DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) $994,800,000 +$58,980,000 / 6.3%

CISE Funding

(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Advanced Cyberinfrastructure (ACI)	219.19	222.30	236.31	14.01	6.3%
Computing and Communication Foundations (CCF)	195.69	194.23	206.47	12.24	6.3%
Computer and Network Systems (CNS)	231.45	231.10	245.66	14.56	6.3%
Information and Intelligent Systems (IIS)	194.58	194.90	207.20	12.30	6.3%
Information Technology Research (ITR)	92.07	93.29	99.16	5.87	6.3%
Total, CISE	**$932.98**	**$935.82**	**$994.80**	**$58.98**	**6.3%**

Totals may not add due to rounding.

The FY 2017 Budget Request for CISE is $994.80 million, of which $938.43 million is discretionary funding and $56.37 million is new mandatory funding. The major focus of the mandatory funding is support for CISE's core activities, with special emphasis on early-career investigators.

CISE's request is shaped by a special emphasis on early-career researchers, especially in terms of its new mandatory funding. Early-career investigators not only catalyze the next generation of breakthrough discoveries, but they also embrace novel approaches for accelerating the research enterprise more broadly; today these approaches include significant use of computation and data-intensive techniques, along with the pursuit of increasingly interdisciplinary research that falls at the boundaries of traditional academic disciplines.

Examples of CISE activities related to fostering early-career researchers include:

- Improvement in the overall success rate of high-quality research proposals for core disciplinary programs, including broadening the participation of early-career investigators, women, and underrepresented minorities;
- Emphasis on computational and data-intensive science, well-aligned with CISE's investments in this area;
- Support for research enhancing the robustness and reliability of science and engineering advances; and
- Resources to bridge CISE's core activities further, spanning research and research infrastructure, including interdisciplinary activities with other science and engineering disciplines.

About CISE

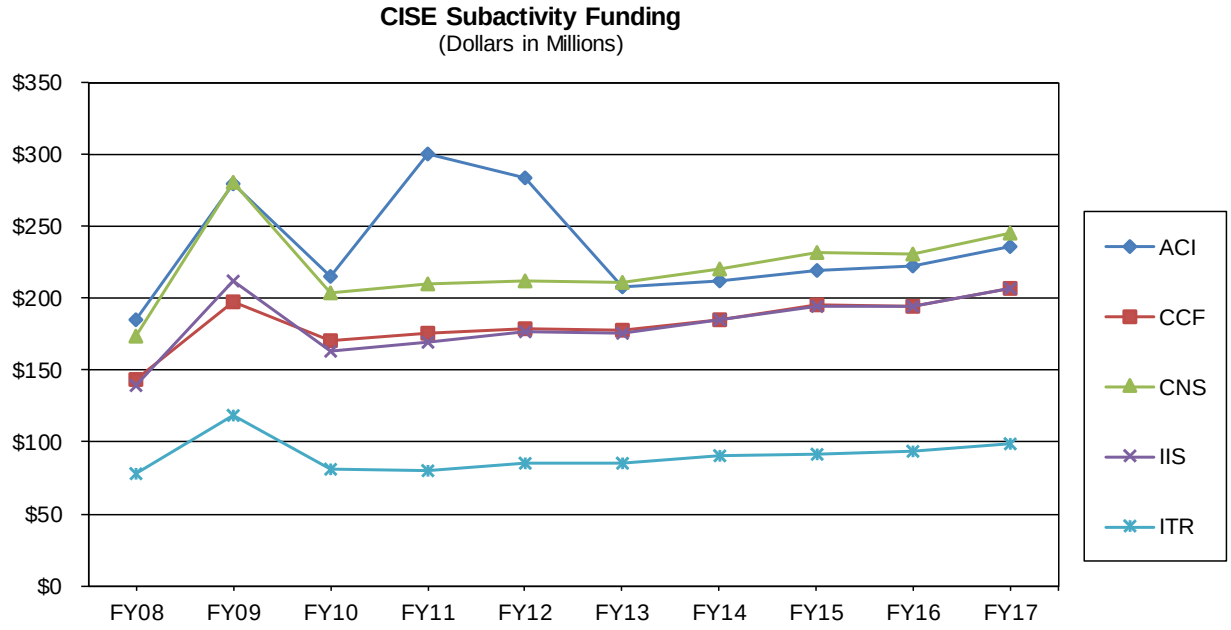
CISE's mission is to promote the progress of computer and information science and engineering research and education, and advance the development and use of cyberinfrastructure across the science and engineering research enterprise; to promote understanding of the principles and uses of advanced computer, 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 sub-fields 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's FY 2017 Budget Request is shaped by the following NSF-wide priorities: Cyber-Enabled Materials, Manufacturing, and Smart Systems (CEMMSS), which includes Advanced Manufacturing, Designing Materials to Revolutionize and Engineer our Future (DMREF), and Smart Systems, which will span a new investment area in Smart and Autonomous Systems (S&AS), along with continuing investments in Cyber-Physical Systems (CPS) and the National Robotics Initiative (NRI); Clean Energy Technology, which includes Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS); Cyberinfrastructure Framework for 21st Century Science, Engineering, and Education (CIF21), which will begin transitioning to the NSF-wide National Strategic Computing Initiative (NSCI) and Data for Scientific Discovery and Action (D4SDA); Secure and Trustworthy Cyberspace (SaTC); Smart and Connected Communities (S&CC); Risk and Resilience; Understanding the Brain (UtB); Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES); NSF Innovation Corps (I-Corps™); and NSF Research Traineeship (NRT).

CISE continues to provide leadership for the multi-agency Subcommittee on Networking and Information Technology Research and Development (NITRD), which is co-chaired by the CISE Assistant Director. All research, education, and research infrastructure projects supported by CISE enrich the agency's NITRD portfolio. As noted by the President's Council of Advisors on Science and Technology (PCAST) in its *Report to the President and Congress – Ensuring Leadership in Federally Funded Research and Development in Information Technology* (August 2015),[1] advances in Networking and Information Technology (NIT) are key drivers of U.S. economic competitiveness. Essentially all practical applications of information technology (IT) are based on ideas and concepts that emerged from investments in basic computing research, driving discovery and innovation in many other areas. This includes frontiers of scientific research, advanced manufacturing, education and workforce development, health and wellness technologies, sustainability and energy science, transportation, national and homeland security research, and public and private organizational effectiveness and efficiency. These fundamental ideas and concepts have enabled innovative products and applications that now permeate all areas of modern life, positioning NSF and CISE in a central and essential role in improving the Nation's economic outlook and advancing a highly trained, technologically astute workforce.

CISE provides about 82 percent of the federal funding for basic research at academic institutions in the computer sciences.

[1] www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/nitrd_report_aug_2015.pdf



FY 2009 funding reflects both the FY 2009 omnibus appropriation and funding provided through the American Recovery and Reinvestment Act of 2009 (P.L. 111-5).

The FY 2011 budget for ACI [then the Office of Cyberinfrastructure (OCI)] includes $90.50 million in OCI funds that were obligated in FY 2010, de-obligated in FY 2011, and then re-obligated to other projects in the OCI portfolio. Similarly, the FY 2012 ACI budget includes $71.59 million over the enacted level for OCI due to recoveries of prior-year unpaid OCI obligations that were in turn re-obligated toward other OCI projects in FY 2012.

FY 2017 Summary by Division

- ACI's FY 2017 Budget Request focuses on maintaining its support of research cyberinfrastructure to advance all areas of science and engineering. ACI will begin transitioning its investment from the sunsetting in FY 2017 NSF-wide CIF21 priority area to NSCI and D4SDA, while continuing its investments in programs such as Data Infrastructure Building Blocks (DIBBs), Software Infrastructure for Sustained Innovation (SI^2), EarthCube, and Computational and Data-Enabled Science & Engineering (CDS&E). Together with the Mathematical and Physical Sciences (MPS) directorate, ACI will co-lead the NSF-wide NSCI activity, and will represent NSF in its leadership role across the federal government. ACI's NSCI activities will cultivate an enduring high-performance computing ecosystem, including highly capable, shared research cyberinfrastructure in support of national and Foundation-wide priority areas such as INFEWS and UtB. In coordination with other directorates' research priorities and cyberinfrastructure investments, ACI's D4SDA activities will emphasize both innovative and sustainable data science infrastructure for research communities as well as new approaches to community governance and research data lifecycles in alignment with NSF's *Public Access Plan.*[2] Beyond CIF21, NSCI, and D4SDA, ACI will continue to invest in existing programs in computational science, software, data, networking, and cybersecurity. ACI will also continue to support other cross-disciplinary activities, including transitioning discoveries to practice in SaTC, and fostering resilient critical infrastructure systems through participation in Risk and Resilience. ACI will remain responsible for providing national resources and instruments to facilitate collaborations and greater data sharing across research communities. ACI-supported infrastructure will be used to address some of the most difficult and complex research problems in all areas of science and engineering.

