NITRD Networking and Information Technology Research and Development

FY 2003

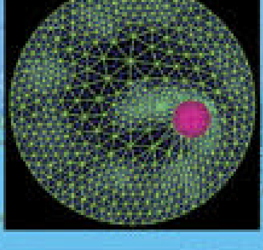
EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

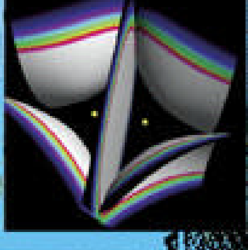
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

Strengthening National, Homeland, and Economic Security

Networking and Information Technology Research and Development

Supplement to the President's Budget





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NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT

SUPPLEMENT TO THE PRESIDENT'S FY 2003 BUDGET

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

STRENGTHENING NATIONAL, HOMELAND, AND ECONOMIC SECURITY

A Report by the Interagency Working Group
on Information Technology Research and Development

National Science and Technology Council

JULY 2002

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

MEMBERS OF CONGRESS:

I am pleased to forward with this letter the annual report on the multiagency Networking and Information Technology Research and Development (NITRD) Program. Advanced networking and information technologies developed through Federal NITRD investments are providing an essential infrastructure for economic strength and national security. As outlined in the attached report, these investments have enabled extraordinary advances in biomedical research, the sciences, and engineering. The Federal government is deploying new technologies developed through NITRD to increase the security of our borders, our transportation systems, and our critical national infrastructures.

Investments in fundamental R&D are essential to our global leadership in science and engineering. Programs such as NITRD will help assure that the United States continues to lead the global science and engineering community by supporting fundamental research, education, and the development of advanced networking and information technologies.

Sincerely,

John H. Marburger III
Director

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Introduction

This Supplement to the President's FY 2003 Budget describes the Federal Networking and Information Technology Research and Development (NITRD) Program, the unique endeavor of Federal agencies collaboratively engaged in advanced research and development in these technologies.

The multiagency NITRD portfolio spans a balanced, diverse set of long-term, fundamental research efforts in all aspects of large-scale and broadband networking and information technologies. This ongoing research provides leading-edge networks, technologies, and tools for vital Federal missions, drives innovation throughout the U.S. economy, and supports the research talent that sustains U.S. global leadership in science and technology.

The first computers, the Internet, the graphical user interface, high-end parallel processing, the first end-to-end optical networks, advanced computational modeling and simulation, and search engine technologies are just a few of the results of Federal information technology (IT) research that have fueled the digital revolution from which we all benefit. Today the NITRD Program continues to be the Nation's primary source of fundamental technological breakthroughs and skilled human resources in the advanced computing, networking, software, and information management technologies on which our 21st century infrastructure and quality of life will rely.

The Supplement to the President's Budget, also known as the Blue Book, reports on the coordinated research priorities and activities of the NITRD agencies for FY 2003. In the post-September 11 world, highest-quality IT capabilities and technical advances with broad applications are needed more than ever. In that context, the Blue Book's first two sections – "From Research to Reality" and "U.S. Priorities" – highlight ways in which technologies developed through Federal NITRD investments aided in disaster response efforts after 9/11 and are playing critical roles in Federal initiatives to strengthen national, homeland, and economic security. The next section – "The NITRD Program" – outlines the Program's goals, management, and research structure. Subsequent sections are devoted to each of the NITRD enterprise's major research areas: high-end computing, large-scale and broadband networking, human-computer interaction and information management, high-confidence software and systems, software design and productivity, and socieconomic and workforce implications of IT and IT workforce development. Each section describes current issues and major research challenges and lists the proposed FY 2003 research activities of the participating agencies.

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FROM RESEARCH TO REALITY

Federal IT R&D Technologies Play Key Roles in Disaster Response

The memorial "Towers of Light" at the World Trade Center.

In the hours immediately following the September 11 terrorist attacks, four unusual rescue teams sped toward New York City in cars, vans, and planes from as far away as California and Florida. Each team included computer scientists and a collection of miniature robotic vehicles, many of them first-generation prototypes developed with funding from the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation (NSF), and the Office of Naval Research (ONR). At Ground Zero, the teams' work was coordinated by the Federal Emergency Management Agency (FEMA).

Over the next two weeks, the teams' shoebox- to suitcase-sized, track-wheeled vehicles penetrated up to 45 feet inside the mountainous, fiery devastation of the World Trade Center buildings through openings too small or too hazardous for human rescuers to investigate. The density of the collapsed rubble rendered the larger robots useless, but the smallest ones could be inserted into spaces less than a foot wide. The vehicles sent back video images of their surroundings and many carried microphones, transmitters, and infrared sensors to detect any signs of life and enable communication to and from the surface. They were able to find pockets of space where survivors might be and to identify structural conditions that posed dangers to those trying to remove debris. But like the rescuers working frantically at the surface of the gigantic smoking piles, the robots found no life, only remains.

The World Trade Center effort marked the first known use of robots in an urban search and rescue operation. Other technologies pioneered through Federal information technology (IT) research and development (R&D) investments provided advanced scientific maps and hazard assessments at Ground Zero and the Pentagon that were critically important to emergency-response activities after 9/11.

The advanced technologies – robotics, global positioning satellite (GPS) technologies, optical technologies for remote sensing and environmental monitoring, high-speed networking, computational chemical analysis techniques, and mapping, modeling, and simulation software – used in three separate disaster response activities described here originated in Federally funded IT R&D. In each effort, diverse information technologies working together provided the human responders with essential, timely, and otherwise unavailable findings to guide their decisions and actions. These IT capabilities made it possible to rapidly gather vast quantities of real-time data through remote sensing devices, to process and analyze the data, and to represent the scientific results graphically – transforming raw information into timely tools for human understanding and informed action. Federal IT research generates a continuing cycle of such advances from bench research to prototype demonstration to wide-scale deployment. The constant developmental effort supports critical Federal missions, seeds private-sector enterprise, and provides the lift for what John H. Marburger III, director of the White House Office of Science and Technology Policy (OSTP), calls the U.S. "trajectory of world leadership in science."

Small volunteers ideally suited for dangerous missions

DARPA prototype "pacbot" robot at Ground Zero.

The robotics teams were called into action by a DARPA program manager specializing in robotic systems who had developed a strong interest in the potential applications of robots in urban search and rescue operations. DARPA's ongoing R&D in small, portable, unmanned systems aims to increase the agility, mobility, and autonomy of these systems for the tactical battlefield while decreasing their size – characteristics that also are relevant in disasters.

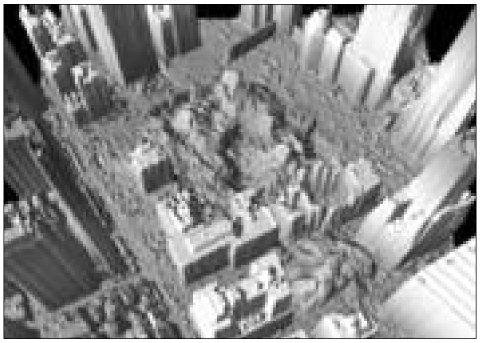
On September 11, DARPA Director Anthony J. Tether quickly approved the idea of sending an agency team with some DARPA prototype robots to the World Trade Center. Other robotics specialists also were called on, including Navy researchers in San Diego, personnel from the Massachusetts technology firms Foster-Miller and iRobot, and Dr. Robin Murphy, a leading robotics researcher at the University of South Florida whose work has been supported by DARPA, the National Aeronautics and Space Administration (NASA), ONR, and NSF. In addition to conducting her own research, Murphy introduces undergraduate and graduate students to the theoretical and technical issues of robotics engineering, in part with funding from NSF's Research Experiences for Undergraduates program. On 9/11 the professor of computer science and cognitive neuroscience loaded her van with graduate students and robot prototypes and drove straight through to the teams' rendezvous site, arriving the morning of September 12. As things turned out, an overriding issue for all the robotics specialists at Ground Zero was platform size: only 7 of the 17 vehicles brought to the site were small enough to be used amid the dense rubble.

Since 9/11 the value of robotic devices for search and rescue work and remote reconnaissance in hazardous conditions is increasingly recognized within the Department of Defense and in the emergency response community. For example, Murphy now works as a volunteer to train local police, fire, and other first responders in urban search and rescue techniques, including uses of robotic devices. And she and other robotics researchers examining the technical lessons of the World Trade Center experience are making use of a portable test course established in 2000 by the National Institute of Standards and Technology (NIST) to evaluate robots' functioning in disaster environments. NIST, DARPA, and robotics research groups use the reference-testing facility to develop objective performance metrics; several of the Ground Zero robots had been run through the course prior to the disaster.

Although current technology shows significant progress over earlier generations, the systems employed in New York were still research platforms and exhibited serious shortfalls. Murphy noted at a recent NSF briefing that, although the prototype vehicles successfully contributed to the Ground Zero crisis response, their frustrated operators took away a long list of needed improvements requiring a continued advanced research effort. The research issues include durability (every robot used was damaged); speed, power, and maneuverability (robots flipped over and could not right themselves, or got stuck, or could not surmount obstacles); computational component issues (the smallest robots had no onboard processing, so they had to be wireline-tethered to surface-level controls, limiting mobility); camera occlusion and poor image quality; inadequate sensing capabilities (disaster-response robots need to be able to relay fine-grained and 3-D information about topology, materials, and other environmental characteristics, as well as about their own situation and physical state); and serious software problems (interfaces were difficult to use and software was not interoperable across robots).

As in tactical battlefield situations, the promise of robotics in disaster response is to undertake critical tasks, such as real-time information gathering and transmission, under conditions that are life-threatening for humans. Murphy noted that in the 1985 Mexico City earthquake, 65 of the 135 rescuers who died lost their lives inside damaged buildings. "It's not about the robots," Murphy said. "They are just another tool for emergency rescuers to use. Urban search and rescue is all about information – and the information technology it takes to get findings that rescuers urgently need into their hands right away."

Scientific maps and analyses to assess environmental, structural hazards

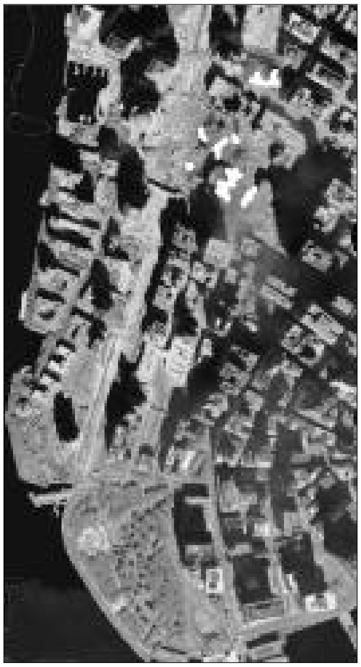


NOAA airborne laser swath mapping (ALSM) image looking southwest over the World Trade Center (WTC). The rubble of 7WTC is at lower right. Behind it are 5WTC (left) and 6WTC (right, damaged). Tower 1 stood behind 6WTC and Tower 2 stood behind and to the left of Tower 1. A wing of 4WTC remains standing at the left-rear of the site.

Shortly after the terrorist attacks, the geosensing systems unit in the University of Florida (UF) Department of Civil and Coastal Engineering received a phone call from the Joint Precision Strike Demonstration Group of the Department of Defense (DoD) asking for its laser-mapping expertise in a collaborative effort with Federal agencies to develop advanced scientific maps and damage and hazard assessments at the World Trade Center and the Pentagon. The UF researchers, whose Federally supported work applies scanning laser technologies to topographical and structural analysis, joined personnel and equipment from the National Oceanographic and Atmospheric Administration (NOAA), NOAA's National Geodetic Survey, and Optech, Inc., a Canadian manufacturer of laser devices, in the data-collection and analysis activity. Optech provided airborne and ground-based laser scanning instruments, and NOAA contributed a plane and pilot to collect the airborne observations. NSF added some "quick response" funding to enable the UF team, which is developing a novel 3-D structural mapping technique, to make additional laser observations and conduct a study of the results.

At the same time, Robert O. Green, a scientist at NASA's Jet Propulsion Laboratory (JPL), was on the phone with research colleagues at the Environmental Protection Agency (EPA) and the U.S. Geological Survey (USGS) discussing what contribution the three agencies might make to help emergency officials understand the environmental conditions at Ground Zero. They agreed that NASA, USGS, and EPA technologies and analytical capabilities could provide assessments of friable asbestos levels at the site and obtained a go-ahead from officials at their agencies to do the work. As the activity developed, however, the scientists realized there were other significant issues – such as the locations and temperatures of fires burning at Ground Zero, and the types and dispersion of airborne particulates – about which emergency workers needed strategic scientific information for decision making. FEMA and OSTP officials, recognizing the utility of the initial findings, asked the Federal scientists to continue collecting data over the following week.

NASA's hyperspectral imaging system assays hot spots, airborne particulates



NASA's September 16 AVIRIS flight over Ground Zero (upper right) at mid-day revealed dozens of thermal "hot spots" with temperatures as high as 1,300 degrees F. In this image, areas with the highest recorded temperatures are shown as white patches. Analyses of AVIRIS data also showed composition of airborne particulates.

