CYBER-ENABLED DISCOVERY AND INNOVATION

In the last 50 years, investments in fundamental research led to science and engineering innovations and the suite of computational algorithms, concepts, methods, models, and tools that drive today's economy. The Nation's preeminence in science and engineering is unquestionably recognized as an essential element of competitiveness in the economic, social, and technology sectors. As indicated in NSF's "*Cyberinfrastructure Vision for the 21st Centur*y," the infusion of advanced computational capabilities into the traditional experimentation-observation-analysis-theory research paradigm is now revolutionizing how we conduct STEM research and education.

The Cyber-enabled Discovery and Innovation (CDI) investment promotes the advancement of science and engineering along fundamentally new pathways opened by computational thinking. Investments in FY 2009 will contribute to the agency's strategic goal of advancing the frontier of science and engineering knowledge by creating new computational concepts, methods, models, algorithms, and tools that promise a wave of innovations in the public and private sectors for years to come. These investments will also contribute the preparation of a workforce with the computational competencies critical to continued U.S. competitiveness. In addition, they will lead to the development and innovative use of cyberinfrastructure that will accelerate the process of converting discovery into useful constructs.

FY 2008 will be the inaugural year for the agency's CDI investment. In FY 2009, the agency will build upon the core themes developed for FY 2008, highlighting new activities that hold significant promise for economic competitiveness and societal impact. These themes fall into two major dimensions of technical focus: From Data to Knowledge and Understanding System Complexity. A cross-cutting third dimension, Virtual Organizations, focuses on how science and innovation across geographic, disciplinary, and cultural boundaries will be increasingly practiced in the future. All of NSF's investments in CDI also support the interagency NITRD program.

From Data to Knowledge: Analyzing animal and plant genomes for markers of disease risk or resistance, discovering new fundamental particles, and observing new planets and proto-stars—all are like "finding a needle in a haystack." Research advances in From Data to Knowledge include but are not limited to new fundamental mathematical and computational abstractions to represent and manage data, multidisciplinary and international efforts on knowledge extraction, including data mining, data federation, and extraction strategies in demanding scientific applications, and the development of sophisticated data manipulation, visualization and delivery tools. These advances will help individuals, organizations, and society at large derive new knowledge from an abundance of digital data. As one example, in FY 2009 researchers will undertake an Earth-system science approach to Arctic and Antarctic studies, addressing the synthesis of multidisciplinary data relating to system-scale environmental change observed in both regions.

In FY 2009, researchers will explore a new computing paradigm called Data-Intensive Super Computing (DISC). In DISC systems, storage and computation are co-located, providing fast interactive response time to the end user. To realize the full potential of DISC, we need innovative basic research in algorithms, programming languages, programming models, resource management, and system design. With the massive amounts of data collected and generated in science and in everyday life, DISC systems can transform application areas from science and engineering, to healthcare, finance, and the humanities.

Understanding Complexity in Natural, Built, and Social Systems: Future generations of computational algorithms, concepts, methods, models, and tools will enable scientists to better understand complexity in systems found in nature, built by humans, and manifest in society. Researchers will shed new light on protein folding, the flow of electricity across networks, and "tipping points" when new species evolve or languages undergo major structural shifts. They will develop principles for scaling from the quantum- to the nano- to the macro-scales in complex systems, and design and synthesize new resilient complex engineering systems, such as materials, sustainable resilient civil infrastructure, etc. Characteristics common to complex systems are the large number of interacting elements, the non-linearity of these interactions, and/or aggregate or emergent phenomena observed within and across multiple scales. For FY 2009, we highlight two themes, to recognize the need for predictive models and simulation for harnessing complexity and the critical reliance on software in the operation of complex systems:

- **Computational Simulation and Prediction.** Predicting turbulence in airflow over aircraft wings, the collapse of financial markets, or the occurrence of natural disasters such as earthquakes and tornadoes are examples of where improving our capability to predict could have direct impact on the frontiers of science and engineering, and national competitiveness. The development and use of computational methods for predicting the behavior of highly dynamic features in the environment will change the way we study and understand challenging problems, including weather forecasting, interactions between climate variability, biogeochemical cycles and ecosystems, coastal zone management, and natural disaster recovery. Simulation and computational models have emerged as important investigative tools for understanding complex physical, social, engineering, and life science phenomena, and will significantly impact the health and safety of all citizens and the stability of the national economy. The next generation of predictive models must offer the ability to rapidly synthesize design alternatives for systems and processes of unprecedented scales; they must capture temporal dynamics and spatial variations in a unified fashion, across large-scale heterogeneous media, systems and processes.

- **Software for Complex Systems.** Society is witnessing a growth in and reliance on cyber-physical systems, such as smart automobiles, sensor nets for environmental monitoring, and embedded medical devices; and similarly, in mobile, portable, and pervasive computing devices, such as cell phones, digital cameras, flexible displays, multi-media multi-modal handhelds, and household robots. It is the software that integrates these and other complex systems into a seamless, globally networked, 24/7 world. Teams of multidisciplinary researchers will work together to explore the engineering of software for complex systems with complementary themes: (1) exploring scientific and engineering principles, e.g., inspired by complexity sciences, for developing software for tomorrow's complex cyber-based systems, and (2) exploiting computational models underlying software systems to understand natural and physical systems. Research outcomes in this area are potentially enormous. Innovations in software and software services contribute more than $1.7 trillion to the global economy, making U.S. competitiveness in this area essential to our continued economic prosperity.

Virtual Organizations: Virtual organizations built upon cyberinfrastructure to link teams of people and resources distributed across institutional and geographic boundaries are increasingly essential for science and engineering, enabling global collaborations. We are just beginning to explore their potential to enhance discovery, learning, and innovation. CDI investments support interdisciplinary research to create more systematic knowledge about the intertwined social and technical issues of effective virtual organizations, changing both how we practice research and what we produce from it. FY 2009 activities focus on building and applying more principled understanding of the design of effective virtual organizations needed to achieve the flexibility and agility to respond to new and emerging challenges in an increasingly competitive knowledge-based economy. This focus includes exploration of virtual organizations as a primary vehicle for broadening participation in not just research but also exciting inquiry-based STEM education, with the potential to reach students at all levels and the public at large.

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(Dollars in Millions)

FY 2008 Estimate	FY 2009 Request
$47.90	$100.00