[2] www.nsf.gov/pubs/2015/nsf15052/nsf15052.pdf

- CCF's FY 2017 Budget Request focuses on maintaining support for its core programs as well as NSF-wide investments. CCF will discontinue support for CIF21 as that NSF-wide priority area sunsets, reinvesting some of these funds in NSCI and D4SDA. CCF investments in NSCI will build on past investments in eXploiting Parallelism and Scalability (XPS) to pursue hardware and software research leading to high-performance computing (HPC) systems in the post-Moore's Law era. This includes algorithms and architectures for massive concurrency, energy-efficient computing, and system resilience at extreme scales. CCF investments in D4SDA will pursue foundational techniques to enable computationally efficient storage and processing of big data and more effective query and analysis from heterogeneous data sources. CCF will continue investing in INFEWS, focusing on innovative optimization techniques, algorithms, and software development, as part of its support for Clean Energy Technology; and in UtB, supporting the foundational capabilities necessary to integrate computational models across multiple scales. CCF will also continue to support foundational research in SaTC, including new theories, models, methods, architectures, and tools for increased security, privacy, and trust. As part of the National Nanotechnology Initiative (NNI), CCF will focus on foundational research and nanoscale devices and systems, and will invest in the National Nanotechnology Coordinated Infrastructure (NNCI).

- CNS's FY 2017 Budget Request focuses on maintaining support for its core programs as well as NSF-wide investments. CNS will continue to lead the SaTC program in partnership with the Education and Human Resources (EHR); Engineering (ENG); MPS; and Social, Behavioral, and Economic Sciences (SBE) directorates, as well as the other divisions in CISE. CNS will support CEMMSS through leadership of the CPS program in partnership with the Department of Homeland Security (DHS), Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), U.S. Department of Agriculture (USDA), ENG, and other CISE divisions. While CNS will discontinue support for CIF21 as that NSF-wide priority area sunsets, the division will reinvest some of these funds in NSCI to advance systems architecture and D4SDA to pursue data-focused research on computer systems. CNS will support the NSF-wide multi-disciplinary activity in S&CC, building on previous investments in Urban Science and US Ignite. These investments will advance fundamental research in advanced networking, physical sensors/devices, and large-scale data management, analysis, and decision making to improve quality of life, health, well-being, and learning in smart and connected communities. With EHR and the other CISE divisions, CNS will continue to support the STEM + Computing (STEM+C) Partnerships program. Along with EHR, CISE through CNS will also support the Administration's Computer Science (CS) for All initiative, which accelerates NSF's ongoing efforts to enable rigorous and engaging computer science education in schools across the Nation. CNS will continue its support for mid-scale network infrastructure. This includes transitioning NSFFutureCloud prototypes to full-fledged operations; providing programmable testbeds for experimenting with novel cloud architectures; and developing and deploying next-generation software-defined infrastructure, including wireless testbeds.

- IIS's FY 2017 Budget Request focuses on maintaining support for its core programs as well as NSF-wide investments. IIS will increase its investments in cognitive science and neuroscience in support of UtB, building on investments in computational neuroscience and foundational research programs to advance understanding of brain functions. IIS will participate in CEMMSS through leadership of NRI, in partnership with the Department of Defense (DOD), Department of Energy (DOE), NASA, NIH, and USDA, three other NSF directorates (ENG, EHR, and SBE), and other CISE divisions. NRI will accelerate the development and use of robots in the U.S. that work beside or cooperatively with people. In addition, IIS will provide initial support for a new emphasis on S&AS within CEMMSS. S&AS will focus on fundamental science and engineering addressing how intelligent physical systems sense, perceive, and operate in environments that are dynamic, uncertain, and unanticipated. While IIS will discontinue support for CIF21 as the NSF-wide priority area sunsets, the division will reinvest some of

these funds in D4SDA and NSCI. IIS investments in D4SDA 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. These investments will also include NSF's continued leadership of the National Big Data R&D Initiative. IIS will invest in INFEWS, supporting novel approaches for large-scale data analysis and management. Additionally, IIS will continue to lead the joint NSF-NIH Smart and Connected Health (SCH) program, in partnership with ENG, SBE, and other CISE divisions. Alongside EHR and ENG, IIS also will continue to lead the Cyberlearning and Future Learning Technologies (CFLT) program, which aims to integrate advances in technology with advances in understanding how people learn, with a focus on online learning environments.

- ITR's FY 2017 Budget Request supports emerging high-priority areas of potentially transformative research. Through continued investments in NSF I-Corps™, ITR will build on foundational research and guide the output of scientific discoveries in the development of technologies, products, and processes that benefit society. ITR will continue to invest in the center-scale Expeditions in Computing program. ITR will invest in multi-disciplinary national and international research networks, aiming to build communities across emerging areas of research and education as well as across geographic boundaries. Working with EHR, ENG, Geological Sciences (GEO), SBE, and other CISE divisions, ITR will invest in S&CC, transitioning prior ITR investments in Urban Science and US Ignite. As part of S&CC, ITR will support fundamental research on advanced networking, physical sensors/devices, and large-scale data management, analysis, and decision making, together with the necessary community building efforts, to improve quality of life, health, well-being, and learning in smart and connected communities. ITR will continue its investments in NSF INCLUDES and NRT. ITR will also continue its investments in mid-scale network infrastructure, including transitioning NSFFutureCloud prototypes to full-fledged operations, providing programmable testbeds for experimenting with novel cloud architectures; and developing and deploying next-generation software-defined infrastructure, including wireless testbeds.

Major Investments

CISE Major Investments

(Dollars in Millions)

Area of Investment	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
CAREER	46.76	39.92	40.46	0.54	1.4%
CEMMSS	89.00	90.98	92.50	1.52	1.7%
Advanced Manufacturing	*41.27*	*43.25*	*41.27*	*-1.98*	*-4.6%*
Clean Energy Technology	21.00	22.57	45.90	23.33	103.4%
CIF21	88.34	84.21	50.00	-34.21	-40.6%
Computer Science for All	-	10.00	10.00	-	-
D4SDA	-	-	19.60	19.60	N/A
INFEWS	-	9.00	6.00	-3.00	-33.3%
National Strategic Computing Initiative	-	-	19.70		
NSF I-Corps™	11.02	11.65	11.65	-	-
NSF INCLUDES	-	1.87	1.78	-	-
NRT[1]	13.38	6.69	7.10	0.41	6.1%
Risk and Resilience	5.50	6.00	6.00	-	-
SaTC	70.56	70.50	70.50	-	-
SEES	13.32	-	-	-	N/A
Smart & Connected Communities/Urban Science	1.00	3.50	16.50	13.00	371.4%
Understanding the Brain	16.50	29.72	23.58	-6.14	-20.7%
BRAIN Initiative	*5.65*	*10.00*	*10.00*	-	-

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

[1] Commitments for Integrative Graduate Education and Research Traineeship (IGERT) are included in the NRT line and were $130,000 in FY 2015. FY 2015 Actual NRT funding includes FY 2014 and FY 2015 NRT awards.

- CAREER: This program invests in 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: CISE, in partnership with BIO, EHR, ENG, and MPS, aims 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 systems in their full complexity and dynamics, and develop a smart systems technology framework spanning robotic, cyber-physical, and autonomous systems. In FY 2017, CISE will leverage synergistic advances made in earlier years of CEMMSS to place an emphasis on Smart Systems. As part of this emphasis, CISE will continue to lead the CPS and NRI programs, and will also provide initial support for a new investment in S&AS. This investment area will focus on fundamental science and engineering addressing how intelligent physical systems sense, perceive, and operate in environments that are dynamic, uncertain, and unanticipated. This research activity will accelerate the transformation of static systems, processes, and edifices into intelligent, autonomous systems, such as those that can sense, learn, and adapt.

- Advanced Manufacturing: As part of CEMMSS, CISE, in partnership with ENG and MPS, will invest in research that integrates ubiquitous sensors, computational tools, and highly connected cyber-physical systems in smart processing and cyber-manufacturing systems. This investment will enable new functionalities 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.

- Clean Energy Technology: CISE will increase support for foundational research in energy-intelligent computing; the development of new theory, algorithms, and design principles to investigate energy versus computation and communication tradeoffs; and the scalability and sustainability of smart energy production software and hardware. CISE research on clean energy is supported partially via investments in INFEWS, and includes investments in basic research in support of alternative energy and energy efficiency related to batteries, energy storage, and vehicle technologies.