Information technologies applied in these two collaborative Federal efforts included NASA's advanced remote sensing capabilities, DoD's global positioning satellite (GPS) technology, USGS's world-leading topographical and chemical analysis techniques, and computer modeling and visualization technologies developed by DARPA, the Department of Energy (DOE), NASA, NOAA, and NSF. These capabilities, along with advances in networking and computational power driven by IT R&D, enabled scientists involved in each of the mapping and hazard-assessment projects to turn very large and complex streams of sensor data rapidly into site maps and analyses.

NASA's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) was flown by its JPL team over the Trade Center area on September 16, 18, 22, and 23. AVIRIS is a unique hyperspectral remote sensing instrument that delivers calibrated images of rising spectral radiance in 224 contiguous bands with wavelengths from 400 to 2,500 nanometers. (The various bands make possible high-accuracy measurements across a wide variety of target surfaces, ranges, and atmospheric conditions.) After the initial flyovers, the Federal team was able on September 18 to provide emergency workers with the first information identifying three dozen thermal "hot spots" at Ground Zero, ranging from 800 degrees to more than 1,300 degrees Fahrenheit. By focusing on the targeted hot spots, firefighters were able to reduce temperatures to near-normal by September 23, as verified by the hyperspectral data collected in NASA's flyover on that day.

Computational tools enable data analyses

Digital spectral data collected in the NASA flights were delivered by FEMA courier to JPL in California, where Robert Green and colleagues worked through the night to process the findings via high-performance computing. Then they were networked to the USGS Imaging Spectroscopy Lab in Denver, where scientist Roger Clark and colleagues performed computational analyses including surface reflectance calibration and spectral mapping. Physical

PENTAGON RENOVATION PROGRAM: Around-the-clock efforts by thousands of workers have put the reconstruction of the 60-year-old Pentagon ahead of schedule, and more than 2,000 employees have already returned to their desks in the damaged section.The completed structure will be dedicated on September 11,2002.

samples collected at the site by USGS personnel also were analyzed for mineralogical and chemical properties using such technologies as reflectance spectroscopy, scanning electron microscopy, and X-ray diffraction.

On September 23, the researchers provided World Trade Center emergency workers with complete maps and reports detailing the substances in the air and on the ground. The results were consistent with the EPA ground team's assessment that only trace levels of asbestos were present in the air. But the spectral and sample analyses provided additional significant details, pinpointing the precise composition and dispersion of particulates. Other particulates included glass fibers, gypsum, concrete, paper, other substances commonly used in construction, and some heavy metals such as chromium and molybdenum. The analyses found that there were higher concentrations of asbestos on beam coatings but that the Ground Zero asbestos was composed only of chrysotile asbestos, which studies have found to be less carcinogenic than other forms. The interagency team agreed, however, with New York Public Health recommendations that cleanup work should be done with appropriate respiratory protection and dust control measures.

ALSM technologies provide accurate views of damage to buildings

Meanwhile, the University of Florida group was working with a combination of imaging and computing capabilities it has developed to generate a new type of 3-D map that can be particularly useful in assessing structural integrity and vulnerabilities.The technique starts with airborne laser swath mapping (ALSM), also called light detection and ranging (LIDAR), a line-of-sight technology first developed by NASA and USGS in the 1980s for wide-area topographic mapping. In ALSM, a pattern of narrow pulses or beams of light (of much finer resolution than the broad radio waves of radar) is directed to the surface being mapped. A digital optical receiver in the plane records, counts, and times the returning light pulses. Since light travels at 30 centimeters per nanosecond, high-speed computation and visualization software can convert these data points into high-resolution maps of topographical features.

NOAA's Cessna Citation flew over the 16-acre World Trade Center site, scanning with an Optech ALSM unit. The system recorded data points from 33,000 laser pulses per second hitting and bouncing off the terrain at intervals of less than one meter across a swath parallel to the plane's path. At the same time, UF team members on the ground used an Optech tripod-mounted laser scanner to record structural and ground surface data points at intervals of a few centimeters. GPS receivers positioned at the site provided precision calibration and orientation for both the air and ground-level laser scans. Using ALSM data only, the researchers supplied the city with a preliminary topographical map of a six-kilometer-square area around Ground Zero. They also developed high-resolution ground-level images of structures still standing at the site. These images were used by emergency teams to help assess the severity of structural damage and possible dangers to workers.

At the Pentagon, the NOAA aircraft made 30 ALSM scans totaling more than 31 million data points, and an Optech crew conducted 13 ground-level scans. The company processed the data rapidly, providing Defense officials within days with topographical and eye-level images of Pentagon structural damage.

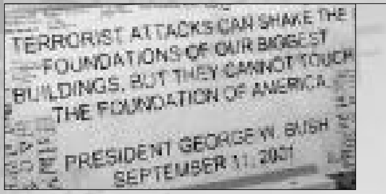
Turning laser dots into precision 3-D digital elevation maps

Back at the University of Florida's ALSM processing lab, the hundreds of millions of data points gathered at the World Trade Center underwent intensive computational processing and filtering, using algorithms developed by the researchers to eliminate irrelevant topographical "noise" such as cars, airborne particulates, and vegetation, and to generate geo-referenced data grids. The output images look like black and white photographs, but they are in fact vast clouds of data points, each with its own spatial coordinates on three axes, accurate to within a few centimeters. With these 3-D digital elevation maps, a viewer can look at a structure from above and then zoom in to see the same view from other angles. The map user can search for cracks and fissures, estimate the volume (and thus the mass) of debris fields or holes, and superimpose a geometric mesh over a structural element to compute its degree of deformation or deflection (thus stress) and the size and shape of surface damage.

As part of the NSF "quick response" funding, the University of Florida researchers will recommend ways that their innovative mapping system can be used in future disaster prevention and mitigation efforts – such as mapping potential earthquake and flood zones and evacuation routes – as well as in emergency response situations.

The coordination of Federal IT research investments across many agencies and private-sector partnerships leverages the Government's mission-related research, producing general-purpose, broadly useful, and interoperable technologies, tools, and applications. That makes the NITRD Program a powerful engine of technology transfer. The large number of Federally funded IT breakthroughs subsequently commercialized in the private sector – often by graduates of U.S. research universities whose education was supported by NITRD funding – leverage the Federal investments even further. The following pages describe the IT research priorities and plans of the NITRD agencies.

Strengthening National, Homeland, and Economic Security



Workers at the Byee Stone Company of Elletsville, Indiana, engraved and signed this stone, which will be placed at the Pentagon crash site during September 11, 2002, dedication ceremonies. Also signed by construction workers at the site, the plaque – and stones for the restoration itself – come from the same quarry used to build the Pentagon originally.

National security, homeland security, and economic security – the three interconnected Administration priorities set forth by President Bush in his January 29 State of the Union address – have turned an unprecedented spotlight on the critical significance of advanced information technologies in safeguarding American citizens and institutions in the 21st century. In the war on terrorism, capabilities conceived through Federal investment in fundamental IT R&D are being deployed in advanced weaponry, battlefield reconnaissance, and information operations environments; bioterrorism countermeasures; intelligence gathering and analysis; increased security for critical U.S. infrastructure, including digital communications systems; and surveillance of our national borders and visitor access processes. And in its plan for the 2003 fiscal year, Dr. Marburger said at a recent scientific gathering, "the President's Budget acknowledges that the Nation's highest priorities are all served by investments in science, engineering, and education."

In the computing field, Moore's Law has for three decades reliably predicted the doubling of transistors per silicon chip – and thus computing speeds and IT advances – every 18 months. Today's IT components must be rapidly and continuously improved to sustain U.S. technological leadership for both national security and economic development.

NITRD agencies aid in Federal response

The NITRD agencies are active participants in Administration working groups that have been tasked on a rapid-response basis to coordinate Federal technological resources and needs for combatting terrorism. In recent remarks to the President's Council of Advisors on Science and Technology, Secretary of Commerce Donald Evans noted that the National Institute of Standards and Technology (NIST) within the Department of Commerce (DOC) supports 75 programs related to defense against terrorism. NIST is also the formal research and technical resource for FEMA efforts to apply state-of-the-art technologies to disaster preparedness and crisis response. The Secretary also cited the role of NOAA, another DOC agency, in providing satellite-based weather and environmental analysis capabilities that help counter terrorist threats and strengthen U.S. economic security. In addition, NITRD agency funding supports the development of the Nation's leading IT, science, and engineering researchers, including the foremost specialists in cybersecurity technologies and tools. (Please see page 31 for more on NITRD's role in building the skilled IT workforce that U.S. economic security requires.)

High-end computing plan for national security

NITRD agencies are also participating in the development of a plan for a long-term integrated supercomputing R&D program to strengthen national security. In its report accompanying the FY 2002 Defense appropriation bill, Congress tasked the Secretary of Defense to prepare such a plan by July 2002.

Keeping IT R&D pipeline full of innovations

The information technologies now being fielded in U.S. counterterrorism activities represent the outflow of the IT R&D pipeline. Fundamental Federal IT research keeps the pipeline full of powerful, innovative ideas so that next-generation technical advances can be prototyped and commercially developed even as the current generation is deployed. This is the process that fueled the digital revolution and continues to drive U.S. economic growth.

Addressing networking and IT challenges in the national interest

Particularly in the areas of critical and networking infrastructure protection and intelligence management, national and homeland security require:

- Intensified research in cybersecurity technologies and methods to develop advanced networks that can replace the vulnerabilities of today's Internet with self-healing, trusted, high-bandwidth systems for secure U.S. commerce, communication, and connectivity
- Advanced software algorithms for high-performance data mining, synthesis, analysis, and management of massive quantities of unstructured, heterogeneous information from many sources
- New hardware and software assurance technologies
- Innovative methods to protect U.S. citizens from theft and misuse of their identity information and to assure the security of travel

Major Research Challenges

- Cost-effective advances in high-end computing to provide the data storage and compute power for intelligence analysis, high-performance national defense systems, and critical scientific research
- Large-scale data mining, intelligence analysis, and information management technologies
- Advanced cryptography and authentication technologies for secure communications
- New methods to achieve security, attack-resistance, and self-healing in high-speed wireless and wired networks
- Embedded, networked sensor technologies for reconnaissance and autonomous weapons systems
- High-assurance software design for mission-critical systems
- Improved interfaces and interoperability of heterogeneous, multimodal IT devices and functionalities

CIA Report: Maintain U.S. Leadership in Key Technologies To Enhance National Security

The war on terrorism, the President said in his State of the Union address, makes this "a decisive decade in the history of liberty." This Supplement to the FY 2003 Budget describes the ways in which IT capabilities developed by the NITRD agencies are supporting immediate Federal efforts to strengthen national, homeland, and economic security.

Federal IT R&D investments also play a long-range strategic role in sustaining the Nation's overall strength, according to a November 2001 report by the Central Intelligence Agency (CIA). In the report, "Global Technology Scenarios Through 2015," a panel of experts concludes that U.S. national and economic security in the years ahead will be inextricably linked to our continuing world leadership in science and technology innovation.

The panel identifies six technologies – gene therapy, wireless communications, image understanding, cloned or tailored organisms, MicroElectroMechanical Systems (MEMS), and nanotechnology – as those most likely to have "high impact" on U.S. national security.

The rapid emergence of these high-impact technologies is enabled by cutting-edge IT capabilities – such as computational modeling, simulation, and interactive digital instrumentation – pioneered in Federal R&D, and all the high-impact technologies will rely on continuing advances in IT R&D to further their development. Four of the six technologies – wireless communications, image understanding, MEMS technologies, and nanotechnologies for advanced computation and computing components – are the focus of current research in the NITRD Program.

Five additional technologies that the CIA panel calls "enablers" are seen as having a significant impact on national security by 2015 if technological innovation, market demand, and synergy among the emerging technologies are all robust between now and then. The enablers are: optical communications, regenerative medicine, efficient software development, sensor webs, and advanced materials.

Three of these five enabling technologies are high priorities today in the Federal NITRD program, and research in the other two areas – regenerative medicine and advanced materials – requires high-end data storage and management, computation, and networking technologies developed by the NITRD agencies.

Among the hallmarks of new technologies that are successfully adopted, the panel notes, are that they result from Federal or commercial R&D "in specific fields of technological innovation" and "they are platform technologies with many potential spinoff applications." Predicting that the pace of technological change will accelerate over the period examined, the panel envisions that all six of the high-impact technologies will have been adopted in the U.S. by 2015.

The uncertainties affecting the relative advantage or disadvantage for this country, the panel concludes, lie in "the intensity of technological development, the degree of U.S. leadership, and the level of diffusion of technologies (new and existing) to developed, developing, and less developed nations."

The panel argues that "the United States is well positioned to maintain its current leadership role in technology." But it cautions that "continued investments by government and industry in R&D" and "an educational system capable of producing sufficient graduates in science, engineering, and medicine" will be critical to sustaining U.S. preeminence.

Leveraging IT Talents and Resources Through Interagency Collaboration

Overview

The multiagency Networking and Information Technology Research and Development (NITRD) Program occupies a unique position in the Federal science and technology research portfolio. There is no other single area of either science or technology whose impacts on government and society are at once so pervasive, so profound, and so critical to the national interest. Information technology is the ultimate interdisciplinary enabler, reaching into many basic and applied sciences for its source materials and producing devices and capabilities with universal applications.

