THE NITRD PROGRAM:
FY 2004
INTERAGENCY COORDINATION
REPORT

Interagency Working Group on
Information Technology Research and Development
(IWG/ITR&D)

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EXECUTIVE SUMMARY

This Interagency Coordination Report (ICR) provides a comprehensive description of the FY 2004 activities of the multi-agency $2 billion Federal *Networking and Information Technology Research and Development (NITRD) Program* and the organizations that implement them. The NITRD Program is one of several formal interagency programs in the Federal government. It provides agencies that perform ITR&D with the ability to plan, budget, coordinate, implement, and assess their ITR&D programs. The agencies that formally participate in the NITRD Program in FY 2004 are:

- Agency for Healthcare Research and Quality (AHRQ)
- Defense Advanced Research Projects Agency (DARPA)
- Defense Information Systems Agency (DISA)
- Department of Energy/National Nuclear Security Administration (DOE/NNSA)
- Department of Energy/Office of Science (DOE/SC)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Institute of Standards and Technology (NIST)
- National Institutes of Health (NIH)
- National Oceanographic and Atmospheric Administration (NOAA)
- National Science Foundation (NSF)
- National Security Agency (NSA)

Additionally, six agencies that are not formal NITRD members participate in the FY 2004 NITRD Program activities. They are:

- Air Force Research Laboratory (AFRL)
- Department of Defense/High Performance Computing Modernization Program Office (DoD/HPCMPO)
- General Services Administration (GSA)
- Federal Aviation Administration (FAA)
- Food and Drug Administration (FDA)
- Office of Naval Research (ONR)

The NITRD Program is coordinated through the Interagency Working Group on Information Technology Research and Development (IWG/ITR&D) of the National Science and Technology Council (NSTC). (The NITRD Program, the NSTC, and the IWG are described in chapter 1 of this report.) This FY 2004 ICR is the successor to past Implementation Plans (IPs).

The ICR focuses on the building blocks of the NITRD Program – seven Program Component Areas (PCAs) and six Coordinating Groups (CGs). The PCAs are the subject areas where agency investments are made in ITR&D and the CGs are the structured groups of NITRD agency program managers that guide the PCA investments through planning, coordinating, implementing, and assessing NITRD Program activities. The ICR's focus on the PCAs and the CGs enables an in-depth view of the coordinated NITRD activities.

The seven PCAs are:

- High-End Computing Infrastructure and Applications (HEC I&A)
- HEC 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 Implications of IT and IT Workforce Development (SEW)

CGs map one-to-one and onto the PCAs, except in the case of the HEC CG, which coordinates the activities in both the HEC I&A and HEC R&D PCAs.

The coordinated FY 2004 NITRD Program activities described in this report are wide and varied and include:

- The release of NITRD agency reports including:

    o Budget-related reports such as the FY 2004 *Supplement to the President's Budget* (Blue Book), formally entitled, *NITRD: Advanced Foundations for American Innovation*

    o A special OSTP/NSTC-sanctioned interagency report entitled the *Federal Plan for High-End Computing*

    o A special IWG-sanctioned report called *Grand Challenges: Science, Engineering, and Societal Advances Requiring Networking and Information Technology Research and Development*

    o Individual CG-sanctioned research needs reports such as the HCI&IM CG's *Human-Computer Interaction and Information Management Research Needs*

- The development of ITR&D research scopes such as SDP's taxonomy

- The assembly of NITRD agency representatives in quarterly IWG meetings, monthly CG meetings, and Task Forces such as the Grand Challenges Task Force

- The assembly of Federal, university, and industry experts in science, technology, and engineering in multi-agency activities such as the NASA-hosted workshop on Optical Network Testbeds (ONT)

- Single agency activities such as DOE/SC's Scientific Discovery through Advanced Computing (SciDAC) program

ABOUT THIS REPORT

The material in this report comes from detailed summaries of activities and plans presented by agency representatives at Special Meetings of the CGs held between November 2003 and March 2004. This ICR is a snapshot of FY 2004 activities and plans at the time these summaries were made. Many of these activities are multi-year. Occasionally, FY 2003 or earlier activities are reported. An example is workshops to plan R&D activities that are funded in FY 2004. Some agency FY 2004 activities and plans changed after this snapshot was taken.

The report was prepared by the National Coordination Office for Information Technology Research and Development (NCO/ITR&D). It is organized into seven chapters. Chapter 1 describes the organizational structure of the NITRD Program, its authorizing legislation, the short versions of the recently updated PCA definitions, and the IWG-level NITRD activities. Each of the subsequent six chapters describes activities of one CG. They are in descending order of their NITRD budgets. Each chapter includes:

- A detailed PCA definition(s)
- *FY 2004 CG activities* that are sponsored by a CG and involve more than one CG member agency
- *FY 2004 multi-agency activities* that are cooperatively implemented by multiple CG member agencies
- *FY 2004 agency activities* that address an agency's mission goals

The CG chapters are followed by five appendices and acknowledgements. Appendix A provides an overview of the missions of the NITRD agencies, Appendix B lists the members of the IWG, Appendix C lists the PCA Coordinating Groups and team chairs, Appendix D lists the report contributors and NITRD contacts, and Appendix E provides the glossary and spells out the acronyms found throughout this report.

1. ORGANIZATIONAL STRUCTURE AND OVERARCHING ACTIVITIES OF THE NITRD PROGRAM

The NITRD Program is one of a small number of formal interagency programs in the Federal government. It provides agencies that perform ITR&D with the ability to plan, budget, coordinate, implement, and assess their ITR&D activities.

1.1 GOALS OF THE NITRD PROGRAM

The NITRD Program goals are to:

- Assure continued U.S. leadership in computing, networking, and information 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, networking, and information technologies

1.2 THE NITRD AGENCIES

1.2.1 Principal NITRD Agencies

Agencies that formally participate in the NITRD Program are:

- Agency for Healthcare Research and Quality (AHRQ)
- Defense Advanced Research Projects Agency (DARPA)
- Defense Information Systems Agency (DISA)
- Department of Energy/National Nuclear Security Administration (DOE/NNSA)
- Department of Energy/Office of Science (DOE/SC)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Institute of Standards and Technology (NIST)
- National Institutes of Health (NIH)
- National Oceanic and Atmospheric Administration (NOAA)
- National Science Foundation (NSF)
- National Security Agency (NSA)

1.2.2　Participation of Other Federal Agencies in NITRD Program Activities

Participation in NITRD activities is open to other Federal agencies. In FY 2004, the following agencies participated in NITRD activities:

- Air Force Research Laboratory (AFRL)
- Department of Defense/High Performance Computing Modernization Program Office (DoD/HPCMPO)
- Federal Aviation Administration (FAA)
- Food and Drug Administration (FDA)
- General Services Administration (GSA)
- Office of Naval Research (ONR)

The agencies listed in sections 1.2.1 and 1.2.2 participated in the production of this report.

1.3　THE NITRD PROGRAM AUTHORIZING LEGISLATION

The NITRD Program stems from the High-Performance Computing (HPC) Act of 1991 (P.L. 102-194) as amended by the Next Generation Internet (NGI) Act of 1998 (P.L. 105-305).[1] These Acts authorize Federal agencies to set goals and prioritize their investments in networking and information technology research and development (including high performance computing) and authorize the establishment of what is now known as the President's Information Technology Advisory Committee (PITAC).

1.4　OFFICE OF SCIENCE AND TECHNOLOGY POLICY (OSTP) AND NATIONAL SCIENCE AND TECHNOLOGY COUNCIL (NSTC) OVERSIGHT OF THE NITRD PROGRAM

The Office of Science and Technology Policy (OSTP)[2] was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976.[3] OSTP advises and oversees the formulation of policies and budget developments on all questions in which science and technology (S&T) are important elements; it articulates and directs the President's S&T policies and programs; and it creates and sustains scientific partnerships among Federal, state, and local government, industry, and academic organizations.

The Cabinet-level NSTC,[4] established by Executive Order on November 23, 1993, is the principal means for the President to coordinate science, space, and technology policies across the Federal government. The President chairs the NSTC and the membership consists of the Vice President, the Assistant to the President for Science and Technology, Cabinet Secretaries, agency heads with significant S&T responsibilities, and other White House officials. The Assistant to

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[1] Both Acts can be found at http://www.nitrd.gov/congressional/laws/index.html
[2] http://www.ostp.gov
[3] The Act (P.L. 94-282) can be found at http://www.thomas.loc.gov/
[4] http://www.nstc.gov

the President for Science and Technology directs both the OSTP and the NSTC on behalf of the President.

The Interagency Working Group for ITR&D is the organizational framework established by the NSTC to coordinate the work of the NITRD Program. The IWG reports to the Committee on Technology of the NSTC.

1.4.1 Special NSTC Project: High-End Computing Revitalization Task Force (HECRTF)

As part of the President's FY 2004 Budget, OSTP sanctioned the creation of the HECRTF whose work was chartered under the auspices of the NSTC. The HECRTF was charged with developing a plan for undertaking and sustaining a robust Federal high-end computing program to maintain U.S. leadership in S&T. Following approval by the members of the NSTC Committee on Technology, the HECRTF released its *Federal Plan for High-End Computing*[5] in May 2004. The HECRTF and its activities are described in section 2.6.

1.5 INTERAGENCY WORKING GROUP ON INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT (IWG/ITR&D): COORDINATION OF THE NITRD PROGRAM

The IWG/ITR&D[6] (henceforth called the "IWG") provides hands-on coordination of the NITRD Program. It comprises senior ITR&D managers from the participating agencies and representatives from the Office of Management and Budget (OMB), OSTP, and the National Coordination Office for Information Technology Research and Development (NCO/ITR&D).[7] The IWG meets quarterly. The NCO supports the IWG.

The building blocks of the NITRD Program are called Program Component Areas (PCAs) and Coordinating Groups (CGs). PCAs – the conceptual building blocks – are the subject areas across which R&D investments are made by the NITRD agencies. CGs – the operational building blocks – are the groups of agency representatives that coordinate the activities funded under the PCAs.

1.5.1 Program Component Areas (PCAs)

There are seven PCAs in the NITRD Program. The two HEC PCAs – HEC Infrastructure and Applications (I&A) and HEC Research and Development (R&D) – are coordinated by the HEC CG. The PCAs are briefly defined below (detailed definitions appear at the beginning of each CG chapter):

High-End Computing Infrastructure and Applications (HEC I&A) – The activities and facilities funded under the NITRD Program's HEC I&A PCA include R&D infrastructure and

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[5] http://www.nitrd.gov/pubs/2004_hecrtf/20040510_hecrtf.pdf
[6] http://www.nitrd.gov/iwg/program.html
[7] http://www.nitrd.gov/about/index.html

R&D to extend the state of the art in computing systems, science and engineering applications, and data management necessary to keep the United States at the forefront of 21st century science and engineering discoveries.

High-End Computing Research and Development (HEC R&D) – The activities funded under the HEC R&D PCA include R&D to optimize the performance of today's high-end computing systems and to develop future generations of high-end computing systems to address Federal agency mission needs and in turn many of society's most challenging large-scale computational problems in order to strengthen the Nation's global leadership in the sciences, engineering, and technology.

Human Computer Interaction and Information Management (HCI&IM) – The activities funded under the HCI&IM PCA have the goal of increasing the benefit of computer technology to humans through the development of future user interaction technologies, cognitive systems, information systems, and robotics.

Large Scale Networking (LSN) – The activities funded under the LSN PCA maintain and extend U.S. technological leadership in high performance networks through R&D in leading-edge networking technologies, services, and techniques to enhance performance, security, and scalability.

Software Design and Productivity (SDP) – The activities funded under the SDP PCA focus on achieving fundamental advances in concepts, methods, techniques, and tools for software design, development, and maintenance that address the widening gap between society's need for usable and dependable software-based systems and our ability to produce them in a timely, predictable, and cost-effective manner.

High Confidence Software and Systems (HCSS) – The activities funded under the HCSS PCA focus on the basic science and information technologies necessary to achieve affordable and predictable high levels of safety, security, reliability, and survivability in U.S. national security and safety-critical systems in critical domains such as aviation, healthcare, national defense, and infrastructure.

Social, Economic, and Workforce Implications of IT and IT Workforce Development (SEW) – The activities funded under the SEW PCA focus on the nature and dynamics of IT impacts on technical and social systems as well as the interactions between people and IT devices and capabilities; the workforce development needs arising from the growing demand for workers who are highly skilled in information technology; and the role of innovative IT applications in education and training. SEW also supports efforts to transfer the results of ITR&D to the policymaking and IT user communities in government at all levels and the private sector.

1.5.1.1 FY 2004 NITRD AGENCY BUDGET REQUESTS BY PCA (dollars in millions)[8]

Agency	HEC I&A	HEC R&D	HCI&IM	LSN	SDP	HCSS	SEW	TOTAL
NSF	218.1	97.9	125.3	103.4	55.0	59.9	74.0	**734**
NIH	87.6	41.7	99.0	132.2	9.2	3.7	12.2	**386**
NASA	45.9	34.6	67.1	28.9	59.2	24.2	6.7	**267**
DARPA		108.5	78.4	18.2	13.3	4.0		**222**
DOE/SC	88.9	51.3	16.4	30.0			3.5	**190**
AHRQ			32.0	25.0				**57**
NSA		21.3		1.9		28.1		**51**
NIST	3.5		6.2	3.2	7.5	2.0		**22**
NOAA	13.5	1.8	0.5	2.8	1.5			**20**
EPA	1.6		0.2					**2**
DOE/NNSA	41.5	37.3		14.4	32.8		4.4	**130**
DISA			46.2	13.2		6.1		**66**
TOTAL	**500.6**	**394.4**	**471.3**	**373.3**	**178.5**	**128.1**	**100.8**	**2,147**

1.5.1.2 Coordinating Groups

The NITRD Program's six CGs comprise program managers who plan, coordinate, implement, and assess the associated PCA investments. The CGs meet approximately monthly and report to the IWG.

1.5.2 Overarching Activities Under the IWG

In FY 2004, the IWG sanctioned the following activities:

- The preparation of the FY 2005 Blue Book, which is required by law
- The preparation of the Grand Challenges Task Force report
- The CG Special Meetings
- The preparation of the ICR
- The PCA/CG Task Group that, among other things, shepherded the updates to the PCA definitions

1.5.2.1 FY 2004 Supplement to the President's Budget ("The Blue Book")

Officially called Supplements to the President's Budget, Blue Books provide descriptive accounts of the extensive and diverse portfolio of activities funded under the NITRD Program and a breakdown of the corresponding budget details of these activities. Required by the HPC Act of 1991, the NCO/ITR&D prepares Blue Books on an annual basis with input from the NITRD agencies.

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[8] FY 2004 Blue Book, Agency NITRD Budgets by Program Component Area, p. 39.

Released in September 2003, the FY 2004 Blue Book, entitled *Networking and Information Technology Research and Development: Advanced Foundations for American Innovation,*[9] highlighted outcomes of Federal NITRD activities and specifically concentrated on the critical role of fundamental IT research executed by the Federal agencies. This IT research resulted in many of the advanced foundations for innovation in key dimensions of national interests including foundations for national security, scientific leadership, research and learning, and 21st Century society.

1.5.2.2 Relationship Between the ICR and the FY 2005 Blue Book

The ICR documents the NITRD Program activities within a single fiscal year, with an emphasis on coordination. These activities are described from both multi-agency and agency-specific coordination perspectives. The FY 2005 Blue Book is an abbreviated adaptation of the ICR that is accompanied by the agency budgets by PCA.

1.5.2.3 FY 2004 Grand Challenges Task Force and Booklet

In November 2002, the IWG established a Grand Challenges Task Force and charged it with identifying a set of science, engineering, and societal challenges that require innovations in ITR&D. The goal was to update the list presented in the FY 1994 Blue Book that was called for in the HPC Act of 1991. The Task Force comprised volunteers from ten NITRD agencies and FAA, OSTP, and the NCO.

The work of the Task Force culminated in the first NITRD report of its kind: *Grand Challenges: Science, Engineering, and Societal Advances Requiring Networking and Information Technology Research and Development*[10] which was released in November 2003.

Recognizing that IT advances will enhance existing applications and enable new ones that can have even greater impact, the Task Force updated the "grand challenge" definition. The new definition of a NITRD grand challenge is:

> *A long-term science, engineering, or societal advance, whose realization requires innovative breakthroughs in information technology research and development (ITR&D) and which will help address our country's priorities.*

The Task Force identified 16 new NITRD Illustrative Grand Challenges. Its goal in doing so was to identify a set of grand challenges that are expected to yield significant breakthroughs of practical importance to mankind. Criteria to guide the development of the grand challenges are reflected in the template used to describe them:

- Description of the multi-decade grand challenge
- Focus of the grand challenge in the next ten years

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[9] http://www.nitrd.gov/pubs/blue04. 2,500 printed copies have been distributed.
[10] http://www.nitrd.gov/pubs/200311_grand_challenges.pdf. 1,500 printed copies have been distributed.

- Benefits of the grand challenge to the social, economic, political, scientific, and technological well-being of mankind
- Relationship of the grand challenge to our country's national priorities. In consultation with OSTP the Task Force identified six national priority areas that reflect the country's broad scientific, military, social, economic, and political values and goals. They are:

  - Leadership in S&T
  - Homeland and National Security
  - Health and Environment
  - Economic Prosperity
  - A Well-Educated Populace
  - A Vibrant Civil Society

- Relationship to Information Technology Hard Problem Areas (ITHPAs) (described below)
- Indications of progress

The 16 new NITRD Illustrative Grand Challenges are:

- Knowledge Environments for Science and Engineering
- Clean Energy Production Through Improved Combustion
- High Confidence Infrastructure Control Systems
- Improved Patient Safety and Health Quality
- Informed Strategic Planning for Long-Term Regional Climate Change
- Nanoscale Science and Technology: Explore and Exploit the Behavior of Ensembles of Atoms and Molecules
- Predicting Pathways and Health Effects of Pollutants
- Real-Time Detection, Assessment, and Response to Natural or Man-Made Threats
- Safer, More Secure, More Efficient, Higher-Capacity, Multi-Modal Transportation System
- Anticipate Consequences of Universal Participation in a Digital Society
- Collaborative Intelligence: Integrating Humans with Intelligent Technologies
- Generating Insights From Information at Your Fingertips
- Managing Knowledge-Intensive Organizations in Dynamic Environments
- Rapidly Acquiring Proficiency in Natural Languages
- SimUniverse: Learning by Exploring
- Virtual Lifetime Tutor for All

The Task Force also developed a list of 14 IT Hard Problem Areas (ITHPAs) – broad categories of topics of interest to the NITRD Program and the ITR&D community and for which solutions or advances are required to achieve progress towards the grand challenges. The 14 ITHPAs are:

- Algorithms and Applications
- Complex Heterogeneous Systems
- Hardware Technologies

- High Confidence IT
- High-End Computing
- Human Augmentation IT
- Information Management
- Intelligent Systems
- IT System Design
- IT Usability
- IT Workforce
- Management of IT
- Networks
- Software Technologies

The Grand Challenges booklet provides further details about the grand challenges and the ITHPAs.

1.5.2.4 FY 2004 PCA/CG Task Group And Update To The PCA Definitions

At its September 2003 meeting, the IWG chartered the NITRD PCA/CG Task Group to assess the impact of their R&D advances on agency NITRD investments and to update the existing PCA definitions.

Composed of the CG Co-Chairs and supported by the NCO, the Task Group was given the following charge:

- Examine the current foci of PCAs and CGs
- Recommend any changes to the PCAs and CGs to better serve the needs of the NITRD Program and participating agencies

The Task Force identified broad issues affecting both the PCAs and the CGs and reported the following actions:

- The Task Force established Temporary Linkages Groups (TLGs) in open source software and security. These two topics are crosscutting issues that are of interest to several CGs. The TLGs will operate in the same manner as the CGs.
- The CGs and the Task Force revised the PCA definitions. The abbreviated versions of the definitions will be used in the Executive Summary of the FY 2005 Blue Book and section 1.5.1 of this ICR. The detailed versions appear in the main chapters of the Blue Book and open each CG chapter of this report.

1.5.2.5 FY 2004 Special Meetings

Between November 2003 and March 2004, each CG held a Special Meeting at which the CG members summarized current and future agency and, in some cases, Team activities over the course of FY 2004. The information gathered at the Special Meetings provided information useful to the CGs in fulfilling their responsibilities and served as input to the work of the IWG's PCA/CG Task Group and to the preparation of this ICR.

At each Special Meeting, agencies were asked to present the following information:

- Major agency plans and agency workshops, conferences, principal investigator (PI) meetings, planning meetings, and reports
- Multi-agency plans and multi-agency workshops, conferences, and reports that are sponsored by a CG member agency, but not necessarily by a CG, and that involve more than one CG member agency

1.6   ABOUT THE NCO

The NCO/ITR&D provides the technical and administrative support for the IWG, the PCA Coordinating Groups, and the President's Information Technology Advisory Committee (PITAC). The HPC Act of 1991 authorizes the functions performed by the NCO to support the IWG and the CGs. Executive Order 13035 authorizes NCO support for the PITAC. The National Science Foundation (NSF) serves as the host agency for the NCO.

2.   HIGH-END COMPUTING (HEC)

2.1   INTRODUCTION

High-End Computing (HEC) programs of the Federal agencies in the NITRD Program are reported under two Program Component Areas (PCAs): HEC Infrastructure and Applications (HEC I&A) and HEC Research and Development (HEC R&D). The first two sections of this chapter give their detailed definitions.

2.2   DEFINITION OF THE HEC I&A PCA

The activities and facilities funded under the NITRD Program's HEC I&A PCA include R&D infrastructure and R&D to extend the state of the art in computing systems, science and engineering applications, and data management necessary to achieve the breakthroughs necessary to keep the United States at the forefront of 21st century science and engineering discoveries. HEC researchers develop, deploy, and apply the most advanced hardware, systems, and applications software to model and simulate objects and processes in biology, chemistry, environmental sciences, materials science, nanoscale S&T, and physics; address complex and computationally intensive national security applications; and perform large-scale data fusion and knowledge engineering. For scientific researchers in every field, these advanced computing capabilities have become a prerequisite for discovery.

The R&D that produces these capabilities requires collaborations across Federal and academic institutions, industry, and the international research community. Interdisciplinary teams of scientists, engineers, and software specialists design and maintain the large, complex body of applications software. The largest and fastest computational platforms available are required because of the great range of space scales (from subatomic to supernova) and time scales (such as nano-second to multi-century climate model) in the models and simulations. Modeling and simulation produce vast amounts of data that require leading-edge storage and visualization technologies.

Even with skilled teams and leading-edge technologies, however, today's HEC systems remain, for the most part, fragile and difficult to use. Specialized systems and applications software are needed to distribute calculations across hundreds or thousands of processors in a variety of massively parallel systems. Computational scientists are faced with a proliferation of architectures and variety of programming paradigms, resulting in a multitude of questions that must be addressed and tasks that must be performed in order to implement a modeling or simulation algorithm on any specific architecture. But while this work progresses, advances in the size and speed of computing systems open up opportunities to increase the size, scale, complexity, and even nature of the modeling and simulation problems that can be addressed. The result is that a new cycle of systems and applications software R&D is required to enable scientists to take advantage of the increased computing power.

In order to maintain or accelerate the pace of scientific discovery, HEC I&A efforts are needed to develop breakthroughs in algorithm R&D, advances in systems software, improved programming environments, and computing infrastructure for development of the next-

generation applications that will serve Federal agency missions. Focus areas include, but are not limited to, tools to facilitate high-end computation, storage, and visualization of large data sets encountered in the biomedical sciences, climate modeling and weather forecasting, computational aerosciences, crisis management, Earth and space sciences, and a vast range of human activities.

Broad areas of HEC I&A concerns include:

- Algorithm R&D
- Data management and understanding
- Programming environments
- Scientific applications
- Computational facilities

To address these concerns, HEC I&A R&D pursues the following technical goals:

- Understand the interaction between applications and architectures.
- Provide mathematical and computational methods needed for scientific and critical mission agency applications.
- Provide technology base for next generation data management and visualization.
- Enable new generations of scientific and mission agency computational applications.
- Reduce time and effort in HEC procurements
- Reduce cost of ownership of HEC systems
- Provide measures of progress

Illustrative technical thrusts of HEC I&A programs include:

- Scientific discovery through advanced computing
- Cyberinfrastructure
- Leadership computing
- System monitoring and evaluation
- Integrated end-to-end data management
- Visualization clusters
- Common procurement methodology

2.3   DEFINITION OF THE HEC R&D PCA

The activities funded under the HEC R&D PCA include R&D to optimize the performance of today's high-end computing systems and to develop future generations of high-end computing systems to address Federal agency mission needs and, in turn, many of society's most challenging large-scale computational problems in order to strengthen the Nation's global leadership in the sciences, engineering, and technology.

Current high-end systems typically are clusters of processor nodes developed for the commercial computing market for use in personal computers and Web servers, and are not specifically

targeted for HEC computing. Although the "peak" performance of these processors has followed Moore's Law, increasing more than five orders of magnitude in speed in the last decade, the sustained performance of scientific applications measured as a fraction of the peak value has continued to decline. Two reasons for this decline are: (1) these HEC systems are hundreds of times larger than those used in commercial applications and require a highly specialized software infrastructure to use effectively, and (2) these current HEC systems are unbalanced in that they do not have the optimal ratios of system parameters such as computation rate versus memory bandwidth.

To remedy this situation, HEC R&D supports both hardware and software R&D specifically aimed at scientific applications. HEC R&D focuses on teraflop[11] through petaflop[12] scale systems and computation. Research activities in this area seek fundamental, long-term advances in technologies to maintain and extend the U.S. lead in computing for generations to come. Current research focuses on advanced computing architectures, software technologies and tools for high-end computing, mass storage technologies, and molecular, nano-, optical, quantum, and superconducting technologies.

HEC R&D engages collaborative research teams from academic institutions, national laboratories, and industrial partners in the development of new architectures that are well suited for algorithms used in scientific applications. HEC R&D supports fundamental investigations in memory, interconnect, and storage technologies in order to improve system balance. HEC R&D involves research across the entire spectrum of software issues – operating systems, languages, compilers, libraries, development environments, and algorithms – necessary to allow scientific applications to use the hardware effectively and efficiently. In addition, HEC R&D supports system modeling and performance analysis, which enable researchers to better understand the interaction between the computational requirements of applications and the performance characteristics of any proposed new high-end architectures.

Broad areas of HEC R&D concern include:

- Hardware architecture, memory, and interconnects
- Power, cooling, and packaging
- I/O and storage
- Comprehensive system software environment
- Programming models and languages
- System modeling and performance analysis
- Reliability, availability, serviceability, and security

To address these concerns, HEC R&D pursues the following technical goals:

- Parallel architecture designed for scientific application requirements
- Parallel I/O and file systems for sustained high data throughput

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[11] 10^{12} floating point operations per second
[12] 10^{15} floating point operations per second

- Systems scalable to hundreds of thousands of processors
- Reliable and fault tolerant systems
- Improved programming model expressibility and parallel compiler support
- Effective performance measurement and optimization tools
- Improved ease of use and time to solution

Illustrative technical thrusts of HEC R&D programs include:

- Parallel component architecture
- Parallel I/O and high performance file systems
- Next generation architecture
- Extreme scale operating and runtime systems
- Global address space language
- Software infrastructure tools
- Development and runtime performance tools
- High productivity computer systems
- Quantum computing

2.4   HEC CG ACTIVITIES

The HEC Coordinating Group (HEC CG) coordinates activities funded under the HEC I&A and HEC R&D PCAs by providing a forum for Federal agency program managers to coordinate and collaborate on HEC research programs and on implementing Federal high-end computing activities. It is charged with:

- Encouraging and facilitating interagency coordination and collaborations in HEC I&A and R&D
- Addressing requirements for HEC technology, software, infrastructure, and management by fostering Federal R&D efforts
- Providing mechanisms for cooperation in HEC R&D and user access among Federal agencies, government laboratories, academia, industry, application researchers, and others

At HEC CG meetings, HEC agencies inform each other of upcoming agency meetings and workshops so that program managers from all HEC agencies can participate and benefit. Between March 2003 and March 2004, HEC agencies participated in the HECRTF and the HEC CG did not meet. (The HECRTF is discussed in section 2.5.)

The HEC CG held a Special Meeting on March 19, 2004 with presentations and program descriptions provided from the following Federal agencies: NSF, DOE/SC, DARPA, NASA, DOE/NNSA, NSA, NOAA, NIST, EPA, and DoD/HPCMPO. This meeting enabled the agencies to identify opportunities for collaboration and coordination, areas for HEC CG focus, and areas whose scope is greater than the HEC CG, such as open source software.

