DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) **$925,420,000**
-$10,510,000/ -1.1%

CISE Funding
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Percent
Office of Advanced Cyberinfrastructure (OAC)	$223.36	-	$210.09	-$13.27	-5.9%
Computing and Communication Foundations (CCF)	193.57	-	183.03	-10.54	-5.4%
Computer and Network Systems (CNS)	231.36	-	217.09	-14.27	-6.2%
Information and Intelligent Systems (IIS)	194.58	-	192.07	-2.51	-1.3%
Information Technology Research (ITR)	93.06	-	123.14	30.08	32.3%
Total	**$935.93**	**-**	**$925.42**	**-$10.51**	**-1.1%**

About CISE

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

Specifically, CISE's mission is to promote the progress of computer and information science and engineering research and education, and advance the development and use of cyberinfrastructure across the science and engineering research enterprise; to promote understanding of the principles and uses of advanced computer, communication, and information systems in advancing science and engineering and in service to society; and to contribute to universal, transparent, and affordable participation in a knowledge-based society. CISE supports ambitious, long-term research and research infrastructure projects within and across the many subfields of computing, as well as cyberinfrastructure for all areas of science and engineering; contributes to the education and training of computing professionals; and more broadly, informs the preparation of an American workforce with computing and computational competencies essential to success in an increasingly competitive global market. CISE executes its mission through its Divisions of Computing and Communication Foundations (CCF), Computer and Network Systems (CNS), Information and Intelligent Systems (IIS), and Information and Technology Research (ITR), and the Office of Advanced Cyberinfrastructure (OAC)—and in close partnership with other NSF units, federal agencies, international funders, and the private sector, including foundations, private companies, and nonprofits.

CISE's FY 2019 Budget Request is shaped by support for several of NSF's 10 Big Ideas for Future NSF Investments, including co-leadership of Harnessing the Data Revolution for 21st-Century Science and

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

Engineering (HDR), Future of Work at the Human-Technology Frontier (FW-HTF), and The Quantum Leap (QL): Leading the Next Quantum Revolution; support for several ongoing NSF-wide priority areas, including Improving Undergraduate STEM Education; NSF Innovation Corps™ (NSF I-Corps™); NSF Research Traineeship (NRT); Secure and Trustworthy Cyberspace (SaTC); and Understanding the Brain (UtB); and support for the all-of-government National Strategic Computing Initiative (NSCI).

As part of HDR, and in partnership with the other research directorates and offices, CISE will invest funds in its ITR division to support convergent activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. These activities will enable pursuit of fundamental research in data science and engineering; the development of a cohesive, federated, national-scale approach to research data infrastructure; and the development of a 21st-century data-capable workforce. While budget management and reporting for this ITR investment will be the responsibility of CISE, the convergent activities will be overseen and managed collaboratively by the multi-directorate/office HDR leadership team. Also through HDR, and with funds from all of its divisions and office, CISE will continue to support key foundational programs, including Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Science; Cyberinfrastructure for Sustained Scientific Innovation (CSSI): Data Elements, Frameworks, and Community Cyberinfrastructure; EarthCube; and Transdisciplinary Research in Principles of Data Science. Collectively, these investments will complement the HDR Convergence Accelerator based in the NSF Office of Integrative Activities (OIA), which will support translational activities in partnership with other federal agencies, the private sector, and international funders.

CISE will also actively participate in FW-HTF, building on a long history of foundational investment in this area to advance understanding of how constantly-evolving technologies are changing the world of work and the lives of American workers, and how Americans can in turn shape these technologies. As part of FW-HTF, CISE will continue to support Cyber-Physical Systems, Cyberlearning for Work at the Human-Technology Frontier, National Robotics Initiative 2.0: Ubiquitous Collaborative Robots, Smart & Connected Communities, and Smart and Connected Health.

CISE investments in QL will focus on experimental platforms enabling exploration of novel quantum computing approaches, support for faculty and students to enhance capacity within the CISE research community, and the development of new instructional materials and pedagogical approaches for quantum computing education.

In partnership with other NSF directorates and offices, CISE will also participate in the Navigating the New Arctic and Understanding the Rules of Life Big Ideas.

CISE, through OAC, will co-lead NSCI with the Directorate for Mathematical and Physical Sciences (MPS) and, in partnership with other NSF directorates and offices, will represent NSF in its leadership role for NSCI across the federal government. CISE will support research advances in new computing technologies, architectures, and platforms for the future, as well as the development and deployment of advanced high-performance computing (HPC) systems, including maximizing the benefits of these systems through the deep integration of cyberinfrastructure with science and engineering research. As part of NSCI, CISE will support Computational and Data-Enabled Science and Engineering, CSSI: Software Elements, Frameworks, and Community Cyberinfrastructure, and Scalable Parallelism in the Extreme.