The new American infrastructure

Networks and other information technologies today provide the core infrastructure, platforms, and tools for necessary activities across the whole spectrum of American endeavor – from national defense and national security, to communications, commerce, and industry, to biomedical and scientific research, to health care and education, to agriculture and transportation, to weather forecasting, energy management, environmental protection, and citizen services. The critical components of IT systems and devices combine fundamental and applied knowledge in mathematics, physics, chemical, electrical, and mechanical engineering, and computer science. Tailoring these components to specific application fields – such as aerospace transportation and communication systems, weapons systems, telecommunications networks, biomedical research, large-scale information collection, storage, and management, and the like – requires additional interdisciplinary collaboration between the technology builders and users.

Coordination,partnerships with academe and industry prove productive

Even at the time the Congress called for interagency IT research collaboration in the High-Performance Computing (HPC) Act of 1991 (P.L. 102-194), it was by no means clear that computing and networking technologies would, in only a few years, dramatically transform society. But the bipartisan HPC legislation turned out to be prescient. It established a strong interagency framework for Federal IT research, combining ambitious goals with requirements for interagency cooperation, coordination, and partnerships with academe and industry. The program has grown steadily into a highly productive research enterprise involving all the major Federal science and research agencies and collaborations with virtually all major U.S. research universities and with many companies developing new information technologies and applications.

Collaboration advances enabling technologies

Over the course of the decade, not just the wisdom but the necessity of interdisciplinary collaboration and coordination in IT research has become more widely recognized, as the complexity and heterogeneity of systems and software continue to spiral upward with the demand for new IT capabilities and protections. In this context, the coordination of Federal IT R&D investments – the Nation's most important source of fundamental IT research – across many agencies and private-sector partnerships powerfully leverages both human talents and mission-related research. This accelerates advances in the underlying technologies – called "enabling" technologies – on which all computing and networking devices and systems are based. The results are general-purpose, broadly useful, and interoperable technologies, tools, and applications that enable Federal deployment of state-of-the-art systems for critical agency missions and spur commercial development and innovation throughout the economy.

About the multiagency NITRD Program

The NITRD Program is one of the very few formal interagency research efforts in the U.S. government. It has become a model for success in such a collaborative enterprise. Criteria for participation are outlined on page 38.

Participating agencies

The NITRD agencies are:

- Agency for Healthcare Research and Quality (AHRQ)
- Defense Advanced Research Projects Agency (DARPA)
- Department of Defense, Office of the Director, Defense Research & Engineering (ODDR&E)
- Department of Energy (DOE) National Nuclear Security Administration (NNSA)
- Department of Energy (DOE) Office of Science
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Institutes of Health (NIH)
- National Institute of Standards and Technology (NIST)
- National Oceanic and Atmospheric Administration (NOAA)
- National Security Agency (NSA)
- National Science Foundation (NSF)

Program Component Areas (PCAs)

The collaborative research agenda of the NITRD agencies is expressed in seven Program Component Areas (PCAs), each of which focuses on particular aspects of IT research. Each PCA has a Coordinating Group made up of agency program managers in the relevant research fields. These groups meet monthly to exchange information and coordinate multiagency activities in their areas.The PCAs are:

- High End Computing (HEC), which includes both HEC R&D and HEC Infrastructure & Applications (I&A)

- Human Computer Interaction & Information Management (HCI & IM)
- Large Scale Networking (LSN)
  - LSN also fields three targeted teams – Joint Engineering Team (JET), Middleware and Grid Infrastructure Coordination (MAGIC), and Networking Research Team (NRT) – that address specific technical issue areas. These teams include non-Federal members from academe and industry.
- Software Design and Productivity (SDP)
- High Confidence Software and Systems (HCSS)
- Social, Economic, and Workforce Implications of IT and IT Workforce Development (SEW)

Interagency Working Group (IWG) on IT R&D
and
National Coordination Office (NCO) for IT R&D

Overall coordination of NITRD activities is handled by the Interagency Working Group (IWG) on IT R&D of the National Science and Technology Council. The IWG is made up of representatives from each of the participating agencies and from the Office of Management and Budget (OMB), the Office of Science and Technology Policy (OSTP), the National Economic Council (NEC), and the National Coordination Office (NCO) for IT R&D. The IWG is co-chaired by NSF's Assistant Director for the Computing and Information Science and Engineering Directorate and the Director of the NCO, which coordinates planning, budget, and assessment activities for the NITRD Program.

NITRD Program funding

Agencies' NITRD activities are funded through standard budgeting and appropriations measures that involve the participating agencies and departments, OMB, and the Congress and are signed into law by the President. NITRD efforts typically involve multiagency collaboration, with mutual planning and mutual defense of budgets; agencies provide funding and management for their research contributions to the NITRD enterprise.

About the Supplement to the President's Budget for FY 2003

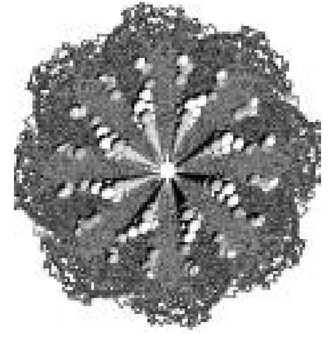
This Supplement to the President's Budget for FY 2003 outlines the current activities and plans of the NITRD Program, as required by the HPC Act of 1991. The Supplement describes key roles being played by the NITRD agencies in the war on terrorism and highlights major NITRD research efforts to develop and prototype the next-generation IT component technologies and tools that will power U.S. scientific and economic innovation in the years ahead. The proposed NITRD budget for FY 2003 is $1,889 million, a $59-million increase above the estimated $1,830 million in FY 2002. FY 2002 budget estimates and FY 2003 requests for the NITRD Program, by agency and by PCA, are shown on pages 36 and 37.

Information on the Web

Copies of NCO publications, including this report, information about NITRD activities, and links to participating agency and related Web sites can be found at:

http://www.nitrd.gov/

New Technologies To Explore the Frontier of Complexity



Head-on view of a protein nanotube from prototype NASA Growler software for visualizing molecular structures of 1,000 or more atoms.

Representative FY 2003 agency activities

NSF: Terascale infrastructure; systems software, middleware, software environments, libraries, visualization, data management, and algorithms for heterogeneous distributed high-end systems; grid resource management; quantum and biological concepts

DARPA: Polymorphous architectures; high-end productive, robust, intelligent computing systems; very large-scale integration of photonics for intra- and inter-chip communication, including processor-in-memory arrays

DARPA/NSF: Biomolecular structures applied to terascale computation and storage

NASA: High-end software and systems tuning and management techniques; Information Power Grid technologies and tools; information physics (properties of sensing, processing, and storage systems); quantum and nanoscale technologies

We are in the early stage of a revolution in science nearly as profound as the one that occurred early in the last century with the birth of quantum mechanics. This revolution is caused by two developments: one is the set of instruments such as electron microscopy, synchrotron x-ray sources, lasers, scanning microscopy, and nuclear magnetic resonance devices; the other is the availability of powerful computing and information technology. Together these have brought science finally within reach of a new frontier, the frontier of complexity.

– John H. Marburger III, Director, OSTP

Beyond this frontier lie the tiniest units and processes of organic and inorganic matter, the largest structures and farthest reaches of the universe, the interactions and patterns of change among the elements of the biosphere that enables life on Earth, and the possibility of novel materials, pharmaceuticals, technologies, and tools we can barely imagine today.

The NITRD agencies are aggressively pursuing technical breakthroughs in component technologies, high-end system and storage architectures, systems software, and programming environments that will enable U.S. science to lead the world in these promising realms. Attaining the necessary highest-performance capabilities requires fundamental long-term research in computer architecture, semiconductor design, and systems software, as well as in areas with revolutionary potential, such as quantum and biomolecular concepts, in all aspects of high-end systems and software (see pages 15-17). NITRD research provides an essential bridge between the requirements of the Federal government for cutting-edge national defense, national security, and scientific applications and commercially available computing products.

In addition, NITRD-funded research is developing technologies and tools for high-end collaboratories – “virtual” lab facilities shared over high-performance networks by distributed teams of scientists. The goal is a networked infrastructure for advanced research that can seamlessly connect distributed teams to the high-end computing systems, instruments, advanced simulation and visualization software, and sensor networks they need to work collaboratively on data- and computation-intensive problems.

One form of such interconnections is called “grid computing” because it works as a patterned overlay on advanced networks, creating a grid of linked, interoperating resources that can be widely distributed, with a governing fabric of protocols and protections for the grid and its users as a whole. In effect, a grid leverages the Internet to provide some of the infrastructure for

NIH: High-end biomedical computing; tools for determining 3-D molecular structures; methods for displaying and analyzing images from instrumentation data

DOE Office of Science: Scalable mathematical algorithms and software infrastructure (operating systems, component technologies, optimal mathematical solvers) for terascale modeling and simulation applications; partnerships for terascale science

DOE/NNSA: Science and engineering innovations in high-speed computation, terabyte data storage and retrieval, and visualization to enable supercomputer modeling and simulation for U.S.nuclear stockpile stewardship

NSA: Collaborations with high-end systems manufacturers; operating system and programming language improvements; fundamental technologies for special-purpose devices (power controls, cooling, interconnects, switches,and design tools); computer memory performance; fundamental physics of quantum information systems

NOAA: Improved climate and weather models via enhanced Modular Ocean Model, Flexible Modeling System, and Scalable Modeling System

NIST: Research in quantum computing,secure quantum communication, optimization and computational geometry, photonics, nanotechnologies, optoelectronics, and new chip designs and fabrication methods

ODDR&E: University-based research in quantum communications and memory

EPA: Paradigms, techniques, and tools for modeling complex environmental phenomena such as interactions of air, water, and soil

large-scale, distributed, high-performance computing, and it extends high-end capabilities to a wider community of scientists, engineers, and students.

With early, visionary support from DARPA, DOE, NASA, and NSF over the past five years, researchers at the leading edge of grid design prototyped and experimented with the open-standard Globus Toolkit™. Developed at DOE's Argonne National Laboratory (ANL) and the University of Southern California, Globus is the first suite of middleware software tools for linking and using computing resources in a grid environment. NASA adopted Globus to build its Information Power Grid, an ambitious initiative to network the agency's high-end computing resources and data repositories. In FY 2002, NSF brought national visibility to the grid concept when it awarded an unprecedented $53 million to four institutions to create a "Distributed Terascale Facility" with Globus as the underpinning that knits the components into a whole (story on next page).

In recent months, 12 leading hardware and software vendors – including Compaq, Cray, Fujitsu, Hitachi, IBM, Microsoft, NEC, SGI, and Sun Microsystems – have announced that they will adopt the Globus Toolkit™ as the basis for grid computing with their products. An IBM executive has predicted that grid computing will transform U.S. business practices.

Even as NITRD research generates many such promising technology transfers, the Program's primary focus in high-end computing continues to be on research to increase the most advanced and exacting capabilities of high-end platforms for critical U.S. defense and civilian requirements, including global science and technology leadership. For FY 2003, the NITRD agencies will support research in: 1) the fundamental science of supercomputing component technologies and system designs, and 2) technologies, tools, and applications to enable the Nation's researchers to work computationally at the state of the art.

Major Research Challenges

- High performance computer architecture – understanding and managing the complexity tradeoffs among hardware design and architecture, systems software, and scientific applications to deliver the greatest capability for scientific discovery and national security
- Revolutionary approaches – such as innovative processing and storage concepts, including novel architectures, quantum and biomolecular components, hybrid technologies, reconfigurable systems on a chip, and processor-in-memory (PIM) technologies – to enable next-generation supercomputing platforms
- Systems software – advanced programming environments, compilers, libraries, middleware, and performance engineering technologies
- New high-end algorithms and codes for scientific computation and simulation; integrated and optimized software infrastructure for distributed terascale computing environments

Terascale Infrastructure for Discovery

Tera- = A prefix denoting 10^{12}, or a trillion. A terascale computing system can make a trillion calculations, called floating point operations or “flops,” per second. A terabyte is a trillion bytes of data. Federal research seeks to achieve petascale (10^{15}, or a thousand trillion calculations per second) systems by the end of this decade.

NSF’s Distributed Terascale Facility

NSF’s new $53-million initiative aims to bring the power and benefits of terascale computing to the Nation’s college and university campuses. The effort will build a unique distributed terascale system outfitted for grid computing that will serve as the experimental prototype for a wider-scale academic computing infrastructure of the future.

A longtime champion of improved computing infrastructure for academe, NSF has, since the mid-1990s, supported development of the Partnerships for Advanced Computational Infrastructure (PACI), two networks of universities working to expand campus researchers’ access to high-end computing facilities and tools.The National Partnership for Advanced Computational Infrastructure (NPACI) based at the University of California-San Diego’s (UCSD) San Diego Supercomputing Center (SDSC) is a collaboration of 30 other funded partners and 16 domestic and international affiliates; the National Computational Science Alliance (the Alliance) is a group of more than 50 academic, government, and business organizations based at the National Center for Supercomputing Applications (NCSA) on the campus of the University of Illinois at Urbana-Champaign.