2.5 HEC MULTI-AGENCY ACTIVITIES

The HEC agencies have common interests and commitments across a wide range of topics including:

- Acquisition coordination: DoD/HPCMPO, DOE/NNSA, NASA
- Air quality modeling applications: DOE/SC, EPA, NOAA
- Applied research for end-to-end systems development: NASA, NOAA, NSF
- Benchmarking and performance modeling: DoD/HPCMPO, DOE/NNSA, DOE/SC, NASA, NSA, NSF
- Connectivity and technology delivery to universities: NOAA, NSF
- Climate and weather applications: DOE/SC, NASA, NOAA, NSF
- Earth System Modeling Framework (ESMF): DOE/SC, NASA, NOAA, NSF/NCAR
- Grid demonstrations: DOE/SC, NOAA, NSF
- Hardware development: DARPA, DOE/NNSA, NSA
- HECRTF: DoD/HPCMPO, DoD/OSD, DOE/NNSA, DOE/SC, EPA, NASA, NIST, NOAA, NSA, NSF
- HEC-URA: DARPA, DOE/SC, NSA, NSF
- HPCS Phase II: DARPA, DOE/NNSA, DOE/SC, NASA, NSA, NSF
- HPCS productivity metrics:[13] DARPA, DoD/HPCMPO, DOE/NNSA, DOE/SC, NASA, NSA, NSF
- Joint memo expecting open source software and Service Oriented Data Access (SODA) for work funded at DOE labs: DOE/NNSA, DOE/SC
- MOU among HPCS mission partners for joint planning, coordination of directions, and leveraging each other's activities: DARPA, DoD/OSD, DOE/NNSA, DOE/SC, NSA
- National Research Council study on the "Future of Supercomputing:" DOE/NNSA, DOE/SC (report expected in 2004)[14]
- Optical switches and interconnects: DARPA, DOE/NNSA, NSA
- Quantum information science: DARPA, NIST, NSA
- Quarterly reviews of Cray X1e/Black Widow R&D programs: DoD/HPCMPO, DOE/NNSA, DOE/SC, NASA, NRO, NSA
- Reviews of ASC White and ASC Q software environments: DOE/NNSA, DOE/SC
- Reviews of SV2: DOE/NNSA, DOE/SC, NSA
- Single photon sources: DARPA, NIST
- Spray cooling: DOE/NNSA, DOE/SC
- Standards: DoD/HPCMPO, NIST, NOAA, NSA
- Technology transfer from universities: DoD/HPCMPO, DOE/NNSA
- Testbeds: DARPA, DoD/HPCMPO, NIST, NOAA, NSA
- Unified Parallel Compiler (UPC): DOE/SC, NSA
- Weather Research and Forecast (WRF): NOAA, NSF/NCAR

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[13] http://www.highproductivity.org/
[14] http://www.nap.edu/ [NAP is the National Academies Press.]

The HEC agencies cooperate on many multi-agency workshops such as:

- ORNL Cray X1 Review (February 2004)[15]
- Interagency HPC Metrics Workshop (June 28, 2004)

Additional multi-agency workshops are noted below in agency activity descriptions. Other agencies are usually invited to attend single-agency workshops.

2.5.1   Earth System Modeling Framework

Another broad-based NITRD activity that involves collaboration among multiple Federal agencies and coordination across multiple CGs, including HEC and SDP, is the building of the Earth System Modeling Framework (ESMF). The ESMF is a high-performance, flexible software infrastructure designed to increase ease of use, performance portability, interoperability, and reuse in climate, numerical weather prediction, data assimilation, and other Earth science applications. The ESMF is an architecture for composing multi-component applications and includes data structures and utilities for developing model components. The goal is to create a framework usable by individual researchers as well as major operational and research centers, and to engage the weather research community in its development.

The ESMF addresses the challenge of building increasingly interdisciplinary Earth systems models and the need to maximize the performance of the models on a variety of computer architectures, especially those using upwards of thousands of processors. The new structure allows physical, chemical, and biological scientists to focus on implementing their specific model components. Software engineers design and implement the associated infrastructure and superstructure, allowing for a seamless linkage of the various scientific components.

The following agency organizations collaborate in the ESMF effort:

- NSF-supported National Center for Atmospheric Research (NCAR)
- NOAA's Geophysical Fluid Dynamics Laboratory (GFDL)
- NOAA's National Center for Environmental Prediction (NCEP)
- DOD's Air Force Weather Agency (AFWA)
- DoD's High Performance Computing Modernization Program Office (HPCMPO)
- DOD's Naval Research Laboratory (NRL)
- DOE's Argonne National Laboratory (ANL) and Los Alamos National Laboratory (LANL)
- NASA's
    - Goddard Space Flight Center (GSFC)
    - Goddard Global Modeling and Assimilation Office (GGMAO)
    - Goddard Institute for Space Studies (GISS)
    - Goddard Land Information Systems project (GLIS)

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[15] http://csm.ornl.gov/DOE/Feb2004/DOE-04index.html

ESMF Version 2.0, the first version of the software usable in real applications, was released in June 2004. It includes software for: (1) setting up hierarchical applications, (2) representing and manipulating modeling components, fields, bundles of fields, and Grids, and (3) standard services such as time management and logging messages.

2.6 HIGH-END COMPUTING REVITALIZATION TASK FORCE (HECRTF)

A primary focus of the HEC CG during FY 2004 has been interagency participation in and cooperation on the High-End Computing Revitalization Task Force (HECRTF) commissioned by OSTP in coordination with the NSTC. Participating Federal organizations were DoD/HPCMPO, DoD/OSD, DOE/NNSA, DOE/SC, EPA, NASA, NIST, NOAA, NSA, NSF, OMB, OSTP, and the NCO.

2.6.1 HECRTF Report Released at House Science Committee Hearing

On May 13, 2004, following approval by the members of the NSTC Committee on Technology, the HECRTF released its final report entitled *Federal Plan for High-End Computing* (henceforth called the *Federal Plan*) at a House Science Committee hearing[16] on H.R. 4218, the High Performance Computing Act of 2004.[17]

2.6.2 Charge to the HECRTF

The report fulfilled the charge given to the HECRTF to develop a five-year plan to guide future Federal investments in high-end computing.[18] The Task Force was given subtasks to develop:

- A roadmap for core technology development including key technologies and strategies for their development
- A roadmap for HEC computing capability, capacity, and accessibility including plans to address capability or capacity gaps and performance targets for proposed HEC systems linked to applications and user needs
- Findings and recommendations about Federal procurement of HEC systems including strategies for performance measures, methods for deriving system performance targets, and discussion of total cost of ownership
- A roadmap for the Federal role in HEC R&D, utilization, and procurement that integrates the three components above

2.6.3 HECRTF Report: *Federal Plan for High-End Computing*

The HECRTF identified key areas for HEC R&D:

- Hardware

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[16] http://www.house.gov/science/hearings/full04
[17] http://thomas.loc.gov/cgi-bin/query
[18] http://www.nitrd.gov/hecrtf-outreach/index.html, which includes the full OSTP charge to the HECRTF

- o Microarchitecture
- o Memory
- o Interconnect
- o Power, cooling, and packaging
- o I/O and storage

- Software
  - o Operating systems
  - o Languages, compilers, and libraries
  - o Software tools and development environments
  - o Algorithms

- Systems
  - o System architecture
  - o System modeling and performance analysis
  - o Programming models
  - o Reliability, availability, serviceability, and security

To address the requirements for HEC resources from a broad range of scientific disciplines across the Federal government, two classes of issues were identified:

- Architectural availability – the Government could help close the gap between scientific and defense needs and commercial IT by investing in research and prototype development to ensure a mix of architectures to meet Federal computing needs.

- HEC capacity to address agency mission needs – Federal S&T agencies identified high-end computing requirements that are about three times the current capacity and are growing about 80 percent per year.

The HECRTF made recommendations about access, availability, and leadership-class systems:

- *Accessibility*
  - o Agencies whose researchers currently obtain HEC resources from other agencies should examine options for formalizing the provision of these resources to their research communities through cooperative agreements. For example, agencies with longstanding HEC programs, including DoD, DOE, and NSF, could serve as models for doing this.
  - o Each agency should assess and make arrangements to provide for its own resource needs based on mission priorities.

- *Availability*
  - o Agencies should examine the value of reallocating resources to respond to the growing demand for computational resources and the increasing stress that will result from an already overburdened system.

- Agencies might also assess and adjust the relative balance among research and engineering (R&E) modes (theory, experiment, and computation) to ensure optimal allocation of resources.

- *Leadership Systems*
  - High cost limits the number of Leadership Systems to a few.
  - Agencies should manage Leadership Systems as national resources for all participating agencies.
  - Agencies should operate Leadership Systems as an open user facility with cooperative stewardship practices similar to those used by large national resources such as the Hubble Space Telescope and the Spallation Neutron Source.
  - Access to these systems should be governed by a peer review process managed by a council of representatives from the agencies involved.

The report also proposed three multi-agency HEC pilot projects to improve the efficiency of Federal procurement practices:

- *Benchmarking* — to develop a single suite of benchmarks based on applications and use the suite in a pilot collective acquisition cycle

- *Enhanced Total Cost of Ownership (TCO)* — to develop best practices for determining TCO. Elements include acquisition and maintenance, personnel, extra-center communications, user productivity (including applications software development cost), as well as Grid and distributed computing, large remote data sets, long-haul communications, and cost of systems software and middleware.

- *Procurement* — to develop a common solicitation and use a single suite of benchmarks. Each participating agency would weight the benchmarks and apply relevant parts of the TCO model according to its needs.

2.6.4   Workshop and Report on the Roadmap for the Revitalization of High-End Computing

To solicit inputs from the national community including researchers, applications developers, commercial providers, HEC managers, and other interested parties, the HECRTF participated in an independent workshop convened by the Computing Research Association on *The Roadmap for the Revitalization of High-End Computing* on June 16-18, 2003 in Washington, D.C. Participation in the workshop was limited to approximately 200 individuals who were selected from a pool of candidates who submitted white papers on key aspects of supercomputer requirements, technologies, software, applications, metrics, and management plus key participants from Federal agencies. Based on workshop deliberations, CRA prepared a report entitled *Workshop on the Roadmap for the Revitalization of High-End Computing* [19] that includes

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[19] http://www.cra.org/Activities/workshops/nitrd/

findings and recommendations to advance the state of high-end computing in the United States. These include:

- *Develop enabling technologies:* A variety of new device technologies and three-dimensional integration and packaging concepts show promise in ameliorating the interconnect bandwidth and heat dissipation problems. Software for large-scale systems requires scaling demonstration.

- *COTS-based architectures:* Develop COTS enabling technology including memory-class ports, higher-speed signaling, higher-radix routers, and FPGAs.

- *Custom architectures* need proof of concept demonstration: Spatially direct-mapped architecture, vectors, streaming architecture, processor-in-memory, and special purpose devices.

- *Runtime and operating systems:* Beyond UNIX, alternate resource management models are needed for dynamic adaptation.

- *Programming environment and tools:* Multidisciplinary research will require improved quality, availability, and usability of the software tools used throughout an application's life cycle.

- *Performance analysis:* Develop modeling to predict future system performance based on time-to-solution for applications

- *Applications driven system requirements:* A wide range of applications need system speedups in sustained performance of 50 to 100 fold.

- *Procurement, accessibility, and cost-of-ownership:* Functional specifications should be used for science requirements and total cost of ownership, together with technical and risk assessments, should be the primary evaluation criterion.

These results provided input to the preparation of the HECRTF report.

2.6.5   HEC–University Research Activity (HEC-URA)

DARPA, DOE/SC, NSA, and NSF collaboratively developed the HEC-URA[20] that began in FY 2004. It is an outgrowth of the HECRTF activity. It funds universities to conduct research in software specifically for high-end computing. Their strategy is to invest in:

- Basic and applied research to refill the academic pipeline with new ideas and people
- Advanced development of component and subsystem technologies
- Engineering and prototype development

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[20] http://www.nitrd.gov/hecrtf-outreach/hec-ura/

- o Integration at the system level
- o Development of new technologies (serial number one)
- Test and evaluation to reduce the risk for development, engineering, and government procurement

They will participate in annual topic selections, solicitations, peer review selections, PI meetings, and the overall execution of this activity. Selections will be in accordance with individual agency requirements. Both university and industry researchers will be invited to make proposals.

In its first year (FY 2004), the HEC-URA is focused on software R&D to build a critical mass in research teams, advance the field toward 2010/2015 HEC software, avoid duplication, share lessons learned, and develop links between basic research and advanced development and engineering. To achieve these ends, the HEC-URA agencies coordinated their planning, with DOE/SC and DARPA focusing on operating systems for extreme-scale scientific computations, NSF and DARPA focusing on languages, compilers, and libraries, and NSF focusing on software tools and development environments.[21]

2.6.6   Implementation of the HECRTF Plan

In June 2004, the HECRTF Implementation Committee began to implement the recommendations called for in the *Federal Plan*, starting with a series of activities that include:

- A meeting to coordinate FY 2006 agency HEC budget requests
- A meeting to plan cooperative development and use of HEC benchmarks and metrics. The goal is to make agency procurement solicitations and vendor responses easier and less expensive to prepare.
- Planning for workshops on testbeds for computer science research and on file systems

2.6.7   Study on High-End Computing in Japan

In January 2004, DOE/SC, NASA, and NSF commissioned, and the NCO/ITRD coordinated, an almost year-long study on high-end computing in Japan. The study was implemented by WTEC, Inc., an organization that conducts S&T/R&D assessments. The purpose and scope of the study were to:

- Gather information on current status and future trends in Japanese high-end computing from government agencies, research organizations, and the private sector
- Compare Japanese HEC R&D and applications activities with those in the United States
- Assess long-term HEC research in Japan, including follow-on machines to Japan's Earth Simulator (JES) and other architectures
- Review JES development process and operational experience including user experience and its impact on computer science and computational science communities
- Determine HEC areas amenable for Japan-U.S. cooperation to accelerate future advances

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[21] The DOE/SC and NSF solicitations can be found at: http://www.nitrd.gov/hecrtf-outreach/hec-ura/index.html

The study panel includes expert computer scientists from the U.S. Government and academia. A key component of the panel's information gathering process was a March 28-April 3, 2004 fact finding mission to 21 industrial, academic, and government sites in Japan.

In May 2004, the panel completed a preliminary report of its findings and conclusions about Japan's HEC environment that addressed three topic areas: Japanese Earth Simulator, Grids and Clusters, and Business and Government. The panel reported these conclusions at a May 24-25, 2004 workshop in Washington, D.C.

- Japanese Earth Simulator
  - The JES is a superb engineering achievement and will continue to lead the world for a while. Considering the whole spectrum of HEC, the United States is ahead of Japan.
  - Three reasons the Earth Simulator came about:

    - Government funding was robust in Japan
    - Problem area was important to Japan
    - Visionary and driving force in the late Dr. Hajime Miyoshi, who had been the Director of the Earth Simulator Research and Development Center (ESRDC) and who had championed the development of the JES

  - There are no plans to expand the JES itself. However, a new heterogeneous generation machine has been proposed that is 10,000 times more powerful and that would be internationally funded.
  - Japan has had a broad-based strategic effort in high performance computing over the past decade.
  - For the JES, the investment in software was not in proportion to the investment in hardware.
  - JES is extending its applications to other fields beyond Earth sciences to include biosciences and nanotechnology.
  - There is resentment to the JES by some research groups in Japan that claim that it is too expensive and drains resources.

- Grids and Clusters
  - There is more emphasis on Grids than the study panel had expected.
  - Computational, data, and business Grids are included
  - Japan is actively concentrating on Grid computing software with the SuperSINet that will tie all of Japan together.

- Business and Government Environment
  - The CSTP is the highest policy-making body for S&T R&D in the Japanese government, with the Prime Minister presiding at its monthly meetings.
  - METI is not giving emphasis to funding high performance scientific computing.
  - Japan relies primarily on foreign software and standards.

- o Over the years, Japanese government projects have encouraged new architectures that have since been commercialized.
- o The new policy toward Independent Administrative Institution (IAI) at the universities seems to be a major change in government funding.
- o The commercial viability of "traditional" supercomputing architectures with vector processors and high-bandwidth memory subsystems is problematic. NEC continues to be committed to traditional parallel-vector architectures targeted for high-end scientific research.
- o Commodity clusters are replacing traditional high-bandwidth systems and shrinking their market. NEC, Fujitsu, and Hitachi have products in the commodity cluster space.

A full study that will include recommendations to the U.S. Government about its own levels of HEC software and hardware investments is projected for publication in FY 2005.

2.7   HEC AGENCY ACTIVITIES

Each HEC agency focuses on programs and activities that address the mission needs of the agency while cooperating with other HEC agencies to meet these needs and to expand their awareness and involvement in other HEC areas of interest. This section reviews the programs and activities of the HEC agencies. The activities described below cover both HEC I&A and HEC R&D.

2.7.1   National Science Foundation (NSF)

High-end computing is important to work supported by all NSF research directorates and offices:

- Biological Sciences (BIO)
- Computer and Information Science and Engineering (CISE)
- Education and Human Resources (EHR)
- Engineering (ENG)
- Geosciences (GEO)
- Mathematical and Physical Sciences (MPS)
- Office of Polar Programs (OPP)
- Social, Behavioral, and Economic Sciences (SBE)

The directorates have complementary HEC investments. For example:

- Computer architecture, networking, software, and cyberinfrastructure are funded by CISE
- HEC devices are funded by MPS and ENG
- Mathematical algorithms are funded by MPS and CISE
- Computational algorithms and libraries are funded by CISE with some funding from MPS
- Science and engineering applications are primarily developed with funding from MPS, ENG, GEO, and BIO

The main HEC programs at NSF are:

- HEC R&D
- Shared Cyberinfrastructure
- HEC-URA (discussed in section 2.6.5)

2.7.1.1 NSF HEC R&D Programs

NSF's largest investments in HEC resources are in the CISE Directorate. All CISE divisions are responsible for HEC activities:

- Computing and Communication Foundations (CCF)[22] Division has responsibility for:

    - Formal and Mathematical Foundations – in particular algorithmic and computational science
    - Foundations of Computing Processes and Artifacts – in particular high-end software, architecture, and design
    - Emerging Models for Technology and Computation – including biologically motivated computing models, quantum computing and communication, and nanotechnology-based computing and communication systems

- Computer and Network Systems (CNS) Division supports programs in computer and network systems – in particular distributed systems and next-generation software systems.

- The Information and Intelligent Systems (IIS) Division supports programs in data-driven science including bioinformatics, geoinformatics, cognitive neuroscience, and other areas.

- The Shared Cyberinfrastructure (SCI)[23] Division supports programs in:

    - Infrastructure development – creating, testing, and hardening next-generation deployed systems
    - Infrastructure deployment – planning, construction, commissioning, and operations

The following examples illustrate ongoing HEC R&D:

- Chip Multiprocessor Architectures: on-chip shared-cache architectures, arithmetic logic unit (ALU) networks, shared memory architectures, and networks
- Scalable Multiprocessing Systems: system architecture (communication substrate) and (heterogeneous) ensembles of chip multiprocessors
- System-on-a-Chip: building blocks and integrated functionality

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[22] http://www.cise.nsf.gov/div/index.cfm?div=ccf
[23] http://www.cise.nsf.gov/ funding/pgm_display.cfm?pub_id=5584&div=sci

- Dynamic and Static (compiler) Optimizations, for example:

  - Memory systems
    - Simultaneous multi-threading/chip multi-processing (SMT/CMP) to support latency reduction
    - Prefetching
    - Speculative execution (load/value prediction)

  - Verification and runtime fault tolerance

- Networking and Storage

NSF also funds speculative research that could provide breakthrough technologies for HEC including:

- Nanotechnology that promises unprecedented scale-up in computing and communication through research to apply them in architecture and design methods
- Post-silicon (quantum, DNA, chemical, etc.) computing that may provide radically new models of computation, algorithms, and "programming techniques"

2.7.1.2 NSF Cyberinfrastructure Framework

The NSF integrated cyberinfrastructure framework will support the communities performing research and using computing resources. The components of this framework are hardware (distributed resources for computation, communication, storage, etc.), shared software cybertools (Grid services and middleware, development tools and libraries), domain specific cybertools, and applications. This infrastructure enables discovery and innovation and education and training. The cyberinfrastructure framework will consist of:

- Computation engines (supercomputers, clusters, workstations) – both capability and capacity hardware
- Mass storage (disk drives, tapes, etc.) with persistence
- Networking (including wireless, distributed, ubiquitous)
- Digital libraries and databases
- Sensors and effectors
- Software (operating systems, middleware, domain specific tools, and platforms for building applications)
- Services (education, training, consulting, user assistance)

R&D in every component of this infrastructure is needed to enable HEC.

2.7.1.3 Support for the Supercomputing Needs of the Broad Scientific Community

NSF plays a unique role nationally in supporting supercomputing needs across the entire academic spectrum of scientific research and education. NSF's SCI Division provides support

for and access to high-end computing infrastructure and research. NSF supports more than 22 high-performance computing systems that include both capacity and capability systems.

In FY 2004, NSF supports supercomputing resources at the following national partnerships and leading-edge sites:

- The National Computational Science Alliance (the Alliance) led by the National Center for Supercomputing Applications (NCSA) at the University of Illinois, Urbana-Champaign

- The National Partnership for an Advanced Computational Infrastructure (NPACI) led by the San Diego Supercomputer Center (SDSC) at the University of California, San Diego

- The Pittsburgh Supercomputing Center (PSC) led by Carnegie Mellon University and the University of Pittsburgh, with its Terascale Computing System (TCS)

Support for these activities will continue in FY 2005 as part of new activities in NSF/CISE/SCI.

2.7.1.3.1 Extensible Terascale Facility (ETF)

ETF, also known as TeraGrid, is a multi-year effort to build and deploy the world's largest, most comprehensive, distributed infrastructure for open scientific research. Four new TeraGrid sites, announced in September 2003, will add more scientific instruments, large datasets, computing power, and storage capacity to the system. The new sites are ORNL, Purdue University, Indiana University, and the University of Texas at Austin. They join NCSA, SDSC, ANL, CalTech, and PSC.

With the addition of the new sites, the TeraGrid will have over 20 teraflops of computing power, be able to store and manage nearly 1 petabyte of data, and have high-resolution visualization environments and toolkits for Grid computing. All components will be tightly integrated and connected through a network that operates at 40 gigabits per second.

2.7.1.3.2 NSF HEC Users

In FY 2003 NSF had 4,450 total users including 1,800 NPACI users, 1,200 NCSA users, and 1,450 PSC users. It is estimated that there were 3,000 unique users, since many users use more than one center.

2.7.2   Department Of Energy/Office of Science (DOE/SC)

DOE/SC supports basic research that underpins DOE missions and constructs and operates large scientific facilities such as accelerators, synchrotron light sources, and neutron sources for the U.S. scientific community. Six offices oversee DOE/SC research:

- Basic Energy Sciences: Materials, chemistry, and nanoscale science
- Biological and Environmental Research: Global climate and genomics research

- Fusion Energy Sciences: Magnetic fusion, inertial fusion, plasma physics
- High Energy Physics: Accelerator design and petascale experimental data analysis
- Nuclear Physics: Quantum ChromoDynamics (QCD) and astrophysics
- Advanced Scientific Computing Research

Computational science is critical to the DOE/SC mission in energy production, novel materials, climate science, and biological systems, where:

- Systems are too complex for direct calculation and descriptive laws are absent.
- Physical scales range up to 50 orders of magnitude.
- Several scientific disciplines are involved (for example, combustion and materials science).
- Multidisciplinary teams are required.
- Experimental data may be costly to develop, insufficient, inadequate, or unavailable.
- Large data files are shared among scientists worldwide.

2.7.2.1 DOE's Scientific Discovery Through Advanced Computing (SciDAC) Program

The DOE/SC SciDAC Program[24] provides terascale computing and associated information technologies to many scientific areas to foster breakthroughs through simulation. Through collaborations among application scientists, mathematicians, and computer scientists, SciDAC is building community simulation models in plasma physics, climate prediction, combustion, and other application areas. State-of-the-art collaboration tools facilitate access to these simulation capabilities by the broader scientific community and are bringing simulation to a level of parity with theory and observation in the scientific enterprise.

2.7.2.2 DOE/SC HEC R&D Programs

Major recent DOE/SC accomplishments in HEC R&D that help address DOE/SC's computational science needs include:

- PVM — widely used early message passing model
- MPI, MPICH — THE standard message passing model in use today
  - MPICH is the reference implementation used by all commercial vendors to develop tuned versions
- Global arrays — global memory model used by NWChem, which greatly simplified electronic structure programs in computational chemistry
- Co-Array Fortran — the first and only open source Co-Array Fortran compiler
- UPC — first open source Unified Parallel C compiler
- SUNMOS/Puma/Cougar/Catamount — microkernel operating system used by ASC Red system and its 40 teraflops replacement being developed by Cray, Inc.

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[24] http://www.osti.gov/scidac/

- Science Appliance — pseudo single system image Linux-based operating system used by large-scale (10 teraflops) clusters
- OSCAR — in a partnership with industry, the most widely used open source toolkit for managing Linux clusters
- Low cost parallel visualization — use of PC clusters to achieve high performance visualization

2.7.2.2.1 SciDAC Integrated Software Infrastructure Centers (ISICs)

Three Applied Mathematics ISICs will develop new high-performance scalable numerical algorithms for core numerical components of scientific simulation, and distribute those algorithms through portable scalable high-performance numerical libraries. These three ISICs are:

- Algorithmic and Software Framework for Applied Partial Differential Equations (PDE) – to provide new tools for (nearly) optimal performance solvers for nonlinear partial differential equations (PDEs) based on multilevel methods

- Terascale Optimal PDE Solvers (TOPS) – hybrid and adaptive mesh generation and high-order discretization techniques for representing complex, evolving domains

- Terascale Simulation Tools and Technologies (TSTT) – tools for the efficient solution of PDEs based on locally structured Grids, hybrid particle/mesh simulations, and problems with multiple length scales

Four Computer Science ISICs[25] will work closely with SciDAC application teams and the math ISICs to develop a comprehensive, portable, and fully integrated suite of systems software and tools for the effective management and use of terascale computational resources by SciDAC applications. The four Computer Science ISICs are:

- Center for Component Technology for Terascale Simulation Software ISIC – to address critical issues in high performance component software technology

- High-End Computer System Performance: Science and Engineering ISIC – to understand relationships between application and architecture for improved sustained performance

- Scalable Systems Software ISIC – for scalable system software tools for improved management and use of systems with thousands of processors

- Scientific Data Management ISIC – for large-scale scientific data management

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[25] http://www.osti.gov/scidac/computing/research_area.html

2.7.2.2.2 SciDAC National Collaboratory Software Environment Development Centers and Networking Research

DOE's investment in National Collaboratories includes SciDAC projects focused on creating collaboratory software environments to enable geographically separated scientists to effectively work together as a team and to facilitate remote access to both facilities and data.

2.7.2.3 DOE/SC HEC Workshops

Workshops are a standard DOE/SC planning tool. Such workshops are either general or focused. DOE/SC has held the following general workshops:

- DOE/SC Science Computing Conference (June 19-20, 2003, Arlington, Virginia)[26]
- Science Case for Large Scale Simulation (SCALES) (June 24-25, 2003, Arlington, Virginia)[27]
- SciDAC (March 2004, Charleston, South Carolina)[28]

Focused workshops, which address specific application area needs, include:

- Fast Operating Systems[29]
- Multiscale Mathematics Workshop (May 3-5, 2004) – to bridge the wide scale between modeling on continuum or atomistic basis – expected output includes a roadmap
- High Performance File Systems (Summer 2004) – such file systems should support parallelism, be efficient, and be reasonably easy to use
- Distributed Visualization Architecture Workshops (DiVA)[30]
- Data Management Workshop series to address where file system ends and data management system begins[31]
- Raising the level of parallel programming abstraction (TBD)
- Parallel tool infrastructure (TBD)

2.7.2.4 DOE/SC HEC I&A Programs

2.7.2.4.1 National Energy Research Supercomputing Center (NERSC)

NERSC[32] delivers high-end capability computing services and support to the entire DOE/SC research community. NERSC provides these services to the DOE community, to the other DOE laboratories, and to major universities performing work relevant to DOE missions. NERSC provides the majority of resources and services that are used to support the SciDAC program. The Center serves 2,000 users working on about 700 projects; 35 percent of users are university based, 61 percent are in national laboratories, three percent are in industry, and one percent in

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[26] http://www.doe-sci-comp.info
[27] http://www.pnl.gov/scales/
[28] http://www.osti.gov/scidac/
[29] http://www.cs.unm.edu/~fastos/
[30] http://vis.lbl.gov/Research/DiVA/Workshops/index.html#Findings
[31] http:www-conf.slac.Stanford.edu/dmw2004/
[32] http://www.nersc.gov/

other government laboratories. The major computational resource at NERSC is an IBM SP computer whose capacity was doubled to 10 teraflops in FY 2004. These computational resources are integrated by a common high performance file storage system that facilitates interdisciplinary collaborations.

