enduring yet agile to accelerate robust research. These OAC research activities in NSCI are complemented by Advanced Computational Infrastructure activities, as noted below. In coordination with NSF research priorities and CI investments by other directorates/offices, OAC investments in HDR will recognize the enormous potential of data science to all fields of science and engineering. OAC will emphasize support for innovative, reusable, and sustainable data science tools and data sharing infrastructure for all research communities. OAC will also collaborate with other NSF directorates/offices on new approaches to community data governance and research data lifecycles in alignment with NSF's *Public Access Plan.*

- OAC will continue to invest in UtB (-$5.0 million to a total of $1.0 million) to support exploration of research infrastructure for neuroscience in collaboration with BIO and MPS and in alignment with HDR.
- OAC will discontinue support for INFEWS (-$3.0 million to a total of zero) and R&R (-$2.48 million to a total of zero), but will continue to support research related to these areas through investments in other programs.

Education

- OAC will invest in CyberTraining (+$3.50 million to a total of $3.50 million) to prepare, nurture, and grow the national scientific workforce for creating, utilizing, and supporting advanced CI that enables cutting-edge science and engineering and contributes to the Nation's overall economic competitiveness and security.
- OAC will continue to invest in CSforAll (level at $500,000), which seeks to enable rigorous and engaging computer science education in schools across the Nation.
- OAC will continue to invest in Research Experiences for Undergraduates (REU) sites and supplements (-$1.26 million to a total of $1.20 million).
- OAC will discontinue support for NRT (-$3.0 million to a total of zero).

Infrastructure

- OAC will continue to support Advanced Computational Infrastructure (-$7.15 million to a total of $89.50 million), to enable research priorities and advances beyond the grasp of individual institutions OAC investments will be in alignment with NSCI and the recommendations of a recent National Academies study, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering 2017-2021*. As part of NSCI, $60.0 million of OAC's HPC investment will be for a new leadership-class computing resource (see Appendix A for more information on the HPC portfolio).
- OAC will continue to invest in SaTC (-$1.50 million to a total of $2.50 million), leading the Transition to Practice (TTP) Option, which explores new approaches for adopting advances in security for research CI, including emphasizing interagency and cross-sector collaborations.

DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) — $174,140,000 / -$19,990,000 / -10.3%

CCF Funding

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
Total	**$194.13**	**-**	**$174.14**	**-$19.99**	**-10.3%**
Research	**183.75**	**-**	**163.54**	**-20.21**	**-11.0%**
CAREER	15.82	-	12.10	-3.72	-23.5%
Centers Funding (total)	8.00	-	8.00	-	-
STC: Center for the Science of Information	5.00	-	5.00	-	-
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	3.00	-	3.00	-	-
Education	**9.78**	**-**	**10.00**	**0.22**	**2.2%**
Infrastructure	**0.60**	**-**	**0.60**	**-**	**-**
National Nanotechnology Coordinated Infrastructure (NNCI)	0.60	-	0.60	-	-

CCF contributes to scientific advancement, economic growth, human health, and national security by laying the foundations of the theory and practice of computing and communication. CCF supports research and education activities that explore the foundations and limits of computation, communication, and information; advance algorithmic knowledge for research areas within and outside computer science; and advance software and hardware design. CCF's research investments support advances in the design and analysis of algorithms, computational complexity, theoretical and experimental studies of algorithms and their resource requirements, and formal models of computation. These research investments include approaches for parallel, distributed, and heterogeneous multi-core machines. CCF invests in research that addresses 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 achieving performance, correctness, usability, reliability, and scalability. CCF research explores the potential impact of emerging technologies on computation and communication, including nanotechnology, biotechnology, and quantum devices and systems.

In general, 77 percent of the CCF portfolio is available for new research grants and 23 percent is available for continuing grants.

FY 2018 Summary

All funding decreases/increases represent changes over the FY 2016 Actual.

Research

- CCF will continue to invest in early-career researchers through CAREER (-$3.72 million to a total of $12.10 million).
- CCF will continue to support the NSF-wide CEMMSS investment through CPS (-$1.0 million to a total of $4.50 million) and NRI (-$1.50 million to a total of $1.50 million). This investment will emphasize development of new methods for specification and verification of software and hardware systems useful for various sectors including cyber-manufacturing.

- CCF will transition support for CIF21 (-$9.50 million to a total of zero), investing in SPX (-$2.0 million to a total of $4.50 million) as part of NSCI, and BIGDATA (level at $5.0 million) and TRIPODS (+$1.0 million to a total of $1.0 million) as part of HDR. CCF investments in NSCI will pursue foundational research leading to future HPC systems beyond the limits of current semiconductor technology, including addressing the challenges of performance, scalability, programmability, portability, and reliability. CCF investments in NSCI will also support quantum technologies. CCF investments in HDR will pursue research on the foundations of data science, from the generation and collection of data to analytics and decision making; and on foundational techniques that enable computationally-efficient storage and processing of big data, as well as more effective query and analysis from heterogeneous data sources.
- CCF will invest in S&CC (+$1.50 million to a total of $1.50 million), pursuing interdisciplinary, integrative research and research capacity-building activities that improve understanding and design of intelligent infrastructure for communities, leading to enhanced quality of life for residents.
- CCF will continue to invest in UtB (-$750,000 to a total of $7.90 million) through investments in core and crosscutting research, including integrating computational models across multiple scales for improved understanding of the theory of brain function.
- CCF will continue to invest in SaTC (-$2.50 million to a total of $11.75 million), supporting research on theories, models, algorithms, architectures, and programming languages for increased security, privacy, and trust, as well as in new cryptographic approaches for hardware assurance.
- CCF will continue to invest in Smart and Connected Health (SCH) (-$2.0 million to a total of $1.0 million), supporting signal processing and control research with application to devices and sensors for person-centered health and wellbeing.
- CCF will continue to invest in two STCs, the Center for the Science of Information at Purdue University (level at $5.0 million) and the Center for Brains, Minds, and Machines: The Science and the Technology of Intelligence at the Massachusetts Institute of Technology (MIT) (level at $3.0 million). The CCF investment in the MIT STC is shared with the IIS and ITR divisions.
- CCF will discontinue support for INFEWS (-$2.50 million to a total of zero) but will continue to support research related to this area through investments in CEMMSS, notably CPS and S&CC.