In FY 2000, NSF commissioned an initial effort to develop a terascale academic computing platform at the Pittsburgh Supercomputing Center. That system, built in partnership with Compaq, came online ahead of schedule in 2001 with a peak performance of 6 teraflops and realized 75 percent of peak with an existing application code. The three-year Distributed Terascale Facility (DTF) program will add to this developing academic infrastructure the world’s first multisite terascale computing system, with peak performance of 11.6 teraflops and more than 450 terabytes of storage.

The four sites chosen for DTF awards – SDSC, NCSA, DOE’s Argonne National Laboratory (ANL), and the California Institute of Technology (Caltech) – will work with primary corporate partners IBM, Intel, Myricom, Oracle, Qwest, and Sun – to build the computing platforms and link them through a 40-gigabit (40 billion bits-per-second) optical network. The DTF institutions will divide up the developmental responsibilities:

- NCSA will be the lead in computational aspects with an IBM Linux cluster using Intel’s 64-bit Itanium “McKinley” processors. Peak performance will be 6.1 teraflops, with 240 terabytes of secondary storage
- SDSC will head the project’s data- and knowledge-management effort, with a 4-teraflops IBM Linux cluster using McKinley processors, 225 terabytes of storage, and a Sun high-end server for managing data
- ANL will have a 1-teraflops IBM Linux cluster to host advanced software for high-resolution rendering, remote visualization, and grid computing
- Caltech will focus on data, with a 0.54-teraflops McKinley cluster and a 32-node IA-32 cluster to manage 86 terabytes of online storage

These computational resources will be woven together as the “TeraGrid,” a grid computing framework using Globus that participants see as the potential blueprint for tomorrow’s advanced academic computing. The four sites are expected to be linked and operational in FY 2003.

Scientific Discovery Through Advanced Computing (SciDAC) at DOE

Scientific inquiry at the frontier of complexity requires computational modeling and simulation, a critical component of research across all areas of DOE's Office of Science. Today, the astonishing advances in processing speeds over the last decade have opened the prospect of new, even more accurate physical, chemical, and biological models. But these highly complex models can only be effectively developed by interdisciplinary teams of applications scientists, applied mathematicians, and computer scientists.

The Office of Science's Scientific Discovery through Advanced Computing (SciDAC) program, a new initiative in FY 2001, has assembled such teams to develop the scientific computing software and hardware infrastructure needed to use terascale computers to advance fundamental research in areas related to DOE missions. Under the multiyear SciDAC program, 51 projects have received a total of $57 million to build terascale capabilities for climate modeling, fusion energy sciences, chemical sciences, nuclear astrophysics, high-energy physics, and high-performance computing.

The SciDAC effort will help create a new generation of scientific simulation codes. The codes will take full advantage of the extraordinary computing capabilities of terascale platforms to address ever-larger, more complex problems. The program also includes research on improved mathematical and computing systems software that will enable these codes to use modern parallel computers effectively. Collaboratory software developed within the SciDAC program will enable geographically separated scientists to use scientific instruments and computers remotely and work together with distant colleagues as a team, sharing data more readily.

Selected from more than 150 proposals, the SciDAC activities include large projects funded for three to five years and smaller projects supported for three years. Success of the SciDAC program depends on multidisciplinary teams from universities and laboratories working in close partnership. The projects involve collaborations among 13 DOE laboratories and more than 50 colleges and universities.

Thirty-three projects are in the biological, chemical, and physical sciences. Specifically, 14 university projects will advance the science of climate simulation and prediction. These projects involve novel methods and computationally efficient approaches for simulating components of the climate system and work on the integrated "climate model of the future."

Ten projects will address the areas of quantum chemistry and fluid dynamics, which are critical for modeling energy-related chemical transformations such as combustion, catalysis, and photochemical energy conversion. The scientists involved in these activities will develop new theoretical methods and efficient computational algorithms to predict complex molecular structures and reaction rates with unprecedented accuracy.

Five projects are focused on developing and improving the physics models needed for integrated simulations of plasma systems to advance fusion energy science. These projects will focus on such fundamental phenomena as electromagnetic wave-plasma interactions, plasma turbulence, and macroscopic stability of magnetically confined plasmas.

Four projects in high energy and nuclear physics will significantly extend our exploration of the fundamental processes of nature. The projects include the search for the explosion mechanism of core-collapse supernovae, development of a new generation of accelerator simulation codes, and simulations of quantum chromodynamics.

Seventeen projects are to develop the software infrastructure to support research collaboration using distributed resources and scientific simulation on terascale computers.

Three Applied Mathematics Integrated Software Infrastructure Centers will take on the challenge of providing scalable numerical libraries. The centers will provide new tools for near-optimal complexity solvers for nonlinear partial differential equations based on multilevel methods, hybrid and adaptive mesh generation, and high-order discretization techniques for representing complex, evolving domains, and tools for the efficient solution of partial differential equations based on locally structured grids, hybrid particle/mesh simulations, and problems with multiple-length scales.

Four Computer Science Integrated Software Infrastructure Centers will address critical issues in high-performance component software technology, large-scale scientific data management, understanding application/architecture relationships for improved sustained performance, and scalable system software tools for improved management and utility of systems with thousands of processors.

Four national collaboratory, two middleware, and four network research projects will have general applicability. This work will investigate, develop, deploy, and refine the underpinning software environment that will enable innovative approaches to scientific computing through secure remote access to shared distributed resources, large-scale transfers over high-speed networks, and integration of collaborative tools with the researcher's desktop.

Long-Range Research in Revolutionary Architectures

Radically new component technologies and system architectures are needed to make it possible to design smaller supercomputing platforms that cost less to build and maintain but increase speeds, portability, and scalability. The current generation of U.S. high-end platforms requires many thousands of square feet of floor space and megawatts of power. This approach, which packages many commodity multiprocessor nodes into one large system, is reaching the limits of scalability and affordability.

The NITRD research agenda supports long-range efforts seeking fundamental breakthroughs in high-end processor and systems architectures to reduce the size, cost, and power requirements of platforms and mass storage devices.This work includes high-risk experimentation with promising concepts in biomolecular, quantum, and hybrid nano-technologies for processing and storage; reconfigurable systems on a chip; systems architectures integrating component and device technologies; and programming environments.

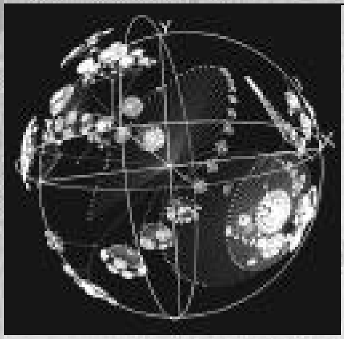
To create a supercomputing platform, very large numbers of components must be brought together and assembled. Achieving maximum possible computational speeds dictates that all these components be tightly spaced and closely interconnected. To build such a platform on a scale that increases portability and scalability will require solution of the high-end field's most difficult challenges in fundamental science, including power requirements, thermal management, component and system architecture miniaturization, and superconducting switches and interconnects.

Advanced national defense applications are a key area in which new approaches to high-end computing systems are urgently needed, a DoD official noted at a March 2002 conference. To achieve the necessary breakthroughs, DARPA is undertaking an ambitious "High Productivity Computing Systems" program, which challenges industry, working with academic research partners, to think "out-of-the-box" about architectures and component technologies, with the goal of producing an entirely new commercial system by 2010.

Working through three R&D phases from innovative concept to technical design to prototype fabrication, the DARPA development teams will be expected to achieve the following metrics: 10 to 40 times today's supercomputing performance; significantly increased productivity through reduced application development time and operational costs; better portability (application software insulated from system specifics); and substantially improved robustness and reliability.

In addition, NSA is leading an effort involving the national security R&D agencies and user community to develop a plan for a long-term integrated R&D program in high-end computing. Congress has asked the Secretary of Defense to provide the research blueprint by July 2002.

Future Nets: Dynamic Flexibility, High Bandwidths, and Security



Visualization of a directory tree, created with Walrus software tool (see inside back cover for details). Image courtesy of CAIDA.

Representative FY 2003 agency activities

NSF: Research in middleware to optimize the performance of networked applications; high-performance connections for colleges and universities; strategic Internet technologies such as network monitoring,problem detection and resolution, automated advanced tools for active and intelligent networks, collaborative applications, and innovative access methods

NIH: Demonstrate application of scalable, network-aware, wireless, geographic information system (GIS), and security technologies for networked health-related environments

DARPA: Scalable network modeling and simulation tools capable of predicting behavior at scales ranging from milliseconds to hours on networks of hundreds of nodes;demonstrate hybrid optical/RF self-healing networks

Three decades ago, a handful of Federally funded researchers invented a way to send messages from one computer to another over telephone lines. Their world-changing breakthrough, elaborated in subsequent Federal and private sector R&D, has evolved into the Internet – the basic, if awesomely diverse and powerful, infrastructure for human enterprise in the new century.

Federal research in large-scale and broadband networking continues to support U.S. leadership in advanced communications by developing and prototyping next-generation technologies to dramatically increase the speed, reliability, security, and versatility of networks. In the wake of 9/11, the NITRD agencies' ongoing research emphasis on network reliability, security, and privacy has also become a shared national concern.

Although the Internet still has the aura of novelty about it, the reality is that the Net is the product of older technologies that limit the speed and size of data transfers, open networked devices to cyber attacks, and are not scalable enough to extend reliable connectivity to fast-growing numbers of wireless, mobile, and embedded devices. NITRD research focuses on achieving the fundamental technical advances needed to make end-to-end high speeds, reliability, security, and flexible access the standard features of the Nation's digital communications systems.

One key research area is optical technologies, which offer exponentially higher bandwidths than today's Internet and thus make possible advanced applications and future network expansion. The NITRD agencies have demonstrated the world's first end-to-end optical network that is thousands of times faster than the Internet and are working to further develop optical systems, which also offer far greater network security and reliability than are currently possible. For example, the NSF-supported STAR TAP, a Chicago-based cross-connect of U.S. and international high-speed networks, is evolving into StarLight, an experimental optical testbed and infrastructure for network services optimized for bandwidth-intensive applications. StarLight will support experimental networks at 1, 2.5, and 10 gigabits per second and research networks at speeds up to 10 gigabits. The connections will allow production (ordinary uses) networks to operate at 1 gigabit levels.

NITRD research at the nexus of high-speed optical and wireless technologies provides the basis for the significant networking advances the Nation needs to keep pace with accelerating demands, including:

NASA: Implement a high-speed testbed network to develop and demonstrate advanced computing, networking, and collaborative technologies; integrate network services (QoS, passive monitoring, resource reservation) for grid environments; demonstrate hybrid satellite/mobile wireless/ad hoc network applications and Office of the Future work environment

DOE Office of Science: Research in high-performance transport protocols enabling reliable TCP delivery of terabits/sec throughput to distributed high-end science applications; development of end-to-end performance monitoring, network diagnosis, and scalable cybersecurity services for large-scale scientific collaborations

NSA: Research on advanced network topologies and protocols, network convergence, all-optical networking, and network management, including burst switch technology, provisioning, message passing, low-power wireless nets, firewalls in high-speed systems, and security and interoperability issues

NIST: Standards for networked communication of pervasive computing devices, including models of industry protocols, validation of emerging specifications, evaluation of adaptive control mechanisms; metrics and protocols for ad hoc wireless networks; approaches to agile switching infrastructure; protocols and standards for Internet infrastructure security

NOAA: Early adoption of scalable network capabilities and applications in support of severe weather forecasting and warning, and hazardous materials response

ODDR&E: University-based research in real-time fault-tolerant network protocols

- High levels of network trust (the system is highly reliable and the information it carries is secure and private)
- Anytime, anywhere network connectivity
- End-to-end high bandwidths for high-performance applications
- Grids to connect computing systems, storage, and instrumentation
- Collaboratory security and quality of service (QoS), meaning uninterrupted, uniform high network speeds with low latency
- Sensor nets – billions of networked, embedded sensors

In March 2001, the agencies held a major "Workshop on New Visions for Large-Scale Networks: Research and Applications" in Vienna, Virginia. More than 160 participants from government, academia, and industry analyzed six scenarios for the networking future (including intelligent warfare, disaster response, and air transport) and identified the research needed to realize these visions (http://www.nitrd.gov/iwg/pca/lsn.html). Their recommendations are helping guide NITRD research planning.

For FY 2003, NITRD focus areas include technologies and services to enable wireless, optical, mobile, and hybrid communications; networking software to enable information to be disseminated to individuals, multicast to select groups, or broadcast to an entire network; research on scalability and on modeling and simulation of the Internet; improved end-to-end performance and performance measurement; software for efficient development and execution of scalable distributed applications; software components for distributed applications, such as electronic commerce, digital libraries, and health care; and infrastructure support and testbeds.

NIH's National Library of Medicine, for example, will extend its leading-edge research in telemedicine with a new program to demonstrate the application of scalable, network-aware, wireless, geographic information systems (GIS), and security technologies to networked health-care environments. Project proposals will focus on applications for health-care delivery systems, medical decision making, public health networks, large-scale emergencies, health education, and medical research.