2.7.2.4.2   Advanced Computing Research Testbeds (ACRT)

This activity supports the acquisition, testing, and evaluation of advanced computer hardware to assess the prospects for meeting future DOE/SC computational needs, such as SciDAC and special purpose applications. The ACRT activity provides two types of computer testbeds for evaluation - early systems and experimental systems. These research and evaluation (R&E) prototypes have been identified as a critical element in the HECRTF plan because they enable early partnerships with vendors to tailor architectures to scientific requirements. The results from these partnerships also play a key role in the choice of both high performance production systems and potential leadership class systems government-wide.

2.7.2.4.3   Scientific Application Pilot Programs (SAPP)

The Scientific Application Pilot Programs (SAPP) support targeted efforts to integrate new applied mathematics and computer science algorithms into SciDAC applications projects through strong liaisons between applications projects and ISICs. It provides expertise in adapting high-performance algorithms to terascale computers and in adapting numerical modules to include application-specific knowledge.

2.7.2.5   Innovative and Novel Computational Impact on Theory and Experiment (INCITE) Projects

INCITE is a competitive program that supports a small number of computationally intensive, large-scale research projects that can make high-impact scientific advances through the use of a substantial allocation of computer time and data storage at NERSC. INCITE encourages proposals from universities and other research institutions.

In December 2003, DOE/SC selected three projects to receive a total of 4.9 million hours of supercomputing time — 10 percent of the total computing time available this year on NERSC's Seaborg system. The projects are expected to significantly advance our understanding of the makeup of the universe, the chemical process by which plants convert sunlight to energy while removing carbon dioxide from the atmosphere, and the turbulent forces that affect everything from weather to industrial processes. The projects are:

- Thermonuclear Supernovae: Stellar Explosions in Three Dimensions
- Quantum Monte Carlo Study of Photoprotection via Carotenoids in Photosynthetic Centers
- Fluid Turbulence and Mixing at High Reynolds Number

2.7.3   Defense Advanced Research Projects Agency (DARPA)

DARPA has four HEC R&D programs:

- The High Productivity Computing Systems (HPCS) program that addresses all aspects of HEC systems including packaging, processor/memory interfaces, networks, operating systems, compilers, languages, and runtime systems
- Polymorphous Computing Architectures (PCA) so computers can adapt to applications
- Networked Embedded Systems Technology (NEST) that looks at hundreds of thousands of tiny simple computing nodes interacting with each other
- HEC – URA

The first three are described below. HEC-URA is described in section 2.6.5.

2.7.3.1   High Productivity Computing Systems (HPCS)

The HPCS program[33] has a goal of providing a new generation of economically viable high productivity computational systems for the national security and industrial user community in the time frame of FY 2009 to FY 2010. Sustained petaflop performance and shortened development time are key targets. DARPA is working with DOE/SC and other agencies to understand how long it takes to develop solutions today. These systems will be designed to have the following impact:

- *Performance (time to solution):* provide a speedup in performance of 10 to 40 times on critical national security applications
- *Programmability (idea to first solution):* reduce the cost and time of developing applications solutions
- *Portability (transparency):* insulate the research and operational application software from the system it is running on
- *Robustness (reliability):* apply all known techniques to protect against outside attacks, hardware faults, and programming errors

Target applications are intelligence and surveillance, reconnaissance, cryptanalysis, weapons analysis, airborne contaminant modeling, and biotechnology.

The HPCS program is structured to provide for the continuous fielding of new high performance computer technology through a phased concept, research, development, and demonstration approach. The program is in its second phase. The productivity goals of this phase are to provide:

- Execution (sustained performance) of one petaflop/second (scalable to over four petaflops)
- Development productivity gains of 10 times over today's systems

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[33] http://www.darpa.mil/iptoPrograms/hpcs/index.htm

In phase two, the productivity framework has been baselined to today's systems, used to evaluate vendors' emerging productivity techniques, and provides a reference for use in phase three to evaluate vendors' proposed designs.

Phase two subsystem performance indicators are a 3.2 petabytes/second bisection bandwidth, 64,000 giga updates per second (GUPS), 6.5 petabytes/second data streams bandwidth, and 2+ petaflops Linpack Fortran benchmark (a HPC Challenge) that augments the TOP500[34] benchmarks.

In FY 2004 DARPA supported two HPCS-related workshops. They included:

- The HPCS Productivity Team/Task Group that met June 29-30 and July 1, 2004, in the Washington, D.C. area.[35] The meeting targeted an expanded technical audience.

- The ninth international workshop on High-Level Parallel Programming Models and Supportive Environments (HIPS 2004) on April 26, 2004, in Santa Fe, New Mexico.[36]

The NITRD agencies that provide additional funding for HPCS activities are DOE/SC, DOE/NNSA, NASA, NSA, and NSF; DoD's HPCMPO provides complementary support. Cray, Inc., IBM, and Sun Microsystems are phase two industry partners. Customers include DoD (NSA and NRO), DOE/NNSA, DOE/SC, NASA, NIH, NSF, DHS, and the commercial sector.

A Council on Competitiveness HPC Initiative co-funded by DARPA, DOE/SC, and DOE/NNSA has the goal of raising high productivity computing to be a major economic driver in the United States. It includes:

- An HPC Advisory Committee with representatives from the private sector
- An annual private-sector user survey
- Annual user meetings

    o The first conference, entitled "HPC: Supercharging U.S. Innovation and Competitiveness," was held July 13, 2004 in Washington, DC.[37] Senior application users, HPC center directors, industry executives, and policy and funding decision makers participated.

2.7.3.2 Grand Challenge Case Study: Field Test of Autonomous Ground Vehicles

DARPA, DOE/SC, and the private sector hold workshops and conduct industry Grand Challenge case studies. DARPA conducted its first Grand Challenge, a field test of autonomous ground vehicles, March 8-13, 2004.[38] Its purpose was to encourage the accelerated development of autonomous vehicle technologies that could be applied to military requirements.

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[34] http://www.netlib.org/benchmark/top500.html
[35] http:// www.HighProductivity.org
[36] http://csdl.computer.org/comp/proceedings/hips/2004/2151/00/2151toc.htm
[37] http://www.hpcusersconference.com/agenda.html?print=1
[38] http://www.darpa.mil/grandchallenge/

2.7.3.3 Polymorphous Computing Architectures (PCA) Program

The Polymorphous Computing Architectures (PCA) Program has a goal to develop the computing foundation for agile systems by establishing computing systems (chips, networks, software) that will morph to changing missions, sensor configurations, and operational constraints during a mission or over the life of the platform. Response (morph) times may vary from seconds to months. The PCA objective is to provide:

- *Processing diversity* with a breadth of processing to address signal/data processing, information, knowledge, and intelligence, and uniform performance competitive with best-in-class capabilities

- *Mission agility* to provide retargeting within a mission in milliseconds, mission-to-mission adaptation in days, and new threat scenario adaptation in months

- *Architectural flexibility* to provide high efficiency selectable virtual machines with two or more morph states, mission adaptation with N minor morph states, and portability/evolvability with two layer morphware

PCA hardware being developed includes:

- *Monarch/MCHIP.* A prototype in 2005 is projected to demonstrate 333Mhz, 64 Gflops, 64 GOPS, and 12 Mbytes erasable dynamic random access memory (EDRAM).

- *Smart Memories.* A prototype in 2005 is projected to demonstrate streaming applications based on modified commercial Tensilica CPU cores.

- *TRIPS.* A prototype in 2005 is projected to demonstrate 500 MHz, 16 Gflops peak floating point, and 16 GIPS peak integer. Production technology is projected to provide 4 TFLOPS peak floating point and 512 GIPS peak integer.

- *RAW (early prototype)* to provide chips and development boards (available now) and kernel evaluations with test results in 2004. This technology provides early morphware, software, and kernel performance evaluation.

The morphware[39] will be demonstrated in a development environment in which APIs including Brook will use high-level compilers to provide stream and thread virtual machine APIs to low level compilers using PCA technology such as TRIPS, Monarch, Smart Memories, RAW, and others.

2.7.3.4 Networked Embedded Systems Technology (NEST)

The NEST program will enable fine-grain fusion of physical and information processes. The quantitative target is to build dependable, real-time, distributed, embedded applications

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[39] http://www.morphware.org/PCA101/right1.html

comprising 100 to 100,000 simple compute nodes. The nodes include physical and information system components coupled by sensors and actuators.

2.7.4　National Aeronautics and Space Administration (NASA)

NASA's mission is to:

- Understand and protect our home planet
- Explore the universe and search for life
- Inspire the next generation of explorers

Until recently, NASA accomplished its mission through seven strategic enterprises:[40]

- Earth Science
- Space Science
- Biological and Physical Research
- Aeronautics
- Exploration Systems
- Space Flight
- Education

2.7.4.1　NASA HEC Accomplishments

FY 2004 NASA HEC accomplishments include the following:

- Testbeds
    - Built the first single system image (SSI) Linux-based supercomputer, which was the world's fastest machine on the triad benchmark – an industry standard measurement of memory bandwidth – and which will be used on the Space Shuttle

- Advanced Architectures
    - Invested in new streams and PIM architectures and worked on languages, compilers, and key application kernels for stream technology (this is tied into DARPA's PCA and morphware efforts)

- Grid Technology
    - Continued work on its Information Power Grid (IPG) demonstrations in cooperation with Earth science and Shuttle payload management

- Applications
    - Developed advanced applications for aerospace, nanotechnology, and radiation biology

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[40] Future documentation will be consistent with NASA's new organizational structure.

- Major advance in ocean modeling in the "Estimating the Circulation and Climate of the Ocean" (ECCO) code. (ECCO is further described in section 2.7.4.2.)
- Major advance in aerospace vehicle modeling

- Programming Environments
  - Improved scalability multi-level parallelism (MLP)

- Tools
  - Workflow and data base management programming environments
  - Aero data base/IPG Virtual Laboratory for workflow management and ensemble calculation data base management prototypes
  - Hyperwall (for viewing large datasets) used in nanotechnology research, Sloan Digital Sky Survey, and the February 1, 2003 Columbia Space Shuttle Mission accident investigation. This technology is now being transferred for general use within NASA.

2.7.4.2 Estimating the Circulation and Climate of the Ocean (ECCO)

The goal of the ECCO project is to use NASA data and community code to improve Earth oceans modeling. Starting in August 2003, the project has:

- Developed serial #1 512 Altix supercomputer
- Ported and scaled ECCO code from 64 to 128 to 256 to 512 processors
- Determined correct environment variables and optimized code
- Assisted in revamping Grid technique to improve prediction at poles
- Developed Kalman filter techniques at high resolution for data assimilation
- Developed an archive for community access to data
- Improved resolution from 1 degree to 1/4 degree
- Developed unique visualization approaches

As a result:

- Time to solution dropped from approximately 1 year to 5 days (a 50-fold speedup)
- Resolution improved by a factor of 4 — from 1 degree to 1/4 degree
- Code accuracy and physics improved
- Data assimilation at high resolution was enabled

An outcome of this work is that Shuttle return-to-flight problems are now being ported to the Altix supercomputer for a speedup by a factor of four or more for some turbo-machinery.

2.7.4.3 Supercomputing Support for the Columbia Accident Investigation Board (CAIB)

NASA Ames supercomputing-related R&D assets and tools were used to produce time-critical analyses for the CAIB. In particular, R&D and engineering teams modeled a free object in the

flow around an airframe, with automatic regridding at each time step. The environment in which this was accomplished consisted of:

- State-of-the-art codes
    - Codes honed by R&D experts in large-scale simulation, with their environment of programmer tools developed to minimize the effort of executing efficiently

- A modeling environment that included experts and tools (compilers, scaling, porting, and parallelization tools)

- Supercomputers, storage, and networks
    - Codes and tools tuned to exploit the advanced hardware that was developed for large tightly-coupled computations

- Computation management by components of the AeroDB and the iLab
    - An environment and tools for efficient executions of hundreds or thousands of large simulations and handling of results databases

- Advanced data analysis and visualization technologies to explore and understand the vast amounts of data produced by this simulation

2.7.4.4 NASA HEC Resources

NASA HEC resources are located at Goddard Space Flight Center and Ames Research Center, which closely collaborate to provide resources to users. Current demand for computational resources is two times capacity and stated requirements are four times capacity. A 300 Terabyte archive was moved from Ames to Goddard with less than ten percent of the transfer supported by networks.

High-end computing resources include:

- Goddard, where the foci are in Earth Science and Space Science
    - 1,392 processing element (PE) Compaq (2.2 Teraflops)
    - 640 PE SGI O3K (410 Gigaflops)
    - Sun QFS (340 Terabytes)
    - SGI DMF (370 Terabytes)

- Ames, where the foci are in Aeronautics and Earth Science
    - 512 PE SGI Altix (2.3 Teraflops)
    - 1,024 PE SGI O3K (850 Gigaflops)
    - SGI DMF (1,600 Terabytes)

Recent increases in computational resources will significantly improve trajectory and mission simulations for digital flight crew exploration vehicle (CEV) development and launch-to-orbit simulations to perform risk assessments.

2.7.5   DOE/National Nuclear Security Administration (DOE/NNSA)

DOE/NNSA's Office of Advanced Simulation and Computing (ASC) provides the means to shift promptly from nuclear test-based methods to computer-based methods and thereby predict with confidence the behavior of nuclear weapons through comprehensive science-based simulations. To achieve this capability, ASC has programs in:

- Weapons codes and the science in those codes (advanced applications, materials and physics modeling, and verification and validation)
- Computational platforms and the centers that operate them
- Software infrastructure and supporting infrastructure (Distance Computing (DisCom), Pathforward, Problem Solving Environments, and VIEWS)

2.7.5.1 ASC Focus Areas

ASC focuses on:

- *Software quality engineering* that is oriented to processes to provide for longevity of codes
- *Verification* to ensure numerical solutions are accurate
- *Validation* to ensure a problem is understood correctly
- *Certification methodology* to make improvements through scientific methods
- *Capability computing* to meet the most demanding computational needs
- *Capacity computing* to meet current stockpile stewardship workloads
- *Problem Solving Environments (PSEs)* to create usable execution environments for ASC-scale applications
- *Industry collaboration* to accelerate key technologies for future systems
- *Tracking requirements*

2.7.5.2 ASC Activities

Pathforward activities include:

- Optical switch (with NSA)
- Memory usage
- Lustre file system
- Spray cooling (with DOE/SC)

Topics of multidisciplinary academic collaborations include fires, rocket motors, astrophysics, jet engines, and shock. ASC works with industry to develop new technologies in optical switches, scalable visualization, memory correctness, spray cooling, and the Lustre File System.

2.7.5.3 ASC HEC I&A Platforms

ASC uses HEC systems and software from Cray, HP, IBM, Intel, SGI, and Linux Networx. It procures machines of differing technologies to support diverse requirements.

These types include:

- *Capability systems:* Vendor-integrated symmetric multiprocessing (SMP) clusters used for critical Stockpile Stewardship Program (SSP) deliverables and for particularly demanding calculations. (These systems run a small number of large jobs.)

- *Capacity systems:* Linux high performance computing (HPC) clusters that support the largest workloads in terms of numbers of jobs supporting current weapons activities and as development vehicles for the next generation capability systems. (These systems run a large number of smaller jobs.)

- *Disruptive technologies:* The Blue Gene/L system, for example, is being procured as a highly scalable, low power, low cost computer. It is the first high performance computing system to incorporate all three attributes in a single system. ASC works with vendors and universities to push production environments to petaflops scales.

2.7.6   National Security Agency (NSA)

NSA has unclassified HEC R&D programs in:

- Architectures and systems
- High speed switches and interconnects
- Programming environments
- Quantum information sciences
- Vendor partnerships

2.7.6.1 Cray X1e/Black Widow

Under a multi-year joint development effort, NSA supports Cray, Inc., in extending its X1 NSA/ODDR&E/Cray development to build its next generation, scalable, hybrid, scalar-vector high performance computer. The Black Widow system to be introduced in CY 2006 will provide outstanding global memory bandwidth across all processor configurations and will be scalable to hundreds of teraflops. It should be the most powerful commercially available system in the world at that time. Many agencies participated in the quarterly development reviews.

2.7.6.2 HPC Applications Benchmarking Study

A select set of HPC users, the HPC User Forum[41], and IDC are sponsoring a study of the performance of applications on leading supercomputers. The project will expand the understanding of the performance of a set of complete difficult HPC applications on the largest computers around the world. Each application will have a specific data set and will represent an actual scientific problem. The results will be posted at the HPC User Forum Web site.[42] This

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[41] http://www.hpcuserforum.com/
[42] http://www.idc.com/hpc

study's objectives are to compare leading large HPC capability class computers on a small set of large HPC problems, show major science accomplishments on these capability systems, explore the relative performance characteristics of the machines on these problems, and explore the scaling abilities of these computers. The HPC User Forum effort is funded by DoD/HPCMPO, NSA, and other agencies.

2.7.6.3 Reconfigurable Computing R&D

The reconfigurable computing program is an approach to general-purpose high performance computing that takes advantage of field programmable gate array (FPGA) technologies and commercial platforms. This continuing effort is leveraging prototype results from academic, industrial, and government research and the continuing increase in the computational capability of commercial FPGA chips. NSA is conducting experiments and demonstrations of commercial reconfigurable computing machines using its applications and benchmarks. The principle difficulty being addressed is the need for software-level programming tools. NSA collaborates with other agencies in this effort.

Major achievements in FY 2004:

- Demonstration on an NSA application of the C compiler on a particular reconfigurable computer achieved a 65-fold performance improvement over a modern 64-bit commodity microprocessor
- Co-funded an NSA vendor partnership to develop an FPGA addition to a commercial architecture, with a prototype machine to be delivered in FY 2004

2.7.6.4 Fine-Grain Multithreaded Architectures and Execution Models

Performance analysis of many real-world applications on today's large-scale massively parallel processor systems indicates that often a small fraction of the potential performance of these machines is achieved in practice. Applications that exhibit these problems are generally characterized by memory access patterns that are dynamic and irregular, and hence difficult to partition efficiently, by either programmers or compilers. This situation frequently results in processors being "starved" for data due to relatively high memory latencies. Fine-grain multithreaded models coupled with effective compilation strategies provide a promising and easy to use approach to reducing the impact of long, unpredictable memory latencies. NSA is pursuing research to develop architectures, execution models, and compilation techniques that can exploit multithreading to manage memory latency and provide load balancing. Work in the past year has resulted in an FPGA-based implementation of a hardware emulation platform and a compiler infrastructure that is enabling experimentation with thread scheduling and synchronization units.

2.7.6.5 Optical Technologies

NSA is investigating high-end computer optical interconnect systems. A comparison of electrical and optical technologies showed that specifically-designed all-optical switching can significantly outperform current and future electronic switches. The effort demonstrated that optical

technologies can significantly improve bandwidth if implementation difficulties of all-optical switching can be overcome.

2.7.6.6 Quantum Computing

Through its ARDA affiliate, NSA conducts research in quantum computing. Efforts focus on quantum information sciences including investigation of selective materials, related quantum properties, and managing decoherence and entanglement issues. This research is part of a multi-agency collaboration with DARPA and others.

2.7.7   National Oceanic and Atmospheric Administration (NOAA)

NOAA uses HEC resources and advanced applications to provide users with advanced products and services.[43] NOAA's HEC strategy is to:

- Develop skills, algorithms, and techniques to fully use scalable computing for improved environmental understanding and prediction
- Acquire and use high performance scalable systems for research
- Optimize the use of HEC resources across all NOAA activities. This reflects NOAA's changing view of HEC, which is more an enterprise resource.

2.7.7.1 NOAA HEC Resources, Activities, and Plans

NOAA HEC resources are located at:

- Geophysical Fluid Dynamics Laboratory (GFDL)[44] in Princeton, New Jersey
- Forecast Systems Laboratory (FSL)[45] in Boulder, Colorado
- National Centers for Environmental Prediction (NCEP)[46] headquartered in Camp Springs, Maryland

In FY 2003, GFDL acquired a 1,408 processor SGI system.

NOAA expedites the development and use of improved weather and climate models by:

- Supporting advanced computing for NOAA environmental modeling research
- Developing software tools to optimize the use of scalable computing
- Infusing new knowledge through new talent such as post-doctoral students and contractors

NOAA plans are to:

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[43] HPCC office: http://www.cio.noaa/hpcc/index.html.
[44] http://www.gfdl.noaa.gov
[45] http://www.fsl.noaa.gov
[46] http://www.ncep.noaa.gov

- Develop the Earth System Modeling Framework (ESMF) for climate model development and extend it to all domains (ESMF is described in section 2.5.1.)
- Explore the use of specific types of Grid technology
- Develop a common weather research computing environment
- Apply the Weather Research and Forecast (WRF) (described below) modeling system standards and framework to NCEP's Mesoscale Modeling Systems, including the continental domain Meso Eta and the nested Nonhydrostatic Meso Threats runs

2.7.7.1.1 Weather Research and Forecasting (WRF) Development Test Center (DTC)

NOAA/FSL is establishing a multi-agency DTC which will initially focus on the development of the WRF model that is designed as both an operational model and a research vehicle for the larger modeling community. WRF is a regional atmospheric model for operational numerical weather prediction and atmospheric research focusing on one to ten kilometer resolution. At the DTC, NOAA personnel will work with university researchers to develop and add specific model improvements to the modular WRF framework. Potential benefits include frequent high-resolution analyses and forecasts produced in real time that are valuable to commercial aviation, civilian and military weather forecasting, the energy industry, regional air pollution prediction, and emergency preparedness. The WRF model will greatly increase the accuracy and specificity of weather forecasts. This work is joint with NSF and the National Center for Atmospheric Research (NCAR).

2.7.7.2 NOAA Workshops and Meetings

The semi-annual HPCC PI status meeting was held in the Spring of 2004 and the Tech Biennial Meeting to review progress will be held in October 2004.

2.7.8   National Institute of Standards and Technology (NIST)

NIST works with industry and with educational and government organizations to make IT systems more usable, secure, scalable, and interoperable; to apply IT in specialized areas such as manufacturing and biotechnology; and to encourage private-sector companies to accelerate development of IT innovations. It also conducts fundamental research that facilitates measurement, testing, and the adoption of industry standards.

2.7.8.1 NIST HEC I&A

NIST developed the Interoperable Message Passing Interface (IMPI)[47] to support parallel computing research. The standard enables interoperability of different implementations of the Message Passing Interface (MPI) with no change to user source code.

In distributed computing, NIST has developed a Java/Jini/Javaspaces-based screen-saver science system.[48] The environment leverages Java's portability to use otherwise unused cycles on any set

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[47] A tester is at http://impi.nist.gov.

of computing resources accessible over a local network (including desktop PCs, scientific workstations, and cluster compute nodes) to run any compute-intensive distributed Java program. The environment is being used to compute property data (virtual measurements via computer codes), augmenting property values obtained from laboratory measurement.

NIST has created infrastructure to use immersive visualization to explore scientific data sets drawn from both computer and laboratory experiments. Visualization projects include a three-wall Immersive Virtual Reality System that uses the Device Independent Virtual Environments – Reconfigurable, Scalable, Extensible (DIVERSE)[49] open source software and locally-built visualization software to see results at scale.[50] The local software includes the glyph toolbox, techniques for immersive volume visualization, surface visualization, and techniques for interaction. All the software runs unchanged on Linux machines.

NIST is developing fundamental mathematical software tools to enable high-end computing applications. Examples include:

- The Parallel Hierarchical Adaptive Multilevel (PHAML)[51] code , a parallel adaptive Grid refinement multigrid code for PDEs
- The Sparse Basic Linear Algebra Subroutines (Sparse BLAS)[52]
- The Template Numerical Toolkit (TNT)[53] for object-oriented linear algebra

NIST HEC applications often combine parallel computing with immersive visualization for basic sciences, such as physics, and applications, such as building structure and material strength. Some typical applications to which NIST applies these resources are:

- Nanostructure modeling and visualization (especially in nano-optics)[54]
- Modeling cement and concrete, including modeling the flow of suspensions and fluid flow in complex geometries[55]
- Computation of atomic properties
- Visualization of "smart gels"[56] (which respond to specific physical properties such as temperature or pressure) to gain insight into the gelling mechanism
- Visualization of tissue engineering[57] to study and optimize the growth of cells on scaffolding

In addition, NIST is developing applications-oriented problem-solving environments, such as Object-Oriented Finite Element Modeling of Material Microstructures (OOF)[58] for modeling

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[48] http://math.nist.gov/mcsd/savg/parallel/screen/
[49] http://diverse.sourceforge.net
[50] http://math.nist.gov/mcsd/savg/software/
[51] http://math.nist.gov/phaml/
[52] http://math.nist.gov/spblas/
[53] http://math.nist.gov/tnt/
[54] http://math.nist.gov/mcsd/savg/parallel/nano/
[55] http://math.nist.gov/mcsd/savg/parallel/dpd/, http://math.nist.gov/mcsd/savg/parallel/lb/, http://math.nist.gtov/mcsd/savg/vis/concrete/, http://math.nist.gov/mcsd/savg/vis/fluid/
[56] http://math.nist.gov/mcsd/savg/vis/gel/
[57] http://math.nist.gov/mcsd/savg/vis/tissue/
[58] http://www.ctcms.nist.gov/oof/

materials with complex microstructure and Object-Oriented MicroMagnetic Computing Framework (OOMMF)[59] for micromagnetics modeling.

2.7.8.2 NIST HEC R&D

NIST is performing research in quantum computing and secure quantum communications, in measurement science aspects of nanotechnology, photonics, optoelectronics, and new chip designs, and in fabrication methods.

NIST activities in quantum information science[60] have both theoretical and experimental components. It conducts research in algorithms and architectures for scalable quantum computing and demonstrates quantum computing within specific physical systems such as ion traps, neutral atoms, and Josephson junctions. NIST has developed a testbed for high-speed quantum key distribution and conducts associated research on single photon sources and detectors and on quantum protocols.

2.7.9   Environmental Protection Agency (EPA)

EPA's mission is to protect human health and safeguard the environment through research, regulation, cooperation with state governments and industry, and enforcement. Areas of interest are wide ranging and diverse, extending from groundwater to the stratosphere.

EPA HEC programs are focused on tools to facilitate sound science using high-end computation, storage, and analysis. These programs enable relevant, high-quality, cutting-edge research in human health, ecology, pollution control and prevention, economics, and decision sciences facilitating the proper characterization of scientific findings and the appropriate use of science in the decision process. The HEC programs are performed in-house and as problem-driven research.

EPA is launching the Center of Excellence (CoE) for Environmental Computational Science to integrate cutting edge science and emerging IT solutions to facilitate Federal- and state-level partnerships and enhance the availability of scientific tools and data for environmental decision making. The CoE will enable collaboration from within and without the organization and will provide a flexible, dynamic computing and information infrastructure to ensure optimized yet secure access to EPA resources.

In FY 2004, EPA's HEC programs[61] include:

- Multimedia Assessments and Applications Framework
- Uncertainty Analysis Framework Development
- Air Quality Modeling Applications
- HEC visualization

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[59] http://math.nist.gov/oommf/
[60] http://qubit.nist.gov/
[61] HPCC Office: http://www.epa.gov/hpcc

- HEC infrastructure, Grid, and science subnet

2.7.9.1 Multimedia Assessments and Applications (MAA) Framework

The MAA framework provides a foundation for research on how to structure compartmental models and improve model integration and interchangeability. The framework's objective is to provide software that supports composing, configuring, applying, linking, and evaluating complex systems of models. It will improve EPA's ability to simulate the interaction between individual environmental media components (for example, chemical fluxes, water cycle) and will enable distributed computation.

The MAA framework is tailored to multimedia models but is adaptable and generalized. It supports EPA programs such as the Chesapeake Bay Program, the Tampa Bay Region Atmospheric Chemistry Experiment, and the Office of Air Quality Planning and Standards. The framework is currently being tested by a number of clients.