- CIF21: CISE will continue to lead CIF21 while at the same time beginning the transition to new activities under NSCI and D4SDA as the NSF-wide CIF21 priority area begins to sunset. Investments in the Big Data, DIBBs, SI^2, EarthCube, and CDS&E programs will continue. Big Data research will focus on core scientific and technological means of managing, analyzing, visualizing, and extracting useful information from large, distributed, and heterogeneous data sets as well as applications in specific research domains. DIBBs will continue to aim to develop, implement, and support new data cyberinfrastructure to store and manage the diversity, size, and complexity of current and future data sets and streams. To advance new computational infrastructure, SI^2 will seek to advance new paradigms and practices in the development and use of robust, reliable, usable, and sustainable software. Additional information about CISE investments in D4SDA and NSCI is provided below.

- CS for All: Together with EHR, CISE will continue to invest in the CS for All initiative to accelerate NSF's ongoing efforts to enable rigorous and engaging computer science education in schools across the Nation. This funding will support continued prototyping of instructional materials, scalable and sustainable teacher professional development models, approaches to pre-service preparation for CS teachers, and teacher resources, along with research to study their effectiveness.

- D4SDA: CISE will lead the cross-disciplinary D4SDA activity, which will begin enabling 21st-century science, engineering and education to move toward effective use of digital data to advance discovery through activities that promote foundational research in critical techniques and technologies; supporting high-priority, data-intensive science with innovative, reusable data and knowledge infrastructures; enabling and incenting scientific communities to address data governance issues and research data lifecycle issues in alignment with NSF's *Public Access Plan*; and educating the future data-savvy workforce of scientists, engineers, and educators. D4SDA also will develop additional collaborations and partnerships as appropriate.

- INFEWS: CISE will support research on the safety and security of the food-energy-water nexus through investments in new resource management algorithms and architectures; real-time coordination and communications; robust observation, sensing, and inference; large-scale data analysis and management, including modeling and simulation; and optimization of complex systems. As noted below, CISE will support shared cyberinfrastructure for INFEWS through its support for NSCI.

- NSCI: Through ACI, CISE will co-lead the NSF-wide NSCI activity with MPS, and will represent NSF in its leadership role across the federal government. The goal of NSCI is to maximize the benefits of HPC for scientific discovery and economic competitiveness. Under NSCI, CISE will enable advances in HPC systems and maximize their benefits through deep integration of HPC cyberinfrastructure with science and engineering research along a number of key fronts, including 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, networking technology, accessibility, workflow, and workforce development. CISE's investments will lead to shared cyberinfrastructure for priority areas including INFEWS and UtB.

- NSF I-Corps™: CISE will continue to support I-Corps™ Teams, Sites, and Nodes 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's investment 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: CISE will participate 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.

- NRT: CISE will continue to fund STEM graduate students in interdisciplinary areas of national priority, and to support the development of transformative and scalable models for STEM graduate education.

- Risk and Resilience: In partnership with ENG and SBE, CISE supports the science and engineering necessary to enable advances in large-scale resilient and interdependent infrastructures, particularly in the context of smart and connected communities that are increasingly dependent upon the successful operation of such infrastructures.

- SaTC: NSF continues to align its cybersecurity investments (including investments from EHR, ENG, MPS, and SBE) with the federal cybersecurity R&D strategy through its support of SaTC. This investment area aims to support the research and education that will ensure society's ubiquitous computing and communication systems deliver the quality of service they are designed to achieve without disruption, while enabling and preserving privacy, security, and trust. As part of this investment, CISE will continue collaborating with EHR to support cyber-secure workforce development to enable a growing pipeline of researchers and educators, and to develop a citizenry that understands the security and privacy of the digital systems on which society depends. This investment also includes support for the Comprehensive National Cybersecurity Initiative (CNCI) ($48.0 million).[3]

- S&CC: In collaboration with EHR, ENG, GEO, and SBE, CISE will support this NSF-wide multidisciplinary activity, building upon previous CISE investments in US Ignite and Urban Science. As part of this investment, CISE will support a network of regional research hubs that will advance fundamental research on advanced networking, physical sensors/devices, and large-scale data management, analysis, and decision making, together with the necessary community building efforts, to improve quality of life, health, well-being, and learning in smart and connected communities. CISE's investment 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.

- UtB: In collaboration with other NSF directorates and offices, CISE will support 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 knowledge across

[3] www.whitehouse.gov/issues/foreign-policy/cybersecurity/national-initiative

scales and across multiple disciplines; and innovative neurotechnologies to monitor and further brain function. This research aims to accelerate the formulation of an integrative, quantitative, and predictive theory of brain function. A portion of CISE funding will continue to support exploration of a National Brain Observatory together with BIO and MPS. As noted above, through NSCI, CISE will support shared cyberinfrastructure for UtB.

CISE Funding for Centers Programs and Facilities

CISE Funding for Centers Programs

(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Total, Centers Programs	**$10.00**	**$10.00**	**$10.00**	**-**	**-**
STC: Science of Information (CCF)	5.00	5.00	5.00	-	-
STC: The Center for Brains, Minds and Machines: the Science and the Technology of Intelligence (CCF, IIS, ITR)	5.00	5.00	5.00	-	-

Totals may not add due to rounding.

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

- CISE will provide the seventh year of funding for the STC Science of Information at Purdue University. The goal of this center is to develop a new science of information, incorporating common features associated with data/information, such as space, time, structure, semantics, and context, but which are not addressed by earlier mathematical theories, e.g., data obfuscation and hiding techniques. This new science of information will enhance robustness and the principles of redundancy and fault tolerance found in natural systems.
- CISE will provide the fifth year of funding for the STC The Center for Brains, Minds and Machines: the Science and the Technology for Intelligence at MIT. This center has five main research themes: circuits for intelligence; the development of intelligence in children; social intelligence; the integration of visual, motor, language, and social intelligence; and theoretical aspects of intelligence.

CISE Funding for Facilities

(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Total, Facilities	**$0.60**	**$0.60**	**$0.60**	**-**	**-**
Nanotechnology Infrastructure Coordinated Program (CCF)	0.60	0.60	0.60	-	-

Totals may not add due to rounding.

For detailed information on individual facilities, please see the Facilities chapter.

Summary and Funding Profile

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

In FY 2017, the number of research grant proposals is expected to increase by approximately 7.0 percent compared to the FY 2016 Estimate. CISE expects to award approximately 1,700 research grants in FY 2017. Average annualized award size and average award duration are expected to remain constant between the FY 2016 Estimate and FY 2017 Estimate.

Funding for research infrastructure represents 17.4 percent of the CISE Request. Most of CISE's research infrastructure support is for High Performance Computing (HPC) (see Appendix A for more information on the HPC portfolio).

CISE Funding Profile

	FY 2015 Actual Estimate	FY 2016 Estimate	FY 2017 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,038	8,600	9,200
Number of New Awards	1,887	1,950	2,100
Funding Rate	23%	23%	23%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,627	8,150	8,700
Number of Research Grants	1,590	1,650	1,750
Funding Rate	21%	20%	20%
Median Annualized Award Size	$160,297	$165,000	$165,000
Average Annualized Award Size	$187,106	$200,000	$200,000
Average Award Duration, in years	2.9	3.0	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. CISE is not holding any COVs in FY 2016.

Science and Technology Policy Institute (STPI) Reports and Evaluations

- In FY 2012, the Science and Technology Policy Institute (STPI) was tasked to conduct program evaluation feasibility studies for the SaTC and CEMMSS investments. These feasibility studies are providing methods for examining baseline portfolio investments and identifying metrics to measure progress toward program goals. They are a part of a broader effort to develop a plan for impact assessments, particularly of the SaTC investment. The preliminary work to identify baseline evaluation metrics was conducted in FY 2013 – FY 2015, and it is anticipated that further program evaluation analyses will begin once one or more contracts are put into place in FY 2016. In the case of SaTC, yearly program-wide assessments are being presented to NSF senior management.

Computing Education Evaluation

- In addition, evaluation is a key part of CISE's education programs. The STEM+C Partnerships program projects managed by CISE include rigorous research and/or evaluation plans designed to guide project progress and measure project impacts. These plans include descriptions of the instruments and metrics that are to be used in the assessments. CISE has contracted with STPI to conduct an evaluation feasibility study for its STEM+C Partnerships portfolio, and with the Education Development Center,

Inc. (EDC) to develop an evaluation instrument for the CS 10K track. The first program evaluation of the CS 10K track is currently being initiated.