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

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

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

Major Investments

CISE Major Investments
(Dollars in Millions)

Area of Investment	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Change over FY 2017 Actual Percent
ADVANCE	$3.58	-	-	-$3.58	-100.0%
CAREER	49.69	-	46.85	-$2.84	-5.7%
IUSE	1.99	-	2.00	0.01	0.5%
NSF I-Corps™	11.65	-	11.65	-	-
NSF Research Traineeship	7.10	-	10.95	3.85	54.2%
SaTC	73.00	-	65.75	-7.25	-9.9%
Understanding the Brain	25.84	-	22.15	-3.69	-14.3%
BRAIN Initiative	*10.67*	*-*	*9.50*	*-1.17*	*-11.0%*
NSF's Big Ideas		-			
Harnessing the Data Revolution	*-*	*-*	*30.00*	*30.00*	*N/A*
NSF INCLUDES	*1.52*	*-*	*-*	*-1.52*	*-100.0%*

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

While CISE will continue to participate in ADVANCE: Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers (ADVANCE) and Inclusion across the Nation of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES) in FY 2019, the funds for these NSF-wide education-related programs will be centrally located in EHR.

CISE Funding for Centers Programs and Facilities

CISE Funding for Centers Programs
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Change over FY 2017 Actual Percent
Total	**$10.00**	**-**	**$8.70**	**-$1.30**	**-13.0%**
STC: Center for the Science of Information (CCF)	5.00	-	3.70	-1.30	-26.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR)	5.00	-	5.00	-	-

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

CISE Funding for Facilities
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change Over FY 2017 Actual Amount	Change Over FY 2017 Actual Percent
Total, Facilities	**$0.60**	**-**	**$0.60**	**-**	**-**
National Nanotechnology Coordinated Infrastructure (NNCI) Program (CCF)	0.60	-	0.60	-	-

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

Funding Profile

CISE Funding Profile

	FY 2017 Actual Estimate	FY 2018 (TBD)	FY 2019 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,723	-	9,500
Number of New Awards	1,819	-	1,800
Funding Rate	21%	-	19%
Statistics for Research Grants:			
Number of Research Grant Proposals	8,390	-	9,100
Number of Research Grants	1,547	-	1,530
Funding Rate	18%	-	17%
Median Annualized Award Size	$156,667	-	$150,000
Average Annualized Award Size	$188,410	-	$180,000
Average Award Duration, in years	2.9	-	3.0

Number of People Involved in CISE Activities

Number of People Involved in CISE Activities

	FY 2017 Actual Estimate	FY 2018 (TBD)	FY 2019 Estimate
Senior Researchers	7,230	-	7,200
Other Professionals	1,086	-	1,050
Postdoctoral Associates	489	-	450
Graduate Students	6,359	-	6,300
Undergraduate Students	2,624	-	2,600
K-12 Teachers	-	-	-
K-12 Students	-	-	-
Total Number of People	**17,788**	**-**	**17,600**

Program Monitoring and Evaluation

Committees of Visitors (COV)

- In early FY 2018, OAC convened a Committee of Visitors (COV) to examine and assess the quality of the merit review process across the Office. The report from the COV will be presented to the Advisory Committee for Cyberinfrastructure (ACCI) at its Spring 2018 meeting.

Program Evaluations

- In FY 2012, the Science and Technology Policy Institute (STPI) conducted a program evaluation feasibility study for SaTC. This feasibility study provided methods for examining baseline portfolio investments and identifying metrics to measure progress toward program goals. It was part of a broader effort to develop a plan for a future impact assessment. STPI identified baseline evaluation metrics in FY 2013 - FY 2015, and completed the evaluation feasibility study in FY 2016. CISE, together with the NSF Evaluation and Assessment Capability (EAC), funded a program evaluation of SaTC in FY 2016; that program evaluation is currently underway.
- Evaluation is a key part of CISE's education programs. All K-12 computer science education projects managed by CISE include rigorous research and evaluation plans designed to guide project progress and measure project impacts. CISE also tasked STPI to conduct an evaluation feasibility study for STEM+C Partnerships, and the Education Development Center, Inc. (EDC) to develop a program evaluation instrument for legacy K-12 computer science education projects. The first program evaluation of these projects is currently underway.