Major Research Challenges

- Trust: security, privacy, and reliability
- Adaptive, dynamic, and smart networking
- Measurement and modeling of network performance
- Scalable technologies for massive increases in heterogeneous network traffic, including billions of wireless devices and sensors
- Networking applications, including vertical integration and supporting tools and services such as middleware (see page 20)
- Revolutionary research: theories of complexity, generalized control theory, other models to address evolution of network functionality amid exponential growth in connectivity

Middleware MAGIC To Outfit Networks for Grids

Middleware is vertical integration software that enables networked resources and multiple applications to work smoothly together to provide end user services. As the name suggests, middleware operates in between top-level software that end users interact with and core networking and operating system software at the lower end of the software stack. Middleware is a facilitator and middle manager. It provides transparency among network service providers, for example, to enable information to flow seamlessly and securely in a trustworthy framework, and assures software functionality across heterogeneous computing and storage systems to meet user requirements, including the ability to develop new applications.

Although state-of-the-art middleware is crucial to improving the networked performance of most applications, middleware development frequently confronts two competing and contradictory demands: optimizing the entire network for a single application and sharing limited resources for the common good of all applications.

Middleware R&D has begun to sort out these seemingly incompatible requirements, most notably through experimentation with implementations of the Globus middleware suite (details on page 14). But the area still requires significant attention from the research community. To close the gap, a new NSF middleware initiative aims to assemble components already available and pinpoint those areas that require new scientific knowledge and insight. The initiative will focus on:

- Applied infrastructure research specifically directed at middleware services, with the goal of producing working prototypes
- A software distribution based on research prototypes and operational middleware services
- Deployment of this middleware infrastructure to experiment with new distributed applications

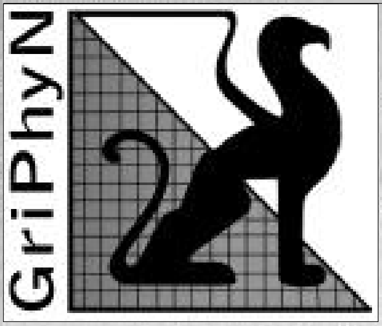
In addition to the NITRD agencies' middleware research, in January 2002 the Large Scale Networking Coordinating Group added a new Middleware And Grid Infrastructure Coordination (MAGIC) team to its research program.The new team joins two existing teams, the Joint Engineering Team and the Network Research Team. MAGIC is chartered to:

- Coordinate interagency middleware and grid efforts
- Enhance and encourage interoperable grid technologies and deployments
- Promote usable, widely deployable middleware tools and services
- Provide a forum for effective international coordination of these technologies

MAGIC membership includes representatives of Federal agencies with responsibility for middleware and grid projects and researchers, implementers, operators, and users of middleware and grid technologies from academia, the commercial sector, and other institutions. Participants view the group as a mechanism for exchanging information about major agency efforts, such as NSF's TeraGrid, DOE's Science Grid, and NASA's Information Power Grid, and addressing common technical issues and concerns. At its initial meeting, the MAGIC team set its sights on completing the following three near-term tasks:

- Document the significant number of domestic and international grid projects
- Develop a Summer 2002 workshop focusing on middleware and grids to identify research, development, implementation, and maintenance needs to provide guidance to Federal research and funding agencies
- Increase participation in MAGIC by application developers, the commercial sector, and middleware and grid users

Connecting People and IT Resources for U.S. Scientific Leadership



Logo of the Grid Physics Network, which will develop grid technologies enabling researchers to access and use large-scale data from the world's most advanced physics experiments.

Because of their mission-oriented focus on advanced computing and networking for scientific research, the NITRD agencies are the world's leaders in forging a technical path toward the convergence of high-end computing and high-speed networks. The fundamental paradigm shift in scientific research methods now under way is highlighted by the increasing number of Federally supported networking applications that call for a grid infrastructure of connectivity to supercomputing platforms, advanced instrumentation, and terascale data storage systems. In addition to their scientific purposes, these initiatives are prototyping more cost-effective, efficient models for future societal uses of high-end computing and networking resources. The following examples of current Federal networking applications point to what lies ahead.

Selected agency activities

NSF

Network for Earthquake Engineering Simulation (NEES)

The NEES program will use IT to serve a critical national need – finding new ways to reduce the hazard that earthquakes present to life and property. The NEESgrid, an Internet-based computational and collaboratory infrastructure for the earthquake engineering community, will link earthquake engineering research sites across the country, provide data storage facilities and repositories, and offer remote access to the latest research tools. The systems integration and development component of the NEES program was established in 2001 by a consortium of institutions led by NCSA. Grid components will be deployed by 2004.

National Virtual Observatory (NVO)

In the NVO project, launched in FY 2002, astronomers at 17 universities led by Johns Hopkins and Caltech will use grid techniques to enable researchers for the first time to access and computationally analyze data from multiple sources among the leading archives of astronomical information. In the absence of supercomputing resources, astronomers traditionally have constructed theoretical models for simulations of astrophysical phenomena. Networked high-end computing capabilities will allow astronomers to explore massive amounts of observational data and build their models and simulations inductively.

Grid Physics Network (GriPhyN)

GriPhyN is an ambitious effort to make data from the world's leading physics research – such as the results of supercollider experiments – available to and usable by the wider physics community. Expected to reach many petabytes per year within a decade, the raw data generated by particle detectors are simply too massive for most single computing systems to store or analyze. Bringing together seven IT research groups and scientists in four major NSF physics projects, this effort aims to establish a common "virtual data" framework and protocols that will enable physicists to use distributed high-end storage and computational resources over a grid.

DARPA
Network-Based Total Surveillance System (NBTS)

The NBTS system can be deployed to aid force protection in tactical settings as well as to enhance security both indoors and outdoors around critical locations such as military bases, embassies, and airports. The system processes and integrates feeds from tens to hundreds of video cameras onto 3-D site models, and it provides a remotely observable single integrated picture of actions and movements within complex, 3-D settings. Using enhanced image-processing, moving-target indication signals can also be overlaid on the background. The NBTS prototype, developed for DARPA by Sarnoff Laboratory, has been tested by the U.S. Air Force.

NASA
Aviation safety simulations

NASA computer scientists and aviation experts are using the agency's Information Power Grid (IPG), which won a NASA award for excellence in 2001, to conduct simulations in NASA's aviation safety program, a collaborative initiative with the Federal Aviation Administration (FAA). One simulation employed IPG resources to model commercial air traffic flow across the U.S. using real-time data from radar tracks of departing and arriving flights at Atlanta's Hartsfield International Airport. The simulation is part of a planned FAA National Airspace Simulation System.

DOE
Connecting researchers to science and computing facilities

The DOE national collaboratories program integrates national and international facilities, distributed terascale computing resources, and several thousand investigators into a virtual laboratory infrastructure.This infrastructure enables easy access to computing resources, science facilities, and research collaborators by providing advanced collaboratory technologies, middleware, advanced network services, and scalable cybersecurity services.

NIST
Software interoperability testbed for manufacturing

The current lack of software interoperability sharply limits the ease and speed of manufacturing processes and business-to-business interactions. In collaboration with business partners, NIST is developing a Shared Manufacturing B2B (business-to-business) Interoperability Testbed to help companies boost the cost-effectiveness and efficiency of the mission-critical software products they increasingly rely on for managing production, sales, supply chains, customer relations, transaction records, and the like. Software components are run through the testbed's Web-based, distributed evaluation process, which checks the software's conformance to emerging B2B interoperability standards. NIST and its private-sector partners hope to expand the capabilities of the testbed and turn it into an independent testing facility that can be used by both government and business.

International iGrid demonstrations

Several NITRD-supported grid applications will be showcased at the international iGrid show in autumn 2002 in Amsterdam, including: the Telescience Portal (National Center for Microscopy and Imaging Research/ UCSD), enabling remote manipulation of electron microscopy specimens; and Collaborative Visualization over the Access Grid (ANL/University of Chicago), a demonstration of high-bandwidth QoS and capabilities.

Broadening IT Capabilities To Support Human Needs and Goals

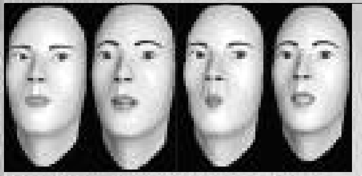
NITRD research to advance U.S. computing and networking capabilities to the highest levels of performance, reliability, and security is complemented by significant efforts to expand the scope of what digital technologies can do to serve human needs and goals. One key emphasis of NITRD efforts is to make computing capabilities and devices easier for people in all circumstances and walks of life to use. A second emphasis is to develop technical innovations that broaden the range and types of services that information technologies can provide.

In FY 2003, the NITRD agencies will support research in multiple modalities of human-computer interaction, such as by voice, sound, gesture, touch, and vision. Development of systems integrating multimodal forms of interaction is particularly important for advanced military and aerospace applications, where operators need hands-free, untethered devices for communications, command and control functions, and intelligence management. Language-engineering technologies, which are a major focus in this area of NITRD research, play a vital role in advanced national defense and national security activities and international commercial development. Capabilities under development include rapid automated translation between languages and between spoken and written languages, and spoken-language query systems for intelligence gathering and analysis.

Multimodal attributes also have vital applications in technologies, tools, and devices that enable people to live full and independent lives, regardless of their physical limitations. NSF-sponsored IT research, for example, has generated "Baldi," a talking and listening virtual tutor who helps hearing-impaired students understand and produce spoken language.

Major Research Challenges

- Advanced functionalities (language technologies; spoken, aural, and multimodal interfaces; sensor technologies)
- Cognitive performance-based interactive system design – to present the right information in the right form for increased human capability; computer-assisted prosthetics for motion, sight, and hearing; monitoring systems; and remote consultation technologies
- Methods and technologies for modeling and sharing expertise; models and metrics for collaborative performance of complex tasks



Baldi, the virtual tutor developed with NSF funding, helps hearing- and speech-impaired children model speech and build vocabulary by demonstrating audiovisually how the mouth shapes word sounds.

Representative FY 2003 agency activities

NSF: Innovative IT applications for learning; stochastic models of human interaction; interactive multimodal devices and assistive technologies; technologies for collaborative work

DARPA: Spoken dialogue systems; enhanced cognitive processing

NIH: Modeling and simulation tools for exploring biomedical data

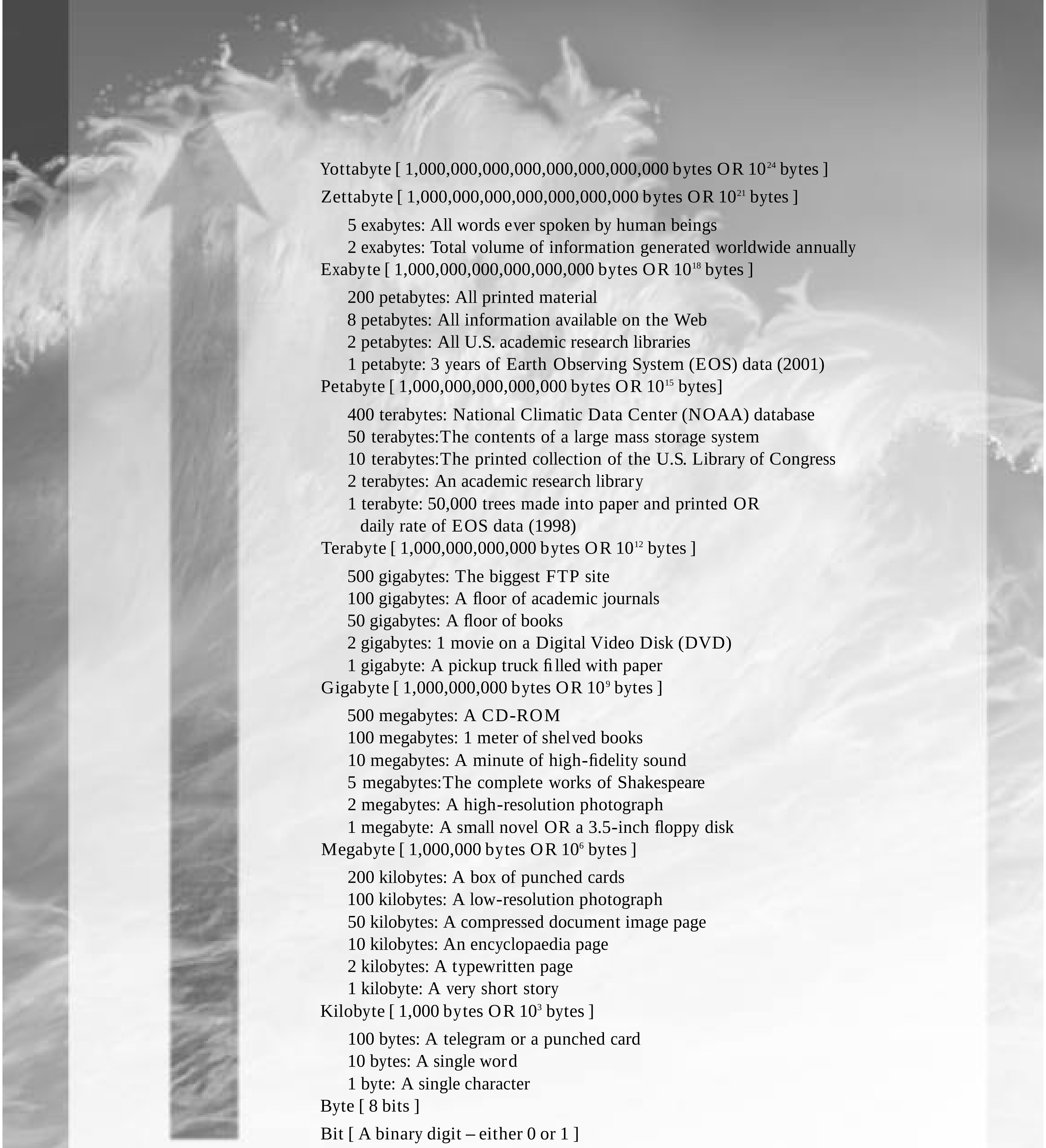
NASA: Use neuro-engineering to develop and integrate technologies for task management, enhanced cognitive performance of teams; model knowledge use in context of work; develop "smart" software and autonomous devices