Education

- CCF will continue to invest in NRT (level at $1.0 million) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- CCF will continue to invest in CSforAll (level at $4.0 million), which seeks to enable rigorous and engaging computer science education in schools across the Nation.
- CCF will continue to invest in REU sites and supplements (+$220,000 to a total of $4.40 million).

Infrastructure

- CCF will continue to invest in the National Nanotechnology Coordinated Infrastructure (NNCI) (level at $600,000), supported primarily by ENG.

DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS) $207,210,000
-$23,780,000 / -10.3%

CNS Funding

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
Total	**$230.99**	**-**	**$207.21**	**-$23.78**	**-10.3%**
Research	**182.57**	**-**	**166.12**	**-16.45**	**-9.0%**
CAREER	9.60	-	9.60	-	-
Education	**18.43**	**-**	**13.09**	**-5.34**	**-29.0%**
Infrastructure	**29.99**	**-**	**28.00**	**-1.99**	**-6.6%**
Research Resources	29.99	-	28.00	-1.99	-6.6%

CNS contributes to scientific advancement, national security, and societal welfare through 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, and mobile systems. CNS also provides scientific leadership in cybersecurity, supporting research and education activities 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, 67 percent of the CNS portfolio is available for new grants and 33 percent is available for continuing grants.

FY 2018 Summary

All funding decreases/increases represent changes over the FY 2016 Actual.

Research

- CNS will continue to invest in early-career researchers through CAREER (level at $9.60 million).
- CNS will continue to lead SaTC (level at $43.70 million) in partnership with EHR, ENG, MPS, SBE, and the other CISE divisions. CNS will invest in areas of current critical importance, such as network and cloud security, cybereconomics, usability of security and privacy technologies, and assurance of software security, along with the science of security and the science of privacy. These investments also will address education and workforce issues related to cybersecurity. SaTC leverages NSF funding through joint programs with private industry and peer funding agencies.
- As part of its CEMMSS investment, CNS will continue to lead CPS (-$3.50 million to a total of $19.50 million) in partnership with five other federal agencies—Department of Homeland Security (DHS), Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), and U.S. Department of Agriculture (USDA)—ENG, and other CISE divisions. As a critical underpinning of CEMMSS, CNS investment in CPS will support foundational interdisciplinary research and education in adaptive and pervasive smart systems supporting applications such as cyber-manufacturing, smart grid, intelligent transportation systems, and

medical devices. CNS will also continue to invest in NRI (-$2.0 million to a total of $2.50 million).

- CNS will continue to lead S&CC (level at $7.50 million) in partnership with EHR, ENG, GEO, SBE, and the other CISE divisions. CNS will pursue interdisciplinary, integrative research and research capacity-building activities that improve understanding and design of intelligent infrastructure for communities, leading to enhanced quality of life for residents.
- CNS will transition support for CIF21 (-$6.50 million to a total of zero), investing in SPX (-$1.50 million to a total of $3.0 million) as part of NSCI and BIGDATA (level at $3.50 million) as part of HDR. CNS investments in NSCI will pursue foundational research leading to future HPC systems beyond the limits of current semiconductor technology, including addressing performance and scalability of parallel computing, cross-layer approaches, and novel systems architecture. CNS investments in HDR will support research on data-driven approaches to enhance performance, efficiency, and adaptability of computer systems, as well as the design and implementation of systems to support collection, curation, storage, and processing of massive data sets.
- CNS will continue to invest in UtB (-$290,000 to a total of $1.45 million), supporting research leading to improved systems for collection and analysis of physiological, cognitive, and behavioral data.
- CNS will discontinue support for INFEWS (-$2.50 million to a total of zero) and R&R (-$3.50 million to a total of zero), but will continue to support research related to these areas through investments in CEMMSS, notably CPS and S&CC.

Education

- CNS will continue to invest in NSF INCLUDES (+$130,000 to a total of $1.0 million) to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved or underrepresented in STEM.
- CNS will continue to invest in CSforAll (level at $1.50 million), in partnership with EHR, which seeks to enable rigorous and engaging computer science education in schools across the Nation. This investment will enlarge the pool of K-14 students and teachers who develop and practice computational competencies in a variety of contexts, thus advancing the 21st-century digital economy.
- CNS will continue to invest in REU sites and supplements (-$2.62 million to a total of $5.0 million).
- CNS will continue to invest in NRT (level at $490,000) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- CNS will invest in novel approaches for "CS+X" (+$20,000 to a total of $2.0 million) through IUSE, enabling the diffusion of the fundamentals of computational thinking and computer science across a broad array of other disciplines at the undergraduate level.