Reports

- In 2008, CISE funded the Computer Science and Telecommunications Board (CSTB) within the National Academy of Sciences, Engineering, and Medicine to study the IT innovation ecosystem and to assess the long-term economic impacts of CISE investments. The resulting report, *Assessing the Impacts of Changes in the Information Technology R&D* Ecosystem,[2] 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

[2]www.nap.edu/catalog.php?record_id=12174

investments. The National Academies published the resulting report, *Continuing Innovation in Information Technology*, in 2012.[3] A more recent CSTB study, *Continuing Innovation in Information Technology: A Workshop* (described below), employed this report's framework.

- In FY 2012, a CSTB study, *The Future of Computing Performance: Game Over or Next Level?*,[4] together with a white paper from the CISE-funded Computing Community Consortium (CCC), *21st Century Computer Architecture*,[5] outlined the need for advances in computer architecture research, leading to the development of the Exploiting Parallelism and Scalability (XPS) program in FY 2013. In FY 2019, CISE will continue to invest in advanced computer architecture research through the Scalable Parallelism in the Extreme (SPX) program, leveraging past investments in XPS, as part of NSCI.
- 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;[6] this led to the development of the NSFFutureCloud program, which began in FY 2014 and entered a second phase in FY 2017. In FY 2019, CISE will continue to invest in NSFFutureCloud.
- Since FY 2014, the CCC has led several additional community visioning efforts that have the potential to influence CISE programs in FY 2019:
  - *Computing Visions 2025:*[7] inspired the computing community to envision future trends and opportunities in computing research. Two workshops were held under this initiative: *Interacting with Computers All Around Us*, and *The New Making Renaissance: Programmable Matter and Things.*
  - *Toward a Science of Autonomy for Physical Systems:*[8] offered a series of white papers framing the challenges and opportunities associated with a future of autonomous physical systems across a range of domains including health care, transportation, and disaster response. These white papers have the potential to influence CISE investments in CPS and NRI-2.0.
  - *A New Age of Computing and the Brain:* brought together computer and information scientists and engineers and brain scientists to explore opportunities and connections at the intersection of computer and information science and brain science. The resultant workshop report summarizing the key findings has the potential to influence CISE and NSF investments in UtB.[9]
  - *Intelligent Infrastructure:*[10] presented a national research agenda for intelligent infrastructure, or the deep embedding of sensing, computation, and communication capabilities into traditional physical infrastructure such as roads, bridges, railways, and buildings, for enhancing efficiency, resiliency, and safety. These white papers, which the CCC produced jointly with the Electrical and Computer Engineering Department Heads Association (ECEDHA), have the potential to influence CISE investments in S&CC.
- Similarly, since FY 2014, CISE has funded several CSTB studies that have the potential to influence CISE programs in FY 2019:
  - *Continuing Innovation in Information Technology: A Workshop:* conducted a public workshop to highlight additional examples of the impacts of computing research using the framework established in the "tire tracks" figure published in CSTB's 2012 report *Continuing Innovation in Information Technology*. The resultant workshop report was published in 2016.[11]
  - *Toward 21st-Century Cyber-Physical Systems Education:* published a report in 2016 on the current

[3] www.nap.edu/catalog.php?record_id=13427
[4] www.nap.edu/openbook.php?record_id=12980
[5] http://cra.org/ccc/docs/init/21stcenturyarchitecturewhitepaper.pdf
[6] http://cra.org/ccc/visioning/visioning-activities/mid-scale-infrastructure-investments-for-computing-research
[7] http://cra.org/ccc/visioning/computing-visions-2025/
[8] http://cra.org/ccc/resources/ccc-led-whitepapers/#toward-a-science-of-autonomy-for-physical-systems
[9] http://cra.org/ccc/wp-content/uploads/sites/2/2014/12/BRAIN-Report.pdf
[10] http://cra.org/ccc/resources/ccc-led-whitepapers/#infrastructure
[11] https://www.nap.edu/catalog/23393/continuing-innovation-in-information-technology-workshop-report

and future needs in education for cyber-physical systems (CPS), articulating a vision for a 2l[st]-century CPS-capable U.S. workforce.[12]