Reports

- In 2008, CISE funded the Computer Science and Telecommunications Board (CSTB) within the National Academy of Sciences (NAS) 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*,[4] 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.[5] A current CSTB study, *Continuing Innovation in Information Technology: A Workshop* (described below), is employing this report's framework.
- In FY 2012, a CSTB study, *The Future of Computing Performance: Game Over or Next Level?,*[6] together with a white paper from the CISE-funded Computing Community Consortium (CCC), *21st Century Computer Architecture,*[7] outlined the need for advances in computer architecture research which led to the development of the XPS program that was initiated in FY 2013.
- 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;[8] this led to the development of the NSFFutureCloud program started in FY 2014.
- In FY 2014 through FY 2015, the CCC led several additional community visioning efforts that have the potential to influence the development of CISE programs in FY 2017:
  - *Computing Visions 2025:*[9] sought to inspire 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.*
  - *A New Age of Computing and the Brain*: sought to bring together computer and information scientists and brain researchers to explore opportunities and connections at the intersection of computer and information science and brain science. The CCC has published a workshop report summarizing the key findings, which stands to influence CISE's and NSF's UtB investment.[10]
  - *Toward a Science of Autonomy for Physical Systems:*[11] sought to offer a series of white papers framing the challenges and opportunities associated with a future of autonomous physical systems across a range of domains including healthcare, transportation, and disaster response. These white papers have the potential to influence CISE's S&AS investment.
- CISE also funded four CSTB studies that are currently ongoing and have the potential to influence the development of CISE programs in FY 2017:
  - *Continuing Innovation in Information Technology: A Workshop:*[12] conducted a public workshop that highlights 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*

[4] www.nap.edu/catalog.php?record_id=12174
[5] www.nap.edu/catalog.php?record_id=13427
[6] www.nap.edu/openbook.php?record_id=12980
[7] http://cra.org/ccc/docs/init/21stcenturyarchitecturewhitepaper.pdf
[8] http://cra.org/ccc/visioning/visioning-activities/mid-scale-infrastructure-investments-for-computing-research
[9] http://cra.org/ccc/visioning/computing-visions-2025/
[10] http://cra.org/ccc/wp-content/uploads/sites/2/2014/12/BRAIN-Report.pdf
[11] http://cra.org/ccc/resources/ccc-led-whitepapers/#toward-a-science-of-autonomy-for-physical-systems
[12] http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_086055

Information Technology and explore further uses of the figure and framework.

- *A Primer on Cybersecurity: Leveraging Two Decades of National Academies Work:*[13] is examining what is known about effective technical and nontechnical approaches, the state of the art and open challenges, why relatively little progress has been made in cybersecurity despite the recommendations of many reports from the Academies and elsewhere, and potential policy responses.
- *Toward 21st-Century Cyber-Physical Systems Education:*[14] is completing a study on the current and future needs in education for cyber-physical systems (CPS), and articulating a vision for a 21st-century CPS-capable U.S. workforce.
- *Future Directions for NSF Advanced Computing Infrastructure to support U.S. Science in 2017-2020:* is examining anticipated priorities and associated tradeoffs for advanced computing in support of NSF-sponsored science and engineering research. An interim report was published in FY 2014,[15] and a final report is anticipated in FY 2016.

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

Number of People Involved in CISE Activities

	FY 2015 Actual Estimate	FY 2016 Estimate	FY 2017 Estimate
Senior Researchers	7,302	7,400	7,800
Other Professionals	1,278	1,300	1,400
Postdoctoral Associates	498	500	500
Graduate Students	6,423	6,500	6,900
Undergraduate Students	2,367	2,400	2,600
Total Number of People	**17,868**	**18,100**	**19,200**

[13] http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_073130
[14] http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_084351
[15] www.nap.edu/catalog/18972/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-and-engineering-in-2017-2020

DIVISION OF ADVANCED CYBERINFRASTRUCTURE (ACI) $236,310,000
+$14,010,000 / 6.3%

ACI Funding
(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Total, ACI	**$219.19**	**$222.30**	**$236.31**	**$14.01**	**6.3%**
Research	**93.62**	**93.30**	**107.31**	**14.01**	**15.0%**
CAREER	1.52	2.00	2.00	-	-
Education	**9.12**	**5.20**	**5.20**	**-**	**-**
Infrastructure	**116.45**	**123.80**	**123.80**	**-**	**-**
Networking and Computational Resources Infrastructure and Services	116.45	123.80	123.80	-	-

Totals may not add due to rounding.

The FY 2017 Budget Request for ACI is $236.31 million, of which $222.92 million is discretionary funding and $13.39 million is new mandatory funding. The mandatory funding is within the research line in the above table.

ACI partners with other CISE divisions and NSF directorates and offices to support the advancement of science and engineering research and education by exploring, developing, creating, and supporting secure, advanced, and global cyberinfrastructure (CI). This includes the acquisition, integration, coordination, and operations associated with data, networking, computation, and software, and the development of computational and data-enabled science and engineering tools and expertise. ACI focuses on the development of these resources and capabilities, as well as on the expertise to conduct next-generation science and engineering, in order to address complex and multidisciplinary discovery, prediction, and innovation. ACI provides computational support to more than 8,000 faculty and researchers, and supports international activities in networking, software, data, and computation, including connectivity to major international resources and scientific instruments. ACI also fosters relationships among academic research infrastructure groups, as well as among other federal agencies and international research funding agencies with shared scientific priorities to promote collaborative research cyberinfrastructure.

At present, about 36 percent of the ACI portfolio is available for new grants and 64 percent is available for continuing grants.

Approximately 60 percent of ACI's budget is used to support individuals and small groups of researchers in pilot, prototype, and innovative multidisciplinary projects. The remaining 40 percent of the budget goes toward the support of larger cyberinfrastructure consortia, including the eXtreme Digital (XD) shared services program, the Blue Waters Petascale Computing program, and the Innovative High-Performance Computing (HPC) program. Collectively these larger-scale initiatives complement and connect both smaller NSF-supported as well as university-supported cyberinfrastructure as part of a larger, integrated, national cyberinfrastructure ecosystem.

FY 2017 Summary

All funding decreases/increases represent change over the FY 2016 Estimate.

Research

- ACI will continue to support early-career researchers through investments in the CAREER program ($2.0 million).
- ACI will begin to transition its investment from the sunsetting NSF-wide CIF21 investment (-$12.71 to $50.0 million) to NSCI ($7.70 million) and D4SDA ($4.70 million). Together with MPS, ACI will co-lead the NSF-wide NSCI activity, and will represent NSF in its leadership role across the federal government. ACI's NSCI research activities in FY 2017 will emphasize the creation of novel scientific software architectures that are resilient, reusable, and enduring yet agile to accelerate computational discovery in national research priority areas. ACI research activities in NSCI are complemented by computational infrastructure activities, as noted below. In coordination with other directorates' research priorities and cyberinfrastructure investments, ACI's D4SDA activities will emphasize both innovative and sustainable data science infrastructure for research communities as well as new approaches to community governance and research data lifecycles in alignment with NSF's *Public Access Plan*.
- ACI will continue its investment in Risk and Resilience ($2.50 million), enabling advances in large-scale resilient, secure, and interoperable research cyberinfrastructure.
- ACI will continue its support of SaTC ($3.0 million), leading the Transition to Practice (TTP) Option, which explores new approaches for adopting advances in security, including emphasizing interagency and cross-sector collaborations.
- ACI will continue its research support for INFEWS ($500,000), enabling the development of robust and resilient software for multidisciplinary research. This investment is part of ACI's support for Clean Energy Technology ($5.0 million).

Education

- ACI will continue to support the NSF Research Traineeship program ($2.50 million) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training for research areas of national priority and in alignment with NSCI objectives.
- ACI will maintain its investments in STEM+C Partnerships ($500,000), which seek to enhance computational competencies for students and teachers.
- ACI will maintain support for Research Experiences for Undergraduates (REU) sites and supplements ($1.20 million).

Infrastructure

- ACI's support (-$1.30 million to $91.0 million) in Advanced Computational Infrastructure will retain its alignment with research priorities and its focus on a highly interoperable research infrastructure (see Appendix A for more information on the HPC portfolio).
- ACI will make an initial investment in NSCI-specific activities ($7.50 million), transitioning INFEWS-specific (-$2.50 million) and UtB-specific cyberinfrastructure investments (-$5.0 million) to shared cyberinfrastructure in NSCI. A portion of the UtB-specific cyberinfrastructure investment ($1.0 million) will be retained to support exploration of a National Brain Observatory in collaboration with BIO and MPS.

DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) — $206,470,000 / +$12,240,000 / 6.3%

CCF Funding

(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Total, CCF	**$195.69**	**$194.23**	**$206.47**	**$12.24**	**6.3%**
Research	**182.24**	**184.53**	**196.61**	**12.08**	**6.5%**
CAREER	16.90	12.18	12.35	0.17	1.4%
Centers Funding (total)	8.00	8.00	8.00	-	-
STC: The Center for Science of Information	5.00	5.00	5.00	-	-
STC: The Center for Brains, Minds and Machines: the Science and the Technology of Intelligence	3.00	3.00	3.00	-	-
Education	**12.85**	**9.10**	**9.26**	**0.16**	**1.8%**
Infrastructure	**0.60**	**0.60**	**0.60**	**-**	**-**
National Nanotechnology Coordinated Infrastructure (NNCI)	0.60	0.60	0.60	-	-

Totals may not add due to rounding.