2.7.9.2 Uncertainty Analysis (UA) Framework Development

The UA framework program is developing tools to support the analysis of model sensitivities and the effects of input uncertainties on model predictions. Specific tasks are to:

- Construct a 400-node Intel-based supercomputing cluster called Supercomputer for Model Uncertainty and Sensitivity Evaluation (SuperMUSE)
- Develop platform-independent systems software for managing SuperMUSE
- Conduct uncertainty and sensitivity analyses of the Multimedia, Multipathway, Multireceptor Risk Assessment (3MRA) modeling system
- Develop advanced algorithmic software for advanced statistical sampling methods and global sensitivity analyses

2.7.9.3 Air Quality Modeling Applications (AQMA)

The AQMA program has the objective of advancing the state-of-the-art Community Multi-scale Air Quality (CMAQ) Chemistry-Transport Modeling System computational performance while maintaining modularity, portability, and single source code. Efforts to improve CMAQ take into account both the typical Linux cluster in the States and also HEC deployments. Major areas of effort include algorithmic improvement, microprocessor tuning, and architecture assessment. The AQMA program is using a phased deployment that enables the States, which are the key stakeholders, to participate in the development.

2.7.9.4 Grid Deployment

EPA has a goal to provide phased deployment of an EPA-wide enterprise Grid that will identify, develop, and integrate key technologies, align organizational policies such as security and networking, and field Grid pilot systems to demonstrate success and benefits. Historically, agency researchers with high-end applications competed for time on EPA's high performance computing resources located at the National Environmental Scientific Computing Center (NESC2). With the implementation of Grid middleware, agency researchers will be able to tap

unused processing capacity on local and remote clusters at the campus-level or enterprise-level. EPA's compute Grid is being implemented in a phased approach with parallel development of both Grid infrastructure and security policy. Pilot clusters have now been linked to demonstrate EPA Compute Grid Services internally and also to external partners. Ultimately, EPA researchers and trusted partners will be able to access a Partner (or Global) Grid extending to organizations outside the agency.

2.7.9.4.1 Grid Demonstration Project

EPA is working to combine state-of-the-science air quality modeling and observations to enable timely communication of meaningful environmental information, improve emission management decisions, and track progress toward achieving air quality and public health goals. Air quality has been selected as a Grid demonstration project. Technical collaborators include DOE/Sandia and NOAA and pilot partners include the State of New York and regional planning organizations. Phase I of the Grid demonstration project includes delivering an optimized CMAQ model and datasets to the client community in the summer of 2004 and then eventually to run CMAQ over the Grid and at client sites.

2.7.10 Department of Defense/High Performance Computing Modernization Program Office (DoD/HPCMPO)

DoD/HPCMPO's mission is to deliver world-class commercial, high-end, high performance computational capability to DoD's S&T and test and evaluation (T&E) communities, thereby facilitating the rapid application of advanced technology into superior warfighting capabilities. DoD/HPCMPO's vision is to create a pervasive culture among DoD's scientists and engineers in which they routinely use advanced computational environments to solve their most demanding problems.

HPC modernization is essential to future technology development in a wide range of areas critical to the DoD missions. Development of future technologies supported by HPC includes:

- Micro Air Vehicles
- Joint Strike Fighter
- Surveillance systems
- Smart weapons design
- Ocean modeling
- Parachute simulations
- Unmanned Air Vehicles
- Blast protection

2.7.10.1 User Base and Requirements

HPCMPO's S&T and T&E communities involves some 4,482 users working on 667 projects at approximately 175 sites at Air Force, Army, and Navy high performance computing centers and defense agencies such as DARPA. FY 2004 non-real-time user requirements are estimated at 134 Teraflop-years. HPCMPO requirements are categorized in ten key Computational Technology

Areas (CTAs). They are:

	DoD Users	
	Primary	Total
• Computational Structural Mechanics (CSM)	528	1,019
• Computational Fluid Dynamics (CFD)	1,154	1,612
• Computational Chemistry and Materials Science (CCM)	243	593
• Computational Electromagnetics and Acoustics (CEA)	295	575
• Climate/Weather/Ocean Modeling and Simulation (CWO)	284	521
• Signal/Image Processing (SIP)	239	815
• Forces Modeling and Simulation (FMS)/C4I	527	913
• Environmental Quality Modeling and Simulation (EQM)	120	295
• Computational Electronics and Nanoelectronics (CEN)	35	135
• Integrated Modeling and Test Environments (IMT)	994	1,201
• Others	63	219

HPCMPO capabilities include approximately 30,000 Gigaflop-years in FY 2004. The demand for capability is 130,000 in FY 2004.

2.7.10.2   High Performance Computing Centers

Among HPCMPO's high performance computing centers, four are major shared resource centers (MSRCs) and 16 are distributed centers.

MSRCs provide complete networked HPC environments, world-class HPC compute engines, high-end data analysis and scientific visualization support, massive hierarchical storage, proactive and in-depth user support, and computational technology area expertise to nation-wide user communities. The MSRCs are ARL, ASC, ERDC, and NAVO.

There are two categories of distributed centers:

- Allocated Distributed Centers (ADCs) that support the annual service or agency project allocation and/or challenge project allocation process by providing reserved compute resources. These include large systems that support a few high priority projects. ADCs include Army High Performance Computing Research Center (AHPCRC), Arctic Region Supercomputing Center (ARSC), Maui High Performance Computing Center (MHPCC), and Space Missile Defense Command (SMDC).
- Dedicated Distributed Centers (DDCs) that support a dedicated project or projects for which each independent DDC was awarded an HPC system. These include moderate systems to support dedicated local needs. DDCs include the Arnold Engineering Development Center (AEDC), Air Force Research Laboratory/Information Directorate (AFRL/IF), Air Force Weather Agency (AFWA), Fleet Numerical Meteorology and Oceanography Center (FNMOC), Joint Forces Command (JFC/J9), Naval Air Warfare Center Aircraft Division (NAWCAD), Naval Research Laboratory – Washington, D.C. (NRL-DC), Redstone Technical Test Center (RTTC), Simulation and Analysis Facility

(SIMAF), SPAWAR Systems Center – San Diego (SSC-SD), and White Sands Missile Range (WSMR).

2.7.10.3 Software Applications Support

Software Applications Support (SAS) has four components:

- Common HPC Software Support Initiative (CHSSI)
- HPC Software Applications Institutes (HSAIs)
- Programming Environment and Training (PET) program to enhance user productivity
- Software Protection Center (SPC) to develop the best techniques for the protection of HPC applications

Each is now described.

2.7.10.3.1 Common HPC Software Support Initiative (CHSSI)

The HPCMPO CHSSI supports the development of common, efficient HPC applications. CHSSI has the following features:

- It provides core software applications, models, and simulations that exploit HPC capabilities in areas of most concern to DoD.
- Multi-purpose codes perform on a range of HPC platforms, with focus on accuracy, efficiency, reusability, and scalability.
- Inter-service, multi-disciplinary teams include algorithm and code developers, applications specialists, computer scientists, and end users who are responsible for development, dissemination, technology transfer, and follow-on support.
- Collaboration with PET academics and MSRCs on innovative software tools, training, and other elements common to HPC programming environments

2.7.10.3.2 HPC Software Applications Institutes (HSAIs)

There are between five and eight HPC HSAIs in a given year. Each involves between three and twelve computational and computer scientists for a period of three to six years to develop new code or support existing code, and adjust local business practices to use science-based models and simulation.

2.7.10.3.3 Programming Environment and Training (PET)

The HSAIs are integrated with the PET program whose mission is to enhance the productivity of the DoD HPC user community. Its goals are to:

- Transfer leading-edge HPC (computational and computing) technology into DoD from other government, industrial, and academic HPC communities
- Develop, train, and support new and existing DoD HPC users with the education, knowledge, access, and tools to maximize productivity

2.7.10.3.4 Software Protection Center (SPC)

DoD implements protections on national security applications software. The SPC is responsible for developing software protection technologies, supporting the insertion of software protections into applications codes, working with the services and agencies to improve the effectiveness of export control regulations for software, and serving as an information center for best practices and guidelines. A Red Team tests and validates protection technologies and implementations.

3. HUMAN COMPUTER INTERACTION AND INFORMATION MANAGEMENT (HCI&IM)

3.1 INTRODUCTION

The HCI&IM CG plans, coordinates, and evaluates Federal R&D of technologies for mapping human knowledge into computing systems, communications networks, and information systems and back to human beings, all for the benefit of human understanding, analysis, and use.[62] The HCI&IM CG comprises expert volunteers from nine NITRD agencies – NSF, NIH, DARPA, NASA, AHRQ, DOE/SC, NIST, NOAA, and EPA – and one non-NITRD agency, FAA – who meet monthly to exchange information and coordinate their HCI&IM R&D programs and activities. The HCI&IM CG succeeds the Human Centered Systems (HuCS) CG of the late 1990s. The IM component was formally added in 2000 in response to the recommendations made in the 1999 PITAC report.[63]

3.2 DEFINITION OF THE HCI&IM PCA

The activities funded under the NITRD Program's HCI&IM R&D PCA have the goal of increasing the benefit of computer technology to humans through the development of future user interaction technologies, cognitive systems, information systems, and robotics. Current systems overwhelm the user with information, but provide little in the way of adaptable access, necessitating adaptability on the part of the user. The HCI&IM research vision is to provide information that is available everywhere, at any time, and to everyone regardless of their abilities; to increase human use of this information by providing customized access including the ability to interact using a variety of devices, and to meet varied needs for manipulation, analysis, and control; and to provide comprehensive management of vast information environments. HCI&IM R&D focuses on developing systems that understand the needs of the users and adapt accordingly.

Broad areas of HCI&IM concern include:

- Usability and universal accessibility
- Interaction
- Cognitive systems, learning, and perception
- Information management and presentation
- Autonomous agents and systems

To address these concerns, HCI&IM R&D pursues the following technical goals:

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[62] http://www.nitrd.gov/pubs/hci-im_research_needs_final.pdf
[63] "Information Technology Research: Investing in Our Future," Report of the President's Information Technology Advisory Committee (PITAC), February 24, 1999, http//www.nitrd.gov/pitac.

- By their very nature, most of the problems in this multidisciplinary field require contributions from different branches of science and engineering, and the needed technological convergence will require exceptional communication and coordination efforts.
- Scientific understanding of both human and machine cognition is central to the area, linking the various parts of human-computer interaction and information management together.
- We must learn how to build machines and systems that employ the human senses of perception to their full potential, maximizing the information-flow bandwidth between people and their tools.
- We must discover new and better ways to achieve information integration, across a wide range of different modalities, media, and distributed resources.
- Tying together information management and human needs as data burgeons and becomes useful in all aspects of science, manufacturing, and commerce will require tools that are increasingly able to take on planning, aid in decision making, learn from experience, and develop knowledge from raw data.
- Flexible systems of control must be developed that manage the degree of autonomy exhibited by machines according to the constantly changing needs of humans, especially in that broad and extremely valuable area where HCI and IM unite for the benefit of people.

Illustrative technical thrusts of HCI&IM programs include:

- Fundamental science and engineering on human-computer interfaces for stationary, mobile, and ubiquitous computing and communications environments
- Multi-modal, speech, gesture, visual, language, haptic, and physical interactions
- Efforts to improve the collection, storage, organization, retrieval, summarization, analysis, and presentation of information of all kinds in databases, distributed systems, or digital libraries
- An understanding of the use of multiple modalities and their relation to information content
- Information management and access that adapts to the needs and preferences of a diverse population including young, old, and disabled users as well as expert and novice users and complex, multi-person, collaborative and distributed systems
- Research and technology development related to perception, cognition, and learning by machines and by human beings interacting with machines
- Mobile autonomous robots
- Remote or autonomous agents
- Collaboratories
- Visualizations
- Web-based repositories
- The semantic Web
- Information agents
- Evaluation methodologies and metrics for assessing the progress and impact of HCI&IM research

3.3   HCI&IM CG ACTIVITIES

3.3.1   Release of the "Human-Computer Interaction and Information Management Research Needs" Report

In October 2003, the HCI&IM CG released its *Human-Computer Interaction and Information Management Research Needs* report (henceforth referred to as the *Research Needs Report*). The report identifies and illustrates the problems that underlie HCI&IM R&D to achieve benefits such as:

- Changing the way scientific research is conducted
- Expanding the science and engineering knowledge base
- Enabling a more knowledgeable, capable, and productive workforce

It places agency FY 2002 HCI&IM R&D investments and R&D needs within a conceptual framework and elucidates what is meant by the words "human-computer interaction and information management." The framework is used to depict why humans use computing systems, what humans use these systems for, and how humans and computing systems use data and information both separately and together. HCI&IM R&D needs are organized in four areas:

- Information creation, organization, access, and use
- Managing information as an asset
- Human-computer interaction and interaction devices
- Evaluation methods and metrics

3.3.2   HCI&IM R&D Planning and Coordination

In FY 2004 the HCI&IM CG is using its *Research Needs Report* to identify and assess current agency investments, research gaps, and plans. In formulating these plans and directions, the focus is on:

- Refining plans in new R&D areas such as cognition, robotics, and devices
- Identifying and coordinating activities in areas of shared interests with other CGs. Potential areas are:

  - With LSN in moving the bits in distributed data and in middleware
  - With SDP in automatic software design and integration
  - With SEW in universal accessibility in the use of multi-agent systems, and in the impact of distributed data on organizations and groups sharing data

3.3.3   HCI&IM CG Special Meeting in December 2003

Complementary to the release of the *Research Needs Report*, the HCI&IM CG held a Special Meeting in December 2003, among other things, to assess and refine its R&D agenda. The following sections reflect the presentations made at the meeting.

3.4   HCI&IM MULTI-AGENCY ACTIVITIES

The following are activities in which more than one HCI&IM agency participates. The activities often also include agencies outside the NITRD Program, which are not identified here.

3.4.1   DARPA

DARPA coordinates with other HCI&IM agencies on the following programs:

- With NSF in its Improving Warfighter Information Intake Under Stress Program
- With NIST and NSA in Translingual Information Detection, Extraction, and Summarization (TIDES)
- With NIST and NSA in Effective, Affordable, Reusable Speech-to-Text (EARS)

These programs are described in section 3.5.3.

3.4.2   NASA

NASA collaborates with the following partners on activities that have HCI&IM R&D components:

- DOE/SC on high-end modeling and simulation
- The weather community, including NOAA, on global climate modeling
- FAA on automated vehicle cockpits and air traffic management and risk

3.4.3   AHRQ

- NIH/NLM has joined with AHRQ in considering proposals submitted to AHRQ's Health Information Technology (HIT) program for funding.
- NIH/NLM will work with AHRQ to develop standards critical to improving patient safety, as part of the Patient Safety Task Force.
- NIST will work with AHRQ to develop a U.S. health data standards landscape model and application.
- The Food and Drug Administration (FDA) in HHS will work with AHRQ to develop data standards critical to improving patient safety in the use of prescription drugs.
- AHRQ invites other agency experts to participate in peer reviews of its grant proposals.

3.4.4 NIST

NIST coordinates with DARPA and NSA on the Human Language Technology Program[64] that involves the measurement and evaluation of speech recognition; speaker recognition; spoken language understanding; information search, retrieval, and filtering; document understanding; summarization; interactive speech interfaces; and on the Interactive Systems Technology Program[65] that involves measurement, standards, and evaluation for usability of interactive systems; Web usability testing; usability reporting formats; and accessibility testing.

3.5 HCI&IM AGENCY ACTIVITIES

3.5.1 NSF

The bulk of NSF's HCI&IM R&D investments are in its Directorate for Computer and Information Science and Engineering (CISE). In FY 2004, CISE was reorganized into four Divisions, including the Division of Information and Intelligent Systems (IIS), within which a large share of NSF's HCI&IM investments fall. Other HCI&IM activities lie in the NSF-wide Information Technology Research Program (ITR).

3.5.1.1 CISE/Information and Intelligent Systems (IIS) Division

The goals of CISE/IIS[66] are to:

- Increase the capabilities of human beings and machines to create, discover, and reason with knowledge
- Advance the ability to represent, collect, store, organize, locate, visualize, and communicate information
- Conduct research on how empirical data leads to discovery in the sciences and engineering

CISE/IIS has three clusters with investments in HCI&IM R&D:

- The *Systems in Context* cluster supports research and education on the interaction between information, computation, and communication systems and users, organizations, Government agencies, and the environment. This cluster integrates the following programs:

  - Human-Computer Interaction (HCI)
  - Universal Access (UA)
  - Digital Society and Technologies (DST)
  - Robotics
  - Digital Government (DG)

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[64] http://www.itl.nist.gov/iad/programs.html
[65] http://www.itl.nist.gov/iad/programs.html#USERS
[66] http://www.cise.nsf.gov/div/cluster.cfm?div=iis&cluster_id=3947

- The *Data, Inference, and Understanding* cluster supports basic research with the goal of creating general-purpose systems for representing, sorting, accessing, and drawing inferences from data, information, and knowledge. This cluster integrates the following programs:

  - The Artificial Intelligence and Cognitive Science (AI&CS) program focuses on advancing the state of the art in AI&CS. It includes research fundamental to the development of computer systems capable of performing a broad variety of intelligent tasks and to the development of computational models of intelligent behavior across the spectrum of human intelligence.
  - Computer Vision
  - Human Language and Communication
  - Information and Data Management (IDM)
  - Digital Libraries

- The *Science and Engineering Informatics* cluster includes:

  - Collaborative Research in Computational Neuroscience that will continue as a collaborative program
  - Science and Engineering Information Integration and Informatics, which focuses on the development of information technology to solve a particular science or engineering problem and generalizes the solution to other related problems.
  - Information Integration to provide a uniform view to a multitude of heterogeneous, independently developed data sources through reconciling heterogeneous formats, Web semantics, decentralized data-sharing, data-sharing on advanced cyberinfrastructure, on-the-fly integration, and information integration resources.

3.5.1.2 NSF's Information Technology Research (ITR) Program

Other NSF HCI&IM investments are in the NSF-wide ITR Program that involves all NSF Directorates and Offices including BIO, ENG, GEO, MPS, SBE, OPP, and EHR.

3.5.1.3 NSF Workshops

The following FY 2003 workshops are indicative of the nature of NSF-sponsored HCI&IM-related workshops that are being held in FY 2004:

- HCI program workshops:

  - Association for Computing Machinery Computer Human Interaction (ACM CHI) '03 Doctoral Consortium held in Ft. Lauderdale, Florida, April 7-10, 2003[67]
  - Workshop on Dialogue Processing held in Edmonton, Canada, May 27 to June 1, 2003, provided a forum to assess the current state of the art of dialogue

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[67] http://cise.nsf.gov/events/wksp/display_workshops.cfm?evnt_id=40069&div=cise

processing and identify key themes and directions that are driving research in the field.[68]

- o An annual six-week workshop that trains graduate students and junior faculty in research techniques for computational linguistics. More than 30 graduates and undergraduates participated in the workshop.[69]

- IDM program sponsored workshops:

  - o Joint Conference on Digital Libraries,[70] June 7-11, 2004, in Tucson, Arizona
  - o International Workshop on Data Engineering for Wireless and Mobile Access (MobiDE '03)[71] held September 19, 2003 in San Diego, California. MobiDE is a bridge between the data and information management community and the mobile computing community.
  - o IDM-2003 PIs Workshop held September 14-16, 2003[72] in Seattle, Washington
  - o Workshop on Research Directions for Digital Libraries, June 15-17, 2003, in Chatham, Massachusetts. The workshop report is entitled "Knowledge Lost in Information."[73]
  - o Workshop on Bioinformatics held March 5-8, 2003 in Bangalor, India, provided an international forum for researchers, professionals, and industrial practitioners to share their knowledge of how to manage biological information. The workshop was held in conjunction with the 19th International Conference on Data Engineering (ICDE 2003)[74] to encourage database researchers to become involved in bioinformatics research.

3.5.2   NIH

Illustrative of NIH HCI&IM activities is the Joint NIH Bioengineering Consortium/NIH Biomedical Information Science and Technology Initiative Consortium (BECON/BISTIC) 2004 Symposium on Biomedical Informatics for Clinical Decision Support: A Vision for the 21st Century[75] held June 21-22, 2004. The Symposium involved 15 NIH Institutes seeking to gain consensus about standards for reducing medical errors and variability in patient information by reviewing software tools and approaches to deliver the benefits of biomedical information technologies to patients at the time and place of decision making regarding risk, diagnosis, treatment, and follow-up. Specifically, the meeting provided a scientific vision of the healthcare information technologies that may be more fully deployed in the workflow to improve efficiency and outcomes.

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[68] http://www.cise.nsf.gov/events/wksp/display_workshops.cfm/evnt_id=5054&di=cise

[69] http://www.cise.nsf.gov/events/wksp/workshops.cfm?event_id=40067&div=cise

[70] http://www.jcdl.org

[71] http://db.cs.pitt.edu/mobide03/

[72] http://www2.cs.washington.edu/nsf2003/home.html

[73] http://www.sis.pitt.edu/~dlwkshop/ contains information about the workshop and contains the report.

[74] http://www.aztecsoft.com/_icde2003/

[75] http://www.becon.nih.gov/symposium2004.htm

3.5.3   DARPA

DARPA's HCI&IM investments include four programs that fall within the agency's Information Processing Technology Office (IPTO). IPTO's mission is to create a new generation of computational and information systems that posses capabilities far beyond those of current systems.[76] The programs are:

- Compact Aids for Speech Translation (CAST)
- Improving Warfighter Information Intake Under Stress (formerly Augmented Cognition)[77]
- Translingual Information Detection, Extraction, and Summarization (TIDES)[78]
- Effective, Affordable, Reusable, Speech-to-Text (EARS)[79]

3.5.3.1 Compact Aids for Speech Translation (CAST)

The goal of CAST is to develop rapid, two-way, natural language speech translation interfaces and platforms for the warfighter for use in field environments for force protection, refugee processing, and medical triage. The program will focus on overcoming the many technical and engineering challenges limiting current multilingual translation technology to enable future full-domain, unconstrained dialog translation in multiple environments. This technology will replace the DARPA RMS (One-Way) translator in two phases – the DARPA 1+1 Way and the DARPA Two-Way. The four major thrusts in this program are:

- Core Research
- DARPA 1+1 Way
- DARPA Two-Way
- Evaluation and Data Collection

Potential users are the U.S. Armed Forces and Intelligence Community in foreign countries. It involves the voluntary collection of foreign speech and language data and domain specific data from subject matter experts. It will improve the ability of operators to converse with, extract information from, and give instructions to a foreign language speaker encountered in the field.

3.5.3.2 Improving Warfighter Information Intake Under Stress

The mission of this program is to extend, by an order of magnitude or more, the information management capacity of the human-computer warfighting integral by developing and demonstrating quantifiable enhancements to human performance in diverse, stressful, operational environments. Specifically, this program will empower one human's ability to successfully accomplish the functions currently carried out by three or more individuals. This will be done by enabling computational systems to dynamically adapt to users by developing the following:

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[76] http://www.darpa.mil/ipto/Programs.htm
[77] http://www.darpa.mil/ipto/Programs/augcog/index.htm
[78] http://www.darpa.mil/ipto/Programs/tides/index.htm
[79] http://www.darpa.mil/ipto/Programs/ears/index.htm

- Real-Time Assessment of Warfighter Status (Phase One)
- Real-Time Maximization of Warfighter Potential (Phase Two)
- Autonomous Adaptation to Support Warfighter Performance Under Stress (Phase Three)
- Operational Demonstration and Test (Phase Four)

Warfighters are constrained in the amount of information they can manage. Adaptive strategies will mitigate specific information processing roadblocks to increase performance and information flow. Strategies include:

- Intelligent interruption to improve limited working memory
- Attention management to improve focus during complex tasks
- Cued memory retrieval to improve situational awareness and context recovery
- Modality switching (that is, audio, visual) to increase information throughput

The program has two technical challenges:

- Demonstrating enhancement of warfighter performance
  - Assess warfighter status in less than two seconds with 90 percent accuracy
  - Adapt information processing strategies in less than one minute, with no performance degradation

- Overcoming information processing bottlenecks
  - 500 percent increase in working memory throughput
  - 100 percent improvement in recall and time to reinstate context
  - 100 percent increase in the number of information processing functions performed simultaneously
  - 100 percent improvement in successful task completion within critical time duration

A PI meeting was held January 6-8, 2004 in Orlando, Florida.[80]

3.5.3.3 Translingual Information Detection, Extraction, and Summarization (TIDES)

The TIDES program seeks to:

- Develop advanced language processing technology to enable English speakers to find and interpret critical information in multiple languages without requiring knowledge of those languages
- Develop sophisticated statistical modeling techniques for human language
- Take advantage of substantial increases in electronic data and computational power

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[80] http://www.disc-web.net/meetings/u8baerz/index.html

- Develop and test technology using speech and text from English, Arabic, and Chinese news sources

TIDES has the following military impact:

- Enhancing the ability of U.S. forces to operate safely and effectively around the globe
- Enabling commanders and policy makers to know what is being said in a region by and to the local population
- Lessening dependence on scarce linguists
- Developing potential customers throughout the military and intelligence communities

A PI meeting was held July 13-15, 2004 in Philadelphia, Pennsylvania.

3.5.3.4 Effective Affordable Reusable Speech-To-Text (EARS)

This program is developing speech-to-text (automatic transcription) technology whose output is substantially richer and more accurate than currently possible, so that machines can better detect, extract, summarize, and translate information. It will also enable humans to understand what was said by reading transcripts instead of listening to audio signals.

The EARS goals are to:

- Automatically transcribe and extract useful metadata from natural human speech
- Develop powerful statistical techniques for modeling variability of speech
- Take advantage of substantial increases in electronic data and computational power
- Develop and test technology using broadcasts and conversations in English, Arabic, and Chinese

The military impact of the EARS program includes:

- Substantial increases in productivity and situation awareness
- Enabling analysts to read transcripts rapidly (in lieu of listening to audio slowly)
- Developing many potential customers throughout the military and intelligence communities

DARPA sponsored the Human Language Technology Conference and the North American Association for Computational Linguistics Annual Meeting that both were held May 2-7, 2004 in Boston, Massachusetts.[81] DARPA, NIST, and NSF were represented on the conference oversight committee.

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[81] http://www1.cs.columbia.edu/~pablo/hit-naac104

3.5.4   NASA

NASA's HCI&IM investments include fundamental research in:
- Human information processing and performance
- Multi-modal interaction
- Human-robotic systems
- Automation and autonomy
- Software engineering tools
- Knowledge management and distributed collaboration
- Computational models of human and organizational behavior

Within the aviation domain, HCI&IM investments include:
- Human-computer interaction for highly automated vehicle cockpits
- Aviation/shuttle flight control systems
- System health management systems
- International Space Station interfaces

- Human-computer interaction for air traffic management application
  - Air traffic control
  - Cockpit display of traffic information
  - Distributed air-ground collaboration

- Proactive management of system risk
  - Air traffic management
  - Onboard flight-recorded data
  - Human and organizational risk

Human-computer interfaces for mission control and ground control applications include:

- Shuttle and International Space Station mission control
- Remote interactive automation for near-Earth and planetary missions

In the information management domain, NASA missions require investment in:

- Data mining and scientific discovery
- Interactive visualization of complex systems for analysis, design, and evaluation
- High-end modeling and simulation
  - Vehicle geometry, functions, and behavior
  - Climate, weather, and terrain
  - Science planning and operations with automation support
  - Homeland security

3.5.5 AHRQ

AHRQ's FY 2004 HCI&IM R&D investments are for improved patient safety and health quality. Specifically, these investments support the Patient Safety Health Information Technology (HIT) Initiative. They will support HCI&IM-related work for transforming healthcare quality (for example, promoting and accelerating the development, evaluation, adoption, and diffusion of IT in healthcare) and establishing healthcare data standards (for example, development, evaluation, and adoption of information standards and technology to support patient safety). A major goal is to support the development of a National Health Information Infrastructure (NHII) that includes an Electronic Health Record System (EHRS). The EHRS will be a longitudinal collection of electronic health information for and about persons. It will allow electronic access to person- and population-level information by authorized users. The system will provide knowledge and decision support that enhances the quality, safety, and efficiency of patient care. An EHRS will support more efficient healthcare delivery processes.

In the area of transforming healthcare quality, AHRQ provides:

- Planning grants to rural and small communities for healthcare systems and partners to implement HIT to promote patient safety and quality of care
- Implementation grants for rural and small hospitals to evaluate the measurable and sustainable effects of HIT on improving patient safety and quality of care
- Assessment grants to increase the knowledge and understanding of the clinical, safety, quality, financial, organizational, effectiveness, and efficiency value of HIT.

AHRQ envisions the establishment of a center that will coordinate the vast amounts of HIT information that results from these grants. Potential duties include coordinating and assisting grantees, supporting outreach and dissemination, and hosting meetings.