- *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science in 2017-2020:* published a report in 2016 on anticipated priorities and associated tradeoffs for advanced computing in support of NSF-sponsored science and engineering research, yielding recommendations in support of four broad goals: (1) position the United States for continued leadership in science and engineering, (2) ensure that resources meet community needs, (3) aid the scientific community in keeping up with the revolution in computing, and (4) sustain the infrastructure for advanced computing.[13] Recommendations from goals (1) and (4) led to a new program solicitation in FY 2018, supporting the initial phase of a leadership-class computing facility.
- *Information Technology and the U.S. Workforce: Where Are We and Where Do We Go from Here?:* published a report in 2017 on the interactions between technological, economic, and societal trends, notably how significant advances in IT and automation have profoundly impacted the way work is conducted, and identified open questions and promising research pathways.[14]
- *Growth of Computer Science Undergraduate Enrollments:* published a report in 2017 recommending responses to growing undergraduate computer science enrollments, including: (1) bringing computer science faculty and institutional leaders together to identify best practices and innovation in computer science education across the entire student body; (2) conducting research on how best to use technology in teaching large classes, and on best practices for supporting diversity in computing; and (3) expanding instructional resources for undergraduate computer science education.[15]
- *Envisioning the Data Science Discipline: The Undergraduate Perspective:* published an interim report in 2017 summarizing the initial results toward developing a vision for the emerging discipline of data science at the undergraduate level.[16]

[12] www.nap.edu/catalog/23686/a-21st-century-cyber-physical-systems-education
[13] www.nap.edu/catalog/21886/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-and-engineering-in-2017-2020
[14] www.nap.edu/catalog/24649/information-technology-and-the-us-workforce-where-are-we-and
[15] https://www.nap.edu/catalog/24926/assessing-and-responding-to-the-growth-of-computer-science-undergraduate-enrollments
[16] https://www.nap.edu/catalog/24886/envisioning-the-data-science-discipline-the-undergraduate-perspective-interim-report

OFFICE OF ADVANCED CYBERINFRASTRUCTURE (OAC) **$210,090,000**
-$13,270,000/ -5.9%

OAC Funding
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Percent
Total	**$223.36**	**-**	**$210.09**	**-$13.27**	**-5.9%**
Research	**85.80**	**-**	**82.04**	**-3.76**	**-4.4%**
CAREER	1.95	-	1.83	-0.12	-6.2%
Education	**9.41**	**-**	**8.80**	**-0.61**	**-6.5%**
Infrastructure	**128.15**	**-**	**119.25**	**-8.90**	**-6.9%**
Networking and Computational Resources Infrastructure and Services	128.15	-	117.50	-10.65	-8.3%
Research Resources - Public Access Activity	-	-	1.75	1.75	N/A

OAC Summary

OAC supports the exploration, development, deployment, and expert services necessary for world-leading research cyberinfrastructure (CI), which is critical to the advancement of all areas of science and engineering research and education in the 21st century and therefore essential to sustaining U.S. economic competitiveness and national security. In partnership with all NSF directorates and offices as well as other CISE divisions, OAC support to academic institutions encourages a rich and vibrant ecosystem that blends computer and computational research and research-specific cyberinfrastructure with innovations from the private sector. Specifically, OAC investments include acquisition, integration, coordination, and operations associated with shared data, secure networking, advanced computation, scientific software, and the design and development of computational and data-enabled science and engineering tools and expertise. OAC also nurtures the computational and data skills and expertise needed to conduct next-generation science and engineering. To address complex and multidisciplinary discovery, prediction, and innovation, OAC enables more than 8,000 faculty and researchers to access computational resources and services, along with secure connectivity to major international facilities and scientific instruments. Ultimately, OAC promotes secure CI interoperability, sharing, and collaborations among academic research infrastructure groups, other federal agencies and international research funders, and the private sector.

In FY 2017, about 37 percent of the OAC portfolio was available for new grants and 63 percent was available for continuing grants.

In FY 2018, NSF investments in the Public Access Activity were transferred from SBE to OAC. This NSF-wide activity supports efforts to make NSF-funded research available to the public, including developing outreach and guidance materials.

DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) **$183,030,000**
-$10,540,000/ -5.4%

CCF Funding
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Change over FY 2017 Actual Percent
Total	**$193.57**	**-**	**$183.03**	**-$10.54**	**-5.4%**
Research	**182.91**	**-**	**171.18**	**-11.73**	**-6.4%**
CAREER	16.66	-	15.75	-0.91	-5.5%
Centers Funding (total)	8.00	-	6.70	-1.30	-16.3%
STC: Center for the Science of Information	5.00	-	3.70	-1.30	-26.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	3.00	-	3.00	-	-
Education	**10.06**	**-**	**11.25**	**1.19**	**11.8%**
Infrastructure	**0.60**	**-**	**0.60**	**-**	**-**
National Nanotechnology Coordinated Infrastructure (NNCI)	0.60	-	0.60	-	-

CCF Summary

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

In FY 2017, 72 percent of the CCF portfolio was available for new grants and 28 percent was available for continuing grants.