Infrastructure

- CNS will continue to invest in CISE Research Infrastructure (CRI) (level at $18.0 million), supporting the acquisition, enhancement, community access, and operation of state-of-the-art computing research infrastructure enabling high-quality computing research and education.
- CNS will continue to invest in the development of world-class, mid-scale research infrastructure (-$1.99 million to a total of $10.0 million) through NSFFutureCloud, Platforms for Advanced Wireless Research (PAWR), and Tomorrow's Internet Project Office (TIPOFF). CNS will transition NSFFutureCloud prototypes to full-fledged operations, providing programmable testbeds for experimenting with novel cloud architectures; and develop and deploy next-generation software-defined computing and communication infrastructure. Through PAWR, CNS will support the development of city-scale testbeds that enable research on topics ranging from dynamic spectrum sharing to mobility to measurement and monitoring, thus advancing the next generation of high-performance, robust wireless networks. As part of TIPOFF, CNS will engage the research community to envision, design, deploy and operate highly advanced experimental infrastructure for distributed computing systems.

DIVISION OF INFORMATION AND INTELLIGENT SYSTEMS (IIS) — $174,750,000 / -$20,050,000 / -10.3%

IIS Funding

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
Total	**$194.80**	**-**	**$174.75**	**-$20.05**	**-10.3%**
Research	**184.86**	**-**	**165.25**	**-19.61**	**-10.6%**
CAREER	16.75	-	13.80	-2.95	-17.6%
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	**9.94**	**-**	**9.50**	**-0.44**	**-4.4%**

IIS contributes to scientific advancement, economic growth, human health, and national security by studying the interrelated roles of people, computers, and information. IIS supports research and education activities that develop new knowledge about the role of people in the design and use of information technology with the goal of advancing human capabilities. IIS activities also increase our capability to create, manage, and understand data and information in systems ranging from implanted nano-processors to hand-held computers and globally-distributed systems. IIS research advances our understanding of how computational systems can exhibit the hallmarks of intelligence through investments in artificial intelligence, computer vision, robotics, machine learning, natural language processing, computational neuroscience, cognitive science, and related areas. These activities lay the foundation for work at the human-technology frontier by improving our understanding of how constantly evolving technologies are actively shaping our lives and how we in turn can shape those technologies, especially in a 21st-century digital society.

In general, 73 percent of the IIS portfolio is available for new research grants and 27 percent is available for continuing grants.

FY 2018 Summary

All funding decreases/increases represent changes over the FY 2016 Actual.

Research

- IIS will continue to invest in early-career researchers through CAREER (-$2.95 million to a total of $13.80 million).
- IIS will continue to lead the NRI program (-$2.35 million to a total of $14.50 million) in partnership with five other federal agencies (DOD, DOE, NASA, NIH, and USDA), three other NSF directorates (ENG, SBE, and EHR), and other CISE divisions. As a key component of CEMMSS, NRI focuses on human-centered research in developing service robots, requiring significant advances in human-robot interaction. IIS will focus on fundamental research in robotics, including advanced sensing, control, and power sources; integrated problem-solving architectures and decision algorithms; and safe, flexible and resilient structures. Application domains will include robots as co-workers in advanced manufacturing environments; aides supporting emergency responders and warriors in the field, thereby enhancing our emergency and defense preparedness; and service robots assisting the elderly to live

independently, consequently sustaining quality of life while diminishing costs of care. As part of its CEMMSS investment, IIS will continue to invest in CPS (-$3.50 million to a total of $1.0 million).

- IIS will transition support for CIF21 (-$9.50 million to a total of zero), investing in BIGDATA (level at $9.50 million) as part of HDR. IIS investments in HDR will focus on the development of novel computational, statistical, and mathematical techniques and technologies for data mining, machine learning, knowledge extraction, visualization, predictive modeling, automated discovery, and decision making, as applied to big data challenges.
- IIS will invest in S&CC (+$1.50 million to a total of $1.50 million), pursuing interdisciplinary, integrative research and research capacity-building activities that improve understanding and design of intelligent infrastructure for communities, leading to enhanced quality of life for residents.
- IIS will continue to invest in UtB (-$910,000 to a total of $11.80 million) by supporting core and crosscutting research in developing novel computational tools for performing multi-scale analysis of physiological, cognitive, and behavioral data, and innovative models that accelerate the integration of knowledge across scales and across multiple disciplines. This research aims to accelerate the formulation of an integrative, quantitative, and predictive theory of brain function, with implications for ultimately limiting the effects of mental illness and compensating for cognitive decline.
- IIS will continue to lead SCH (-$2.0 million to a total of $7.0 million) in partnership with six NIH institutes, ENG, SBE, and other CISE divisions. IIS will pursue improvements in safe, effective, efficient, and patient-centered proactive and predictive health and wellness technologies, which will contribute to improved well-being and reduced health care costs.
- IIS will continue to lead Cyberlearning and Future Learning Technologies (CFLT) (-$6.67 million to a total of $5.50 million) in partnership with EHR and other CISE divisions. This activity will integrate advances in technology with advances in the ways people learn, resolve how to use technology more effectively for promoting learning, and design new technologies for integration in learning environments and evaluate their use. New emphasis will be given to the use of technologies based on advances in artificial intelligence, cognitive aids, and learning science to support adult retraining and continuing education, thereby enabling increased employability in higher-paying jobs.
- IIS will continue to invest in SaTC (-$1.40 million to a total of $7.55 million), supporting research in cybersecurity and privacy, with an emphasis on data science, usability, and socio-technical as well as human-centered approaches.
- IIS will continue to invest in one STC, the Center for Brains, Minds and Machines: The Science and the Technology of Intelligence at MIT (level at $1.0 million), along with the CCF and ITR divisions.