In health data standards, AHRQ provides:

- Funding for expert consensus on EHR functions
- Funding for standards development
- Funding for mapping between standards
- Funding for developing a metadata health data registry
- Coordination of U.S. standards developing organizations and standards users
- Consensus of U.S. positions on international health data standards issues

"Making the Health Care System Safer: The 3rd Annual Patient Safety Research Conference" was held September 26-28, 2004 in Arlington, Virginia.[82] The goal of this conference series is to improve patient safety and health quality by:

- Increasing awareness of Patient Safety Events (PSEs) by supporting information systems that collect and analyze (including classification, root cause analysis, failure mode and

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[82] http://www.ahrq.gov/qual/ptsafconf.htm

effects analysis, and probabilistic risk assessment) a large body of medical error data and by disseminating scientific findings that are translated into useful decision making context

- Understanding the organizational, cultural, human, and IT capabilities needed to guide the development of a network for the collection and analysis of PSEs and build capacity for patient safety research
- Developing informatics standards for uniform reporting, storage, and retrieval of comparable PSE data

3.5.6   DOE/SC

3.5.6.1 National Collaboratories Program

DOE/SC uses planning workshops to develop its programs, including those reported in the HCI&IM PCA. Its goal is to support end-to-end scientific discovery processes. Petabyte-scale experimental and simulation data systems will be increasing to exabyte-scale data systems. The sources of the data, the computational and storage resources, the scientific instruments, and the scientists who are consumers of the data and users of the instruments and computation are seldom collocated.

DOE/SC is developing pilot collaboratories for the high energy nuclear physics, supernovae, and cell biology research communities. These pilot collaboratories are early implementations of virtual laboratories.

- They are focused on a problem of national scientific or engineering significance clearly related to DOE's mission and have high visibility.

- They involve geographically separated groups of personnel and/or facilities that are inherently required to collaborate or be used remotely for success of the project.

- They have implementations to test and validate that scientific research programs can integrate unique and expensive DOE research facilities and resources for remote collaboration, experimentation, simulation, and analysis through:

    o Use of middleware technologies to enable ubiquitous access to remote resources – computation, information, and expertise
    o Demonstrate capabilities that make it easier for distributed teams to work together over the short term and the long term

Developing such collaboratories involves creating partnerships among researchers in scientific disciplines and R&D personnel in middleware, networking, and computational science.

DOE/SC's middleware research has two HCI&IM efforts:

- Information integration and access that include:

- o Mechanisms for seamless interface to multiple storage systems and mechanisms for replication management
- o Open issues such as data provenance, metadata standards, and mechanisms to resolve global names into access mechanisms

- Services to support collaborative work
  - o A wide variety of community services such as the Access Grid
  - o Open issues such as scalable easy-to-use primitives to support multiple modes of secure wide-area collaboration

A potential benefit is speeding up the process of multidisciplinary research. Today data resulting from research in one field must be validated and published, then be discovered and understood by people in other fields. DOE/SC is looking to improve data pedigree and communications between groups of researchers.

3.5.7　NIST

NIST's HCI&IM programs are found in the Information Technology Laboratory's (ITL)[83] Information Access Division (IAD)[84] and in the Manufacturing Engineering Laboratory's (MEL)[85] Manufacturing Systems Integration Division (MSID)[86] and Intelligent Systems Division (ISD)[87].

3.5.7.1 Information Technology Laboratory (ITL)

ITL/IAD houses several programs of relevance to HCI&IM. IAD's mission is to accelerate the development of technologies that allow intuitive and efficient access, manipulation, and exchange of complex information by facilitating the creation of measurement methods and standards. IAD's work objectives are to:

- Contribute to the advancement of these technologies
- Enable faster transition into the commercial marketplace
- Enable faster transition into sponsors' applications

IAD accomplishes these objectives through:

- Performance metrics, evaluation methods, test suites, and test data
- Prototypes and testbeds
- Workshops
- Standards and guidelines

IAD works in collaboration with industry, academia, and government.

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[83] http://www.itl.nist.gov
[84] http://www.itl.nist.gov/iaui/
[85] http://www.mel.nist.gov/what.htm
[86] http://www.mel.nist.gov/msid/
[87] http://www.isd.mel.nist.gov

The five IAD HCI&IM programs are:

- The *Human Language Technology Program* that includes TREC, AQUAINT, TIDES/Document Understanding Conference (DUC), TIDES/Topic Detection and Traction (TDT), EARS, Automatic Content Extraction (ACE), TIDES/Machine Translation (MT), Meeting Transcription, Speaker Recognition, and Language Recognition. For FY 2004, NIST plans to continue and expand evaluations for these programs in the following manner:

  - TREC – Continue novelty, Web, and Q&A, add robust retrieval, High Accuracy Retrieval from Documents (HARD), and Genomics (retrieval within that specific domain)
  - AQUAINT – Continue with dialogue testing and "what is" and "who is" questions
  - TIDES/DUC – Continue evaluations and add cross-language Arabic summarization
  - TIDES/TDT – Continue evaluations
  - EARS – Continue speech-to-text (STT) and metadata evaluations
  - ACE – Provide evaluations for foreign languages
  - TIDES/MT – Continue evaluations
  - Meeting Transcription – Implement STT evaluation and work with ARDA's Video Analysis and Content Extraction (VACE) program
  - Speaker/Language Recognition – Continue evaluations

- The *Biometrics Technology Program* that includes fingerprint and face testing and standards. For FY 2004, NIST plans to:

  - Continue testing the FBI's Integrated Automated Fingerprint Identification System (IAFIS) on DHS and other data
  - Continue tests to support conversion of US VISIT to more than two fingers. (US VISIT is the entry/exit system being implemented by DHS at airports, seaports, and land border crossings to secure the Nation's borders.)
  - Help integrate face recognition and multi-vendor verification into US VISIT
  - Carry out fingerprint vendor technology evaluation (FpVTE) testing and analysis
  - Continue data and performance standards development
  - Develop Multi-modal Biometric Accuracy Research Kiosk
  - ANSI and ISO standardization of the Common Biometric Exchange File Format (CBEFF) and the Biometric Application Programming Interface (BioAPI)
  - Continue chairing the International Committee for IT Standards (INCITS) Committee on Biometrics (M1) and the ISO Committee on Biometrics (SC37)

- The *Multimedia Technology Program* includes multi-media standards, video retrieval, and visualization and virtual reality for manufacturing. FY 2004 plans include:

- Continuation of work with industry to use the MPEG-7 (the metadata standard for accessing video information) Interoperability Test Bed
- Development of "light-and-simple" profiles for existing industry-wide formats
- For video retrieval, continue evaluations with a new story segmentation task and more high-level features to extract; process and ship 120 hours of new data
- Continue X3D and Human Animation (H-ANIM) standardization
- Continue seeking medical applications within Web3D and for human modeling

- The *Interactive Systems Technology Program* includes WebMetrics, Industry Usability Reporting (IUSR — a standard by which software development companies can test results and provide results to potential customers), Voting, Novel Intelligence for Massive Data (NIMD), Human Robot Interaction (HRI), Digital Library of Mathematical Functions (DLMF), and Accessibility Standards. FY 2004 plans for this program include:

  - Webmetrics – seek additional opportunities with W3C[88]
  - IUSR – extend Common Industry Format (CIF) to hardware and finalize CIF-requirements
  - Voting – R&D for developing usability and accessibility tests for certifying voting systems
  - NIMD – experiment with glass box data and develop NIMD roadmap
  - HRI – develop a user interface for robotic mobility platform
  - DLMF – usability study for DLMF Web site and animation of Virtual Reality Modeling Language (VRML) worlds
  - Accessibility standards – develop a prototype incorporating the new architecture from the INCITS Committee on Accessibility (V2)

- The *Smart Space Technology Program* includes a smart space testbed and single molecule manipulation and measurement. The testbed is for human interaction in an environment that includes microphones and video cameras. FY 2004 plans include:

  - A new version of NIST's Smart Flow (a system that allows large amounts of data from sensors to be transported to recognition algorithms running on a distributed network) that is easier to use, provides better performance, and is more stable, portable, and scalable
  - Continue upgrading Meeting Room with new capabilities. Originally done for speech, Meeting Room is now being used to analyze videos.
  - Continue INCITS V2 collaboration
  - Provide data acquisition services and analysis methods to NIST's Chemical Science and Technology Lab and Physics Lab and upgrade real-time processing systems

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[88] http://www.w3.org/

3.5.7.2 Manufacturing Engineering Laboratory (MEL)

MEL's mission is to satisfy the measurements and standards needs of U.S. manufacturers in mechanical and dimensional metrology and in advanced manufacturing technology by conducting R&D, providing services, and participating in standards activities.

Most of MEL's HCI&IM activities fall within its Manufacturing Systems Integration Division (MSID). MSID promotes the development of technologies and standards that lead to the implementation of information-intensive manufacturing systems that can be integrated into a national network of enterprises working together to make U.S. industry more productive. MSID has an HCI&IM effort in system interoperability that is based on ontologies (knowledge bases that provide the meaning of information held in databases, whether structured or unstructured, in ways that can be understood across systems and also by humans). Ontologies are important to the development of software systems in general, partly because such systems are often created today by integrating existing systems and partly because they can improve software engineering by carefully and formally defining the requirements in ways that can save money over the software life cycle and avoid hidden mistakes. In commerce, ontologies can address such problems as communication within machine shops and the distribution of higher level information between factories and front offices. MSID hosted an NIST/NSF International Workshop on Semantic Distance, November 10-12, 2003 in Gaithersburg, Maryland.

MEL's Intelligent Systems Division (ISD) develops test arenas for competitions, particularly for urban search and rescue (USAR) applications. The ISD developed the Reference Test Arenas for Autonomous Mobile Robots to focus research efforts, provide direction, and accelerate the advancement of mobile robot capabilities. These arenas, modeled from buildings in various stages of collapse, allow objective performance evaluation of robots as they perform a variety of USAR tasks in both physical and virtual domains. The USAR test arenas have inspired not only replicas to be fabricated, but have provided the foundation for the annual Rescue Robot Competitions that are currently part of the RoboCup – USOpen, RoboCup – Japan Open, and the International Joint Conference on Artificial Intelligence (IJCAI)/American Association for Artificial Intelligence (AAAI) conferences. The first of these competitions was done in cooperation with the AAAI at its 2000 meeting in Austin. Competitions for 2004 are scheduled for New Orleans, Osaka, Lisbon, and San Jose. Testing is available on an individual basis at NIST in Gaithersburg, and year-round arenas are also now available in Tokyo, Pittsburgh, and Rome.[89]

Since FY 2000, ISD also holds annual workshops on Performance Metrics for Intelligent Systems (PerMIS),[90] with the goal of defining measures and methodologies of evaluating performance, inter-comparing research results, and defining measurable program objectives of intelligent systems and sub-components of systems. NIST held a PerMIS workshop[91] in cooperation with DARPA on August 24-26, 2004 that included a session on merging of ontologies that is likely to develop into a larger conference with the cooperation of MSID and ITL.

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[89] http://www.isd.mel.nist.gov/projects/USAR/
[90] http://www.isd.mel.nist.gov/research_areas/research_engineering/Performance_Metrics/
[91] http://www.isd.mel.nist.gov/PerMIS_2004/

3.5.7.3 NIST Workshops

NIST has organized or is organizing the following HCI&IM-related workshops (some are conducted with other agencies):

- PerMIS Workshop in cooperation with DARPA – August 24-26, 2004
- Biometric Consortium Conference – September 2004
- Language Identification Workshop – Spring 2004
- Speaker Identification Workshop – Spring 2004
- Meeting Recognition Technologies – May 2004
- International Biometrics Technical Meeting – March 2004
- Cognitive Task Analysis for Intelligence Analysts – January 21-23, 2004
- Voting Systems Symposium – December 2003
- International Workshop on Semantic Distance – November 10-12, 2003
- Video Retrieval Conference – November 2003
- Text Retrieval Conference – November 2003
- Automatic Content Extraction Workshop – October 2003

3.5.8   NOAA

In digital libraries, NOAA[92] is developing methods of cataloging, searching, viewing, and retrieving NOAA data distributed across the Web. It is exploiting Geographical Information Systems (GIS) and XML technologies to display and describe data and is developing methods for distributing model data. Recent results include:

- Fisheries-oceanography GIS with 3D presentations
- Prototype tools for analyzing and integrating hydrographic data for a multi-server distribution system
- Using Really Simple Syndication (RSS) for service registration and information discovery
- Plans include developing access to current National Weather Service (NWS)[93] model data subsets.

NOAA held its semi-annual PI status reports meeting in the spring of 2004.

3.5.9   EPA

EPA HCI&IM programs are focused on tools to facilitate sound science using information management, analysis, and presentation. These programs enable relevant, high-quality, cutting-edge research in human health, ecology, pollution control and prevention, economics, and decision sciences. They facilitate appropriate characterization of scientific findings in the

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[92] http://www.cio.noaa.gov/hpcc/
[93] http://www.nws.noaa.gov/

decision process and convey important information in such a way that researchers and policy makers can better understand complex scientific data. These programs are performed in-house and as problem-driven research. Current activities cover a broad spectrum of areas, including:

- Integrating data analysis and decision-making across physical, chemical, biological, social, economic, and regulatory influences and effects

- Finding significant relationships, phenomena, differences, and anomalies with multiple data techniques
- Integrating search and retrieval across multiple digital libraries containing environmental and health information

- Enabling efficient management, mining, distribution, and archiving of large data sets

- Creating services to enable and support collaborative science across geographically distributed laboratories and offices including data and computational Grids

- Developing interactive visualizations of complex systems for analysis, design, and evaluation

- Generating knowledge engineering and capture

EPA HCI&IM activities have enabled the following pilot projects:

- Metabonomics Pilot – A collaborative framework to enable shared access to data and results, joint use of computational applications and visualization tools, and participatory analysis across scientific boundaries is underway. Metabonomics data will be harmonized with both proteomics and genomics data in order to better understand and predict chemical toxicity and support risk assessment.

- Air Quality Model Pilot – Tools and approaches to explore potential linkages between air quality and human health are being investigated. Assessments include impacts of regulatory and policy decisions. Exploration of relationships between regulations, emission sources, pollutants, and ecosystems is being completed. Tools and techniques developed in this pilot will be transferred to States and applied to solve real problems such as enhancing States' abilities to predict and evaluate various control strategies, expanding State-level forecasting capabilities to include more pollutants, enhancing the States' abilities to explore potential linkages between air quality and human health, and improving the States' abilities to assess the impact of regulatory and policy decisions.

4.   LARGE SCALE NETWORKING (LSN)

4.1   INTRODUCTION

The agencies that participate in the LSN CG plan, coordinate, and evaluate Federal R&D in advanced networking technologies. The LSN CG comprises expert volunteers from nine Federal agencies who meet monthly to exchange information and coordinate their LSN R&D programs and activities. Eight of these agencies are in the NITRD Program: DOE/SC, DARPA, NASA, NIST, NIH/NLM, NSA, NSF, and NOAA; the ninth is DoD/HPCMPO.

Three Teams report to the LSN CG. In addition to interagency coordination in specific areas, the Teams implement tasks assigned by the LSN CG. These Teams are:

- *Joint Engineering Team (JET),* which coordinates connectivity and addresses management and performance of Federal research networks and their interconnections to the commercial Internet
- *Middleware and Grid Infrastructure Coordination (MAGIC) Team,* which coordinates Federal agency Grid and middleware R&D and supports Grid applications
- *Networking Research Team (NRT),* which coordinates Federal agency research programs in advanced networking technologies and protocols

4.2   DEFINITION OF THE LSN PCA

The activities funded under the NITRD Program's LSN PCA maintain and extend U.S. technological leadership in high performance networks through R&D in leading-edge networking technologies, services, and techniques to enhance performance, security, and scalability. These advances will support Federal agency networking missions and requirements and will provide the foundation for the continued evolution of global scale networks and the services that depend on them. Today's networks face significant challenges in performance, scalability, manageability, and usability that restrict their usefulness for critical national missions. These challenges are addressed by the LSN PCA that encompasses Federal agency programs in advanced network components, technologies, security, infrastructure, and middleware; Grid and collaboration networking tools and services; and engineering, management, and use of large-scale networks for science and engineering R&D.

Broad areas of LSN concern include:

- The development of networks that deliver end-to-end performance at least 1,000 times greater than today
- The development of a manageable, scalable security system to support the evolution of the global Internet and associated applications that require trust
- The development of advanced network services and middleware that enable development of new generations of distributed applications
- Specialized large-scale networks to enable applications with special needs, such as sensor networks and networks for real-time control

Other areas of LSN concern are:

- International cooperation in the areas of optical network coordination and certificate authorities
- Outreach and cooperation with university and commercial communities
- Network science education and workforce issues

To address these concerns, LSN R&D pursues the following technical goals:

- End-to-end performance measurement including measurement across institutional and international boundaries
- Network trust, security, privacy, availability, and reliability through research on vulnerability analysis, scalable technologies, security testbeds, and promotion of best practices
- Collaboration and distributed computing environments including Grid
- Adaptive, dynamic, self-organizing, self-scaling, and smart networking
- Revolutionary networking research including revisiting networking fundamentals

Illustrative technical thrusts of LSN programs are:

- Federal network testbeds and their coordination with non-Federal networks and testbeds
- Infrastructure support such as Federal Internet exchange points
- Network technologies, components, and services for optical, mobile, wireless, satellite, and hybrid communications
- Middleware to enable applications
- Sensornets
- Large-scale network modeling, simulation, and scalability
- Protocols and network services to support high performance networking applications such as high energy physics data transfers, astronomy community collaboration, and biomedical research
- Technologies for measuring end-to-end performance

4.3 LSN CG ACTIVITIES

The LSN CG holds an Interagency Coordination Meeting each year at which each agency describes its programs reported under the LSN PCA. This allows the agencies to identify:

- Opportunities for collaboration and coordination with other agencies on networking R&D activities
- LSN R&D focus areas
- Areas of interest to the LSN agencies outside (or larger than) the stated scope of the LSN CG, such as cybersecurity

The LSN held its annual Interagency Coordination Meeting on November 3, 2003, with presentations and program descriptions from nine Federal agencies and several divisions within

NSF. The LSN Teams also presented their accomplishments and plans. This meeting served as the LSN CG's Special Meeting. Discussion among the meeting participants identified the following three overarching areas where most of the LSN agencies had significant efforts and interests that would benefit from cooperation:

- Network testbed infrastructure
- Network performance measurement
- Grid outreach

These areas are now described.

4.3.1   Network Testbed Infrastructure

Several high performance testbeds are being built to provide an infrastructure for networking researchers within the Federal agencies, some at the national level and others called Regional Operational Networks (RONs). The national networks include:

- NSF's Experimental Infrastructure Networks (EINs)
- DOE/SC's UltraScience Net
- National LambdaRail (NLR)

The RONs include:

- California Research and Education Network 2 (CalREN 2)
- I-Wire (Illinois)
- Mid-Atlantic Exchange (MAX)

There is an opportunity to coordinate connectivity, research, and applications development for these networks to address larger-scale issues such as transparency across the networks. However, controlled-use networks or dual-use networks will be required to assure that researchers doing research for network development (with a high risk of bringing down the network) do not interfere with applications researchers who require highly reliable networks.

The LSN CG tasked the NRT to study the issue of coordination of network testbed infrastructures and report back on their recommendations.

4.3.2   Network Performance Measurement

Many LSN agencies have active network performance measurement programs and others identified the need to measure end-to-end performance for all points of the network. Critical issues include development of standard interfaces and architectures for network performance measurement. This would enable comparisons of performance measurement across network providers to facilitate end-to-end performance measurement, which are needed in identifying and eliminating network bottlenecks and isolating network faults when they occur. The ability to measure and compare performance across network provider boundaries and to isolate network

faults is needed for optimizing end-to-end application performance to take advantage of the increasing network bandwidths.

The LSN CG tasked the JET to investigate mechanisms of coordinating network performance measurement, particularly standard interfaces and architectures, and to provide recommendations on how to improve performance measurement capabilities.

4.3.3   Grid Outreach

Many user and application communities are developing Grid capabilities, often focused on their particular needs. The LSN CG agencies are fostering the development of standardized Grid middleware resources, tools, architectures, and infrastructure to facilitate Grid applications. The LSN CG urged the LSN agencies to provide outreach to the user and application development communities so these users can:

- Benefit from the extensive Grid resource base and tools that currently exist and those that are being developed
- Avoid balkanizing Grid resources by relying on standardized tools, middleware, and architecture rather than unique discipline-specific Grid capabilities
- Benefit from common policies, resource infrastructure, and the Global Grid Forum GGF.[94] The GGF is a community-initiated forum of thousands of individuals from government, industry, and research leading the global standardization effort for Grid computing.

The LSN CG tasked the MAGIC Team to develop a strategy for outreach to Grid user communities to inform them of existing and developing tools, architectures, and capabilities, to promote commonality, and to report back.

4.3.4   Additional Topics for LSN and IWG Coordination

The LSN CG discussion identified three additional topics of interest across several of the CGs that provide opportunities for future collaboration and coordination by the LSN CG and with other CGs. They are:

- Autonomic networking
- High speed transport
- Security

4.4   LSN MULTI-AGENCY ACTIVITIES

4.4.1   Common Interests

The LSN agencies identified a commonality of commitment and interest across a wide range of network research topics, summarized as follows:

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[94] http://www.gridforum.org/

- LSN Agency Networking Programs and Interests
  - Networking Research
    - Basic technologies
    - Optical networks
    - Services
    - Applications
  - Infrastructure
    - Production
    - Experimental
    - Research
  - Collaboration Support
    - Middleware and Grid
    - Collaboration
  - Security
  - Monitoring and Measurement
  - Automated Resource Management
  - Wireless, *Ad Hoc*
    - Wireless/nomadic
    - Crisis response, CIP
    - Sensornet
  - Standards and Specifications
  - Education and Training

4.4.2 Coordination of Network Performance Measurement

The LSN agencies benefit from a strong initiative to coordinate end-to-end performance measurement across the Federal research networks (JETnets, including DOE/SC's ESnet, DOE/SC's UltraScience Net, NASA's NREN, NSF's EINs, DoD's DREN, Abilene, several RONs, and National LambdaRail.) (The complete list of JETnets appears in section 4.5.1.) They are developing a common set of performance measurement tools and capabilities, developing agreements to share performance data among the LSN networking realms, and opening their networks for other LSN networks to measure cross-border performance.

4.4.3 Optical Networking Workshop

At its November 3, 2004 meeting, the LSN CG identified a need to hold a workshop on optical networking. As a consequence, the NASA Research and Education Network (NREN) held a workshop on Optical Networking Testbeds August 9-11, 2004 at NASA Ames Research Center, Moffett Field, California. NREN worked with the LSN agencies to define the objectives, sessions, and key participants. LSN agency representatives participated in the Workshop Organizing Committee to assure that each agency's areas of interest were addressed.

4.4.4 Coordination of Meetings

At LSN CG meetings, the LSN agencies inform each other of upcoming agency meetings and workshops so that program managers from all LSN agencies can participate in and benefit from them.

4.4.4.1 *DREN Workshop on Network Security*

DREN held an interagency workshop on network security in early August, 2004. At this workshop, JET members provided information on their activities, tools, and implementation architectures for network security. The workshop enabled coordination between the Federal research network community and the larger community of Federal networks.

4.4.4.2 *Cooperation on Principal Investigator Meetings*

Individual LSN agencies have adopted a policy of opening Principal Investigator meetings to all other LSN agencies. The researchers benefit from coordinating research plans and results and Federal networking research program managers benefit from a broad view of all the Federal networking research programs.

4.5 LSN TEAM ACTIVITIES

LSN Teams — JET, MAGIC, and NRT — coordinate activities in focused areas of interest with researchers, implementers, and commercial sector participants involved in networking research. The Teams also respond to specific taskings from the LSN CG. The accomplishments, plans, and coordination of the LSN Teams contribute strongly to the objectives of the LSN CG. The LSN Team activities and plans were presented at the November 3, 2003 LSN Interagency Coordination Meeting and are now described.

4.5.1   Joint Engineering Team (JET)

The JET provides for cooperation among the Federal agencies that maintain JETnets and those having an interest in coordinating with or using the JETnets. The JETnets are Federal, academic, and private sector networks supporting networking researchers and advanced applications development. They are:

- Advanced Technology Demonstration Network (ATDnet), established by DARPA and including the Defense Intelligence Agency (DIA), NASA, NRL, NSA, and Bell Atlantic
- DARPA's BOSSnet and SuperNet
- DoD/HPCMPO's DREN
- DOE/SC's ESnet and UltraScience Net
- NASA's NREN and NISN
- National LambdaRail (NLR)
- Next Generation Internet Exchange Points (NGIXs)
- NSF's EINs (now called DRAGON and CHEETAH) and vBNS+
- StarLight, the international optical network peering point in Chicago
- UCAID's Abilene

JET participants include representatives from:

- LSN agencies that operate JETnets: DoD/HPCMPO, DOE/SC, NASA, and NSF
- Other JETnets: Abilene, NLR, and StarLight

- Other LSN agencies – NIH/NLM, NIST, and NSA
- Other interested agencies – USGS
- Other organizations interested in research networking: ANL, ORNL, Indiana University, University of Illinois-Chicago, Cisco Systems, Juniper Networks, and Qwest

JET is focused on:

- Coordinating interconnections among the JETnets
- Providing a forum for collaboration on planning, architecture, implementation, operations, and maintenance among the JETnets
- Encouraging technical consensus and sharing of resources
  - Promoting interoperability and transparency among the JETnets
  - Fostering best practices for advanced networking implementations and infrastructure
  - Enhancing performance to the network edge and end users
  - Encouraging the deployment of interoperable advanced services such IPv6 and Ipv4 and IPv6 multicast
- Serving as a focal point to facilitate operations and resolve emerging problems and technical issues
- Supporting outreach and applications demonstrations to the research network user community (that is, acting as a communication vehicle for the technical community and providing a Federal voice for effective coordination with international research and engineering networks)

Current JET activities include:

- Improving access through Federal peering points and StarLight
- Coordinating and promoting traffic monitoring and performance measurement
- Developing best practices. An example is 9000 Byte Message Text Unit (MTU) size. Increasing the packet size allows transmittal of large amounts of information using fewer packets and results in higher reliability.
- New technology deployment to support the 1 Gigabit Ethernet (1GigE) protocol, 10 GigE, and all-optical networking
- Fostering cooperation on network security best practices
- Coordination with international research networks on connectivity and transparency and cooperation on developing Grid and security standards
- Coordination with MAGIC on network support for Grid applications

Looking forward, the JET will focus on:

- Cybersecurity at line speed
- Firewalls
- Dark fiber deployments and JETnet connectivity to RONs and the NLR
- 10 Gigabits per second (Gbps) Network Interface Cards (NICs)

4.5.1.1 *JET Roadmap Workshop*

The JET held an interagency workshop in April, 2004 at the Thomas Jefferson National Accelerator Facility (JLAB) in Newport News, Virginia, to develop a three-year roadmap for JET activities including coordination of performance measurement, coordination of Federal research network peering points, engineering and coordinating LSN network infrastructure, and coordinating with regional, national-scale, and international research networks.

4.5.1.2 *JETnets Annual Reviews*

Individual JETnets hold annual reviews of their agency-specific programs, plans, and accomplishments. Representatives from other JETnets are invited to participate in these meetings to promote openness, awareness, and opportunities for collaborating and coordinating. For example, several times a year the DOE/SC ESnet holds Joint Techs meetings in coordination with Internet2 meetings. At these meetings the ESnet Steering Committee (ESSC) invites other Federal networks and JET members to participate in their review of ESnet activities.

4.5.2   Middleware and Grid Infrastructure Coordination (MAGIC) Team

MAGIC provides coordination among Federal agencies with responsibility for middleware and Grid projects, individuals involved in middleware and Grid research, individuals involved in implementing or operating Grids, and users of Grids and middleware. MAGIC participants include representatives from the Federal agencies, the commercial sector, academia, and Federally-funded laboratories. Federal agency and Federal lab participants include ANL, DOE/SC, LANL, LBL, NASA, NIH, NIST, NOAA, NSF, PNNL, and UCAR. Non-Federal participants include The Boeing Company, Cisco Systems, Educause, Hewlett-Packard (HP), IBM, Internet2, Information Sciences Institute (ISI), Level3 Communications, Microsoft, the University of Chicago, the University of Illinois at Urbana-Champaign, and the University of Wisconsin.