In FY 2019, CCF support for the STC Center for the Science of Information will ramp down as the center begins its natural sunset.

DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS) **$217,090,000**
-$14,270,000/ -6.2%

CNS Funding
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Change over FY 2017 Actual Percent
Total	**$231.36**	**-**	**$217.09**	**-$14.27**	**-6.2%**
Research	**185.77**	**-**	**176.24**	**-9.53**	**-5.1%**
CAREER	10.89	-	10.22	-0.67	-6.2%
Education	**17.35**	**-**	**13.85**	**-3.50**	**-20.2%**
Infrastructure	**28.24**	**-**	**27.00**	**-1.24**	**-4.4%**
Research Resources	28.24	-	27.00	-1.24	-4.4%

CNS Summary

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

In FY 2017, 69 percent of the CNS portfolio was available for new grants and 31 percent was available for continuing grants.

In FY 2019, CNS will continue to participate in ADVANCE and NSF INCLUDES, but the funds for these NSF-wide education-related programs will be centrally located in EHR.

DIVISION OF INFORMATION AND INTELLIGENT SYSTEMS (IIS) **$192,070,000**
-$2,510,000/ -1.3%

IIS Funding
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Change over FY 2017 Actual Percent
Total	**$194.58**	**-**	**$192.07**	**-$2.51**	**-1.3%**
Research	**184.18**	**-**	**180.82**	**-3.36**	**-1.8%**
CAREER	19.30	-	19.05	-0.25	-1.3%
Centers Funding (total)	1.00	-	1.00	-	-
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	1.00	-	1.00	-	-
Education	**10.40**	**-**	**11.25**	**0.85**	**8.2%**

IIS Summary

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

In FY 2017, 70 percent of the IIS portfolio was available for new grants and 30 percent was available for continuing grants.

DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR) **$123,140,000**
+$30,080,000/ 32.3%

ITR Funding
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request	Change over FY 2017 Actual Amount	Change over FY 2017 Actual Percent
Total	**$93.06**	**-**	**$123.14**	**$30.08**	**32.3%**
Research	**78.55**	**-**	**106.19**	**27.64**	**35.2%**
Big Idea: Harnessing the Data Revolution	-	-	30.00	30.00	N/A
CAREER	0.89	-	-	-0.89	-100.0%
Centers Funding (total)	1.00	-	1.00	-	-
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	1.00	-	1.00	-	-
Education	**2.96**	**-**	**1.95**	**-1.01**	**-34.1%**
Infrastructure	**11.55**	**-**	**15.00**	**3.45**	**29.9%**
Research Resources	11.55	-	15.00	3.45	29.9%

ITR Summary

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

In FY 2019, CISE, in partnership with all of the NSF research directorates and offices, will advance the HDR Big Idea by investing ITR funds to support convergent activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. These activities will enable pursuit of fundamental research in data science and engineering; the development of a cohesive, federated, national-scale approach to research data infrastructure; and the development of a 21st-century data-capable workforce. While budget management and reporting for this ITR investment will be the responsibility of CISE, the convergent activities will be overseen and managed collaboratively by the multi-directorate/office HDR leadership team.

In FY 2017, 57 percent of the ITR portfolio was available for new grants and 43 percent was available for continuing grants.

In FY 2019, ITR will continue to participate in NSF INCLUDES, but the funds for this NSF-wide education-related program will be centrally located in EHR.

APPENDIX A – HIGH-PERFORMANCE COMPUTING PORTFOLIO

High Performance Computing Funding
(Dollars in Millions)

	FY 2017 Actual	FY 2018 (TBD)	FY 2019 Request
Petascale Computing	$0.36	-	$32.48
Innovative HPC Program	29.91	-	30.00
Extreme Digital (XD)	56.73	-	2.40
Total	**$87.00**	**-**	**$64.88**

For nearly four decades, NSF has been a recognized leader in enabling the innovative use and broad availability of a cohesive and powerful High-Performance Computing (HPC) ecosystem to accelerate fundamental science and engineering. NSF aims to sustain America's leadership in the research, development, and broad deployment of existing as well as new HPC technologies and skills—and aims to do so in part through leadership of the National Strategic Computing Initiative (NSCI) jointly with the Department of Defense (DOD) and Department of Energy (DOE), and in concert with other participating federal agencies and the private sector. Key NSF foci include fundamental discoveries to support future generations of advanced computing; research and cyberinfrastructure promoting cohesive platforms and interoperability for large-scale data analytics as well as modeling and simulation; and support for a comprehensive advanced computing ecosystem for science and engineering research. These foci include an emphasis on a holistic approach to America's science and engineering computational infrastructure, spanning both human and technical dimensions.