DOE Office of Science: Integrated set of software tools for scientific collaboratory environments

NIST: Evaluation methods for spoken language technologies; methods to improve usability of automated systems; testing and commercialization of devices for universal access to information

ODDR&E: University-based research in computer-assisted tutorial systems

THE INFORMATION TSUNAMI



Yottabyte [1,000,000,000,000,000,000,000,000 bytes OR 10^{24} bytes]

Zettabyte [1,000,000,000,000,000,000,000 bytes OR 10^{21} bytes]

5 exabytes: All words ever spoken by human beings
2 exabytes: Total volume of information generated worldwide annually
Exabyte [1,000,000,000,000,000,000 bytes OR 10^{18} bytes]

200 petabytes: All printed material
8 petabytes: All information available on the Web
2 petabytes: All U.S. academic research libraries
1 petabyte: 3 years of Earth Observing System (EOS) data (2001)
Petabyte [1,000,000,000,000,000 bytes OR 10^{15} bytes]

400 terabytes: National Climatic Data Center (NOAA) database
50 terabytes:The contents of a large mass storage system
10 terabytes:The printed collection of the U.S. Library of Congress
2 terabytes: An academic research library
1 terabyte: 50,000 trees made into paper and printed OR daily rate of EOS data (1998)
Terabyte [1,000,000,000,000 bytes OR 10^{12} bytes]

500 gigabytes: The biggest FTP site
100 gigabytes: A floor of academic journals
50 gigabytes: A floor of books
2 gigabytes: 1 movie on a Digital Video Disk (DVD)
1 gigabyte: A pickup truck filled with paper
Gigabyte [1,000,000,000 bytes OR 10^{9} bytes]

500 megabytes: A CD-ROM
100 megabytes: 1 meter of shelved books
10 megabytes: A minute of high-fidelity sound
5 megabytes:The complete works of Shakespeare
2 megabytes: A high-resolution photograph
1 megabyte: A small novel OR a 3.5-inch floppy disk
Megabyte [1,000,000 bytes OR 10^{6} bytes]

200 kilobytes: A box of punched cards
100 kilobytes: A low-resolution photograph
50 kilobytes: A compressed document image page
10 kilobytes: An encyclopaedia page
2 kilobytes: A typewritten page
1 kilobyte: A very short story
Kilobyte [1,000 bytes OR 10^{3} bytes]

100 bytes: A telegram or a punched card
10 bytes: A single word
1 byte: A single character
Byte [8 bits]

Bit [A binary digit – either 0 or 1]

Credit: "How Much Information?,"University of California at Berkeley, 2001,http://www.sims.berkeley.edu/research/projects/how-much-info/index.html

Advanced Technologies To Build Knowledge from Data

Information superiority is really decision superiority, an executive recently told a newsweekly. That sounds right – if the critical pieces of information are readily available and identifiable. But today information is, as one IT researcher puts it, a tsunami – an inconceivable volume of data engulfing everyone and everything at an overwhelming rate. A University of California-Berkeley study estimates that the world now produces one to two exabytes of non-redundant information per year, about 93 percent of which is stored in digital form. The U.S. generates more than 50 percent of the total output, much of it in key scientific and government activities.

For example, to produce a single day's 24-hour radar scan of the weather, seen by billions of people around the world in televised weather forecasts, NOAA's National Weather Service collects a half-terabyte of real-time data from Doppler radars and turns that computationally into near-real-time visual images. The flagship Terra Spacecraft in NASA's Earth Observing System (EOS) program circles the globe every 99 minutes, gathering information about the cycling of water, trace gases, energy, and nutrients throughout the Earth's climate system. Terra's instruments generate 850 gigabytes of data every 24 hours – the contents of 100,000 encyclopedias.

The information tsunami, which experts predict will swell by orders of magnitude over this decade, presents enormous challenges for society along with unprecedented opportunities for U.S. advanced research and technological innovation.The September 11 attacks showed that even a few ruthless adversaries within our borders can use everyday information and communication systems to devastating effect. Anticipating, detecting, and thwarting such attacks in the future requires the Nation to sustain an unprecedented level of national alertness. Among the most powerful tools in this work will be high-end computing capabilities first developed by NITRD agencies to collect, manage, search or "mine," synthesize, analyze, and visualize massive amounts of data.

For people who work with advanced scientific, engineering, and commercial processes as well as in such time-critical activities as air traffic control and intelligence gathering, accessing and making use of relevant data are core necessities. NITRD research therefore focuses, not just on technologies to store and organize information, but on how technologies can help people find, "see" the significance of, and interact with the

Idealized simulation of large-scale ocean eddies from NOAA's Geophysical Fluid Dynamics Laboratory. (The lighter areas are warmer water.) Current global models are not able to resolve data for this vigorous oceanic action on scales of 10-100 kilometers. We do not yet understand the effects of the constant eddies on global climate.

Representative FY 2003 agency activities

NSF: Support for development of new online collections; research in architectures, tools, and technologies for digital libraries; preservation of digital records; knowledge discovery, analysis, and visualization in multiscale, heterogeneous data sets;multi-lingual access to large audio archives; methods of information extraction and synthesis

DARPA: Multilingual processing for summarization; data-mining technologies with cross-repository information analysis functionality (semantic retrieval, indexing, value filtering, user-defined alerting, and categorizing); bio-surveillance technologies information they need. These next-generation, interactive information management technologies include the array of innovative hardware and software capabilities we need to maximize the benefits of information to our quality of life. Many scientists consider effectively managing the information tsunami to be the top technical challenge of the new millennium.

In FY 2003, the NITRD agencies, which pioneered the Nation's first digital libraries and Internet search engines, will continue to support R&D in interoperable technologies and tools for archiving, cataloguing, accessing, and using heterogeneous materials in the online environment and development of online information repositories for research and education. The agencies will also support research in advanced search and data-mining techniques; software and hardware issues in integrating, accessing, and using very-large-scale data sets; advanced interactive methods and tools for information display and analysis; and technical issues in scalable archiving and digital preservation.

Major Research Challenges

- Ultra-large-scale data-mining technologies for rapid mining, filtering, correlating, and assessing of vast quantities of heterogeneous and unstructured data (such as text and audio in many languages, video, images, and embedded code); intelligent search agents; tools for abstraction and summarization
- User-oriented frameworks and interfaces for analysis, reporting, and presentation
- Data storage and management technologies:
  - Tools for collecting, indexing, archiving, and synthesis
  - Protocols for data compatibility, conversion, interoperability, and interpretation in networked environments
  - Technologies and tools for fusion of databases, such as molecules and macromolecular structures or disparate real-time weather observations, with remote access and analysis capabilities
  - Component technologies and integration of dynamic, scalable, and flexible information environments
  - Representation, preservation, and storage of multimedia collections
  - Digital classification frameworks and interoperable search architectures
  - Metadata technologies and tools for distributed multimedia archives
  - Testbeds for prototyping and evaluating integration of types of digital content, software functionality, and large-scale applications

NIH: Aggregate and manage large-scale data resources for the medical community

NASA: Novel algorithms and software tools for extraction and visualization of very-large-scale, multisource data sets

DOE Office of Science: Research in software and infrastructure to manage very-large-scale data, instrumentation, and research results; integration of massive, heterogeneous data sets

NIST: Evaluation methods to measure relevance of content extraction; metrics,standards, and testing to advance technologies for access to and use of multimedia information; measuring performance of intelligent systems for information handling

NOAA: Apply advanced communications technologies to speed national dissemination of critical weather information; extend real-time collaborative access to disaster data with synchronous interfaces and tools; enhance scientific study of environmental data through advanced visualization techniques

ODDR&E: University-based research in reasoning across data with diverse measures of uncertainty; representations of uncertainty for decision making

AHRQ: Information management to enable studies of health care and delivery system effectiveness; tools to enhance patient safety by reducing medical errors; IT methods enabling providers to share information with patients; establish and maintain National Quality Measures Clearinghouse™ with detailed online information about health care metrics

Reliability, Security, and Safety for Mission-Critical Systems

As the NITRD research agenda attests, today software itself faces the frontier of complexity. On one hand, software is expected to make enormous systems and networks of systems – such as power grids, air traffic control systems, financial data networks, military command and control systems, and the Internet – function faultlessly. It is also expected to direct the activities of life-critical embedded devices such as implanted heart monitors, nanoscale diagnostic instruments, and digital prostheses. Large-scale systems, which embody hundreds to thousands of platforms, millions of lines of programming, and trillions of bytes of data, are rapidly becoming the norm, as are systems in which the processors themselves are intricately embedded in the fabric of our lives and even our bodies.

On the other hand, all these systems are being asked to function at unprecedented levels of reliability, safety, and security. The events of September 11 pointed to an overarching requirement that the systems governing the Nation's critical infrastructures and critical national defense and national security missions be "hardened" against terrorist attacks, clandestine penetration, and misappropriation. Systems must somehow become more self-diagnosing, self-correcting, and self-healing – equally proof against natural failures, deliberate interference and fraud, and innocent but crucial mistakes by their users. These two features – rapidly expanding size and rapidly expanding complexity – are the twin horns of a difficult dilemma for contemporary software and systems.

To date, U.S. ingenuity in creating and interconnecting the inventions of the IT revolution has outpaced the underlying science needed to assure that the systems we build are engineered for reliability, security, safety, and scalability (can the system grow without weakening its integrity and reliability?). In the security and safety areas, for example, techniques in cryptography, public key infrastructure (PKI), network management, intrusion detection, and fault/failure tolerance have been developed largely independent of core functionality and speed. We have not yet integrated the high-confidence attributes we now know are necessary into the technical design foundations for both large- and small-scale complex software and systems. In the current incremental, add-on development process, the responsibility for determining whether the system works falls largely to a

NASA's prototype Spacecraft Micro Robot (SMR) is a mobile IT assistant for astronauts. It is a softball-sized unit integrating an intricate array of technologies: an operating system and monitor, two-way audio and video, wireless ethernet, propulsion system with remote controls, and environmental and inertial sensors. The SMR patrols the spacecraft, monitoring internal environmental conditions; it can be guided by ground controllers or astronauts, support space-ground teleconferences, and can send and receive timely data in flight. A key issue in SMR design is engineering for ultra-reliability.

Representative FY 2003 agency activities

NSF: Innovative research in trustworthy computing, including scientific principles for construction of high-confidence systems, component technologies, composition and decomposition methods, modeling and analysis techniques, design tradeoffs between security and performance; safety, security, and privacy for Internet-enabled systems; real-time distributed, embedded, and hybrid systems; fault-tolerance approaches for critical infrastructure protection

NIH: Assurance methods and technologies for life-critical medical devices and telemedicine applications; reliability, privacy, and security of medical data and IT infrastructures for research

NASA: Software design for safety, including development of High Dependability Software Consortium with leading universities and industry for proving methods and techniques to achieve very high reliability in mission-critical software; artificial intelligence and formal methods techniques for specification, automated fault detection,and validation

NSA: Research in secure network management, secure switched network technologies, and advanced research in cryptography (key management, algorithms); advanced research in high-confidence system technologies (formal specification and verification tools, domain-specific languages for security evaluation); and continuing advanced research in securing end-user systems (security middleware such as the security-enhanced operating system LINUX kernel, Object Request Brokers)

NIST: Security technologies for critical infrastructure protection; standards, methods,and metrics in authorization and authentication, including biometric techniques; tools for NIST's advanced encryption standard; with NSA, support the National Information Assurance Partnership to promote cost-effective international standards for software evaluation, testing, and certification

ODDR&E: Support for defense-related university research in technical foundations for high-assurance technologies,software control systems, information security, public key infrastructures, and survivability technologies

costly, time-consuming, after-the-fact process of testing, which often fails nonetheless to catch system failure conditions in the subtle interactions among software and hardware components.

The fact is that we do not yet understand the underlying patterns of failures in large complex systems, or even the systems themselves. The NITRD agencies' focused research effort in high-confidence software and systems seeks to provide the missing theoretical and technological underpinnings for assured construction of secure, highly reliable software and systems.This revolutionary work will give system designers and engineers a formal scientific grounding for building sound systems as well as powerful new diagnostic and forensic tools for cost-effectively assessing software and system reliability, security, and performance.

In FY 2003, the NITRD agencies will support research in modeling and reasoning about whole systems and about their component technologies (operating system, middleware, networking, safety and especially security attributes) and mathematical and engineering approaches to specification, component integration, and interoperability issues. Other research focus areas are languages, tools, and automated techniques to eliminate sources of error, and technical strategies for integrating high-confidence properties in software and systems design.