Education

- IIS will continue to invest in NRT (level at $500,000) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- IIS will continue to invest in CSforAll (level at $4.0 million), which seeks to enable rigorous and engaging computer science education in schools across the Nation.
- IIS will continue to invest in REU Sites and Supplements (-$390,000 to a total of $4.40 million).

DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR) **$83,510,000**
-$9,580,000 / -10.3%

ITR Funding
(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request	Change Over FY 2016 Actual Amount	Change Over FY 2016 Actual Percent
Total	**$93.09**	**-**	**$83.51**	**-$9.58**	**-10.3%**
Research	**79.66**	**-**	**69.57**	**-10.09**	**-12.7%**
CAREER	1.00	-	-	-1.00	-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	**4.17**	**-**	**1.94**	**-2.23**	**-53.4%**
Infrastructure	**9.26**	**-**	**12.00**	**2.74**	**29.6%**
Research Resources	9.26	-	12.00	2.74	29.6%

ITR contributes to scientific advancement, economic growth, human health, and national security by providing support for transformative explorations in computer and information science and engineering research, infrastructure, and related education activities, emphasizing the funding of innovative, high-risk/high-reward, multi-investigator projects.

In general, 59 percent of the ITR portfolio is available for new grants and 41 percent is available for continuing grants.

FY 2018 Summary

All funding decreases/increases represent changes over the FY 2016 Actual.

Research

- ITR will continue to invest in NSF I-Corps™ (-$2.06 million to a total of $9.65 million) to provide NSF-funded researchers with additional support—in the form of entrepreneurial training and mentoring—to accelerate innovation and transfer of knowledge from lab to practice. As part of this investment, ITR will support I-Corps™ Sites and Nodes to further grow and sustain a national innovation ecosystem that continues to augment the development of technologies, products, and processes.
- ITR will continue to invest in center-scale Expeditions in Computing (-$4.0 million to a total of $8.0 million). Expeditions projects will continue to pursue transformative research agendas that promise to accelerate discovery at the frontiers of computer and information science and engineering.
- In collaboration with ENG, ITR will continue to invest in innovative partnerships and collaborations between academia and industry. As part of this investment, ITR will support Industry/University Cooperative Research Centers (IUCRCs) (-$1.0 million to a total of $7.0 million).
- ITR will continue to invest in S&CC (level at $6.0 million), pursuing interdisciplinary, integrative research and research capacity-building activities that improve understanding and design of intelligent infrastructure for communities, leading to enhanced quality of life for residents.
- As part of NSCI, ITR will invest in SPX (level at $1.0 million) to pursue foundational research leading to future HPC systems beyond the limits of current semiconductor technology.

- ITR will continue to invest in emerging and urgent high-priority areas of potentially transformative research through various award mechanisms, such as EArly-concept Grants for Exploratory Research (EAGERs) and Grants for Rapid Response Research (RAPIDs).
- ITR will continue to invest in one STC, the Center for Brains, Minds and Machines: The Science and the Technology of Intelligence at MIT (level at $1.0 million), along with the CCF and IIS divisions.

Education

- ITR will continue to invest in NSF INCLUDES (-$70,000 to a total of $780,000) to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved or underrepresented in STEM.
- ITR will continue to invest in NRT (-$1.69 million to a total of $1.01 million) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.

Infrastructure

- ITR will continue to invest in the development of world-class, mid-scale research infrastructure (+$2.74 million to a total of $12.0 million) through NSFFutureCloud and PAWR. ITR will transition NSFFutureCloud prototypes to full-fledged operations, providing programmable testbeds for experimenting with novel cloud architectures; and develop and deploy next-generation software-defined infrastructure, including wireless testbeds that enable research on topics ranging from radio access networks to spectrum sharing and adaptability. Through PAWR, ITR will support the development of city-scale testbeds that will enable research on topics ranging from dynamic spectrum sharing to mobility to measurement and monitoring, to enable the next generation of high-performance, robust wireless networks.

APPENDIX A – HIGH-PERFORMANCE COMPUTING PORTFOLIO

High Performance Computing Funding

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request
Petascale Computing	$8.33	-	$60.00
Innovative HPC Program	42.82	-	19.50
Extreme Digital (XD)	45.50	-	10.00
Total	**$96.65**	**-**	**$89.50**

NSF has been a leader in the use of High-Performance Computing (HPC) to advance discovery for almost four decades. NSF aims to sustain its leadership in the research, development, and broad deployment of existing as well as new HPC technologies and skills in part through its leadership of the National Strategic Computing Initiative (NSCI) in partnership with the Department of Defense (DOD) and Department of Energy (DOE), and together with the participation of other federal agencies and the private sector. OAC co-leads NSCI with MPS, and represents NSF in its leadership role across the federal government. Key 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; and support for a comprehensive advanced computing ecosystem for science and engineering research. These foci include an emphasis on a holistic approach to the Nation's science and engineering computational infrastructure as well as learning and workforce development.