The overall NSF HPC strategy and program portfolio receives guidance and input from the Advisory Committee for Cyberinfrastructure (ACCI); Assistant Directors (AD) Council, which includes ADs and Office Heads from the various NSF research directorates and offices; and cross-directorate working group for NSCI. In 2013, OAC supported a two-year National Academies' study to further inform the implementation of its HPC strategy in the 2017 to 2020 timeframe; the final report, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017-2020*, was published in 2016.[17] In 2017, OAC funded a study of best practices for collaborations between academic or federally-funded HPC centers and industry.

Leadership-Class Computing

Description

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

Since becoming operational in FY 2013, Blue Waters has allowed researchers to tackle much larger and more complex research challenges than ever before possible across and within disciplines as diverse as biology, astronomy, engineering, materials science, and the geosciences. Examples of transformational

[17] www.nap.edu/catalog/21886/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-6

research enabled by Blue Waters include: biophysicist Klaus Schulten and his team at UIUC used experimental data combined with simulations on Blue Waters to discover the precise chemical structure of the hard-shell capsid encasing the HIV virus (with funding from NIH);[18] a public-private collaboration among multiple federal agencies, universities, and companies brought together data, expertise, and the unique capabilities of Blue Waters to create the first-ever publicly-available, high-resolution elevation maps of the Arctic;[19] and ExxonMobil geoscientists and NCSA demonstrated a massive parallel reservoir simulation that ran thousands of times faster than typical oil and gas industry reservoir simulations, in turn allowing faster, more cost-effective, and environmentally-responsible decisions.[20]

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

Current Status

Following system testing and acceptance in December 2012, and acceptance of the NCSA archival system in March 2013, the Blue Waters project entered a five-year operations phase. The acquisition and deployment award provided support for the first six months of operations. A separate award to UIUC in FY 2013 provided support for the remaining operational phase, from FY 2014 through mid-FY 2018. This award was granted a no-cost extension in FY 2016 that runs through mid-FY 2019.

Education and outreach projects are ongoing; they target pre-college, undergraduate, graduate, and post-graduate students. The Blue Waters project also sponsors workshops, conferences, summer schools, and seminars. The project includes industry partnership activities as well. The Industry Partners in Petascale Engagement (IPIPE) program provides industry partners across a wide range of market sectors (e.g., health, energy, advanced manufacturing) with expertise as well as a first look at the technological and scientific developments that flow from the petascale program.

Despite the success of the Blue Waters supercomputer, the system is reaching its natural obsolescence, and will complete its operational cycle in March 2019, when the no-cost extension for the operations and maintenance award ends. With the extension of the operational end date of Blue Waters to 2019, the system will have run for roughly two years longer than the typical lifetime for a system of this type.

In anticipation of the operational end date of Blue Waters, in FY 2017, NSF issued a competitive solicitation[21] for the first phase (Phase 1) of a two-phase plan to deploy a new leadership-class HPC system. The Phase 1 system is expected to be two to three times more powerful in application performance than Blue Waters. In FY 2018, NSF expects to award approximately $60 million for the system acquisition. The operations and maintenance phase of the leadership HPC system is expected to commence in FY 2019 and last for five years under a separate award. When fully deployed, the Phase 1 system is expected to broadly extend new large-scale HPC benefits across the academic landscape, including support for previously unattainable research advances in large-scale modeling and simulation; use of robust data analytics at unprecedented scales for research; and use of HPC in dynamic workflows combining large-scale computation with big data streaming. In addition to the operations and maintenance award, a related

[18]https://news.illinois.edu/blog/view/6367/204804
[19]http://nga.maps.arcgis.com/apps/MapSeries/index.html?appid=cf2fba21df7540fb981f8836f2a97e25
[20]www.ncsa.illinois.edu/news/story/exxonmobil_sets_record_on_ncsas_blue_waters_supercomputer
[21]www.nsf.gov/pubs/2017/nsf17558/nsf17558.htm

FY 2019 award to the Phase 1 awardee is anticipated to fund a Conceptual Design in anticipation of a future Major Research Equipment and Facilities Construction for Phase 2 of the leadership-class HPC system.