MAGIC's responsibilities are 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 focuses on Grid middleware and enabling Grid users. Topics of recent concern include:

- Trust models such as implementing policies and architectures for authentication, authorization, accounting, and revocation of authorization. Of particular concern is implementing trust across institutional and international boundaries and models that scale to large numbers of users.
- Intellectual property and open source software
- Program and project updates

MAGIC plans for the coming year are to:

- Collaborate with the larger Grid community, for example, commercial and international sectors
- Promote progress on key technical and policy issues
- Provide outreach to user communities
- Track Grid R&D progress and promote its visibility

4.5.3   Networking Research Team (NRT)

NRT promotes collaboration and exchange of information on networking research. Specifically, its goals are to:

- Coordinate network R&D efforts across member agencies through joint participation in review panels and program reviews
- Conduct interagency workshops to identify R&D gaps in combined portfolios of member agencies
- Coordinate interagency PI meetings to enable researchers to leverage R&D efforts of member agencies
- Carry out tasks assigned by LSN

Members are DARPA, DOE/SC, NASA, NIH/NLM, NIST, and NSF. NRT plans to open participation to the university and commercial sectors to provide broader research and user participation.

NRT held a workshop on Research Needs for Large Scale Networks on May 13-14, 2003 in Lansdowne, Virginia, to address the following fundamental network security concerns:

- To what extent do non-technical obstacles such as economic factors, policy issues, and man-machine interfaces contribute to network security problems in large-scale networks?
- Is there solid evidence that today's large-scale networks are too insecure to serve their intended purposes?
- To what extent are persistent security problems the result of deployment obstacles?
- Would effective cybersecurity technology, had it been adopted, have solved the problems?

The workshop concluded that:

- Definitions, metrics, standards, and models of security are needed.
- Mathematical methods and theoretical research are needed to understand real-world security.
- Experimental research is needed.

In FY 2004, NRT will develop mechanisms for disseminating NRT information such as by using the NRT Web site.[95]

NSF's EINs and DOE/SC's UltraScience Net will provide high performance networks to support networking research.

Other key NRT topics are:

- Survivability of the Internet: A critical infrastructure assessment
- Building on network R&D of other agencies such as on open source issues
- Outreach to other groups with interests in networking research including JET, MAGIC, Canarie2 (Canadian research network), and EU research networks

4.6 LSN AGENCY ACTIVITIES

Each LSN agency focuses on network research programs and activities that address the mission needs of the agency while cooperating with other LSN agencies to meet these needs and to expand their awareness and involvement in other networking areas in their interest. This section reviews the programs and activities of each LSN agency.

4.6.1 NIH/NLM

The NIH/NLM program on Healthcare and the NGI funds testbeds that demonstrate next generation Internet capabilities by the healthcare community including:

- Quality of Service (QoS)
- Security and medical data privacy
- Nomadic computing
- Network management
- Infrastructure technology as a means for collaboration

In FY 2003, NLM initiated a program in Applications of Advanced Network Infrastructure Technology in Health and Disaster Management that funds work on applications that:

- Demonstrate self-scaling technology
- Use self-optimizing end-to-end network-aware real-time technology and/or middleware
- Depend on wireless technology
- Involve advanced authentication such as biometrics or smartcards
- Are nomadic or use GIS technology

The NLM Scalable Information Infrastructure Awards[96] support 11 testbed projects:

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[95] http://www.nitrd.gov/iwg/lsn/nrt
[96] These programs are described at http://www.nlm.nih.gov/research/siiawards.html

- Scalable Medical Alert and Response Technology (SMART)
- An Adaptive, Scalable, and Secure Internet2-Based Client Server Architecture for Interactive Analysis and Visualization of Volumetric Time Series Data
- National Multi-Protocol Ensemble for Self-Scaling Systems for Health
- Project Sentinel Collaboratory
- Advanced Health and Disaster Aid Network (AID-N)
- Advanced Network Infrastructure for Distributed Learning and Collaborative Research
- Advanced Network Infrastructure for Health and Disaster Management
- Wireless Internet Information System for Medical Response in Disasters (WIISARD)
- Advanced Biomedical Tele-Collaboration Testbed
- A Tele-Immersive System for Surgical Consultation and Implant Modeling
- 3D Telepresence for Medical Consultation: Extending Medical Expertise Throughout, Between, and Beyond Hospitals

4.6.2   NSF

4.6.2.1 CISE Directorate

Computing and networking form a continuum of support services for applications on desktop to high-end platforms. Elements of the continuum include distributed computational resources, clusters of computers, Grid infrastructure and applications, and the Extensible Terascale Facility (ETF). The support networking ranges from high-performance, end-to-end, fine-grained to episodic network services using optical, fiber, wireless, satellite, and hybrid network links.

FY 2003 awards are:

- The Networking Research Testbed (NRT) program that supports prototyping and benchmarking as part of networking research. The Computer and Network Systems (CNS) Division manages this program. The NRT program supports research in:

  - Disruptive technologies and approaches
  - Hybrid and experimental designs
  - End-device research
  - Core technology development
  - New protocol research
  - Alternative network architectures
  - Testbed implementations

  Ten NRT program awards were made in FY 2003, including:

  - A unified experimental environment for diverse networks
  - Testing and benchmarking methods for future network security mechanisms
  - Orbit: Open-access research testbed for next generation wireless networks
  - Agile and efficient ultra-wideband wireless network testbed for challenged environments
  - Heterogeneous wireless access network testbed

- o Scalable testbed for next generation mobile wireless networking technologies
- o National radio network research testbed (NRNRT)

- Experimental Infrastructure Network (EIN) supports research applications with high performance networking. EIN is a complementary program to NRT. Some EIN characteristics are:

  - o Control/management of the infrastructure end-to-end
  - o End-to-end performance/support with dedicated provisioning
  - o Pre-market technologies, experimental hardware, and alpha software
  - o Significant collaboration vertically and across sites
  - o Persistence, with repeatable network experiments and/or reconfigurability
  - o Experimental protocols, configurations, and approaches for high throughput, low latency, and large bursts

  Projects include:

  - o Dynamic resource allocation for Generalized Multi-Protocol Label Switching (GMPLS) optical networks (DRAGON)
  - o End-to-end provisioned optical network testbed for large-scale e-science applications, now called Circuit-switched High-speed End-to-End Transport ArcHitecture (CHEETAH)
  - o Cyber defense technology experimental research (DETER) network
  - o PlanetLab: An overlay testbed for disruptive network services
  - o WAN-in-Lab

- NSF has a continuing NSF Middleware Initiative (NMI)[97] program. The program's goal is to design, develop, deploy, and support a set of reusable, expandable middleware functions and services that benefit applications in a networked environment. In FY 2003, 20 System Integrator (SI) awards, sometimes called the "large" awards, were made to further develop the integration and support for long-term middleware infrastructure. Ten other awards focused on near-term capabilities and tool development. NMI awards are:

  - o Disseminating and supporting middleware infrastructure: Engaging and expanding scientific Grid communities
  - o Designing and building a national middleware infrastructure (NMI-2)
  - o An integrative testing framework for Grid middleware and Grid environments
  - o Extending integrated middleware to collaborative environments in research and education
  - o Instruments and sensors as network services: Instruments as first class members of the Grid
  - o Middleware for Grid portal development

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[97] http://www.nsf-middleware.org/

- FY 2003 theme areas for the NSF Strategic Technologies for the Internet (STI)[98] program are:

    o Complex network monitoring, problem detection, and resolution mechanisms
    o Applications that promote collaborative research and information sharing
    o Networked applications tools or network-based middleware
    o Development of automated and advanced network tools
    o Innovative access network technologies

  The FY 2003 STI awards are for:

    o A security architecture for IP telephony
    o Network Startup Resource Center (NRSC)
    o Plethora: A wide-area read-write object repository for the Internet
    o Marist Grid collaboration in support of advanced Internet and research applications
    o Implementation of a handle/DNS server
    o Efficient diagnostic strategies for wide area networks (tools and technologies to detect, diagnose, and correct network faults in local broadcast domains, whether they are wired (Ethernet) or wireless)
    o Development of an infrastructure for real-time super media over the Internet
    o Viable network defense for scientific research institutions
    o The Strategic Technology Astronomy Research Team (START) collaboratory: Broadening participation in authentic astronomy research
    o Network measurement, monitoring, and analysis in cluster computing
    o Toward more secure inter-domain routing
    o eXplicit Congestion control Protocol (XCP) development, potential future transport protocol for high performance network environments
    o Media-aware congestion control
    o Self-organizing spectrum allocation

4.6.2.2 NSF International Connections

NSF funds several international initiatives:

- The TransPac award supports networking to the Asia-Pacific region with two OC-12 Packet Over SONET (POS) links. It supports a 1 GigE circuit between Chicago and Tokyo.
- The StarLight project provides a 10 GigE facility in Chicago to serve as a peering point for international high performance optical research networks including links to CERN and Amsterdam.
- NaukaNet provides OC-3 links to Moscow and Hong Kong.
- AmPath provides OC-2 service from Miami to the Network Access Point (NAP) of the Americas

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[98] http://www.cise.nsf.gov/funding/pgm_display.cfm?pub_id=5381&div=sci

- The TransLight program supports additional optical networking connectivity to Canada (Canarie2 network), Prague, Stockholm, and London.

4.6.2.3 NSF Information Technology Research (ITR) Program

The NSF ITR Program[99] supports research in theme areas that cut across science disciplines and NSF division interests. ITR research areas that are part of the LSN PCA include:

- Cybertrust: projects in operating securely and reliably and assuring that computer systems protect information
- Education and workforce

Large FY 2003 ITR awards related to LSN include:

- Sensitive Information in a Wired World
- Responding to the Unexpected
- Networked Infomechanical Systems (NIMS)
- 100 Megabits per Second to 100 Million Households

4.6.2.4 Extensible Terascale Facility (ETF) Connectivity

Networks connect the computation and storage components at each ETF site and connect the ETF sites with one another. The sites currently are, or soon will be: ANL, Caltech, IU, NCSA, ORNL, PSC, Purdue University, SDSC, and TACC.

4.6.3 DOE/SC

4.6.3.1 Application Drivers for the High-Performance Network Environment

The needs of the DOE/SC scientific research community are growing:

- Petabyte scale experimental and simulation systems will be increasing to exabyte scale data systems in such areas as bioinformatics, climate, and the Large Hadron Collider.
- Computational systems that process or produce data continue to advance with Moore's Law.
- Network requirements are projected to double every year.
- The sources of the data, the computational resources, and the scientists are seldom collocated.

These changes result in increasing demands being placed on DOE/SC's network. For example, five years out, DOE/SC scientists are expected to need the network to:

- Transfer three petabytes per year

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[99] http://www.nsf.gov/home/crssprgm/itr/

- Move a petabyte of data in 24 hours for the high-energy nuclear physics community using secure file movement over a 160 to 200 Gbps "best effort" service
- Provide the cell biology community with shared immersive environments that include multicast and latency and bandwidth guarantees using 2.4 Gbps links with strong QoS guarantees
- Support real-time exploration of remote data sets using secure remote connectivity over one to ten Gbps links to the desktop with modest QoS services
- Support experimental (non-production) networking and Grid research using unused wavelengths

DOE/SC works with its users to identify its mid- and long-term network requirements. Its Office of Advanced Scientific Computing Research (OASCR) is building partnerships among its networking programs, its researchers, and users of its facilities and with other LSN agencies. Other DOE/SC priorities are program integration and priority setting for its facilities and research.[100]

4.6.3.2 UltraScience Net

The UltraScience Net[101] is a new DOE/SC initiative to support a breakable, schedulable, ultra high speed, all-optical network for conducting networking research. Its technologies rely on fundamental hardware research results of other LSN agencies. The first UltraScience Net link, 10 GigE from Oak Ridge to StarLight, was put in place in early 2004. Linking of Sunnyvale (California), CERN, and LBNL is being done cooperatively with NLR. This network will support end-to-end scientific discovery. Towards that end, DOE/SC is supporting:

- Networking research
- Middleware research
- Connectivity with a high-performance production network
- Collaboratory pilots and testbeds

UltraScience Net technologies will be transitioned to a DOE/SC R&E, high-impact science network as the technology is shown to meet requirements. This R&E prototype will be developed in coordination with other LSN agencies. The prototype will support very high throughput data streams and network measurement and diagnosis.

4.6.3.3 Networking Research

DOE/SC networking research programs address end-to-end network measurement and analysis for applications to enable localization and elimination of bottlenecks, effective tuning of the network path for an application, and resolution of performance issues across provider boundaries. DOE/SC is also addressing current protocol limitations for transporting large data sets. New protocols are being developed to support large data transfers. Cybersecurity will be

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[100] http://www.sc.doe.gov/feature/ASCR.htm
[101] http://www.csm.ornl.gov/ultranet/

needed at OC-12 to OC-192 speeds, requiring policy and technology advances. Research is also being carried out in QoS and dynamic provisioning services.

4.6.3.4 Middleware Research

DOE/SC middleware research is focused on:

- Providing transparent and scalable cybersecurity infrastructure
- Developing services to support collaborative scientific work
- Integrating remote resources and collaboration capabilities into local experimental and computational environments
- Facilitating the discovery and use of scientific data, computers, software, and instruments over the network in a controlled fashion

4.6.3.5 ESnet

DOE/SC network facilities and testbed activities include maintaining the high performance production ESnet for DOE/SC mission requirements. DOE/SC has as a goal to transition the R&E prototype described in section 4.6.3.2 to a production environment and to tighten the coupling of the prototype and ESnet.

4.6.3.6 Connectivity

DOE/SC connectivity programs are developing IPv6 protocol implementation, multiplatform video conferencing services, and implementation of distributed network measurement and analysis tools. DOE/SC is coordinating with other LSN agencies and with the university and commercial sectors through:

- Inviting LSN agencies to ESnet Steering Committee meetings
- Tactical coordination with program managers in other LSN agencies with common interests, particularly in the NSF Cyberinfrastructure program

4.6.4   NASA

4.6.4.1 Adaptive Networking

The NASA Research and Education Network (NREN) adaptive networking program is developing a tool called Resource Allocation, Measurement and Adjustment System (RAMAS) to reserve bandwidth for applications, either when requested or later. RAMAS has the following features:

- Passive monitoring and measurement
- Data capture of OC-3 and OC-12 data streams
- GUI-enabled user-defined specifications to designate traffic of interest and types of information to collect on designated flows

- Data collection summarization delivered to a central process/control management system that archives summaries and generates graphical representations
- Interfaces for Ethernet, Asynchronous Transfer Mode (ATM), POS, and wireless

A RAMAS experiment captured low bandwidth wireless data using secure FTP from a field site connected by wireless to a satellite link to mass storage facilities at Ames Research Center and the University of Cincinnati. It identified the difficulty of optimizing TCP for satellite transmissions.

In FY 2004 RAMAS is developing:

- Upgrades to OC-48 and O-192
- Enhanced data archive capabilities
- Enhanced data analysis to reduce massive amounts of data to information
- Security mechanisms to enable use on the NASA Grid (previously called the Information Power Grid)
- A distributable RAMAS package, possibly on a CDROM
- Identification of performance bottlenecks for selected wireless applications

4.6.4.2 Nomadic Networking: Portable Satellite Dishes

NASA's program in nomadic networking is designed to enable NASA science and engineering in remote locations. It has three components: *ad hoc* networking, hybrid satellite and terrestrial networking, and mobile IP/IPv6. Planned FY 2004 activities include:

- Implementing dynamic source routing, an *ad hoc* network routing protocol
- Investigating use of directional antennas
- Using portable satellite dishes to demonstrate mobile IP in a hybrid environment
- Evaluating mobile IP/IPv6
- Deploying a portable Ka-band (radio spectrum from 18 GHz to 31 GHz used in satellite communications) satellite dish in collaboration with HP Labs

A Mobile Agents Field Experiment is developing techniques for planetary exploration, including command of roving vehicles, wireless on-site networking, and autonomous software testing. Experimental components will include the NREN Transportable Earth Station (TES), a rover, all-terrain vehicles, an astronaut, and a remote mission support team at NASA Johnson Space Center.

NASA is also supporting a "ground-truthing" experiment to calibrate satellite-derived geology data with in-situ data taken in real time by on-site geologists. It uses wireless networking and TES to enable researchers to use mass storage facilities, supercomputers, and the Grid to conduct experiments while they are on site. In one experiment, real-time satellite spectro-radiometer data were transported to a mass storage facility while scientists in Utah uploaded ground spectra data to a second facility. The Grid was used to move both data sets to supercomputers at NASA Glenn and NASA Ames Research Centers for analysis. The results were accessed by local

scientists and sent to the remote science team, which used the results to locate and explore new critical compositions of interest.

4.6.4.3 NASA Wide Area Network (WAN) Testbed

NREN has a WAN testbed that connects five NASA Centers and two exchange points. It uses ATM and POS OC-12 and OC-3 circuits. Satellite connectivity is available at the NASA Glenn Research Center. The purpose of the testbed is to conduct research and develop technology to enable next-generation NASA missions, demonstrate NASA applications, and transfer technology to enhance the capabilities of NASA operational networks. In FY 2004 MPLS, IPv6, and Differentiated Services (DiffServ) will be deployed on the NREN backbone. The PCMon network monitoring tool will be integrated on the Transportable Earth Station (TES) platform.

4.6.5 DARPA

DARPA's Information Processing Technology Office (IPTO)[102] has a program in Network Modeling and Simulation. The program supports projects to:

- Develop modeling and simulation tools for on-line measurement and analysis with the goals of designing better protocols and new services such as for dynamic provisioning
- Predict end-to-end performance and vulnerabilities through traffic pattern analysis
- Dynamically optimize performance

One recent accomplishment is the largest network simulation – of a 1.1 million node network – to date. The simulation used 1,500 parallel processors, illustrating the use of parallel processing to improve the scale of network simulations and advance the modeling of network behavior. The simulation results are used to design better and faster protocols. This work was co-funded with NSF.

A DARPA FAST throughput experiment demonstrated 8.6 Gbps throughput using ten simultaneous flows. It demonstrated 34 petabyte meters per second on a path from CERN through StarLight to Sunnyvale, California. This metric attempts to capture the interrelationship between bandwidth and delay.

DARPA held a Network Modeling and Simulation (NMS) PI meeting in January 2004 in Miami, Florida in coordination with other LSN agencies.

DARPA/IPTO FY 2004 plans also include work in Cognitive Networking and Self-Aware Collective Systems:

- *Cognitive Networking* will assess the feasibility of information and communication networks that possess significant degrees of self-reliance and responsibility for their own behavior and survival. This research will focus on self-diagnosis, automatic adaptation to changing and hostile environments, reconfiguration in response to changes in the

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[102] http://www.darpa.mil/ipto/

environment, intelligent negotiation for tasks, and resources and robustness under attack. It will also explore the possibility of a virtual "application-private network" whose on-demand protocols are based on specific application requirements and current network conditions.

- The *Self-Aware Collective Systems* technology thrust will enable heterogeneous teams of individuals (for example, people, software agents, robots) and/or organizations (for example, coalition forces) to rapidly form and easily manage and maintain virtual alliances concerned with a specific task. This thrust comprises two efforts: Self-Aware Peer-to-Peer Systems and Collective Cognitive Information Processing for Improved Asset Performance:

  o *Self-Aware Peer-to-Peer Systems* will develop resilient, scalable sensor/computation networks with decentralized control. This technology will support battlespace awareness by enabling the self-formation of large *ad hoc* networks of sensors and computational elements within the severely resource-constrained environment (power, bandwidth, stealth) of military operations while enabling networks to survive component failure, network intrusion, and the subversion of elements.

  o *Collective Cognitive Information Processing for Improved Asset Performance* will develop learning and reasoning algorithms that can identify and classify emergent problems and opportunities for proactive maintenance of equipment and use of sensors in a dynamic operational environment. These new self-aware distributed systems will be able to reflect globally on their overall operation (including understanding trends), and make decisions based on the collective disposition of assets connected by networked sensors (for example, vehicles or other equipment).

4.6.6   DOE/NNSA

4.6.6.1 Distance Computing

The Distance Computing (DisCom) program is NNSA's primary component of the LSN PCA. DisCom is an element of NNSA's Advanced Simulation and Computing (ASC) Program, formerly the Accelerated Strategic Computing Initiative (ASCI).

DisCom assists in the development of an integrated information, simulation, and modeling capability to support the design, analysis, manufacturing, and certification functions of DOE's Defense Programs complex through developments in distance computing. Distance Computing will extend the environments required to support high-end computing to remote sites. DisCom provides remote access to major ASC platforms — Red, Blue Mountain, White, and Q. In FY 2004, DisCom is delivering additional key communications technologies to efficiently integrate the ASC platforms of Red Storm, Purple, BlueGene/L, and beyond. DisCom will support tools development for more reliable and persistent file-transfer mechanisms over the WAN for FY 2005 deployment.

DisCom cooperates and collaborates with NSA to closely monitor IP encryptor technology.

4.6.7   NIST

NIST supports network-related programs in its Advanced Network Technologies Division (ANTD) and its Computer Security Division (CSD) within its Information Technology Laboratory (ITL). Their mission is to provide the networking industry with the best in test and measurement research. Their goals are to improve the quality of emerging networking specifications and standards and to improve the quality of networking products based on public specifications. Their core technical contributions are:

- Models and analyses from specifications to assess consistency, completeness, precision, and performance characteristics
- Prototypes and empirical studies from specifications to determine feasibility
- Test and measurement tools, techniques, metrics, and data to assess conformance, interoperability, and performance

ANTD's goal is to provide the networking industry with the best test and measurement research. It supports modeling and analysis, testing, developing methods and tools, and prototypes and empirical studies. Research programs include:

- *Pervasive Computing* including Wireless Personal Area Networks (WPAN), service discovery, wireless access networking, wired access, core networks, and wireless ad-hoc networking. Focus areas are UltraWide Band (UWB) and Grid computing.
- *Agile Switching* including routing, signaling, protection, restoration, and network management and metrology
- *Internet Telephony* including session-initiated protocol (SIP) for voice to support nomadic information appliances, particularly for the healthcare industry
- *Infrastructure Protection* for securing core services, secure BGP,[103] and survivable control planes
- *Wireless Ad Hoc Networks* for architecture, routing, and services, particularly standards, and first responder technologies
- *Cryptographic* standards and quantum encryption keys

Details of some projects follow.

4.6.7.1 Resilient Agile Networking

The Resilient Agile Networking (RAiN) program is developing, testing, and standardizing technologies for fault-tolerant, self-adaptive, and ad-hoc networks. A key challenge is to detect network failures and quickly adapt. RAiN projects include:

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[103] BGP is a protocol for exchanging routing information between gateway hosts (each with its own router) in a network of autonomous systems. It generally is the protocol used between gateway hosts on the Internet.

- *Survivable Control Planes:* Work with the Internet Engineering Task Force (IETF) and the Network Processor Forum to define security mechanisms that will scale to performance levels necessary for the core Internet infrastructure. NIST is developing an architecture for Forwarding and Control Element Separation (ForCES) to improve survivability of the Internet infrastructure.
- *Large Scale BGP Attack Modeling* to characterize the performance impact and benefits of various proposed approaches to secure BGP. NIST is modeling, analyzing, and providing visualization tools for global BGP data. This will enable analysis of alternative approaches for BGP router security. It contributes to characterizing BGP mechanisms and vulnerabilities and to developing standards.
- *New Measurement Platforms*
- *Wireless Ad Hoc Networks:* Work with public safety agencies to develop requirements and standards for emerging public safety communication and networking technologies

4.6.7.2 Self-Managing Systems

NIST is conducting research and developing the test and measurement basis and standards foundations for future self-managing systems. This work is being performed in cooperation with DARPA, the Global Grid Forum, Distributed Management Task Force (DMTF), IETF, the Institute for Electrical and Electronic Engineers (IEEE), IBM, Sun Microsystems, Cisco Systems, HP, and others. NIST is:

- Exploring information and knowledge management, learning, and reasoning techniques to enable new levels of autonomic operation of increasingly complex distributed systems
- Establishing the measurement basis to assist the industry in evaluating the behavior and performance of emerging first generation self-managing systems

4.6.7.3 Information Security

NIST programs in information security are focusing on cryptographic standards and applications:

- Secure encryption, authentication, non-repudiation, key establishment, and pseudo-random number generation algorithms
- Standards and guidance for e-Gov and e-Authentication
- PKI and DNS security standards, interoperability, assurance, and scalability
- Wireless and mobile devices and smart card security
- Quantum computing and quantum cryptography (in coordination with DARPA)

4.6.7.4 NIST GLASS: GMPLS/Optical Simulation Tool

NIST is developing a modeling tool to evaluate architectures and protocols for routing, signaling, and managing of GMPLS for optical networks and to support multi-level, multi-protocol schemes for traffic engineering, QoS, protection, and restoration. NIST is developing a modular simulation framework to support:

- Optical network restoration

- MPLS DiffServ protocol recovery
- GMPLS and optical Common Control and Measurement Plane (CCAMP)

NIST is also developing a protection and restoration tool to provide multi-level recovery schemes.

4.6.7.5 NIST Priority Taskings

NIST is responding to tasking to evaluate the economic consequences of IPv6. At the request of the White House, NIST organized a workshop on Spam in January 2004.

4.6.8   NOAA

NOAA's networking and advanced IT strategy is to:

- Explore advanced technologies to make NOAA's vast amount of environmental data available easily, quickly, and completely
- Exploit innovative data access technologies including Web-based tools and agents as they evolve
- Explore emerging security technologies to safeguard NOAA data and information
- Transfer new technology to other NOAA users

NOAA is implementing that strategy through activities such as:

- *Real-time Collaborations* such as Internet@sea and Ocean Share
- *Seasonal-Interannual Climate Collaboration:* Distributed collaboration visualizing the environment
- *Access to Data:* Satellites, radar, aircraft, in situ, and models
- *Fisheries Model Analysis* such as for Pollack larvae in Shelikof Strait in Alaska
- *Hazardous Spill Response*: Anytime, anywhere connectivity

NOAA projects in computer and network security address:

- Encrypted file systems
- Firewalls and intrusion detection at Gigabit speeds
- Automated enterprise-wide patching
- Wireless security

The goal of NOAA's Next Generation Internet program is to use advanced networking technologies to enhance NOAA data collection and dissemination and to support the NOAA HPC architecture. To that end NOAA provides connectivity to seven NOAA sites and to radar sites providing near-real-time weather data. It is developing phased-array radars (NEXRAD) to collect near-real-time weather data. Near-term deployment of these radars will significantly increase data transport requirements.

NOAA is developing discipline-specific user toolsets to support collaboration and Grid applications. It recently demonstrated an advanced Intrusion Detection System (IDS). It plans to explore the use of Grid systems for data handling, computation, and collaboration. It will test deployment of IPv6 at three NOAA sites. NOAA is considering the impact of deploying optical networking on NEXRAD and to meet other NOAA needs.

NOAA is planning to implement additional applications as they become practical, including:

- Collaboratories
- Grid computing
- Storm-scale simulations with immersive environments
- Wireless: Data anywhere, anytime
- Remote operations

4.6.9   NSA

4.6.9.1 Laboratory for Telecommunications Sciences (LTS)

LTS programs continue to emphasize transmission of quantum communications through optical elements. A quantum channel on the same fiber as a SONET channel was demonstrated. This work is joint with DOE/SC.

In FY 2003, NSA demonstrated techniques for regionalized QoS management and developed a model for QoS pricing of Internet services. In FY 2004, NSA plans to join these two efforts to provide a viable pricing model and requisite enforcement mechanisms.

LTS also continued work on critical infrastructure protection issues for converged networks.

4.6.10 DoD/HPCMPO

DoD/HPCMPO's Defense Research and Engineering Network (DREN)[104] maintains a production WAN to support DoD's HEC systems environment. DREN uses MCI to provide DS-3 through OC-768 links and to deploy GigE and 10 GigE services. This network supports IP, IPv6, and multicast with increased security. It supports both Continental United States (CONUS) and Outside the Continental United States (OCONUS) sites with OC-3 and OC-12 peering to OCONUS. MCI expanded the core DREN network to OC-192 in June 2004 and will expand to OC-768 when required. Services it provides include:

- IP performance: Latency, packet loss, and throughput
- ATM availability
- IPv6 and multicast
- Increased security

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[104] http://www.hpcmo.hpc.mil/Htdocs/DREN/dren-def.html

DREN supports scientists and engineering technologists performing networking research throughout the Unites States. It connects to DoD's ATDnet, StarLight, and other experimental networks to support development of new technologies and services. As new technologies and services are developed and mature, they are transitioned to the operational DREN network.

DREN provides connectivity to remote sites including Alaska with OC-3 connectivity and Hawaii with Synchronous Transport Mode1(STM1) services. DREN is coordinating with NASA on connectivity to Alaska and Hawaii.