The FY 2017 Budget Request for CCF is $206.47 million, of which $194.77 million is discretionary funding and $11.70 million is new mandatory funding. The mandatory funding is within the research line in the above table.

CCF supports research and education activities that explore the foundations and limits of computation, communication, and information; advance algorithmic knowledge for research areas both within and outside computer science; and advance software, hardware, and computer system 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 addressing the theoretical underpinnings and enabling technologies for information acquisition, transmission, and processing in communication and information networks, such as sensor, wireless, multimedia, and biological networks. CCF investments advance the design, verification, evaluation, and utilization of computing hardware and software through new theories and tools that focus on performance, correctness, usability, dependability, reliability, and scalability. CCF also invests in research that explores the potential impact of emerging technologies on computation and communication, including nanotechnology, biotechnology, and quantum devices and systems.

In general, 74 percent of the CCF portfolio is available for new research grants and 26 percent is available for continuing grants.

FY 2017 Summary

All funding decreases/increases represent change over the FY 2016 Estimate.

Research

- CCF will continue to support early-career researchers through increased investments in the CAREER program (+$170,000 to $12.35 million).

- CCF will provide initial support ($1.0 million) for a new emphasis on S&AS within the NSF-wide CEMMSS priority area. CCF investments in S&AS will focus on sensing and navigation for intelligent autonomous physical systems, with an emphasis on novel techniques for signal processing, formal verification, and end-user programming. CCF will also continue its investments in NRI ($3.0 million) and CPS (-$1.0 million to $4.50 million).
- CCF will discontinue support for CIF21 (-$8.25 million) as the NSF-wide priority sunsets, reinvesting some of these funds in NSCI ($3.0 million) and D4SDA ($4.70 million). CCF investments in NSCI will pursue hardware and software research leading to HPC systems in the post-Moore's Law era, including algorithms and architectures for massive concurrency, energy-efficient computing, and system resilience at extreme scales. CCF investments in D4SDA will pursue foundational techniques that enable computationally efficient storage and processing of big data and more effective query and analysis from heterogeneous data sources.
- CCF will invest ($1.50 million) in S&CC. As part of this investment, CCF will support a network of regional research hubs that will advance fundamental research on processing high volumes of sensor data as well as novel advances in control, automation, and decision making in systems affecting quality of life, health, well-being, and learning in smart and connected communities.
- CCF will continue to participate in INFEWS (-$250,000 to $2.25 million), focusing on foundational research on novel approaches for large-scale data analysis and management, innovative optimization techniques, and development of new algorithms and software. This investment is part of CCF's support for Clean Energy Technology ($16.40 million).
- CCF will continue to participate in UtB (-$300,000 to $8.35 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 its investment in SaTC ($14.25 million), supporting research on theories, models, algorithms, architectures, programming languages and tools for increased security, privacy and trust, as well as in new cryptographic approaches for hardware assurance.
- CCF will continue to invest in SCH (-$1.0 million to $2.0 million), supporting signal processing and control research with application to devices and sensors for person-centered health and wellbeing. CCF will decrease SCH investments as it transitions funds to S&CC to support research on improving health and well-being in smart and connected communities.
- CCF will continue to support two STCs, the Center for Science for Information at Purdue University ($5.0 million) and The Center for Brains, Minds, and Machines: The Science and the Technology of Intelligence at MIT ($3.0 million). The total CISE investment in the MIT Center ($5.0 million) is shared with the IIS and ITR divisions.

Education

- CCF will continue to support the NSF Research Traineeship program (+$160,000 to $1.16 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 maintain its investments in STEM+C Partnerships ($4.0 million), which seek to enhance computational competencies for students and teachers.
- CCF will maintain support for REU sites and supplements ($3.25 million).

Infrastructure

- CCF will fund the National Nanotechnology Coordinated Infrastructure (NNCI) ($600,000), supported primarily by ENG.

DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS) $245,660,000
+$14,560,000 / 6.3%

CNS Funding
(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Total, CNS	**$231.45**	**$231.10**	**$245.66**	**$14.56**	**6.3%**
Research	**184.02**	**184.33**	**197.67**	**13.34**	**7.2%**
CAREER	8.03	11.83	12.00	0.17	1.4%
Education	**18.14**	**16.77**	**15.77**	**-1.00**	**-6.0%**
Infrastructure	**29.29**	**30.00**	**32.22**	**2.22**	**7.4%**
Research Resources	29.29	30.00	32.22	2.22	7.4%

Totals may not add due to rounding.

The FY 2017 Budget Request for CNS is $245.66 million, of which $231.74 million is discretionary funding and $13.92 million is new mandatory funding. The mandatory funding is within the research line in the above table.

CNS supports research and education activities that advance understanding of the fundamental properties of computer systems and networks; explore new ways to better use existing computer systems and networks; and develop novel paradigms, abstractions, and tools for designing, analyzing, and building next-generation computer systems and networks that are robust, secure, and trustworthy. CNS investments include, but are not limited to, cyber-physical, embedded, cloud computing, wearable, and "smart dust" systems. CNS investments in fundamental networking research create new insights into the dynamics of complex networks, and explore new architectures for future-generation networks and services. CNS provides scientific leadership in cybersecurity, supporting research and education activities that will ensure society's ubiquitous computing and communication systems 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 research infrastructure resources for the computer and information science and engineering research community, and in the development of the computing workforce of the future.

In general, 68 percent of the CNS portfolio is available for new research grants and 32 percent is available for continuing grants.

FY 2017 Summary

All funding decreases/increases represent change over the FY 2016 Estimate.

Research

- CNS will continue to support early-career researchers through increased investments in the CAREER program (+$170,000 to $12.0 million).
- CNS will provide initial support ($6.0 million) for a new emphasis on S&AS, within the NSF-wide CEMMSS priority area, focusing on fundamental science and engineering addressing programmable, reliable, and secure intelligent autonomous systems. Additionally, in partnership with five other federal agencies (DHS, DOT, NASA, NIH, and USDA), ENG, and other CISE divisions, CNS will continue to lead the CPS program (-$3.50 million to $19.50 million), supporting foundational interdisciplinary research and education in adaptive, scalable, resilient, safe, secure, and usable cyber-physical systems.

CNS will also continue to invest in NRI (-$1.50 million to $3.0 million).

- CNS will invest in S&CC ($6.0 million), building upon previous investments in Urban Science (-$2.50 million) and US Ignite (-$5.0 million). As part of its S&CC investment, CNS will support a network of regional research hubs that will advance fundamental research in advanced networking, physical sensors/devices, and large-scale data management, analysis, and decision making to improve quality of life, health, well-being, and learning in smart and connected communities.
- CNS will discontinue support for CIF21 (-$3.75 million) as the NSF-wide priority area sunsets, reinvesting some of these funds in NSCI ($2.0 million) and D4SDA ($1.0 million). CNS investments in NSCI will support foundational research leading to HPC systems in the post-Moore's Law era, including performance and scalability of parallel computing, cross-layer, and systems architecture research. CNS investments in D4SDA will support data-focused research on computer systems, and associated data and knowledge testbeds and pilot research infrastructures.
- In partnership with EHR, ENG, MPS, SBE, and other CISE divisions, CNS will continue to lead SaTC ($44.30 million). Through SaTC, CNS will invest in areas of current critical importance such as network and cloud security, cybereconomics, and the science of security and privacy, alongside education and workforce issues. Furthermore, through SaTC, CNS will include support for experimental testbeds to enable cybersecurity researchers to experiment in realistic environments.
- CNS will continue its investment in Risk and Resilience ($3.50 million), supporting the science and engineering needed to enable advances in large-scale resilient and interdependent infrastructures.
- CNS will continue its investment in INFEWS (-$250,000 to $2.20 million), focusing on foundational systems research in sensing, control, automation, and optimization of the complex systems underlying the nexus of food, energy, and water systems. This investment is part of CNS's support for Clean Energy Technology ($19.50 million).
- CNS will continue its investment in UtB (-$200,000 to $1.54 million), supporting research developing improved systems for computation and analysis of physiological, cognitive, and behavioral data.