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

Science and engineering research and education activities enabled by Blue Waters

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

To date, there have been more than 200 education, outreach, and training projects engaging over 3,700 individuals at over 160 institutions, including 41 institutions in Established Program to Stimulate Competitive Research (EPSCoR) jurisdictions and 14 Minority-Serving Institutions.

Management and Oversight

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

The National Science Board (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.

The plan for a phased approach to support a next-generation, leadership-class HPC system was discussed with the NSB in advance of the issuance of the FY 2017 solicitation.

Innovative HPC Program

Description

The Innovative HPC program funds nationally-available HPC capabilities that, in aggregate, are technically diverse, reflecting changing and growing use of data-intensive computation in both the research and education processes. At the same time, they are intended to enable discoveries at a computational scale beyond the reach of an individual or regional academic institution.

There is a direct relationship between the Innovative HPC program and the eXtreme Digital (XD) program, as described below. Deployed systems serve as a cohesive set of allocable resources within the XD

integrated services infrastructure. Innovative HPC awards are generally made as two parts: an acquisition/development and deployment award that may be the result of a competitive or a renewal proposal; and a separate award for operations and maintenance following deployment. When an award is made, the awardee institution issues sub-awards to vendors and/or other organizations for acquisitions and services as necessary. Expenditures are contingent on successful completion of deployment milestones.

Beginning with the FY 2011 Innovative HPC program solicitation, *High Performance System Acquisition: Enhancing the Petascale Computing Environment for Science and Engineering*,[22] a more sustained approach for the largest HPC services was initiated in response to community input. This approach recognizes the value and sustained institutional commitment required for building and retaining staff skilled in interdisciplinary computational and data science by allowing, at the discretion of NSF, a longer time horizon of eight to 10 years for a single institutional awardee. This timeline begins with a competitively awarded acquisition but allows for the possibility of a renewal acquisition award four years after the original award. In addition to the acquisition awards, there are accompanying operations and maintenance awards following deployment.

Current Status

Four additional resources, Comet, Bridges, Jetstream, and Wrangler, commenced operations in FY 2015 and FY 2016. In FY 2017, Stampede 2, the largest of the currently active Innovative HPC resources, commenced operation.

Deployed in FY 2015, Wrangler is the most powerful data analysis system allocated in XD, with 10 petabytes (PB) of replicated, secure, high-performance data storage. This innovative system consists of 3,000 embedded processing cores for data analysis; 120 Intel Haswell-based servers for data access and embedded analytics; and a large-scale flash storage tier for analytics, with bandwidth of one terabyte per second (TB/s) and 275 million Input/Output Operations Per Second (IOPS). Wrangler provides flexible support for a wide range of software stacks, including Hadoop and relational data. Support for ongoing Wrangler operations and maintenance is provided to the University of Texas at Austin through FY 2020 at a level of approximately 20 percent of the initial acquisition cost per annum, consistent with the level specified in the FY 2013 Innovative HPC program solicitation.[23]

Comet also came online in FY 2015 at the University of California, San Diego. It supports research interests and priorities requiring large, high-throughput workloads, which in turn prompt massive amounts of computation but at moderate scalability. Notably, as a resource responsive to the "long tail of science," Comet is particularly well-suited for the large-scale computational needs of research community portals such as Cyberinfrastructure for Phylogenetic Research as well as distributed workflows such as those required by the Laser Interferometer Gravitational-Wave Observatory. Comet's heterogeneous configuration supports not only complex simulations but also advanced analytics and visualization of outputs. As a result of its role in machine learning, visualization, and advanced analytics, supplemental funding was provided to increase the graphics processing units component of Comet in FY 2017. Comet is also planned to remain operational through FY 2020.

Bridges came online in FY 2016 at the Pittsburgh Supercomputing Center on the campus of Carnegie Mellon University. Bridges provides an innovative and groundbreaking HPC and data analytics system integrating advanced memory technologies to empower new communities. It brings desktop convenience to HPC, connecting to campuses, and intuitively integrating data-intensive workflows to increase the scientific output of a large community of scientific and engineering researchers that has not traditionally used HPC resources. Bridges extends HPC's impact to EPSCoR jurisdictions and Minority-Serving

[22] www.nsf.gov/pubs/2011/nsf11511/nsf11511.htm
[23] www.nsf.gov/pubs/2013/nsf13528/nsf13528.htm

Institutions, raising the level of computational awareness at four-year colleges, and promoting computational thinking in high-schools.