Major Research Challenges

- Foundations of assurance, including rigorous modeling and reasoning about high-confidence properties; interoperable methods and tools; system composition; specification, safety, and security foundations
- Scalable fault prevention, detection, analysis, and recovery, including robust system architectures and tools for monitoring and adaptive response
- Correct-by-construction software technologies, including programming languages, tools, and environments; systems software, middleware, and networking (reusable middleware services such as efficient, predictable, scalable, dependable protocols for timing, consensus, synchronization, and replication for large-scale distributed embedded applications and domain-specific services)
- Verification and validation technologies
- Forensic and diagnostic tools
- Experimentation with large-scale systems
- Reference implementations
- Domain-specific certification technologies
- Reduction of time, effort, and cost of assurance and certification
- Technological base of public domain, advanced prototype implementations of high-confidence technologies to enable rapid adoption in the private sector and in government

Improved, Cost-effective Software Through Science and Engineering

In 2002 the semiconductor industry will produce more computer chips than there are people on Earth. Only about 1 percent of all these chips will go into recognizable computers. Most will be inserted in other types of equipment – in small devices such as cell phones, pagers, personal digital assistants (PDAs), and remote controls, and in large, complex physical systems such as cars, airplanes, manufacturing machinery, weapons systems, and emergency warning networks. One of the most promising new directions for embedded computing technologies is networked systems of microsensors that can gather and transmit critical data in near real time. Such sensor networks are coming into use in a wide range of applications, including environmental and hazard monitoring, scientific agriculture, transportation management, and reconnaissance and early-warning systems for theaters of battle.

The nascent revolution in embedded technologies confronts IT researchers with unique new challenges, just at the time they are attempting to address critical technical weaknesses in the existing generation of software running the Nation's computing and telecommunications infrastructures. Today's software is not as interoperable, scalable, or cost-effective as it needs to be, despite the enormous sums spent on its development and maintenance.

A key to solving the problem lies in converting software design and development – historically a solitary art practiced by programming "wizards" – into a formal science and engineering discipline governed by widely accepted principles, methods, and best practices for achieving high-quality results. Engineers would not dream of building a suspension bridge without a detailed blueprint of the technical requirements, state-of-the-art disciplinary knowledge of the principles and materials involved, and cost-effective manufacturing processes to produce lasting structural elements of certified quality. As a pervasive, critical underpinning of our national infrastructure, software must be at least as scientifically engineered.

One NITRD research focus is on creating, testing, and evaluating models for a new science of software development. The goal is to move beyond today's idiosyncratic, arcane code to stable, engineered designs that are rational, modular, verifiable, and reusable. Scientific principles and methods

Logo of DARPA's Program Composition for Embedded Systems (PCES) research effort. PCES is developing new strategies for programming embedded systems that reduce technical effort and generate more robust code. Methods involve designing core software to include the cross-cutting properties needed by the embedded system as a whole, such as synchronization of concurrent operations, sensor and actuator timing constraints, and safe, efficient cache, register, and memory management. The goal is reusable software suites, with automated tools for dynamic composition and testing.

Representative FY 2003 agency activities

NSF: Empirical software engineering research; continuous change management of component-based software; profiles and patterns of software evolution; strategic software design to move from a risk-driven to a value-driven development model

DARPA: Model-based integration of embedded software; software-enabled control; dynamic self-composition and assurance in highly complex systems that may be composed of sensor nets or systems of systems

NIH: Software investigations in support of biomedical computing applications

NSF/NASA: Cooperative program in Highly Dependable Computing and Communication Systems Research for projects to design, test,implement, evolve, and certify dependable, cost-effective software-based systems, using a new NASA testbed facility to evaluate research findings on real-world hardware and software artifacts

NASA: Automated software engineering methods, including technologies and tools for embedded and robotic devices; specification using Bayesian techniques; experimental evaluation of software

DOE/NNSA: Create common software development/execution environment for all Advanced Simulation and Computing (ASCI) high-end platforms that supports end-to-end ASCI application needs for robustness and scalability as well as I/O, storage, and visualization needs

NIST: Develop a common reporting format for sharing usability data with consumer organizations;determination of software quality using automated and knowledge-based methods; with industry partners, plan shared manufacturing business-to-business interoperability testbed

NOAA: Develop a component-based modular research model of the geophysical environment

ODDR&E: University-based research in software model checking for embedded systems; real-time fault-tolerant network protocols

will enable developers and users to design, build, test, and stress software products using automated techniques to see how they perform and to pinpoint, prior to deployment, weaknesses that now simply cannot be found amid large-scale software's millions of lines of handcrafted code. Automating aspects of design and implementation and employing empirical testbeds will curb today's very high development costs by not only streamlining the programming stage but speeding and improving the expensive debugging process.

The end result will be a development methodology that dramatically increases the "productivity" of software by making more products of higher quality not only possible but substantially cheaper to generate and easier to maintain.

Scientific foundations for software are vital for embedded systems, where tiny computing components deep inside large-scale physical systems must function in real time to support a huge variety of computing and non-computing tasks. Just as we expect our hearts and lungs to function without having to be commanded no matter where we are or what we are doing, embedded processors must be able to do their jobs automatically and continuously. And just as our lives are little affected as new cells are created and old ones die, embedded systems are expected to keep on working even as some of the individual embedded processors are damaged, destroyed, added, or upgraded while the system as a whole continues to function virtually automatically.

For FY 2003, the NITRD agencies will support fundamental research to improve the quality of software and reduce its cost across the board, so that this indispensable driver of the advanced technologies we increasingly depend on provides greater benefit to society in both large-scale and micro- applications.

Major Research Challenges

- Software and system science, including languages and compilers; composition methods; and design foundations for systems and networks that are distributed and scalable
- Automated engineering, including efficient, reliable software components and integration processes; methods (such as specification, analysis, and verification) for integrated software and systems development; interoperability of concurrently running networked applications; and configurable tool environments for rapid composition and customization of domain-specific development environments
- Pilot applications and empirical studies of technologies for embedded applications and systems development projects

Enhancing IT Education and Training for the High-Skills World

Over the last 10 years, the infusion of networking and computing technologies throughout our society is credited with generating historic rates of productivity growth and the world's most vibrant economy. U.S. Department of Commerce statistics show that between 1996 and 2000, the IT sector accounted for 28 percent of real economic growth, two-thirds of productivity growth, and thousands of new jobs created at twice the national average rate. Even during the economic downturn of 2001, productivity growth continued at a robust 1.9 percent rate instead of decreasing as in all prior recessions, suggesting that information technologies add resilience as well as strength to the economy. R. Glenn Hubbard, chairman of the President's Council of Economic Advisors, put the case forcefully in a recent address, saying, "Our productivity future hinges on IT."

Current predictions see tremendous growth in IT-related employment continuing over the coming decade, with an estimated total of 2.5 million new workers needed, or some 250,000 annually. "The job of the IT professional is more critical than ever before," Vance Coffman, chairman and CEO of Lockheed Martin Corporation, told Federal officials at a March 2002 conference. "IT permeates virtually every system, every process, every action the government undertakes. Consequently, the results – whether it's a missile hitting its target or a commercial airliner taking off on time or a satellite being placed in its proper orbit – very much depend upon the performance of the individual IT professional."

At the same time, however, leaders in industry and IT research are sending strong warning signals of continuing shortages of workers with the education and technical skills required to sustain IT advances and innovation in the years ahead.

Employers suggest that a four-year college degree will be the minimum expectation in the preponderance of IT jobs, along with technical, business, and social skills. Continued U.S. leadership in advanced IT amid increasingly competitive international research efforts will also require increased production of Ph.D. recipients prepared to become the intellectual leaders in next-generation technological research. One urgent example of the IT training gap, noted by computer scientist Eugene Spafford of Purdue

April 2002 NOAA computer graphic of oceanic warming associated with a developing El Niño pattern, which could affect the U.S. climate from summer 2002 through the winter. The lighter ocean areas show the warmer than average water temperatures typical of El Niño (white area at the top is polar ice shelf). The demand for IT professionals with the skills to work with advanced applications of IT such as those used in NOAA climate modeling will grow substantially in this decade. NITRD research dollars have supported the training of the current generation of leading IT researchers and educators.

Representative FY 2003 agency activities

NSF: IT tools and applications in education and training, including approaches to increasing IT literacy; research on barriers to IT careers for women and minorities; and multidisciplinary research opportunities for students

NIH: Expanded opportunities for IT training, especially in bioinformatics; individual and program grants for advanced IT R&D training for health professionals

NASA: Use Internet for training and development of engineers and scientists in IT security and collaborative engineering

DOE Office of Science: Computational Science Graduate Fellowship Program, a nationwide competitive program to train the next generation of leaders in computational science for DOE and the Nation

University in Congressional testimony, is that only about two dozen students trained in computer security technologies earned doctorates from U.S. universities in 2001.

Most of the current generation of IT researchers and many industry leaders were supported in their graduate studies and postdoctoral research with funding from NITRD agencies. As in the field of biomedical research, the Federal government plays the primary role in supporting the fundamental IT research and research leaders that together constitute a strategic national resource. NIH's National Library of Medicine (NLM), for example, has pioneered in supporting advanced training in the emerging field of bioinformatics, whose practitioners bring both high-end computer science and medical expertise to the health care arena, in such areas as biomedical research applications, telemedicine, and large-scale health care systems. The NLM program of institutional support and individual fellowships is establishing an academic training infrastructure and expanding the ranks of bioinformatics professionals, who are still far too few in number to fill the growing nationwide demand for these skills.

In FY 2003, the NITRD agencies will continue support for programs providing advanced and specialized IT training. They will also support efforts to increase IT literacy and to address fundamental questions about the efficacy of IT in education, including theories and models of learning and exploration of high-quality IT applications for learning environments.

Major Research Challenges

- Better understanding of IT workforce dynamics and their relationship to strategic education and training needs
- Better understanding of barriers to IT careers among underrepresented groups, such as women and minorities
- New knowledge about human cognitive development and about group and individual learning in varied settings
- More substantial empirical data on the effects of IT systems in education and training environments
- Software for self-instruction and collaborative learning
- Integration of information technologies in learning environments
- Innovative technologies for use in workforce hiring, retention, development, and training

SOCIOECONOMIC IMPACTS OF IT

Assessing a Transforming Force To Guide Beneficial Human Uses

In the aftermath of the September 11 attacks, more than 100 million Americans – 57 percent of all U.S. Internet users – turned to e-mail to send and receive messages of support and concern; nearly a quarter of those citizens also reported that they received e-mailed expressions of sympathy from outside the country. These are among the findings of a major ongoing survey by the University of California at Los Angeles (UCLA) on the impacts of the Internet. Funded by NSF and private corporations, the study marks the first large-scale effort to assess how the Internet is affecting the lives and habits of Americans. In 2001, the study's second annual report found, the percentage of Internet users climbed to 72.3 percent, up from 66.9 percent in 2000. Internet users enjoy and are spending more time online and less time watching television, but a majority are very concerned about privacy issues, and about 90 percent worry about theft or misuse of personal identity information in the online environment.

Research to anticipate, identify, understand, and address the social and economic impacts of information technology – on commerce, education, employment, government services, civic and organizational structures and practices, personal communication, and scientific research, to name only a few areas – is a significant component of the NITRD program. The overarching goal of such studies is to equip society with the knowledge necessary to maximize the benefits of new information technologies for all citizens and minimize the negative consequences.

Current work in this emerging interdisciplinary research area is examining aspects of electronic markets such as theoretical frameworks, coordination and decentralization, and economic and social dynamics; implications of living with "sociable" technologies in "smart" environments; characteristics of cybercitizenship, online communities, and collaborative distributed work; and value-sensitive design of IT devices, including those to enable successful aging. Researchers supported by NSF are investigating, for example, the concept of robotic pets to provide psychosocial stimulation for elderly people as well as serve as health-data monitors.

In addition to studies of the interactions of people with information technologies, NITRD research encompasses novel applications of computing

Representative FY 2003 agency activities

NSF: Support for research on the socioeconomic implications of IT, including studies of the digital economy and the information society; distributed and collective action mediated by IT, such as in collaborative learning and work settings; human values in IT design; impacts of "smart" technologies and environments; human aspects of cybersecurity and system vulnerabilities; technologies and tools for successful aging; and computational approaches in the economic, social, and organizational sciences in the social, economic, and organizational sciences. In one innovative example of computation-based social research, described in the April 2002 issue of the Atlantic Monthly, NSF-funded investigators are using advanced modeling and simulation capabilities to create miniature computer-screen societies. Unlike conventional social-science models in which the people are assumed to be generally alike, in these artificial societies, called "agent-based models," the "agents" (people or social structures) are randomly given varied individual characteristics and limited knowledge, just as in a real society. In each run of the simulation, the agents act according to their own assigned rules of behavior – a computationally intensive exercise requiring ample computing power.

The process yields remarkable results. While no two runs are ever alike, the ultimate outcome – such as genocide in a simulation with two hostile ethnic groups – is mathematically always the same. This larger result is not intended by the individual agents, who simply make local rule-based choices. But at some point during the simulation, the random assortment of activities progresses to a stage at which it "tips" toward the mathematical end state. On the other hand, a targeted outside intervention – such as adding police to the ethnic groups' scenario – can change the end state, in that case from genocide to a stable minority enclave. A key implication of the simulations is that individual choices collectively generate larger social consequences, but these outcomes are largely unintended and unexpected. By the same token, local interventions – such as introducing midnight basketball into a crime-ridden neighborhood – and individuals making different choices can change the larger social dynamic.