Education

- CNS will continue to invest in NSF INCLUDES ($1.0 million) to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved and/or underrepresented in STEM.
- CNS will maintain its investments in STEM+C Partnerships, which seek to enhance computational competencies for all students ($4.0 million). This program will enlarge the pool of K-14 students and teachers who develop and practice computational competencies in a variety of contexts. This includes partial support for the CS for All initiative.
- CNS will maintain support for REU sites and supplements ($4.48 million).
- CNS will continue to support the NSF Research Traineeship program ($490,000) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- In partnership with ENG and EHR, and under the IUSE investment framework, CNS will continue to invest in IUSE/Professional Formation of Engineers: REvolutionizing engineering and computer science Departments (IUSE:RED) ($2.0 million), with a particular focus on responding to increased enrollments in computer science.

Infrastructure

- Through the CISE Research Infrastructure (CRI) program ($18.0 million), CNS will continue to support acquisition, enhancement, community access, and operation of state-of-the-art computing research infrastructure enabling high-quality computing research and education.
- CNS will continue its support for the development of world-class, mid-scale research infrastructure (+$2.22 million to $14.22 million). 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 infrastructure, including wireless testbeds that enable research on topics ranging from radio access networks to spectrum sharing and adaptability.

DIVISION OF INFORMATION AND INTELLIGENT SYSTEMS (IIS) **$207,200,000**
+$12,300,000 / 6.3%

IIS Funding
(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Total, IIS	**$194.58**	**$194.90**	**$207.20**	**$12.30**	**6.3%**
Research	**184.07**	**185.60**	**197.65**	**12.05**	**6.5%**
CAREER	20.03	13.91	14.11	0.20	1.4%
Centers Funding (total)	1.00	1.00	1.00	-	-
STC: The Center for Brains, Minds and Machines: the Science and the Technology of Intelligence	1.00	1.00	1.00	-	-
Education	**10.51**	**9.30**	**9.55**	**0.25**	**2.7%**

Totals may not add due to rounding.

The FY 2017 Budget Request for IIS is $207.20 million, of which $195.46 million is discretionary funding and $11.74 million is new mandatory funding. The mandatory funding is within the research line in the above table.

IIS supports research and education to develop and apply new information technology to enhance the capabilities of people and machines to create, discover, and reason by advancing their ability to represent, collect, store, organize, visualize, and communicate data and information; to develop new knowledge to support people in the design and use of IT; and to advance knowledge about how computational systems can perform tasks autonomously, robustly, and flexibly. IIS research investments support the exploration of novel theories and innovative technologies that advance understanding of the complex and increasingly coupled relationships between people and computing, and promise to enhance quality of life. Investments in information integration and informatics focus on the processes and technologies involved in creating, managing, visualizing, and fusing diverse data, information, and knowledge from disparate and uncoordinated sources within a changing landscape of computing platforms, from personal devices to globally-distributed networks. IIS also invests in research on artificial intelligence, computer vision, natural language processing, robotics, machine learning, computational neuroscience, cognitive science, and areas leading to the computational understanding and modeling of intelligence in complex, realistic contexts. These investments aim to revolutionize understanding of brain functions.

In general, 70 percent of the IIS portfolio is available for new research grants and 30 percent is available for continuing grants.

FY 2017 Summary

All funding decreases/increases represent change over the FY 2016 Estimate.

Research

- IIS will continue to support early-career researchers through increased investments in the CAREER program (+$200,000 to $14.11 million).
- IIS will provide initial support ($9.50 million) for a new emphasis on S&AS within the NSF-wide CEMMSS priority area. S&AS will focus on fundamental science and engineering addressing how intelligent physical systems sense, perceive, and operate in environments that are dynamic, uncertain, and unanticipated. Additionally, 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, IIS will continue to lead the NRI program (-$3.50 million to $9.50 million). NRI focuses on human-centered research in developing service robots; this requires significant advances in human-robot interaction, advanced sensing and control, integrated problem-solving architectures and decision algorithms; and safe and soft structures. IIS will also continue its investments in CPS (-$3.50 million to $1.0 million).

- IIS will discontinue support for CIF21 (-$9.50 million) as the NSF-wide priority area sunsets, and will reinvest some of these funds in D4SDA ($8.20 million) and NSCI ($500,000). IIS investments in D4SDA 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. These investments will include NSF's continued leadership of the National Big Data R&D Initiative. IIS investments in NSCI will pursue the development of computational techniques and technologies for data-intensive computing, data and image analytics, and distributed machine learning.
- IIS will invest ($5.70 million) in S&CC. As part of this investment, IIS will support a network of regional research hubs that will advance fundamental research on technologies integrating data-intensive computing; physical sensors/devices; and large-scale data management, analysis, and decision making to improve quality of life, health, well-being, and learning in smart and connected communities.
- IIS will continue its investments in UtB (-$640,000 to $12.69 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.
- In partnership with six NIH institutes, ENG, SBE, and other CISE divisions, IIS will continue to lead the SCH program (-$3.0 million to $6.0 million). IIS will pursue improvements in safe, effective, efficient, and patient-centered proactive and predictive health and wellness technologies. IIS will decrease SCH investments as the division transitions funds for health- and wellness- related research to S&CC and S&AS.
- IIS will continue to lead the Cyberlearning and Future Learning Technologies (CFLT) program with EHR, ENG and other CISE divisions (-$4.50 million to $5.25 million). 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. IIS will decrease CFLT investments as the division transitions funds for learning-related research to S&CC and S&AS.
- IIS will continue its investment in SaTC ($8.95 million), supporting research in cybersecurity and privacy, with an emphasis on data science, usability, socio-technical, and human-centered approaches.
- IIS will continue to participate in INFEWS ($1.05 million), focusing on novel approaches for large-scale data analysis, real-time data analytics, and artificial intelligence. This investment is part of IIS's support for Clean Energy Technology ($5.0 million).
- IIS will continue to provide support for STC The Center for Brains, Minds and Machines: The Science and the Technology of Intelligence at MIT ($1.0 million) along with the CCF and ITR divisions.

Education

- IIS will continue to support the NSF Research Traineeship program (+$250,000 to $750,000) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- IIS will maintain its investments in STEM+C Partnerships ($4.0 million), which seek to enhance computational competencies for students and teachers.
- IIS will maintain support for REU sites and supplements ($3.95 million).

DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR) **$99,160,000**
+$5,870,000 / 6.3%

ITR Funding
(Dollars in Millions)

	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request	Change Over FY 2016 Estimate Amount	Change Over FY 2016 Estimate Percent
Total, ITR	**$92.07**	**$93.29**	**$99.16**	**$5.87**	**6.3%**
Research	**76.01**	**76.47**	**79.72**	**3.25**	**4.3%**
CAREER	0.28	-	-	-	N/A
Centers Funding (total)	1.00	1.00	1.00	-	-
STC: The Center for Brains, Minds and Machines	1.00	1.00	1.00	-	-
Education	**2.95**	**3.32**	**3.23**	**-0.09**	**-2.7%**
Infrastructure	**13.12**	**13.50**	**16.21**	**2.71**	**20.1%**
Research Resources	13.12	13.50	16.21	2.71	20.1%

Totals may not add due to rounding.

The FY 2017 Budget Request for ITR is $99.16 million, of which $93.54 million is discretionary funding and $5.62 million is new mandatory funding. The mandatory funding is within the research line in the above table.

ITR provides support for transformative explorations in computer and information science and engineering research, infrastructure, and related education activities, emphasizing the funding of high-risk, multi-investigator projects.

In general, 45 percent of the ITR portfolio is available for new grants and 55 percent is available for continuing grants.

FY 2017 Summary

All funding decreases/increases represent change over the FY 2016 Estimate.

Research

- ITR will invest in NSF I-Corps™ ($11.65 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 build, utilize, and sustain further a national innovation ecosystem that continues to augment the development of technologies, products, and processes.
- In collaboration with ENG, CISE will maintain support for innovative partnerships and collaborations between academia and industry, in part through the Industry/University Cooperative Research Centers (I/UCRC) program, which will continue to support centers that partner university research efforts with industry ($8.0 million).
- ITR will maintain its investments in the center-scale Expeditions in Computing program ($12.0 million). This program will continue to support projects with transformative research agendas that promise to accelerate discovery at the frontiers of computer and information science and engineering.
- ITR will invest in multi-disciplinary research networks ($2.0 million), including support for the Science Across Virtual Institutes (SAVI) activity. These national as well as international research networks

will provide opportunities to develop collaborations in areas of emerging interest to computer and information science and engineering.

- ITR will continue to provide support for 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), and through co-funding of awards with other NSF directorates to pursue important emerging areas.
- ITR will maintain support ($1.0 million) for the STC Center for Brains, Minds and Machines: The Science and the Technology of Intelligence at MIT along with the CCF and IIS divisions.
- ITR will invest in S&CC ($3.30 million), building upon previous investments in Urban Science (-$1.0 million) and US Ignite (-$5.0 million). As part of its S&CC investment, ITR will support a network of regional research hubs that will advance fundamental research on advanced networking, physical sensors/devices, and large-scale data management, analysis, and decision making, together with the necessary community building efforts, to improve quality of life, health, well-being, and learning in smart and connected communities.