Jetstream also came online in FY 2016 at Indiana University. Jetstream is a cloud-based platform that incorporates the best elements of commercial cloud computing resources with some of the best software for solving important scientific problems. Jetstream enables new modes of sharing data and computational analysis, allowing for increased scientific reproducibility and enabling American scientists and engineers to make new discoveries that are important to understanding the world around us, thereby improving the quality of life for all Americans and promoting America's competitive standing in the world.

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 continued to operate through December 2017. The resources and accompanying services targeted science and engineering researchers using both advanced computational methods and emerging data-intensive approaches. The system boosted XD resources to nearly twice their previous capacity and provided researchers with early access to Intel Many Integrated Core processors, which were accepted in August 2013. It operated as the "backbone" for the XD environment, enabling more than 5,000 researchers and annually supporting more than 1,000 computationally intensive research projects across the Nation.

In FY 2016, NSF awarded *Stampede2: The Next Generation of Petascale Computing for Science and Engineering* to the University of Texas at Austin following a rigorous merit review, enabling the acquisition, development, and deployment of "Stampede2" as a successor resource to Stampede. When fully operational, Stampede2 will serve as the primary national resource (i.e., the "workhorse") for thousands of American academic researchers, complement other national HPC resources, and provide capabilities beyond the reach of individual campuses and regional resources, including support for multiscale modeling, simulation, and data-intensive research. Stampede2 is being deployed into production operation through three phases: Knights Landing many-core nodes are already deployed, demonstrating increased performance at lower power rates; the highly complementary SkyLake processors, which are responsive to data-intensive computing, are in early operations and will fully deploy as a peak 18-petaflop system in FY 2018; and the final deployment phase, also in FY 2018, will introduce persistent memory to the previously-deployed Skylake processors to significantly enhance overall system performance. Stampede2 will serve the high-end, open science community through FY 2021.

Science and engineering research and education activities enabled by Innovative HPC

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

Management and Oversight

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

Each Innovative HPC program award is managed under a cooperative agreement. Each awardee is responsible for the satisfactory completion of milestones prior to NSF authorization of spending. Progress

is assessed with the aid of annual external reviews. Each project has a project management plan. Each cooperative agreement includes the management structure, milestones, spending authorization levels, and review schedule.

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

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

Extreme Digital (XD) Program

Description

The XD program adds value to the Innovative HPC program by coordinating the HPC resources and services, providing advanced assistance to the user community, and broadening participation. The XD program's shared services model for coherently and efficiently delivering to researchers both access and expertise to diverse, dynamic, and distributed resources is a cornerstone of America's HPC ecosystem. Enabling the connection between individual campuses and national resources is an essential aspect of the HPC ecosystem.

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

XD shared services consist of several interrelated parts: allocation of resources to computational and data research projects; advanced user assistance; training, education, and outreach; architecture and operation of an integrated digital services infrastructure; metrics services; and overall coordination. The XD Metrics Service (XMS) is a separate award, while all other services constitute the eXtreme Science and Engineering Discovery Environment (XSEDE) project. These elements are designed and implemented in a way that is clearly tied to the requirements of the science and engineering research community, using a flexible methodology that permits the architecture to evolve in response to changing community needs and that presents individual users with a common environment regardless of where the resources or researchers are located.

Current Status

Two awards are currently active within the XD program: XSEDE and XMS. The smaller XMS award was made in FY 2015 to the University at Buffalo – The State University of New York. This award provides metrics services allowing measurement of key operational data for both resources and services. The XSEDE award to UIUC was renewed in September 2016, continuing the prior XSEDE award for another five-year period. There are 18 XSEDE partners engaged via subawards to the University of Tennessee at Knoxville (National Institute for Computational Sciences), Carnegie Mellon University and University of Pittsburgh (Pittsburgh Supercomputing Center), University of Texas at Austin (Texas Advanced Computing Center), University of California, San Diego (San Diego Supercomputing Center), University of Chicago, Indiana

University, Purdue University, Shodor Education Foundation, Ohio Supercomputer Center, Southeastern Universities Research Association, Cornell University, National Center for Atmospheric Research (NCAR), Georgia Institute of Technology, Oklahoma State University, University of Georgia, Oklahoma University, University of Southern California, and University of Arkansas. XSEDE has annual external reviews at NSF. The first external review of the renewed project took place in June 2017.

Science and engineering research and education activities enabled by XD

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

XD provides HPC services; and enables researchers to efficiently manipulate, analyze, visualize, and share extremely large amounts of distributed digital information from simulations, sensors, and experiments.

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

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

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

Management and Oversight

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

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

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

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