In FY 2003, NITRD research emphases will also include IT-related changes in business, labor, and organizational processes; use of technologies in teaching, learning, and collaborative work; life in "smart" environments; and human aspects of cybersecurity and system vulnerabilities.

Major Research Challenges

- New knowledge about the interactions among individuals, groups, computing applications, and information infrastructures across distances and in various cultural, legal, economic, and ethical contexts
- New knowledge about participation in a digital society, including such aspects as electronic markets, modes of work, cybercitizenship, interaction with "sociable" technologies; barriers to universal IT accessibility; and intellectual property and privacy issues
- Research on integration and uses of large-scale technologies for collaboration and learning in science, education, and the workplace
- Significant advances in our scientific understanding of what technologies, tools, and applications are effective for learning
- Greater understanding of the role of human values in IT design; innovative technologies for successful aging
- Innovative IT applications in the social and behavioral sciences

NITRD Agencies and Their IT Research Interests

AHRQ – the Agency for Healthcare Research and Quality – focuses on research into state-of-the-art IT for use in health care applications such as computer-based patient records, clinical decision support systems, and standards for patient care data, information access, and telehealth.

DARPA – the Defense Advanced Research Projects Agency – is focused on future-generations computing, communications, and networking as well as embedded software and control technologies, and human use of information technologies in national defense applications such as battlefield awareness.

DOE/NNSA – the Department of Energy National Nuclear Security Administration – was established to develop new means of assessing the performance of nuclear weapon systems, predict their safety and reliability, and certify their functionality through high-fidelity computer models and simulations of weapon systems.

The DOE Office of Science is exploring, developing, and deploying computational and networking tools that enable researchers in the scientific disciplines to model, simulate, analyze, and predict complex physical, chemical, and biological phenomena important to DOE. The office also provides support for the geographically distributed research teams and remote users of experimental facilities that are critical to DOE missions. FY 2003 is the third year of the office's Scientific Discovery through Advanced Computing (SciDAC) initiative, which is focused on the next generation of scientific simulation and collaboration tools for the scientific areas that are the focus of DOE research.

EPA – the Environmental Protection Agency – has the IT research goal of facilitating multidisciplinary ecosystem modeling, risk assessment, and environmental decision making at the Federal, state, and local levels, and by other interested parties, through advanced use of computing and other information technologies.

NASA – the National Aeronautics and Space Administration – is extending U.S. technological leadership to benefit the U.S. aeronautics, Earth and space science, and spaceborne research communities.

NIH – the National Institutes of Health – is applying the power of computing, both to manage and analyze biomedical data and to model biological processes, in its goal to develop the basic knowledge for the understanding, diagnosis, treatment, and prevention of human disease.

NIST – the National Institute of Standards and Technology – is working with industry and with educational and government organizations to make IT systems more useable, secure, scalable, and interoperable; apply IT in specialized areas such as manufacturing and biotechnology; and encourage private-sector companies to accelerate development of IT innovations.

NOAA – the National Oceanic and Atmospheric Administration – is an early adopter of emerging computing technologies for improved climate modeling and weather forecasting, and of emerging communications technologies for disseminating weather forecasts, warnings, and environmental information to users such as policymakers, emergency managers, and the general public.

NSA – the National Security Agency – is addressing some of the most challenging problems in the country in computing, storage, communications, networking, and information assurance in order to help ensure our national security.

NSF – the National Science Foundation – is the lead NITRD agency, with interest in developing new fundamental IT knowledge; applications in the biological, chemical, geophysical, mathematical, physical, social, and behavioral sciences and engineering; educating world-class scientists and engineers and a knowledgeable IT workforce; and research infrastructure.

ODDR&E – Office of the Director, Defense Research & Engineering, Department of Defense – manages the University Research Initiative, which focuses on IT R&D for Department of Defense applications, research infrastructure, and science and engineering education.

Other Federal agencies participate in networking and information technology research and development, and coordinate with NITRD activities, using funds that are not budgeted under the program.

Agency NITRD Budgets by Program Component Area

FY 2002 Budget Estimate (dollars in millions)

Agency	High End Computing Infrastructure and Applications (HEC I&A)	High End Computing Research and Development (HEC R&D)	Human Computer Interaction and Information Management (HCI & IM)	Large Scale Networking (LSN)	Software Design and Productivity (SDP)	High Confidence Software and Systems (HCSS)	Social, Economic, and Workforce (SEW)	Totals
NSF	225.1	66.4	132.6	102.8	44.4	45.8	58.8	676
NIH	79.5	7.7	82.0	105.6	5.6	3.6	11.4	295
DARPA	17.4	63.9	35.8	35.0	65.6			218
NASA	36.1	26.0	27.8	14.4	22.4	47.1	7.0	181
DOE Office of Science	97.2	29.5	16.4	27.8			3.5	174
NSA		41.6		1.3		32.7		76
NIST	3.5		3.2	6.2	7.5	2.0		22
NOAA	13.8	1.8	0.5	2.8	1.8			21
ODDR&E		2.0	1.8	5.7	1.6	1.0		12
AHRQ			8.0	6.0				14
EPA	1.8							2
Subtotals[a]	474.4	238.9	308.1	307.6	148.9	132.2	80.7	1,691
DOE/NNSA	42.1	33.5		25.9	33.2		4.2	139
Totals[a]	516.5	272.4	308.1	333.5	182.1	132.2	84.9	1,830

Note:

[a] These totals include discrepancies from what appears in the President's FY 2003 Budget due to a combination of rounding and shifts in program estimates.

Agency NITRD Budgets by Program Component Area

FY 2003 Budget Request (dollars in millions)

Agency	High End Computing Infrastructure and Applications (HEC I&A)	High End Computing Research and Development (HEC R&D)	Human Computer Interaction and Information Management (HCI & IM)	Large Scale Networking (LSN)	Software Design and Productivity (SDP)	High Confidence Software and Systems (HCSS)	Social, Economic, and Workforce (SEW)	Totals
NSF	215.2	68.3	132.2	102.4	45.8	50.1	64.8	679
NIH	88.2	8.9	90.8	117.5	5.8	3.7	11.8	327
DARPA	16.8	81.9	35.5	29.2	60.0			223
NASA	68.4	26.0	23.8	4.5	40.0	43.3	7.0	213
DOE Office of Science	98.5	39.3	16.4	28.1			3.5	186
NSA		31.9		1.3		28.1		61
NIST	3.5		3.2	6.2	7.5	2.0		22
NOAA	13.3	1.8	0.5	2.8	1.5			20
ODDR&E		1.8	1.8	6.3	1.9	1.0		13
AHRQ			5.0	4.0				9
EPA	1.8							2
Subtotals[a]	505.7	259.9	309.2	302.3	162.5	128.2	87.1	1,755
DOE/NNSA	41.4	39.5		14.7	34.2		4.3	134
Totals[a]	547.1	299.4	309.2	317.0	196.7	128.2	91.4	1,889

Note:

[a] These totals include discrepancies from what appears in the President's FY 2003 Budget due to a combination of rounding and shifts in program estimates.

Participation in Federal NITRD Activities

The following are criteria developed by the multiagency IT research program that agencies considering participation can use to assess whether their research activities fit the NITRD profile.

NITRD Goals

Assure continued U.S. leadership in computing, information, and communications technologies to meet Federal goals and to support U.S. 21st century academic, industrial, and government interests

Accelerate deployment of advanced and experimental information technologies to maintain world leadership in science, engineering, and mathematics; improve the quality of life; promote long-term economic growth; increase lifelong learning; protect the environment; harness information technology; and enhance national security

Advance U.S. productivity and industrial competitiveness through long-term scientific and engineering research in computing, information, and communications technologies

Evaluation Criteria for Participation

Relevance/Contribution

The research must significantly contribute to the overall goals of Federal Networking and Information Technology Research and Development (NITRD), which includes the goals of the seven Program Component Areas – High End Computing Infrastructure and Applications (HEC I&A), High End Computing Research and Development (HEC R&D), Human Computer Interaction and Information Management (HCI & IM), Large Scale Networking (LSN), Software Design and Productivity (SDP), High Confidence Software and Systems (HCSS), and Social, Economic, and Workforce Implications of Information Technology and Information Technology Workforce Development (SEW) – to enable solution of Grand Challenge- and National Challenge-class applications problems.

Technical/Scientific Merit

The proposed agency program must be technically/scientifically sound and of high quality and must be the product of a documented technical/scientific planning and review process.

Readiness

A clear agency planning process must be evident, and the organization must have demonstrated capability to carry out the program.

Timeliness

The proposed work must be technically/scientifically timely for one or more of the multiagency research endeavor's Program Component Areas.

Linkages

The responsible organization must have established policies, programs, and activities promoting effective technical and scientific connections among government, industry, and academic sectors.

Costs

The identified resources must be adequate, represent an appropriate share of the total available R&D resources (e.g., a balance among Program Component Areas), promote prospects for coordinated or joint funding, and address long-term resource implications.

Agency Approval

The proposed program or activity must have policy-level approval by the submitting agency.

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Acknowledgments

This Supplement to the President's FY 2003 Budget, also known as the Blue Book, reflects the broad impact of Federal Networking and Information Technology Research and Development activities on key agency missions and vital national interests, such as economic development, education, national security, and scientific research. The Blue Book also reflects the editorial contributions of many individuals, to whom we extend sincerest thanks.

The editors thank the agency program managers who developed the research goals and program activities highlighted in this report and the NCO colleagues who provided ready and able support in all aspects of the production process, especially proofreading, preparation of the Web version, and distribution.

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Abstract

The Federal agencies that participate in the Networking and Information Technology Research and Development (NITRD) Program work together to maintain U.S. leadership in advanced computing, networking, and information technologies. NITRD results help these agencies fulfill their 21st century missions.This Supplement to the President's FY 2003 Budget summarizes the major FY 2002 NITRD accomplishments and FY 2003 plans and includes a special section on how IT R&D products played key roles in the response to the September 11, 2001, attack on New York's World Trade Center. The report highlights promising high-end computing technologies to explore the frontiers of complexity; dynamic, flexible, secure networks of the future; R&D on IT to support human needs and goals; technologies to build knowledge from data; reliable, secure, and safe software and systems; improved cost-effective software through science and engineering; and enhancing IT education and training for the high-skills world.

Cover Design and Imagery

The cover design and graphics are by National Science Foundation (NSF) designer-illustrator James J. Caras.

Illustration note: The light areas of the continents on the world map show concentrations of nighttime electrical illumination around the globe.The extraordinary composite view from which the cover map was made was developed by scientists Marc Imhoff of NASA's Goddard Space Flight Center (GSFC) and Christopher Elvidge of NOAA's National Geophysical Data Center using visible radiance data gathered over nine months by the Defense Meteorological Satellite Program sensors; the visualization was created by Craig Mayhew and Robert Simmon of GSFC. See http://antwrp.gsfc.nasa.gov/apod/image/0011/earthlights_dmsp_big.jpg

Front cover images,left to right: 3-D physical model of bacillus anthracis (anthrax) fabricated by computer-controlled prototyping equipment using data from the NITRD agencies' (DOE, NIH, NIST, and NSF) collaborative online Protein Data Bank, an international repository of 3-D macromolecular structure data; the investigator was Michael Bailey of the San Diego Supercomputer Center. High-resolution simulation from NOAA'S Geophysical Fluid Dynamics Laboratory at Princeton University shows vase-like motion of polar air from 14 to 42 kilometers above the earth's surface; this circulation pattern influences ozone concentrations across the lower latitudes. Screen shot from 3-D model of a particle (purple dot) moving through a fluid (green mesh), generated using NWGrid and NWPhys software developed by DOE's Pacific Northwest National Laboratory; these advanced software tools establish hybrid mesh topologies for visualizing and solving computational physics problems – such as thermal diffusion characteristics, hydrodynamic and multimaterial flows, and fluid flows through geological formations – on distributed parallel computing systems. NASA visualization shows five interatomic surfaces, or "zero-flux" surfaces, in the gradient vector field of the electronic charge density for the ethylene molecule (C_2H_4); these surfaces partition space into basins of attraction, constituting "atoms in molecules" as advanced in the quantum theory of Richard Bader, and are precisely analogous to potential flow separation surfaces in aerodynamics.

Back cover image: Visualization of the directory tree of an Internet node, created with Walrus software tool developed by Young Hyun of the Cooperative Association for Internet Data Analysis (CAIDA) with support from DARPA and NSF. From user-supplied data and specifications, Walrus employs 3-D hyperbolic geometry to turn graph data into a multicolor interactive graphic display with a fisheye distortion. Within the fisheye sphere, details are magnified at the center and reduced in size to zero at the periphery; the viewer can navigate the graph to examine every part of the data set at the highest level of detail. Tools such as Walrus enable network analysts to "see" the architectures of network connectivity and to better understand the complexity of Internet topology. CAIDA recently used Walrus to create a visualization of the global spread of the Code Red computer worm in July 2001 (http://www.caida.org/tools/visualization/walrus/examples/codered/). Image courtesy of CAIDA.

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