DREN has had an IPv6 pilot program for several years and now deploys IPv6 native. It supports the Abilene IPv6 Transit Access Point (6TAP) testbed and the IPv6/MPLS end-to-end testbed that will provide users with secure, reliable, global data access by deploying:

- The latest available IPv6 and MPLS services
- Efficient routing using protocols such as BGP+, GMPLS, and Open Shortest Path First (OSPF)
- A range of QoS services
  - Priority, pre-emption, policy, authorization, and audit services
  - Voice, video, and data services support
- Dynamic network monitoring
- Scalable speeds
  - Network test and measurement capabilities
  - Passive monitoring with time-stamping

The DREN performance measurement program is now testing 10 GigE equipment. Supported by the measurement program, DREN is now able to achieve near wire-speed performance over 80 percent of the time across its OC-12 links.

In network security DREN is providing end-to-end WAN encryption. It is developing IPv6 security with beta-testing of NetScreen IPv6 currently in place. It is considering NS-500 firewall protection. [NS-500 is a Gigabit Ethernet security device that uses Virtual Private Network (VPN).]

5. SOFTWARE DESIGN AND PRODUCTIVITY (SDP)

5.1 INTRODUCTION

The Software Design and Productivity (SDP) PCA and CG were established in FY 2001, the same year that High Confidence Software and Systems (HCSS) was renamed to add the word "Software." These developments responded to the 1999 recommendation of the PITAC that the United States "make fundamental software research an absolute priority," which itself reflected the increasing significance of software issues.

The NITRD agencies participating in SDP are NASA, NSF; DOE/NNSA, DARPA, NIH, NIST, and NOAA. DoD/ODDR&E and FAA also participate.

5.2 DEFINITION OF THE SDP PCA

The activities funded under the NITRD Program's SDP PCA will lead to fundamental advances in concepts, methods, techniques, and tools for software design, development, and maintenance that can address the widening gap between society's need for usable and dependable software-based systems and the ability to produce them in a timely, predictable, and cost-effective manner. The SDP R&D agenda spans both the engineering components of software creation and the economics of software management across all IT domains, including the emerging areas of embedded systems, sensor networks, autonomous software, and highly complex, interconnected systems of systems. Today, software development and maintenance represent by far the most costly, time-consuming, labor-intensive, and frustrating aspects of IT deployment in every economic sector. SDP R&D seeks to foster a new era of innovation in software engineering that addresses these serious design issues.

Broad areas of SDP concern are:

- Overall quality of software
- Overall cost – in time, labor, and money – of software development and maintenance
- Growing complexity of software
- Enabling more people to more easily create software and software-based systems
- Need for expertise in emerging software areas such as embedded systems, large-scale sensor networks, autonomous software, and Grid environments
- Workforce development

To pursue these concerns, SDP R&D includes the following technical goals:

- Scientific foundations for creating, maintaining, and improving software that incorporates such qualities as usability, reliability, scalability, and interoperability
- More cost-effective methods for software testing, analysis, and evaluation
- New frameworks for understanding and managing the economics of software
- Methods for developing and evaluating specialized software systems for specific purposes and domains

Illustrative technical thrusts of SDP programs include:

- Development methodologies such as model frameworks; tunable, adaptable processes; component technologies; open source practices for code portability and re-use; integrated environments and tools for development; and programming standards
- Theoretical and technical aspects of programming languages; compilers; software for visualizing and verifying code and data structures; and automatic program synthesis
- Software architectures and component-based methods to incorporate re-usable software resources
- Measuring and managing software quality
- Scalability: Enhancing the ability of software to "grow" along various axes without significant redevelopment
- Interoperability: Software that moves easily across heterogeneous platforms as well as software units that cooperate and exchange information seamlessly
- Fault-tolerant, adaptable software that can continue to function under unexpected conditions
- Enhancing software performance through code modeling and measurement; understanding how to improve runtime effectiveness of applications
- Techniques and tools – including automated approaches, new metrics, and reference data – for testing, analysis, validation, and verification
- Techniques and tools for assessing engineering risks and tradeoffs and estimating and balancing developmental and operational costs
- Specialized and domain-specific software such as for application frameworks, platform reliability, and modeling or control of embedded systems

5.3   SDP CG ACTIVITIES

Since its inception, the SDP CG has worked on developing a common understanding of the SDP R&D terrain. In this process it has worked with the HCSS CG to distinguish their two domains. These efforts contribute to a broader understanding by the policy-making community and the public of software issues and why it is critical that they be addressed.

To achieve this goal, the SDP CG sponsored a workshop in December 2001 at which researchers from academe, industry, and government were encouraged to "think out of the box" about "New Visions for Software Design and Productivity."[105] The participants identified five major facets of the growing problems in contemporary software design and development:

- The large number and inherent complexity of requirements
- Multiple independent sets of requirements and their associated functionalities
- Testing, verification, and certification of large, complex systems

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[105] http://www.nitrd.gov/iwg/sdp/vanderbilt/index.html

- Composition and integration of software from multiple sources
- Multidisciplinary distributed software development

Building on the workshop's conclusions, in FY 2004, the SDP CG began the formulation of a taxonomy of the SDP PCA's domain. The preliminary taxonomy is as follows:

1. Create, maintain, and improve software
    a. Software development methods
        i. Model development framework
        ii. Tunable development processes
        iii. Component technologies
        iv. Open source
        v. Development environments
        vi. Programming standards
        vii. Adaptable systems
        viii. Legacy systems
    b. Languages and tools
        i. Programming languages
        ii. Cross-platform Fortran 90
        iii. Compilers
        iv. Programming environments
        v. Software visualization
        vi. Automatic program synthesis
    c. Runtime environments
2. Investigating and achieving the "-ilities"
    a. Quality management
    b. Platform reliability
    c. Scalability
    d. Interoperability
    e. Robustness
    f. Performance tuning
3. Testing, analysis, and evaluation
    a. Evaluation of complex integrated systems with real-time characteristics
    b. Evaluation of models and simulations
    c. Evaluation of COTS
    d. Metrics and reference data
    e. Automatic verification and validation (V&V)
    f. Testing tools
    g. Software analysis
4. Management and economics
    a. Tools for various aspects of software process management
        i. Project management
        ii. Cost and schedule estimation and prediction
        iii. Cost of testing
        iv. Document management systems
        v. Quality vs. risk measurement and management

5. Software systems for specific domains and specialized software
    a. Application frameworks
        i. Domain-specific tools, etc.
        ii. Specialized software products
        iii. Large-scale data and information access, sharing, security, etc.
        iv. Scientific data management
        v. Visualization and analysis of scientific data sets
    b. Software for platform reliability
        i. Software to model platform architecture
    c. Embedded systems
        i. Software control
        ii. Modeling and simulation
        iii. Self-evolving (adaptable) systems

In FY 2004, the SDP CG began holding briefings by representatives of Federal "IT user" agencies to gather information about software issues from agencies whose missions involve large-scale, critical applications – such as for Social Security records, Medicare transactions, and Internal Revenue systems. The goal is to better understand what IT managers – from their firsthand practical knowledge – perceive to be the key problems of their complex, real-time, real-world software environments. The first briefing of the series was provided by the DHS Customs and Border Protection (CBP) agency, in which the development of a new distributed IT system to manage U.S. export–import procedures was described.

The SDP CG also is planning an FY 2005 workshop to explore software issues in multiscale modeling and simulation of complex physical systems. Modeling and simulation software has become a principal research tool across the sciences, and creating models that combine multiple factors at varying scales — such as climate from global to local scales, or interacting systems in the human body through the shape and functions of protein molecules — is a key opportunity for scientific discovery and a key challenge for both high-end computing and domain sciences. The workshop will bring computer and domain scientists together to assess the state of the art and possible synergies among computational tool sets developed for differing scientific domains.

5.4   SDP MULTI-AGENCY ACTIVITIES

5.4.1   NASA

Earth System Modeling Framework (ESMF) (described in section 2.5.1) partners include DOE/SC, NOAA, and NSF. Other NASA collaborations are:

- Automated software engineering with NSF (described in section 5.5.1.1.1)
- Problem-solving frameworks with DOE/SC and NSF (described in section 5.5.1.1.3)
- Joint work on Grids with DOE/SC and NSF through the Global Grid Forum (described in section 5.5.1.1.3)

5.4.2   NSF

NSF collaborates with NASA, DARPA, and others with overlapping missions, such as in the Highly Dependable Computing and Communications Systems Research (HDCCSR) program with NASA, and the Embedded Systems Consortium for Hybrid and Embedded Research (ESCHER) (described in section 5.4.4) with DARPA.

5.4.3   DOE/NNSA

The Advanced Simulation and Computing (ASC) program is open to collaborations and dialogues with other agencies, such as funding R&D in open source software for high-performance computing. ASC researchers collaborate with ASC university alliance members that are also funded by other NITRD agencies, strengthening the collaborative environment in academic research and education.

5.4.4   DARPA

The Model-Based Integration of Embedded Systems (MoBIES)[106] has an interagency activities aspect - the ESCHER - in which NSF is partnering. ESCHER is a repository of technologies and tools from DARPA and NSF programs in hybrid and embedded systems. The prototypes and documentation are intended to promote rapid transition of MoBIES results to DoD and industry.

5.4.5   NIST

NIST collaborates with a wide range of Federal organizations on SDP-related topics, including the following, about which further information is provided in section 5.5.6:

- Digital Library of Mathematical Functions, with NSF
- NeXus Data Exchange Standard, with DOE/SC
- Numerical Data Markup Language, with DOE/SC
- Product Data Standards for HVAC/R, with DOE
- Product Engineering Program, with DARPA and NASA

5.5   SDP AGENCY ACTIVITIES

5.5.1   NASA

NASA missions are increasingly and critically dependent on complex software systems. In many cases, software cannot be repaired or reloaded after a mission begins. The agency, therefore, has a critical need for:

- Automated software verification and validation tools
- Automated program synthesis
- Evolvable and adaptable software

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[106] http://dtsn.darpa.mil/ixo/programdetail.asp?progid=39

Also, science and engineering applications in general are becoming increasingly complex and multidisciplinary, and require the following distributed collaborative efforts:

- "High performance" applications
- Integration and interoperability of independent components
- Runtime support for efficient discovery, access, and use of distributed resources including data and software

To address NASA missions' SDP requirements, NASA-wide SDP activities can be found in its Computing, Information, and Communications Technology (CICT) Program,[107] Engineering for Complex Systems (ECS) Program,[108] and Earth Science Technology Office (ESTO).[109]

5.5.1.1 Computing, Information, and Communications Technology (CICT) Program

The CICT Program has multiple SDP projects that are spread across three areas including Information Technology Strategic Research (ITSR),[110] Intelligent Systems (IS),[111] and Computing, Networking, and Information Systems (CNIS).[112]

5.5.1.1.1 Information Technology Strategic Research (ITSR)

ITSR has two SDP-related projects. They are Automated Software Engineering Technologies and Evolvable Systems.

In partnership with NSF, the goal of the *Automated Software Engineering Technologies* project is to develop automated mathematical techniques for the software development process, yielding tools for the cost-effective development of high confidence, highly reliable software systems for aerospace applications. Technology development includes:

- Scalable software model checking, automated program abstraction, state-space search algorithms, and formal method verification of integrated modular avionics design to make possible analytical verification of concurrent advanced aerospace software architectures and code
- Program generation through automated reasoning, product-oriented certification methods, and automated tools that certify automatically synthesized code
- The generation of runtime monitors from requirements specifications, automated behavioral verification, machine learning to optimize exploration of potential behaviors, and automated generation of software fault recovery, to enable software that monitors itself and recovers from faults at runtime with minimal computational overhead

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[107] http://www.cict.nasa.gov
[108] http://www.ecs.arc.nasa.gov
[109] http://www.esto.nasa.gov
[110] http://www.itsr.cict.nasa.gov
[111] http://is.cict.nasa.gov
[112] http://cnis.cict.nasa.gov

The goal of *Evolvable Systems* is to dramatically increase mission survivability and science return through development and application of evolutionary and adaptive algorithms. Technology development includes:

- Advanced evolutionary algorithms and automated design and optimization for evolved fault recovery, to enable programmable logic that automatically rewires following damage
- Evolved sensor suite and evolutionary scheduling algorithms to enable sensor electronics that survives extreme radiation and temperature
- Future developments may include defect-tolerant nanosystems, distributed control, and evolved control algorithms for evolvable robotic control and coordination.

On NASA's Technology Readiness Level (TRL) scale – a scale of 1 (basic concept) to 9 (embedded in a mission) – this work is low TRL.

5.5.1.1.2 Intelligent Systems

Intelligent Systems has one project – *Verification and Validation for Autonomy.* The goal is to address the complexity in verifying autonomy systems that operate in rich and uncertain environments with no human intervention due to latency, and that must adhere to internal correctness constraints involving communication among components, control flow, and resource utilization. This project to develop state-of-the-art benchmarking tools for V&V has successfully used rover software to test experimental versions of V&V tools. (TRL level 3.)

5.5.1.1.3 Computing, Networking, and Information Systems (CNIS)

CNIS has five SDP-related efforts:

- Problem Solving Frameworks
- Grid Middleware Services
- Parallel Programming Paradigm
- Automated Programming Tools for Parallelization
- Performance Modeling, Benchmarking, and Optimization

The objective of *Problem Solving Frameworks* (with DOE/SC and NSF) is to develop infrastructures that support the management of simulation, analysis, and data components in application-specific environments. Technical challenges include:

- Component representations that support the access, use, and composition of multi-component applications
- Methods for automatic and user-based generation of work plans
- Efficient management of the flow of work across distributed resources

Expected benefits include:

- Plug-and-play frameworks that allow developers to discover and use components to build multi-component applications to perform new science
- Optimal turn-around time for complex multi-disciplinary and multi-component applications in distributed environments

Projects include:

- Component and Data Representation Models
- GridWorks: Workflow Management Framework
- Computational Intelligence for Aerospace Power and Propulsion (CIAPP) Systems: CORBA-based Framework
- TAF-J: Agent-based Framework
- AeroDB

The goal of *Grid Middleware Services* (with DOE/SC and NSF) is to develop a distributed infrastructure for seamless access to resources that are heterogeneous (computers, data, and instruments), distributed across multiple administrative domains, and dynamically coupled. This involves developing Grid services (for example, application and user-oriented, execution management, Grid management, and data management and access) that provide a useful function independent of the underlying resources, are discoverable, encourage the design and use of reusable software components, and are easily incorporated into application frameworks. NASA was an early sponsor of and active participant in the Global Grid Forum. The runtime aspects of this program also fall under LSN's MAGIC effort.

Parallel Programming Paradigm seeks improvements in parallel programming tools and techniques to increase the performance of HEC systems scaling to thousands of processors, often in a Grid environment of multiple distributed platforms. The portability, scalability, and usability of codes are technology challenges. The effort is evaluating (and, if necessary, extending standards for) parallel multi-level programming paradigms, such as hybrid (vectorization + MPI + OpenMP), and nested OpenMP. Projects are:

- Multi-level Parallelism (MLP)
- MPI + OpenMP Hybrid Parallelism
- Distributed Shared Memory

The objective of *Automated Programming Tools for Parallelization* is to reduce time-consuming and error-prone code porting and development times for applications to run on HEC systems and Grids by providing an integrated set of automated tools for parallelization that retains good performance. Technical challenges include:

- Straightforward porting process
- Accurate, effective code analysis
- Multi-level parallel code generation
- Correct answers with ported code
- Performance analysis

- Good performance

Projects include:

- CAPO: Computer-Aided Parallelizer and Optimizer
- Performance Analysis
- ADAPT: Automatic Data Alignment and Placement Tool
- Automatic Debugging

Performance Modeling, Benchmarking, and Optimization involves developing techniques, strategies, and tools to model, predict, and optimize application performance, and to improve applications' maintainability, portability, and performance in parallel and distributed heterogeneous environments. The technical approach involves:

- Predicting application execution times on various platforms
- Predicting wait times in scheduler queues
- Developing benchmarks to understand the behavior of key NASA applications on single (parallel) and distributed systems
- Understanding application cache usage and optimizing performance of regular and irregular problems

Projects are:

- NAS Parallel Benchmarks
- NAS Unstructured Mesh Benchmarks
- NAS Grid Benchmarks
- Performance Prediction
- Cache Optimization

5.5.1.2 Engineering for Complex Systems

Resilient Software Engineering has two SDP-related projects:

- *High Dependability Computing* to develop tools, case studies, and testbeds to identify and characterize risk precursors in mission software systems. NASA has a user collaboration portal for design and development; computer scientists and mission experts work together on dependability models and metrics. Testing is done on rover software and onboard spacecraft IT systems. The goal of this high-TRL effort is to transfer successful dependability metrics and technologies to missions and industry.

- *Intelligent Software Engineering Software Suite*. The goal of this low-TRL activity is to develop software algorithms, processes, and development procedures to improve software integrity and reliability. The work begins with the study of critical NASA software risks and prototype tool productization (methodology development, tool enhancement, and beta testing), then moves to a tool maturation and evaluation stage

(methodology integration and tool customization), and finally to integration in mission processes and adoption by mission partners.

5.5.2 NSF

5.5.2.1 NSF SDP Support

Applications software development is supported across CISE and specific applications (such as in biology, chemistry, and physics) are developed in other Directorates. Across all NSF Directorates, there will be more emphasis on cyberinfrastructure, including software to support the science and engineering enterprise.[113] A new, cross-divisional "Science of Design" theme is being developed in CISE.[114]

SDP work is funded by CISE and by the ITR program, which involves all NSF Directorates. As of December 2003, there were 1,300 active ITR awards, about 10 percent of which are in SDP research. CISE SDP project areas include:

SEL — Software Engineering and Languages
ASC — Advanced Scientific Computing
EHS — Embedded and Hybrid Systems
NGS — Next Generation Software
DSC — Distributed Systems and Compilers

NSF's SDP research can be mapped into the SDP taxonomy in section 5.3 as follows:

1. Create, maintain, and improve software
   a. Software development methods — ASC, EHS, NGS, SEL, ITR
   b. Languages and tools — ASC, DSC, NGS, SEL, ITR
   c. Runtime environments — DSC, NGS, ITR
2. Investigating and achieving the "-ilities"
   b. Platform reliability — DSC, ITR
   e. Robustness — EHS, SEL
3. Testing, analysis, and evaluation
   b. Evaluation of models and simulations — ASC, DSC, NGS, ITR
   d. Metrics and reference data — SEL, ITR
   e. Automatic V&V — SEL, ITR
   f. Testing tools — SEL, ITR
   g. Software analysis – SEL, ITR
4. Management and economics – SEL, ITR
5. Software systems for specific domains
   a. Application frameworks – ASC, NGS, ITR
   c. Embedded systems – EHS, NGS, ITR

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[113] http://cise.nsf.gov/news/cybr/cybr2.cfm
[114] http://www.nsf.gov/pubs/2004/nsf04552/nsf04552.txt

NSF/CISE held a Science of Design workshop in November 2003.[115]

5.5.3 DOE/NNSA

The Advanced Simulation and Computing (ASC) Program is responsible for providing designers and analysts with a high fidelity, validated, 3D predictive simulation capability to certify the safety, reliability, and performance of the nuclear stockpile in the absence of physical testing. SDP R&D focuses on Problem Solving Environments (PSE), one of four Simulation and Computer Science (SCS) thrusts involved in developing the ASC computational infrastructure. PSE goals are to:

- Create a common, usable application development environment for ASC platforms
- Produce an end-to-end high-performance I/O and storage infrastructure to enable improved code execution
- Ensure secure, effective access to ASC platforms across DOE/NNSA labs for both local and distance computing

FY 2004 priorities include:

- Focus on Red Storm software development environment, preparing for initial delivery and the final integrated platform.
- Plan and prepare software environments for Purple C and BlueGene/L. Planning for new platforms is a significant multi-year activity that involves developing and testing software configurations on smaller platforms and scaling up toward the final ultrascale integrated system.
- Continue performance modeling and measurement for increased effectiveness and efficiency of applications and platforms
- Develop high-performance open source, Linux-based computing environments, targeting capacity computing. Requests for information (RFI) and requests for proposals (RFP) for open source software (OSS) projects are under way.
- Track and test development of Lustre file system for clusters and continue to evaluate alternative file systems.
- Continue to evaluate alternatives to the Distributed Computing Environment (DCE) technology, which DOE/NNSA labs have used for authentication, security, and administrative services, due to technology phase-out at end of calendar year 2005.

5.5.4 DARPA

In FY 2004, DARPA has two programs in the SDP PCA, both within the agency's Information Exploitation Office (IXO). They are:

- Software Enabled Control (SEC)[116] focuses on the design of advanced control systems for innovative vehicles (Unmanned Air Vehicle (UAV), Organic Air Vehicle (OAV),

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[115] http://www.cs.virginia.edu/~sullivan/sdsis
[116] http://dtsn.darpa.mil/ixo/programdetail.asp?progid=39

rotorcraft, fighters), including controls at both the vehicle and mission level. SDP-related technology areas are:

- o Active state models enabling dynamic prediction and assessment
- o Adaptive, dynamic customization of online controls
- o Hybrid, multimodal controls
- o Open-control platform with reusable (CORBA-based) middleware and tool support

Final demonstrations of small rotorcraft and fixed-wing vehicles are scheduled.

- DARPA's Model-Based Integration of Embedded Systems (MoBIES) automates the design, construction, and testing of complex embedded systems by exploiting mathematical relationships between the physical platform, the computational platform, and real-world constraints – that is, "software that is too complex to write manually." Mathematical models are used to meet multiple requirements for application-independent design tools, such as real-time control, network connectivity, fault tolerance, environmental resilience, physical constraints, and component libraries. Resulting tools for designing embedded applications include:

  - o Intelligent programming tools
  - o Smart process schedulers
  - o Communications configuration
  - o Online resource allocation
  - o User interfaces
  - o Automatic code generation
  - o Automatic verification and validation
  - o COTS integration

The MoBIES tool integration framework is being demonstrated in avionics and automotive design projects.

5.5.5 NIH

In FY 2004, the Center for Bioinformatics and Computational Biology of NIH's National Institute of General Medical Sciences (NIGMS) launches several initiatives:

- Establishment of four NIH National Centers for Biomedical Computing:[117] Each center will serve as a node for developing, disseminating, and providing relevant training for computational tools and user environments in an area of biomedical computing.
- A program of investigator-initiated grants to collaborate with the National Centers: The objective is to avoid competition between "big" and "small" science by encouraging collaborations within the Centers.

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[117] http://www.nigms.nih.gov/biocomputing/

- A program for the creation and dissemination of curriculum materials that will embed the use of quantitative tools in undergraduate biology education

The National Centers for Biomedical Computing grants solicitation includes a specific software requirement: Source code supported in this initiative must be shared and users may modify it, creating a pathway to commercialization.

In addition, the FY 2004 grant program of NIH's agency-wide Biomedical Information Science and Technology Initiative (BISTI)[118] includes a category for computer science grants. BISTI also has a program in software development and maintenance.

5.5.6 NIST

SDP-related activities at NIST include:

- *Health*: Informatics, privacy, ubiquitous aids, device controllers, diagnosis aids, decision support, and computer-aided surgery
- *Nanotechnology*: Computer control, modeling, and visualization
- *Information and Knowledge Management*: Data and knowledge bases, formal representations, intelligent access, and manipulation and testing tools
- *Cybersecurity and Critical Infrastructure*: Computer security, encryption, biometrics, monitoring software, and computer forensics as well as precision engineering and calibration for gun-tracing equipment, bullet-proof vests, and other security-related devices
- *Weapons Detection*: Monitoring devices such as sensors, threat-detection information systems
- *Measurement Science*: Conformance testing, scientific visualization and models, intelligent measuring tools, and machine learning tools

Within NIST's Systems Integration for Manufacturing Applications (SIMA) program,[119] SDP-related projects include:

- Automating Equipment Information Exchange (AEX), which aims to automate equipment design, procurement, and operation through software interoperability. Interoperability issues focus mainly on data.
- Digital Library of Mathematical Functions,[120] with NSF. FY 2004 activities include usability studies and completion of the Web site.
- Electronic Commerce for the Electronics Industry (ECEI)[121] – supply chain software interoperability

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[118] http://www.nlm.nih.gov/ep/GrantBISTI.html
[119] http://www.mel.nist.gov/div826/msid/sima/sima.htm
[120] http://www.mel.nist.gov/div826/msid/sima/04_dlmf.html
[121] http://www.mel.nist.gov/div826/msid/sima/04_ecei.html

- IT Infrastructure Conformance Testing[122] – NIST works with industry partners on standards, such as ebXML, a version of XML for electronic business, and is partnering with Korea and Europe on testbeds for trying out b2b solutions.
- Interoperability of Databases for the Structure, Stability, and Properties of Inorganic Materials[123]
- Manufacturing Enterprise Integration involves a testbed and work with industries on software interoperability, including research on automated methods for integrating systems. Research takes an ontological approach, using formal logic, to enable agent technologies and expert systems to automate the process of integrating systems.[124]
- NeXus Data Exchange Standard[125] to have neutron researchers use sharable data structures
- Numerical Data Markup Language[126] to develop UnitsML, an XML schema for encoding measurement units
- Open Architecture Control to develop key interface standards and associated conformance tests to achieve interoperability of manufacturing control systems architectures with security taken into consideration. This has CIP applications, such as electrical generating plants or hydroelectric dams.
- Product Data Standards for HVAC/R[127]
- Product Engineering Program[128] for a semantically-based, validated product representation scheme as a standard for seamless interoperability among CAD systems and with systems that use CAD data
- Standards for Exchange of Instrument Data and NIST Chemical Reference Data[129]
- Standards for Physical and Chemical Property Data Interchange[130]
- Anthropometric Data Standards, with the U.S. Air Force, toward accurate 3-D representation of human measurements; an application is cockpit design.

5.5.7   NOAA

SDP activities focus on using two software modeling frameworks:

- *Flexible Modeling System* (FMS):[131] NOAA's Geophysical Fluids Dynamic Lab (GFDL) uses the FMS programming structure to develop atmosphere, ocean, and coupled climate models for climate projection studies.
- *Earth System Modeling Framework* (ESMF).[132] (Details on ESMF can be found in section 2.5.1.)

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[122] http://www.mel.nist.gov/div826/msid/sima/04_it_infra_ct.htm
[123] http://www.mel.nist.gov/div826/msid/sima/04_inorganic.html
[124] http://www.mel.nist.gov/div826/msid/sima/mee.htm
[125] http://www.mel.nist.gov/div826/msid/sima/04_nexus.html
[126] http://www.mel.nist.gov/div826/msid/sima/04_ndml.html
[127] http://www.mel.nist.gov/div826/msid/sima/04_hvac.html
[128] http://www.mel.nist.gov/div826/msid/sima/pep.htm
[129] http://www.mel.nist.gov/div826/msid/sima/04_spectro.html
[130] http://www.mel.nist.gov/div826/msid/sima/04_chemrefdata.html
[131] http://www.gfdl.noaa.gov/fms/
[132] http://www.esmf.ucar.edu/http://ct.gsfc.nasa.gov/esmf_tasc/index.html

5.5.8   FAA

Safety is the FAA's primary mission. Safety will remain the FAA's top priority as the aviation industry readjusts itself to a world transformed by terrorism and economic challenges. Increasingly, solutions to these challenges depend upon secure and dependable software-based systems and the ability to produce them in a timely, predictable, and cost-effective manner.

The FAA's work straddles SDP and HCSS. FAA HCSS activities are described in section 6.5.7.

6. HIGH CONFIDENCE SOFTWARE AND SYSTEMS (HCSS)

6.1 INTRODUCTION

In FY 2001, the word "Software" was added to the name of the prior High Confidence Systems PCA to reflect the central role played by software in the overall reliability, security, and manageability of the Nation's most complex and critical computing and communications systems. The recommendation to make software a top priority of Federal ITR&D activities had been highlighted by the PITAC in its 1999 report on Federal ITR&D investments. The purview of the High Confidence Software and Systems PCA now includes R&D in all aspects of software development for very-high-assurance trusted systems. The HCSS CG consists of representatives from the following NITRD agencies: NSF, NASA, NSA, NIH, DARPA, and NIST. AFRL, FAA, FDA, and ONR also participate in HCSS CG activities.