Education

- ITR will continue to invest in NSF INCLUDES (-$90,000 to $780,000) to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved and/or underrepresented in STEM.
- ITR will continue to support the NSF Research Traineeship program ($2.20 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 maintain support for the development of world-class, mid-scale research infrastructure (+$2.71 million to $16.21 million). 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.

APPENDIX A – HIGH-PERFORMANCE COMPUTING PORTFOLIO

High Performance Computing Funding
(Dollars in Millions)

	Total of Prior Years	FY 2015 Actual	FY 2016 Estimate	FY 2017 Request
Petascale Computing	$355.02	$42.75	$14.90	$40.50
Innovative HPC Program	241.17	18.50	50.90	26.50
Extreme Digital (XD)	397.26	13.40	26.50	24.00
Total	**$993.45**	**$74.65**	**$92.30**	**$91.00**

Totals may not add due to rounding.

NSF has been a leader in the use of High-Performance Computing (HPC) to advance discovery for almost four decades. As a result of continuous rapid changes in computing and related technologies, coupled with the exponential growth and complexity of data for the science, engineering, and education enterprise, NSF developed a vision and strategy for Advanced Computing Infrastructure (ACI), which expands NSF's leadership role in science and engineering. This coordinated NSF-wide strategy, entitled *Cyberinfrastructure for 21st Century Science and Engineering: Advanced Computing Infrastructure*,[16] seeks to position and support the entire spectrum of NSF-funded communities at the cutting edge of advanced computing technologies, hardware, and software, and aims to promote a more complementary, comprehensive, and balanced portfolio of advanced computing infrastructure and programs for research and education. The strategy enables multidisciplinary computational and data-enabled science and engineering that supports all science, engineering, and education communities. This shift is consistent with the recommendations of recent reviews of the NITRD program by the President's Council of Advisors on Science and Technology (PCAST).[17,18]

The overall HPC strategy and program portfolio receives guidance and input from a number of stakeholder groups. This includes the Advisory Committee for Cyberinfrastructure (ACCI) and its task forces; the NSF cross-directorate Cyberinfrastructure Council (CIC), which includes Assistant Directors (ADs) and Office Directors; the various NSF research directorates and offices; and the NSF-wide Cyberinfrastructure Coordination and Leadership Group (CLG). Additionally, in 2013, ACI supported the initiation of a two-year National Academy of Sciences (NAS) study to further inform the implementation of its HPC strategy in the 2017 to 2020 timeframe. NAS published an interim report in November 2014, and NSF expects to receive the final report by February 2016.[19]

NSF's current HPC portfolio comprises three broad areas of investment that complement large but more discipline-specific investments by other NSF directorates, mission-specific investments by other agencies, and cumulatively massive but individually smaller investments of academic institutions at the regional and campus level:

- **Petascale Computing.** This first investment category focuses on the unique services and resources to advance the most computationally intensive scientific and engineering research, as provided by Blue Waters.

[16] www.nsf.gov/pubs/2012/nsf12051/nsf12051.pdf

[17] *Designing a Digital Future: Federally Funded Research and Development Networking and Information Technology,* President's Council of Advisors on Science and Technology, January 2013.

[18] www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/nitrd_report_aug_2015.pdf

[19] www.nap.edu/catalog/18972/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-and-engineering-in-2017-2020

- **Innovative HPC.** The second investment category focuses on a national portfolio of diverse and innovative resources at large scale, exemplified by Stampede. While the Blue Waters system is targeted to a smaller number of researchers delivering sustained petascale performance on the very largest computational problems across a variety of disciplines, the Innovative HPC systems provide greater community reach through diversity in the types and scale of resources: each system is capable of supporting hundreds to thousands of researchers (over the course of a year) conducting leading-edge science and engineering; and the portfolio of systems supported is intended to be technically diverse, reflecting changing and growing use of computation in research and education.
- **Extreme Digital (XD).** The third investment category focuses on an accompanying set of collaborative and shared services available to the entire HPC community, and is exemplified by the Extreme Science and Engineering Discovery Environment (XSEDE) project. The constellation of general-purpose and specialized HPC resources across the nation described in the first two investment categories is complemented by a unique set of collaborative services under XSEDE, including for coordination, coherency and interoperability, education, outreach and allocation of these diverse computational resources to nearly 2,000 unique scientific projects annually.

As the scientific computing landscape rapidly grows and evolves, and as computing technologies change, NSF's investments in HPC must necessarily evolve rapidly and dynamically to meet current research needs and to support new research opportunities across science and engineering. In 2014, NSF participated in an OSTP-led multiagency activity, which resulted in an Executive Order initiating the National Strategic Computing Initiative (NSCI).[20] NSF, together with the Department of Defense (DOD) and Department of Energy (DOE), is co-leading this initiative. NSF's focus is on scientific discovery advances, notably an emphasis on a holistic approach to the Nation's science and engineering computational infrastructure including new approaches to highly capable, reusable, and agile scientific software, as well as learning and workforce development. Among the anticipated activities will be a follow-on investment to Blue Waters with attributes to be determined based on scientific and engineering priorities. As part of NSCI, NSF participated in a joint Request for Information with NIH and DOE on *Science Drivers Requiring Capable Exascale Computing*.[21] Approximately 250 responses were received, and these are now being analyzed internally and will also inform NSF's support of HPC and its participation in NSCI in FY 2017 and beyond.

PETASCALE COMPUTING PROGRAM – BLUE WATERS

Description

The National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (UIUC) provides computational resources for researchers to tackle much larger and more complex research challenges than previously possible. This capability was accomplished by acquiring, deploying, and operating a petascale leadership-class, high-performance system known as Blue Waters. Blue Waters is one of the most powerful supercomputers in the world, and is the fastest supercomputer on a university campus. It is important to note that this investment complements the DOE Office of Science's program on computing hardware, which provides peak petascale performance as measured by the Top500 list.[22] In contrast, Blue Waters provides sustained petascale performance on a range of scientific applications.

The Blue Waters project includes education and outreach programs that target pre-college, undergraduate, graduate, and post-graduate students. The 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,

[20] www.whitehouse.gov/the-press-office/2015/07/29/executive-order-creating-national-strategic-computing-initiative
[21] www.nsf.gov/pubs/2016/nsf16008/nsf16008.pdf
[22] www.top500.org/

conferences, summer schools, and seminars.

The Blue Waters project includes an annual series of workshops targeted at the developers of simulation packages and aspiring application developers. The project also includes two 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.

The broader impacts of this award include provisioning unique cyberinfrastructure for research and education; extensive efforts accelerating education and training in the use of high-performance computation in science; 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 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

The Blue Waters system was 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. 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 awarded to UIUC in FY 2013.

The Blue Waters education and outreach projects are ongoing. They comprise components on pre-college, undergraduate, graduate, and post-graduate education; training workshops; and outreach. Annual "Petascale Workshops" provide scientists and engineers with the knowledge and expertise needed to develop applications for Blue Waters and other petascale computers. In addition, annual extreme scale workshops are held jointly with the 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, the Blue Waters project offers undergraduate petascale course materials and internships. In 2014, Blue Waters Graduate Fellowships were announced for ten students from nine institutions in eight different states across the U.S. Six Ph.D. students were selected for Blue Waters Graduate Fellowships in 2015.

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, research teams have been allocated time on Blue Waters through the Petascale Computing Resource Allocations (PRAC) program. These allocations began in 2013 with approximately 30 teams awarded time on Blue Waters, with a second round of awards to 14 teams made in 2014 and a third round of awards to 14 teams made in 2015. Over time, approximately 185 requests for usage have been submitted across a wide spectrum of research areas. The next PRAC call is anticipated in April 2016. The research topics awarded time allocations on Blue Waters include: complex biological behavior in fluctuating environments; the electronic properties of strongly correlated systems; the properties of hydrogen and hydrogen-helium mixtures in astrophysically relevant conditions; the electronic and magnetic structures of transition metal compounds; the molecular dynamics responsible for the properties of liquid water; and the propagation of seismic energy through a detailed structural model of Southern California together with the 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 in the dynamics of climate and improving climate models; the 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. Additionally, in collaboration with the National Geospatial-Intelligence Agency (NGA) and the University of Minnesota's Polar Geospatial Center (PGC), Blue Waters is being used to produce elevation models for all landmasses north of the 60th parallel – a significant contribution in support of the President's Executive Order calling for Enhancing Coordination of National Efforts in the Artic.[23]

Over 50 scientific papers were published each year in 2013 and 2014 based on research conducted using Blue Waters allocations. In 2015, the number of scientific papers published exceeded 80. Furthermore, the project has issued annual calls for educational allocations directly involving students, including the Blue Waters Undergraduate Student Internship Program (22 students in 2015) and the Blue Waters Graduate Fellowship Program (six awards in 2015). After more than two years in service, Blue Waters has supported over 150 science projects (spanning research, education, industry outreach, etc.), and more than 1,400 scientists and engineers from over 163 institutions in 33 states.