The overall NSF HPC strategy and program portfolio receives guidance and input from the Advisory Committee for Cyberinfrastructure (ACCI); NSF cross-directorate Assistant Directors (AD) Council, which includes ADs and Office Heads from the various NSF research directorates and offices; and the cross-directorate working group for NSCI. In 2013, ACI supported the initiation of a two-year National Academies' study to further inform the implementation of its HPC strategy in the 2017 to 2020 timeframe. The National Academies published the final report, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017-2020*, in 2016.[20]

PETASCALE COMPUTING – BLUE WATERS

Description

A key component of NSF's current HPC investment is its support of a "leadership-class" HPC resource called Blue Waters. Blue Waters, one of the most powerful supercomputers in the world and the fastest supercomputer deployed on a university campus, is based at the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (UIUC). The Blue Waters system became operational in December 2012, and the archival storage availability came online in March 2013. It is operated by NCSA and includes the Great Lakes Consortium for Petascale Computing (GLCPC) as a partner.

Since becoming operational in 2012, Blue Waters has allowed researchers to tackle much larger and more complex research challenges than ever before possible across and within disciplines as diverse as biology, astronomy, engineering, materials science, and the geosciences. Examples of transformational research enabled by Blue Waters include: biophysicist Klaus Schulten and his team at UIUC used experimental data combined with simulations on Blue Waters to discover the precise chemical structure of the hard-shell

[20] www.nap.edu/catalog/21886/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-and-engineering-in-2017-2020

capsid encasing the HIV virus (with funding from NIH)[21]; a public-private collaboration among multiple federal agencies, universities, and companies brought together data, expertise, and the unique capabilities of Blue Waters to create the first-ever publicly-available, high-resolution elevation maps of the Arctic[22]; and ExxonMobil geoscientists and NCSA recently demonstrated a massive parallel reservoir simulation that ran thousands of times faster than typical oil and gas industry reservoir simulations, in turn allowing faster, more cost-effective, and environmentally-responsible decisions.[23]

Blue Waters complements the diverse set of national resources provided through the Innovative HPC program and eXtreme Digital (XD) environment described below. While Innovative HPC supports a portfolio of technically diverse systems capable of supporting hundreds to thousands of researchers over the course of a year, Blue Waters provides resources to focus on a small set of the largest and most computationally intensive scientific advances demanding petascale capabilities. (For more information on Innovative HPC, see the "Innovative HPC Program" section below.) XD differs as well from Blue Waters in that XD delivers a more diverse set of capabilities generally at smaller scale but to a much larger community. (For more information on XD, see the "XD Program" section below.)

The broader impacts of Blue Waters include provisioning unique infrastructure for research and education; extensive efforts accelerating education and training in the use of HPC in science and engineering; training in petascale computing techniques; promoting an exchange of information between academia and industry about the applications of petascale computing; and broadening participation in computational science and engineering through NCSA's Girls Engaged in Mathematics and Science (GEMS) program. The GEMS program is designed to encourage middle-school girls to consider mathematics- and science-oriented careers.

Current Status

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. Support for the first six months of operations was provided in the acquisition and deployment award. Support for the remaining operational phase, from FY 2014 through mid-FY 2018, was provided in a separate award to UIUC in FY 2013.

The Blue Waters education and outreach projects are ongoing; they target pre-college, undergraduate, graduate, and post-graduate students. For example, a Virtual School of Computational Science and Engineering was established as part of the project, creating courses and certificate programs focusing on petascale computing and petascale-enabled science and engineering.

The Blue Waters project also has sponsored workshops, conferences, summer schools, and seminars. An annual series of Petascale Workshops is targeted at the developers of simulation packages and aspiring application developers, and provides scientists and engineers with the knowledge and expertise needed to develop applications for Blue Waters and other petascale computers. The project also includes industrial partnership activities. The Industry Partners in Petascale Engagement (IPIPE) program provides industrial partners with a first look at the technological and scientific developments that flow from the petascale program. The Independent Software Vendor Application Scalability Forum promotes collaborations among consortium members, independent software vendors, and the industrial end-user community. In addition, annual extreme-scale workshops are held jointly with the Extreme Science and Engineering Discovery Environment (XSEDE) project. The Blue Waters team also hosts summer workshops and has created and offered courses through the Virtual School of Computational Science and Engineering mentioned above. Partnering with the Shodor Foundation, a nonprofit national resource for computational science education,

[21] https://news.illinois.edu/blog/view/6367/204804
[22] http://nga.maps.arcgis.com/apps/MapSeries/index.html?appid=cf2fba21df7540fb981f8836f2a97e25
[23] www.ncsa.illinois.edu/news/story/exxonmobil_sets_record_on_ncsas_blue_waters_supercomputer

the Blue Waters project offers undergraduate petascale course materials and internships.

Despite the success of the Blue Waters supercomputer, the system is reaching its natural obsolescence, and will complete its operational cycle in March 2019, when a no-cost extension for the operations and maintenance award of the system, approved by NSF in FY 2016, ends. With the extension of the operational end date of Blue Waters to 2019, the system will have run for roughly two years longer than the typical lifetime for a system of this type. Among the activities anticipated in FY 2018 is support for a follow-on leadership-class computing resource, succeeding Blue Waters and with attributes to be determined based on scientific and engineering priorities.

Continuation of the program beyond the operational end date of Blue Waters is guided by input from a number of stakeholder groups. These include the ACCI; AD Council; NSF program staff spanning the Foundation's research directorates and offices; the cross-directorate NSCI working group; and the National Academies' study section mentioned above. Additionally, international activities to accelerate investments in leadership-class computing, particularly in Europe and Asia, are providing additional urgency and importance for this investment strategy to maintain the Nation's global leadership role in science and engineering.

Science and engineering research and education activities enabled by Blue Waters

Blue Waters is enabling investigators across the country to conduct innovative research demanding petascale capabilities. In particular, allocations of time on Blue Waters are awarded to research teams through the NSF Petascale Computing Resource Allocations (PRAC) program. To date, the PRAC program has received over 448 requests for usage to support research across a wide spectrum of scientific and engineering disciplines, and it has made 233 awards to research teams—a 95% over-subscription request rate. The next PRAC call is anticipated in November 2017. The research topics 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.

To date, 89 science teams have published over 618 scientific papers based on research conducted using Blue Waters allocations. Furthermore, the project has issued calls for educational allocations directly involving students, including the Blue Waters Undergraduate Student Internship Program (20 students in 2016) and Blue Waters Graduate Fellowship Program (10 awards in 2016). After three years in service, Blue Waters has supported research in 219 U.S. academic institutions, 40 laboratories, institutes, and centers, and 21 industrial organizations.

Management and Oversight

NSF Structure: The project is overseen by OAC's program directors and NSF Division of Grants and Agreement (DGA) staff. These NSF staff receive strategic advice from the AD Council. Advice from the NSF Office of General Counsel (OGC) is also sought as necessary.

External Structure: During the development and acquisition phase of this project, UIUC oversaw work by a number of sub-awardees, conducted software development, and assisted competitively-selected research groups to prepare to use the Blue Waters system. The primary sub-awardee, Cray, is responsible for maintenance of the hardware, system software, and main program development tools. Other sub-

awardees worked on extreme-scale parallel algorithm and method development, the engagement of applications groups, scalable performance tools, undergraduate training, and broadening the participation of underrepresented groups in HPC. During the operational phase, the project team is advised by the Science and Engineering Team Advisory Committee (SETAC) whose composition and roles were reviewed and approved by an external panel in July 2013. This Committee is composed of representatives from research teams with Blue Waters allocations, industry scientists pursuing petascale applications, and the GLCPC.

Risks: The National Science Board (NSB) will receive updates on any major change in risk assessment, which is reviewed annually by an external panel. Risks identified during the operational phase of the project include system security, power costs, and performance/reliability/usability due to large system scale.

Reviews: The project was initially selected through a competitive merit review process in 2007, and a subsequent renewal proposal was reviewed and approved in 2013. An external panel of experts, selected by NSF, periodically reviews the progress of the project including project management, risk management, hardware and software performance, usability and reliability, and the provision of advanced user support to research groups receiving resource allocations on the Blue Waters system. One of the important roles of this external review panel is to analyze the awardee's assessments of intellectual merit and broader impacts based on the use of the system for research and education. To date, these external reviews have been conducted in February 2008, April 2008, October 2008, April 2009, July 2009, December 2009, April 2010, September 2010, December 2010, February 2011, May 2011, September 2011, March 2012, August 2012, December 2012, July 2013, December 2014, December 2015, and January 2017. OAC staff provided an update to the NSB in February 2015. Detailed information on the project's progress can be found in the project's publically-available annual reports.[24]

INNOVATIVE HPC PROGRAM

Description

Systems funded under the Innovative HPC program provide petascale peak performance. The Innovative HPC program portfolio is intended to be technically diverse, reflecting changing and growing use of computation in both the research and education processes, including through systems capable of supporting hundreds to thousands of researchers (over the course of a year) conducting leading-edge science and engineering. Additionally, the Innovative HPC program portfolio supports, complements, and extends campus and regional research cyberinfrastructures. All Innovative HPC program awards are made in the context of the XD program (described below).

There is a direct relationship between the Innovative HPC and XD programs. Several systems are currently serving as allocable resources within XD. Innovative HPC awards are generally made as two parts: an acquisition component with associated funding, and an operations and maintenance component with associated funding. Some Innovative HPC program awards do not separate these components because of the experimental nature of the systems. When an award is made, funding is provided to the institution, which issues sub-awards to vendors for acquisitions as necessary. Once a system has passed the acceptance process, vendors receive final payment for the system. After the system has been fully tested, it becomes an XD resource, and the institution becomes an XD resource provider. At this point, the award funding may be used for operations and maintenance of the system.

Beginning with the FY 2011 Innovative HPC program solicitation, *High Performance System Acquisition: Enhancing the Petascale Computing Environment for Science and Engineering*, a more sustained approach to the largest HPC services was initiated. This solicitation was based on feedback from the scientific and engineering community, providing a longer time horizon for funding HPC providers in recognition of the

[24] https://bluewaters.ncsa.illinois.edu/annual-report

value and time required for building and retaining staff skilled in interdisciplinary computational science. Thus, an eight- to 10-year award horizon is envisioned for a core HPC provider. This timeline begins with an acquisition award, which allows for the possibility of a renewal acquisition award four years after the original award. In addition to the acquisition awards, accompanying operations and maintenance awards are planned.