Management and Oversight

NSF Structure: CISE/ACI program staff and staff from the Division of Acquisition and Cooperative Support (DACS) oversee the Blue Waters project. These NSF staff members receive strategic advice from the CIC. Advice from the Office of General Counsel (OGC) is sought, as necessary.

External Structure: 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 Science and Engineering Team Advisory Committee (SETAC), whose composition and roles were reviewed and approved by an external panel in July 2013, advise the project team. This Committee is composed of representatives from research teams with Blue Waters allocations, industry scientists pursuing petascale applications, and the GLCPC.

Risks: The NSB receives 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: 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, and December 2015. An update to the National Science Board was provided in February 2015.

INNOVATIVE HPC PROGRAM

Description

Innovative HPC systems provide petascale peak performance. The key difference from the DOE Office of Science support for computing hardware is that over the course of a year each system is capable of supporting hundreds to thousands of researchers conducting leading-edge science and engineering. The

[23] www.whitehouse.gov/the-press-office/2015/01/21/executive-order-enhancing-coordination-national-efforts-arctic

portfolio of systems supported by the Innovative HPC program is intended to be technically diverse, reflecting changing and growing use of computation in both the research and education process.

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 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 the system has passed the acceptance process, vendors receive final payment for the system. After the system has been tested fully, 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 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 value and time required for building and retaining staff skilled in interdisciplinary computational science. Thus, an eight- to ten-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 (O&M) awards are planned.

Current Status

Machines that are currently operational in the Innovative HPC program include Stampede at the Texas Advanced Computing Center (TACC), Gordon at the San Diego Supercomputer Center (SDSC), Comet (SDSC), Darter at the National Institute for Computational Sciences (NICS), and Wrangler (TACC).

- NSF support for Gordon and Darter is scheduled to end in FY 2016. Gordon was an early adopter of Flash-based large memory nodes to explore data-intensive science and engineering in areas such as understanding practices and patterns in high-frequency trading on Wall Street; improving the accuracy of predicting high-impact extreme weather events; and examining high-resolution hydrology scenarios for planning more resilient water management in South Florida. The use of Flash-based large memory nodes has become more common and is currently available in other systems. Darter has been especially effective for large-scale scientific applications that are only tractable with low latency for random memory access and/or high memory bandwidth. This is typical of certain large, high-resolution scientific simulations, for example, high-resolution turbulence and large eddy simulations (LES). Thus, fields such as astrophysics, high-energy physics, and fluid mechanics comprised the portfolio of science enabled by Darter. Elimination of Darter's support will partially be offset by new resources planned for deployment in FY 2016.

- 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 is scheduled to operate until January 2017. The resource and accompanying services target science and engineering researchers using both advanced computational methods and emerging data-intensive approaches. The system has boosted XD resources to nearly twice their previous capacity, and has provided researchers with early access to Intel Many Integrated Core (MIC) processors, which were accepted in August 2013.

- 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. In its final configuration, it 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, providing users with up to a half-PB of usable storage, supported with available bandwidth of up to one terabyte per second (TB/s) and 200 million Input/Output Operations Per Second (IOPS). The system 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 continues through FY 2019.

- Comet also came online in FY 2015 at the University of California, San Diego. It is designed to be part of an emerging cyberinfrastructure for 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 that is 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.

Two new resources are now being acquired, developed and deployed through awards made following the FY 2014 solicitation, *High Performance Computing System Acquisition: Continuing the Building of a More Inclusive Computing Environment for Science and Engineering*. These two new resources continue to broaden the spectrum of the program by exploring new and creative approaches to delivering innovative computational resources to an increasingly diverse community and portfolio of scientific research and education projects. A key goal is to include new communities with needs that are different than the more traditional HPC users, but that would benefit from advanced computational capabilities at the national level. This solicitation resulted in two awards that are scheduled to be deployed in FY 2016:

- Bridges, to be deployed at the Pittsburgh Supercomputing Center, will provide an innovative and groundbreaking HPC and data-analytic system that will integrate advanced memory technologies and data-intensive workflows to lower the barrier of entry to HPC and to increase the scientific output of a large community of scientific and engineering researchers who have not traditionally used HPC resources. Bridges will extend HPC's impact to minority-serving institutions and EPSCoR states, raising the level of computational awareness at four-year colleges, and promote computational thinking in high schools.

- Jetstream, to be deployed at Indiana University, will be a new type of data analysis and computational resource for the open science and engineering research community that will be used interactively to conduct research anytime, anywhere. It 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 computations and data, allowing for increased scientific reproducibility and enabling many U.S. researchers 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.

For both Bridges and Jetstream, support for ongoing operations and maintenance will begin in FY 2016 and continue through FY 2019. They represent additional capabilities that are intended to appeal to the larger and increasingly diverse demand for national-scale resources.

Science and engineering research and education activities enabled by Innovative HPC

The complete spectrum of scientific research can leverage Innovative HPC resources. This includes climate and weather modeling, economics, cosmology and astrophysics, geosciences, physics, chemistry, biology and medicine, earthquake engineering, and mechanical engineering.

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, Innovative HPC enables researchers to manipulate extremely large amounts of digital information from simulation, sensors, and experiments, and add needed capabilities in remote visualization, an increasingly important analysis tool for modern science and engineering.

Outreach and training is critical in order to reduce barriers for the research and education community to use HPC systems, and the program is engaging research universities and foundations to achieve this goal. Innovative HPC 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: CISE/ACI's program directors provide direct oversight during both acquisition and operations phases. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors. The program directors also hold biweekly teleconferences with the awardees.

External Structure: Each Innovative HPC award is managed under a cooperative agreement that includes the management structure, milestones, spending authorization levels, and review schedule; and each awardee is responsible for the satisfactory completion of milestones prior to the raising of the spending authorization. Each project also has a detailed management plan in place.

Risks: Any activity of this nature, and at this scale, comes with a certain element of risk. The review process, conducted prior to an award, analyzes the risks as presented in the proposal and identifies any additional risk that should be considered. The awards 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 reduced substantially subsequent to deployment. Thus, pacing of acquisitions and deployments allows balance in overall portfolio risk for Innovative HPC.

Reviews: Semi-annual reviews typically are performed during the acquisition phase. Annual reviews, conducted by an external panel of expert reviewers, are performed during the operational phase of each project. CISE/ACI program directors manage these annual reviews. The reviewers' backgrounds include scientific research, project management, large-scale systems acquisitions and operations, along with familiarity with projects funded by NSF as well as other federal agencies.

EXTREME DIGITAL (XD) PROGRAM

Description

The XD program adds value to the Innovative HPC program by coordinating the resources, providing advanced assistance to the user community, and broadening participation. The vision is to create and sustain an advanced, nationally-distributed, open cyberinfrastructure consisting of 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 cyberinfrastructure 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), formerly the Technology Audit Service (TAS), is a separate award. All other services constitute the XSEDE project. These elements are designed and implemented in a way that is tied clearly 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 the individual user 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. A third award, the Technology Insertion Service (TIS), ended in FY 2016, and in response to external review, NSF determined that TIS would no longer be supported. The XMS award was made in FY 2015 to the State University of New York at Buffalo, renewing the previous TAS project. This award provides metrics services allowing measurement of key operational data for both resources and services. The larger XSEDE award was made to the University of Illinois at Urbana-Champaign in July 2011. The four additional major partners in XSEDE are the University of Texas at Austin (TACC), University of Pittsburgh (Pittsburgh Supercomputer Center), University of Tennessee at Knoxville (National Center for Computational Science), and University of California, San Diego (SDSC). NSF held annual reviews of XSEDE in June 2012, June 2013, and September 2014.

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.

Management and Oversight

NSF Structure: CISE/ACI program directors oversee the XD program. XSEDE has an external advisory board, a user board, and a service provider forum to ensure that all stakeholders can provide project input. CISE/ACI 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 that includes the management structure, milestones, spending levels over time, and review schedule; and each awardee is responsible for satisfactory completion of milestones prior to processing of grant increments. Each project also has a detailed management plan in place.

Risk: While XD is operational in nature, the virtual organizations of the XSEDE project and the services of the 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: External panels of expert reviewers conduct annual reviews (for XSEDE) and mid-project reviews (for XMS). CISE/ACI program directors manage these annual 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.