Current Status

Machines that have been operational in the Innovative HPC program over the years include Stampede, Blacklight, Darter, FutureGrid, Gordon, Keeneland, Kraken, Lonestar, Longhorn, and Trestles. Of these, Stampede continues to be supported by NSF. In addition, four new resources, Comet, Bridges, Jetstream, and Wrangler, began operation in FY 2015 and FY 2016.

Wrangler, came online in FY 2015 at the University of Texas at Austin. Wrangler is the most powerful data analysis system allocated in XD, with 10 petabytes (PB) of replicated, secure, high-performance data storage. The 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 (TB/s) and 275 million Input/Output Operations Per Second (IOPS). Wrangler further provides flexible support for a wide range of software stacks, including Hadoop and relational data. These are integrated with Globus Online services for rapid and reliable data transfer and sharing. Support for ongoing Wrangler operations and maintenance, starting in FY 2015 and continuing through FY 2019, is provided to the University of Texas at 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.

Comet also came online in FY 2015 at the University of California, San Diego. It was deployed to support research interests and priorities requiring large, high-throughput workloads as well as the "long tail of science," which encompasses the idea that a large number of modestly-sized, computationally-based research projects still represent a tremendous amount of research and scientific impact. Notably, as a resource responsive to the "long tail of science," Comet is particularly well-suited for science gateway use. Its heterogeneous configuration supports not only complex simulations, but also advanced analytics and visualization of outputs.

Bridges came online in FY 2016 at the Pittsburgh Supercomputing Center on the campus of Carnegie Mellon University. Bridges provides an innovative and groundbreaking HPC and data analytics system integrating advanced memory technologies to empower new communities, bringing desktop convenience to HPC, connecting to campuses, and intuitively integrating data-intensive workflows to increase the scientific output of a large community of scientific and engineering researchers who have not traditionally used HPC resources by lowering the barrier of entry to HPC. Bridges extends HPC's impact to minority-serving institutions and Established Program to Stimulate Competitive Research (EPSCoR) states, raising the level of computational awareness at four-year colleges, and promoting computational thinking in high-schools.

The fourth resource, Jetstream, also came online in FY 2016 at Indiana University. Jetstream is a new type of data analytics and computational resource for the open science and engineering research community, enabling interactive use by researchers to conduct research anytime, anywhere. Jetstream complements the current NSF-funded computational resources portfolio by bringing online a cloud-based system incorporating the best elements of commercial cloud computing resources with some of the best software in existence for solving important scientific problems. Jetstream enables new modes of sharing data and computational analysis, allowing for increased scientific reproducibility and enabling many U.S. scientists and engineers to make new discoveries that are important to understanding the world around us, improving the quality of life of American citizens, and promoting America's competitive standing.

Bridges and Jetstream, singularly and collectively, significantly broadened the spectrum of system capabilities supported by OAC's Innovative HPC program by delivering innovative computational resources to an increasingly diverse community and portfolio of scientific research and education projects, with the goal of including new communities with new and creative approaches and priorities that are different from the more traditional HPC users, and that would benefit from advanced computational capabilities at the national level.

The Stampede project at the University of Texas at Austin delivered a new system for allocation of NSF XD cyberinfrastructure services in January 2013, and will continue to operate through September 2017. The resources and accompanying services target science and engineering researchers using both advanced computational methods and emerging data-intensive approaches. The system boosted XD resources to nearly twice their previous capacity, and provided researchers with early access to Intel Many Integrated Core (MIC) processors, which were accepted in August 2013. An additional technical upgrade to Stampede was awarded in FY 2016, adding 508 updated "Knights Landing" processors and an Omni Path highspeed interconnect to the system contributing two-fold value to advance research. This technical upgrade provided significantly increased memory and enhanced performance for researchers, along with a production operations platform for researchers to bridge to future many-core computing architectures and computational parallelism through 2021.

Consistent with the FY 2011 Innovative HPC program solicitation, *High Performance System Acquisition: Enhancing the Petascale Computing Environment for Science and Engineering*, that resulted in the acquisition, development, and deployment of Stampede, in FY 2016 NSF awarded *Stampede 2: The Next Generation of Petascale Computing for Science and Engineering* to the University of Texas at Austin following a rigorous merit review, enabling the acquisition, development, and deployment of "Stampede 2" as a successor resource to Stampede. Stampede 2 will serve as the primary national resource ("workhorse") for thousands of U.S. academic researchers, complement other national HPC resources, and provide capabilities beyond the reach of campuses and regional resources, including support for multiscale modeling, simulation, and data-intensive research. Stampede 2 will be deployed into production operation through three phases: progressive installations of Knights Landing many-core nodes responsive to interests in high computation processing; addition of highly complementary SkyLake processors responsive to data-intensive computing; and final deployment of persistent memory to the previously deployed Skylake processors to significantly enhance overall system performance. Stampede 2 will serve the high-end, open science community through production operations beginning in FY 2017 and continuing through FY 2021.

Science and engineering research and education activities enabled by Innovative HPC

Innovative HPC is enabling world-leading transformative advances in science and engineering research, in the integration of research and education, and in broadening participation in science and engineering by underrepresented groups. These advances are enabled by providing researchers and educators with usable access to computational resources beyond those typically available on most campuses, together with the interfaces, consulting support, and training necessary to facilitate their use.

Through the unifying XD framework and services, the Innovative HPC program enables researchers to manipulate extremely large amounts of digital information from simulation, sensors, and experiments, and adds needed capabilities in remote visualization, an increasingly important analysis tool for modern science and engineering. The complete spectrum of scientific research can leverage Innovative HPC program resources. This includes economics, cosmology and astrophysics, geosciences, climate and weather modeling, physics, chemistry, biology and medicine, earthquake engineering, and mechanical engineering.

Outreach and training critical to reducing the barriers to the use of systems supported by the Innovative HPC program by the research and education community will be provided by engaging research universities

and foundations. The Innovative HPC program incorporates new computational technologies and new approaches to software and data management, together with the expertise to enable researchers and students to complement theory and experiment with an equal emphasis in computation.

Management and Oversight

NSF Structure: OAC's program directors provide direct oversight during both the acquisition and operations and maintenance phases. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors. The program directors also hold bi-weekly teleconferences with the awardees.

External Structure: Each Innovative HPC program award is managed under a cooperative agreement. Each awardee is responsible for the satisfactory completion of milestones in order for the spending authorization to be raised. Progress is assessed by annual reviews and the NSF program directors.

Each project has a detailed management plan in place. Each cooperative agreement includes the management structure, milestones, spending authorization levels, and review schedule.

Risks: 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. The funded projects are experimental in nature; therefore, they encompass high-risk, high-reward scenarios. The award process requires that risks be identified and analyzed, and that a mitigation plan be created and followed. One of the activities of the periodic NSF external reviews, conducted by an external panel of experts, is to revisit and assess the risk situation and make recommendations as deemed necessary. Risks that are no longer applicable are retired. New risks may be added, or the degree of risk promoted or demoted as necessary, all of which is documented in a risk register. Typically, project risks are substantially reduced subsequent to deployment. Thus, pacing of acquisitions and deployments allows balance in overall portfolio risk for the Innovative HPC program.

Reviews: Semi-annual reviews are typically performed during the acquisition phase. Annual reviews, conducted by an external panel of expert reviewers, are performed during the operational phase of each project. OAC program directors manage the reviews. The reviewers' backgrounds include scientific research, project management, large-scale systems acquisitions and operations, and familiarity with projects funded by NSF as well as other federal agencies. To the extent possible, continuity through this series of reviews is provided by using the same set of reviewers.

EXTREME DIGITAL (XD) PROGRAM

Description

The Extreme Digital (XD) program adds value to the Innovative HPC program by coordinating the HPC resources, providing advanced assistance to the user community, and broadening participation. The vision is to create and sustain an advanced, nationally-distributed, open cyberinfrastructure comprising shared user and management services, supercomputing, storage, analysis, visualization systems, data services, and science gateways connected by high-bandwidth networks, integrated by coordinated policies and operations, and supported by computing and technology experts.

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. The XD Metrics Service (XMS) is a separate award, while all other services constitute the XSEDE project. 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: XSEDE and XMS. The smaller XMS award was made in 2015 to the University at Buffalo – The State University of New York. This award provides metrics services allowing measurement of key operational data for both resources and services. The XSEDE award to UIUC was renewed in September 2016, continuing the prior XSEDE award for another five-year period. There are 18 XSEDE partners engaged via subawards to the University of Tennessee at Knoxville (National Institute for Computational Sciences), Carnegie Mellon University and University of Pittsburgh (Pittsburgh Supercomputing Center), University of Texas at Austin (Texas Advanced Computing Center), University of California, San Diego (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 (NCAR), Georgia Institute of Technology, Oklahoma State University, University of Georgia, Oklahoma University, University of Southern California, and University of Arkansas. XSEDE has annual external reviews at NSF, with the first review of the renewed project scheduled to take place in June 2017.

Science and engineering research and education activities enabled by XD

XD services enable transformative advances in science and engineering research, in the integration of research and education, and in broadening participation in science and engineering to underrepresented groups. This is 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 provides HPC services; enables researchers to manipulate extremely large amounts of digital information from simulations, sensors, and experiments; and adds needed capabilities in remote visualization, an increasingly important analysis tool for modern science and engineering.

XD's XSEDE project is developing 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 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 the barriers to the use of advanced digital systems by the research and education communities. The project incorporates new ideas and technologies to enable researchers and students to move transparently between local and national resources, substantially lowering the barriers to effective use of cyberinfrastructure and promoting enhanced productivity.

XD's XMS project develops novel methods and tools to collect data from a diverse set of sources, to store the data, and to provide user interfaces for viewing the data by different stakeholder communities. The immediate users of these methods and tools are the operators and users of NSF's HPC resources. However, the new principles and methods have the potential to reach broad communities in research and education that deal with the collection, storage, analysis, and use of data.

Management and Oversight

NSF Structure: 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.

External Structure: Each XD award is managed under a cooperative agreement. Each awardee is responsible for the satisfactory completion of milestones prior to processing of grant increments. Each project has a detailed management plan in place. Each cooperative agreement includes the management structure, milestones, spending levels over time, and review schedule.

Risk: 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. Identified risks and planned actions are reported to, and reviewed with, the program directors.

Reviews: Annual reviews (for XSEDE) and mid-project reviews (for XMS) are conducted by external panels of expert reviewers. OAC program directors manage these reviews. The reviewers' backgrounds include scientific research, project management, operations of HPC centers, and familiarity with projects funded by NSF as well as other federal agencies. To strike a balance between continuity and broad community engagement, approximately half of the annual review panel members have served in this role previously while the other half are new members.