6.2 DEFINITION OF THE HCSS PCA

The activities funded under the NITRD Program's HCSS PCA focus on the basic science and information technologies necessary to achieve affordable and predictable high levels of safety, security, reliability, and survivability in U.S. national security- and safety-critical systems realized in critical domains such as aviation, healthcare, national defense, and infrastructure. Many complex software- and information-intensive systems that have high consequences of failure must be certified as to their safety and security. Currently, however, this certification, even when possible at all, requires overwhelming cost, time, and effort, discouraging and delaying innovation of new technologies and processes. The overall HCSS goal, then, is to develop and demonstrate revolutionary capabilities for system development and assurance that balance and reduce risk, cost, and effort to achieve systems that behave in predictable and robust ways. HCSS R&D will help transform our ability to feasibly build certifiably dependable systems in the challenging environment of an increasingly interconnected and automated society.

Broad areas of HCSS concern include:

- Security and privacy
- Safety, robustness, reliability of software and systems
- Trust, risk, and accountability
- Assured development and certification of software and systems
- Survivability

To address these concerns, HCSS R&D pursues the following technical goals:

- Provide a sound theoretical, scientific, and technological basis for assured construction of safe, secure systems
- Develop hardware, software, and system engineering tools that incorporate ubiquitous, application-based, domain-based, and risk-based assurance
- Reduce the effort, time, and cost of assurance and quality certification processes

- Provide a technology base of public domain, advanced-prototype implementations of high confidence technologies to enable rapid adoption
- Provide measures of results

Illustrative technical thrusts of HCSS programs are:

- Foundations of assurance and composition
- Correct-by-construction system design and software technologies
- Evidence and measurement technologies for verification and validation
- Authentication, access control, intrusion detection, trust models, and forensics
- Dependable open, distributed, and networked systems
- Secure and reliable hardware, network, operating system, and middleware technologies
- Dependable and survivable real-time, embedded, and control system technologies
- Verification and certification technologies
- Dependable technologies for transportation, medical devices and health systems, power generation and distribution systems, financial services, and other critical infrastructures
- Experimentation and reference HCSS implementations
- Assured open source software

6.3   HCSS CG ACTIVITIES

Through monthly meetings, the HCSS CG shares information on agency research programs, upcoming meetings, and workshops. It cooperatively supports studies on specific HCSS topics, holds workshops in key research and programmatic areas, and invites other agencies to conferences and PI meetings.

The CG is working in the following areas:

- A study on *Sufficient Evidence? Building Certifiably Dependable Systems*[133] being conducted by the Computer Science and Telecommunications Board of the National Academies is in progress, having been launched in December 2003. The study is sponsored by NSF, NSA, and ONR; AFRL, ARO, DARPA, FAA, FDA, NASA, and NIST also participate. The study entails convening a broad group of experts to assess current practices for developing and evaluating mission-critical software, with an emphasis on dependability objectives. The study committee is addressing system certification, examining a few application domains (for example, medical devices and aviation systems) and their approaches to software evaluation and assurance. The goal is to provide some understanding of what common ground and disparities exist. The committee hosted a workshop on Software Certification and Dependability on April 19-20, 2004 in Washington, D.C. to survey technical, business, and governmental perspectives and to promote dialogue between the research community and government and industry practitioners who develop safety-critical systems.

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[133] http://www4.nas.edu/webcr.nsf/web/a4362b7f9a6cc0c685256da4004cc0f4

- The HCSS CG hosted an Open Verification Workshop on April 12, 2004 in Arlington, Virginia. The workshop provided an opportunity for leading researchers, developers, and users of verification technologies to determine how these technologies might be brought together, potentially in an open environment. Specifics of the workshop included:

  - A discussion by Government attendees on their interest and investments in open verification technologies
  - A keynote address on a verifying compiler grand challenge
  - User perspectives from the ESCHER Consortium and others
  - A planning session

- A set of aviation safety workshops is being planned to address safety issues related to the use of unmanned aerial vehicles in civilian and military airspace. AFRL, FAA, NASA, and NSF are the major planners of these workshops.

- The HCSS CG is holding a High Confidence Medical Device Software and Systems (HCMDSS) Workshop planning meeting on November 16-17, 2004 in Arlington, Virginia to develop a strategy for a larger HCMDSS Workshop to be held in the Spring of 2005.

6.4   HCSS MULTI-AGENCY ACTIVITIES

HCSS agencies are working together to support several collaborative research projects and workshops in assurance, and cybersecurity:

- Via the use of a new NASA testbed facility, NSF and NASA are jointly sponsoring HDCCSR to promote the ability to design, test, implement, evolve, and certify highly dependable software-based systems.

- DARPA, NSF, and other agencies supported the 2003 kickoff of the ESCHER. (More on ESCHER can be found in section 5.4.4.) This group, which has industry support and participation, focuses on system design tools, open source system software, and reference implementations. (ESCHER is included in both the SDP and HCSS PCAs.)

- NSF is supporting a new NAS/CSTB cybersecurity study and invites participation by other agencies.

- FDA and NSF are exploring a joint project to promote computer science student participation at FDA. Students will work to facilitate the transition of software methods and to expand FDA's expertise in identifying software-enabled medical device needs.

6.5 HCSS AGENCY ACTIVITIES

6.5.1 NSF

NSF's HCSS activities reside under Cyber Trust[134] and Science of Design themes in the CISE Directorate and in the NSF-wide ITR Program:

- *Cyber Trust* is a crosscutting initiative that envisions a society in which:

  o Computing systems operate securely and reliably.
  o Computing systems protect sensitive information.
  o Systems are developed and operated by a well-trained and diverse workforce.

  This program supports research on foundations, network security, systems software, and information systems. It sponsors integrated education and workforce activities. Cyber Trust workshops, including PI workshops, are open to participants from other government agencies. A PI workshop was held August 13-15, 2003 in Baltimore, MD.[135] In other current research efforts, NSF is seeking help from other agencies for identifying technology transfer opportunities and creating and distributing relevant cyber trust data sets.

- *Science of Design* is a crosscutting initiative that emphasizes the design of software-intensive computing, information, and communications systems. The goal is to improve the development, evolution, and understanding of systems of large scale, scope, and complexity. These are systems for which software is the main means of conceptualization, definition, modeling, analysis, development, integration, operation, control, and management. A workshop was held November 2-4, 2003 in Northern Virginia to develop the foundations of this program.[136]

- ITR emphasizes national priorities including national and homeland security, which includes research relevant to critical infrastructure protection and SCADA systems.

CISE's Distributed Computing,[137] Embedded and Hybrid Systems,[138] Networking,[139] and Foundations of Computing Processes and Artifacts[140] also include HCSS work.

6.5.1.1 NSF HCSS Projects

NSF funds the following representative projects that address trustworthy systems topics:

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[134] http://www.nsf.gov/pubs/2004/nsf04524/nsf04524.htm
[135] http://www.jhuisi.jhu.edu/institute/cybertrust.html
[136] http://www.cs.virginia.edu/~sullivan/sdsis/workshop%202003.htm
[137] http://www.nsf.gov/pubs/progdesc/2003/cise/2876.html
[138] http://www.cise.nsf.gov/funding/pgm_display.cfm?pub_id=5351&div=cns
[139] http://www.cise.nsf.gov/div/cluster.cfm?div=cns&cluster_id=207
[140] http://www.nsf.gov/pubs/2004/nsf04519/nsf04519.htm

- Cryptography
  - Information Theoretic Secure Hyper-Encryption and Protocols
- Data, Security, and Privacy
  - Data Motion: Dealing With Fast-Moving Data
  - Deployment-Oriented Security and Content Protection
  - Sensitive Information in a Wired World
- High Confidence Control
  - A Unified Framework for Distributed Control with Limited and Disrupted Communication
  - Algorithmic Synthesis of Embedded Controller
  - Symbolic Approaches to Analysis and Hybrid Systems
- Prevention, Detection, and Response
  - A Semantic-Based Approach for Automated Response to Attacks
  - Architectural Solutions for Preventing Distributed Denial of Service Attacks
  - Automated and Adaptive Diversity for Improving Computer Systems Security
  - Forensix: Large scale Tamper-resistant Computer Forensic System
  - Intrusion Detection Techniques for Mobile Ad Hoc Networks
- Systems Software for Protecting Critical Infrastructure
  - Distributed Authentication and Authorization: Models, Calculi, Methods
  - High-Assurance Common Language Runtime
  - Key Management for Secure Dynamic Group Communications
  - Language-Based Software Security
  - Practice-Oriented Provable Security for Higher-Layer Protocols: Models, Analyses and Solutions
  - Security and Privacy for Publish-Subscribe Systems
  - Survivable Trust for Critical Infrastructure
  - Trusted Peer-To-Peer Systems

6.5.1.2 NSF Workshops

In addition to the workshops mentioned above, NSF has funded or co-funded the following HCSS-related workshops:

- CyberTrust PI meeting, August 18-20, 2004, Pittsburgh, Pennsylvania
- Critical Infrastructure Protection for SCADA and IT Systems,[141] October 20-21, 2003, Minneapolis, Minnesota
- ARO/NSF/ONR/AFOSR Workshop on Software Engineering for Embedded Systems,[142] September 24-26, 2003, Chicago, Illinois
- Computing Research Association Workshop on Grand Research Challenges in Information Security and Assurance, November 16-19, 2003

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[141] http://www.adventiumlabs.org/NSF-SCADA-IT-Workshop/
[142] http://www.cs.uic.edu/~shatz/SEES/

- Two linked workshops that took place in September 2002, Landsdowne, Virginia:
  - o NSF/OSTP Technical Workshop on Information Technology for Critical Infrastructure Protection[143] (final edited report in progress)
  - o International Workshop for R&D Strategy for Sustaining an Information Society: Dependability of Infrastructures and Interdependencies (U.S.-EU Collaboration)

6.5.2   NSA

NSA's Information Assurance Research Group (IARG)[144] promotes HCSS activities through three product assurance capability threads:

- *Trusted by Design* to help software engineers achieve assured designs and reduce the cost of certifying the security of complex information systems
- *Trusted by Analysis* to assess the confidence in a system that has been built outside of NSA control and whose assurance is unknown
- *Containment* to balance granularity of protection against ease of use and cost

Three research areas comprise IARG's HCSS roadmap:

- *Foundations* to develop the supporting theory and scientific basis for HCSS such as automatic theorem proving, design and analysis of protocols, interoperability and composition and decomposition of agents, and systems security and survivability architectures. Activities include:

  - o National Academies certifiability study described in section 6.3
  - o Protocol Specification and Synthesis, an effort on foundational methods of secure communication, with the goal of providing methods and tools upon which the design, analysis, and implementation of security structures might be carried out

- *Tools and technologies* for building high confidence systems of the future through the development of a technology capability that can apply the theoretical foundations of high confidence. Projects include:

  - o Specware, an environment supporting the design, development, and automated synthesis of correct-by-construction software
  - o Cryptol, a programming language focused solely on the domain of cryptography, and recently adopted by General Dynamics
  - o Vulnerability Discovery, focused on developing and demonstrating a support environment for the analyst who is interested in software system vulnerabilities
  - o Java Program Verification Condition Generator, a tool that uses formal analysis to eliminate classes of errors during software development of Java programs

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[143] http://www.eecs.berkeley.edu/CIP
[144] http://www.nsa.gov/ia/index.cfm

- Formal analysis of hardware/software co-design
- Biospark – reliability engineering in biometrics that teamed HCSS, smart card, and biometrics researchers
- Polyspace, a project focused on evaluating the fitness for use of the commercial Polyspace static verifier for detecting runtime software errors

- *Engineering and experimentation* to demonstrate the effectiveness and efficiency of HCSS technologies on diverse hardware and software platforms. These include the following projects:

  - Trusted Web server, focused on developing a cross-domain server that can be certifiable for simultaneous connection to networks spanning two or three domains
  - Osker – the Oregon Separation Kernel, a prototype Portable Operating System Interface (POSIX)-compliant operating system in Haskell (see the next bullet) that provably achieves a strict separation between processes according to a specified security model. Osker is a challenge application for the Programatica project, a system for developing high-assurance software.
  - Haskell on Bare Metal (HBM), an adaptation of the Haskell runtime system, to replace the usual operating system layers between application and hardware
  - Java applet generation, an automatic generator that produces Java Card applets from high-level formal specifications
  - AAMP7 development environment, a partition-aware development environment for Rockwell Collin's AAMP7 microprocessor, that will allow rapid development of partitioned AAMP applications

6.5.2.1 NSA HCSS Conference

NSA hosted its fourth annual HCSS conference on April 13-15, 2004, in Linthicum, Maryland. Additional HCSS agencies participated. This meeting showcased recent technical accomplishments, promising research activities, and future research directions, all focused on improving the confidence of software and systems. Highlights of the technical program included:

- Tutorials on both domain-specific and general purpose program development environments
- A keynote address on a verifying compiler grand challenge
- Two sessions of invited talks by leading industrial and academic experts in the field of high confidence software and systems engineering
- A panel of government, industry, and academic experts motivated by the verifying compiler grand challenge
- A final session of technical talks focused on NSA-sponsored research and centered on the theme of transparency, that is, the creation of an intelligent, secure, flexible, and self-protecting global infrastructure for information assurance (IA)-provisioning of critical end units

6.5.3   NASA

NASA missions have several critical needs that HCSS R&D helps address. They are:

- Mission and safety critical software
- High confidence software within predictable cost and schedule
- High confidence for new types of software such as model-based autonomy and adaptive control
- Sustained engineering (for example, the International Space Station and the Space Shuttle)
- Security for ground and radio frequency networks

Several major programs span the technical readiness level (TRL) scales from one to nine where nine is reached after serving on the shuttle for 50 flights. Low TRL work spans a variety of HCSS-related research areas, mid TRL is work in transition to practice, and high TRL work has a strong process orientation. These programs include:

- Low to mid TRL
    - Computing, Information and Communications Technology Program (CICT)
    - Highly Dependable Computing Platform (HDCP) Testbed

- Mid TRL
    - Mission Data Systems (MDS)
    - Office of Safety and Mission Assurance

- High TRL
    - Software Engineering Initiative (SEI)
    - Software Assurance Program

Each is now described.

6.5.3.1 Computing, Information, and Communications Technology (CICT)

The CICT Program aims to develop automated mathematical techniques for the software development process, yielding tools for the cost-effective development of high confidence, highly reliable software systems for aerospace applications. Its goal is to develop technologies with enhanced capabilities to:

- Analytically verify the next generation of aerospace software that includes:
    - Scalable software model checking
    - Automated program abstraction
    - State-space search algorithms
    - Formal method verification of integrated modular avionics design

- Produce certifiable program synthesis for the following technologies:
    - Program generation through automated reasoning

o Product-oriented certification methods
o Automated tools that certify automatically synthesized code

- Develop adaptive, integrated software verification and monitoring technology, including:
  o Runtime monitors generated from requirements specifications
  o Automated behavioral verification
  o Machine learning to optimize exploration of potential behaviors
  o Automated generation of software fault recovery

These capabilities would then be applied to specific missions such as the Space Station and the Mars Lander.

6.5.3.2 Highly Dependable Computing Platform (HDCP) Testbed

The HDCP testbed effort provides a modern software platform for real-time embedded systems. The approach is to evaluate real-time Java to address in-flight software demands and use the MDS (described in section 6.5.3.3) framework and software as a testbed. While NASA typically runs older hardware on the International Space Station and the Hubble telescope because that hardware is known to be hardened against radiation, it develops software on modern workstations and then ports that software to the older hardware. The real-time Java needs to have demonstrably lightweight CPU usage and provide the desired throughput and response. NASA needs to be sure that timing jitters don't surface and cause problems.

6.5.3.3 Mission Data Systems (MDS)

In preparation for the launching of a mission to Mars in 2009, all needed technologies should be in place in 2005. MDS is developing a reusable infrastructure for flight and ground software for that mission. Specifically, MDS is integrating the best systems engineering and software engineering practices for autonomous control of physical systems. The program was developed for unmanned space science missions involving spacecraft, landers, rovers, and ground systems. It is broadly applicable to mobile and immobile robots that operate autonomously to achieve goals specified by humans. It is also architecturally suited for complex interactive systems where "everything affects everything."

As complexity grows, the line between specifying behavior and designing behavior is blurring. For each of the items in the following illustrative list, systems engineers need to know and want to specify the item, while software engineers want to design software that knows the item:

- How a system is put together (connections and other interactions)
- What functions each element performs (models of behavior)
- How system elements might fail (models of faulty behavior)
- What the environment is like and how it affects the system (more models)
- What the system must be able to do (scenarios and their objectives)
- What operating constraints the system must honor (flight rules, etc.)
- What resources the system must manage (power, data storage, etc.)

The MDS approach is through product line practice to exploit commonalities:

- Define a reference architecture to which missions and products conform
- Provide framework software to be used and adapted
- Define processes for systems engineering and software development

An example is state analysis for embedded systems. The Mars science lab now has some 10,000 state variables. The relationship between each pair (for example a disk drive's power and the heat it produces) is described, and the software is designed to include rules on determining and controlling state. This effort helps systems engineers and software engineers use the same vocabularies.

6.5.3.4 Office of Safety and Mission Assurance Research Program

This program encompasses the following:

- Software assurance practices for auto-generated code:
    - Evaluation of available artifacts from autocode processes
    - Verification of the code generator

- Software assurance practices for COTS integration:
    - V&V of interface to COTS
    - Validation of a COTS application for an intended purpose

- Software assurance practices for reused or heritage software:
    - Reuse or heritage factors that impact software risk
    - Appropriate level of software assurance for reused or heritage code

- Reliability of operating systems

- Tandem experiment to improve software assurance

- Independent Verification and Validation (IV&V): IV&V is verification and validation performed by an organization that is technically, managerially, and financially independent. IV&V focuses on mission critical software, provides addition reviews and analyses, and provides in-depth evaluation of life cycle products that have the highest level of risk. Examples of IV&V activities include:

    - Validation of design to meet system needs and requirements
    - Traceability of safety critical requirements
    - Code analysis of mission-critical software components
    - Design analysis of selected critical algorithms

    IV&V research examines:

    - The effectiveness of existing IV&V effort estimating tools

- Effectiveness of identification of error prone artifacts
- Effectiveness of analysis activities as applied to an artifact
- Effective tailoring of IV&V effort to desired risk reduction levels
  - o Identification of appropriate techniques, artifacts, and NASA projects for practical IV&V model checking
  - o IV&V of software development processes
  - o The appropriateness of IV&V for reused or heritage software
  - o Return on investments

6.5.3.5 Software Engineering Initiative (SEI)

This program was initiated because of the growing complexity, size, and sophistication of software components to meet NASA needs and enhance NASA's software engineering capabilities. An example of this complexity and size is the two Mars missions that landed in January 2004 have 625,000 lines of source code. The goal of the SEI is to advance software engineering development, assurance, and management practices to meet NASA's S&T objectives. Elements of SEI include:

- Plans from each center to improve software process and products
- The use of Carnegie Mellon University's Software Engineering Institute's Capability Maturity Model (CMM) as benchmarks for assessments
- Infusion of the "best of the best" software engineering research and technology
- Software metrics to monitor the SEI's progress and to provide early warning of problems
- Effective guidelines, principles, and standards
- Enhanced knowledge and skills in software engineering through training, education, and information exchange
- Improved software acquisition capabilities

6.5.3.6 Software Assurance

The aims of the Software Assurance program are:

- Software risk mitigation
- Improved quality of software products while using risk mitigation techniques
- Project management insight into software development processes and products throughout the life cycle
- Early error detection, problem prevention, and risk identification and mitigation
- Improved quality of future products and services

The level of software assurance needed is dependent on the software size, complexity, criticality, and level of risk. Software assurance covers practices for auto-generated code, COTS integration, and reused or heritage software. Software assurance work is performed in the following areas:

- Standards
- Guidance

- Policy
- Contractor evaluation criteria
- Metrics
- Means to classify software across NASA
- IV&V
- Research
- Benchmarking
- Outreach

Software assurance involves both software safety and software reliability:

- Software safety includes a systematic approach to identifying, analyzing, tracking, mitigating, and controlling software hazards and hazardous functions (data and commands) to ensure safer software operation within a system.

- Software reliability is the process of optimizing the software through emphasis on requiring and building in software error prevention, fault detection, isolation, recovery, tolerance, and/or transition to planned reduced functionality states. It also includes a process for measuring and analyzing defects in software products during development activities in order to find and address possible problem areas within the software.

6.5.4   DARPA

DARPA's current major HCSS effort is in Self-Regenerative Systems (SRS).[145] The objective of the SRS program is to develop a military exemplar system that shows it is possible to:

- Provide 100 percent critical functions at all times in spite of attacks
- Learn about one's own vulnerabilities to improve survivability over time
- Regenerate service after attack

The result of these activities will be intrusion-tolerant systems that gracefully degrade and recover after an attack by reconfiguring and self-optimizing.

SRS technical areas include:

- *Biologically-Inspired Diversity* to reduce common software vulnerabilities to attack by providing different versions of software with different implementations and configurations.

- *Cognitive Immunity and Healing* systems that incorporate biologically inspired response strategies and machine learning to identify and correct root causes of vulnerabilities.

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[145] http://www.darpa.mil/ipto/solicitation/open/09-44_PIP.htm

- *Reasoning About Insider Threats* to pre-empt insider attacks or detect system overrun by combining and correlating information across system layers, inferring user goals, and enabling effective detection.

- *Granular, Scalable Redundancy* to survive massive attacks or extreme hostility. The approach includes exploiting environmental knowledge for scalability or performance (for example, quorum protocols) and to develop probabilistic consistency protocols that will survive extremely hostile environments and provide "good enough" service.

FY 2004 plans also include research in Security-Aware Systems. The goal of a security-aware system is to minimize unavoidable cyber risk to military missions by having the system itself smoothly adapt to changing resources, building blocks, security requirements, mission goals, and threats. A security-aware system will reason about its own security attributes, capabilities, and the utility of its functions with respect to a mission context. It will dynamically adapt to provide desired levels of service while minimizing risk and providing coherent explanations of the relative safety of service level alternatives.

6.5.5 NIST

Two divisions in the Information Technology Laboratory – the Software Diagnostics and Conformance Testing Division (SDCTD) and the Computer Security Division (CSD) – are the primary NIST organizations involved in HCSS activities.

The SDCTD mission is to develop software testing tools and methods that improve quality, conformance to standards, and correctness, and to work with industry to develop forward-looking standards. Within this division, five technical areas are important to HCSS:

- *Electronic Commerce* focuses on extensible markup language (XML) core technologies. World Wide Web Consortium (W3C) interoperability testing in messaging and smart card services will be conducted. NIST aims to develop and automate consistent, complete, and logical specifications and turn these into performance testing for eventual commercial use.

- *E-Health* includes Health Level Seven (HL-7)[146] standards and conformance and establishment of a standards roadmap so that medical devices, hospital systems, and other healthcare service provider systems can talk to each other while protecting patient privacy. NIST is working with the Department of Veterans Affairs as a trusted impartial "third party" among providers, researchers, manufacturers, and others to promote effective access control procedures.

- *Computer Forensics* is work with the FBI and the National Institute of Justice to develop a National Software Reference Library (NSRL)[147] and to develop specifications and

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[146] http://www.hl7.org/about/
[147] http://www.nsrl.nist.gov/

evaluations of computer forensics tools[148] to use in efficiently analyzing seized property such as disk drives and verifying that rules of evidence are observed.

- *Pervasive Computing* to develop wireless service discovery protocols for devices such as palm pilots to assure trustworthy interactions.

- *Test Method Research* involves fundamental work in automatically generating tests from formal specifications in a cost-effective manner and in object-oriented component testing.

New opportunities for FY 2004 include conformance testing for medical devices and test suites for medical device communication standards; using the NSRL for data reduction, integrity management, and computer security applications; and investigating Grid computing systems vulnerabilities to identify requirements for maintaining system robustness.

The CSD mission is to improve information systems security in the following ways:

- Raise awareness of IT risks, vulnerabilities, and protection requirements
- Research, study, and advise agencies of IT vulnerabilities and devise techniques for cost-effective security and privacy of sensitive Federal systems
- Develop standards, metrics, test, and validation programs
- Develop guidance to increase secure IT planning, implementation, management, and operation

Programs within CSD encompass the following areas:

- *Security Technologies* – cryptographic standards, key management, public key infrastructure (PKI), identity management, protocols and e-government, and agency e-government support

- *Systems and Network Security* – technical guidelines, checklists, smart cards, wireless/mobile, Intrusion Detection System (IDS), ICAT,[149] IP Security (IPSec), authorization management, automated testing, and quantum cryptography

- *Management and Assistance Program* – outreach, expert assistance, policy and guidelines, Information Security and Privacy Advisory Board (ISPAB)

- *Security Testing and Metrics* – security control development, certification and accreditation, cryptographic module validation, laboratory accreditation, and the National Information Assurance Partnership (NIAP)

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[148] http://www.cftt.nist.gov/
[149] A searchable index of standardized vulnerabilities with links to patches is at http://icat.nist.gov

New CSD opportunities include:

- Standard Reference Model (SRM) for source code security - to develop a metric for automated tools to review security properties of software and an SRM database of known security flaws such as buffer overflow and trap doors
- Trust and confidence taxonomy "-ilities" toolkit for reliability, interoperability, security, etc.

6.5.6   AFRL

AFRL in Dayton, Ohio is working on developing certifiability requirements for autonomous aircraft that operate in civilian and military airspace.

6.5.7   FAA

FAA's Chief Information Office (CIO) focuses on security, processes (enterprise architecture), and education issues. The Office must co-sponsor its research, have an FAA customer, and either have a short-term focus or collaborate with others on longer-term issues.

Over the past three years, FAA has evolved a systematic approach to defending the air traffic control system against cyber attack:

- Harden individual system and network elements
- Isolate elements to avoid "viral" spread
- Replicate elements to avoid service disruption

This strategy is difficult because of the size and complexity of the air traffic control system, the increased use of COTS products, and the safety-critical nature of the air traffic control system. Significant challenges such as building trustworthy systems with untrustworthy components remain.

FY 2004 Office of the Assistant Administrator for Information Services and CIO (AIO) activities are:

- Rapid quarantine capability
- Wireless information systems security
- A Common Criteria test lab
- Integrity and confidentiality lab
- Estimating security costs
- A software reliability pilot
- Biometrics for single sign on
- Data mining for vulnerabilities

6.5.8   FDA

FDA, through its Center for Devices and Radiological Health and work with other agencies, develops medical devices that require high confidence, assured, safe software to deliver quality medical care. The FDA Office of Science and Technology leverages funds to work with other agencies. Research interests focus on formal methods of design in three areas:

- Safety and safety modeling
- Certification issues
- Forensic analysis

Specific research projects include:

- An intelligent litter platform Life Support for Trauma and Transport (LSTAT) (with Walter Reed Army Medical Center) (safety and safety modeling)
- Proton beam therapy device (safety and safety modeling)
- Software for an infusion pump with a control loop, which led to an initiative of similar control loop software for a ventilator device (certification)
- Blood bank software regulation (certification)
- Radiation treatment planning systems that employ reverse engineering of C programs to look for inconsistencies and errors in brain tumor analysis (forensics)
- Unintended function checker (with NSA) (forensics)

7. SOCIAL, ECONOMIC, AND WORKFORCE IMPLICATIONS OF IT AND IT WORKFORCE DEVELOPMENT (SEW)

7.1 INTRODUCTION

The SEW PCA was established in FY 2000 as the successor to the Education, Training, and Human Resources (ETHR) PCA. The new name reflects the broader portfolio of research issues the new PCA covers. The agencies reporting SEW investments are NSF, NIH, NASA, DOE/NNSA, and DOE/SC. Other agencies that participate in SEW activities are DOC, DOL, ED, GSA, HHS, and NSA.

7.2 DEFINITION OF THE SEW PCA

The activities funded under the NITRD Program's SEW PCA focus on the nature and dynamics of IT impacts on technical and social systems as well as the interactions between people and IT devices and capabilities; the workforce development needs arising from the growing demand for workers who are highly skilled in information technology; and the role of innovative IT applications in education and training. SEW also supports efforts to transfer the results of ITR&D to the policymaking and IT user communities in government at all levels and the private sector. Amid today's rapid global transformations driven by IT, SEW research aims to provide new knowledge to help society anticipate, identify, understand, and address the diverse issues of the digital age.

Broad areas of SEW concern include:

- Economic, organizational, social, and educational transformations driven by new information technologies
- Participation in the digital society, including e-government
- Intellectual property and privacy rights
- Innovative applications of IT in education
- Workforce development

To pursue these concerns, SEW R&D has the following technical goals:

- Develop baseline empirical findings about the complex interactions between people and information technologies
- Support training to expand the skilled IT workforce
- Increase understanding of intellectual property and privacy issues in the digital society
- Promote linkages between the SEW research community and policymakers
- Demonstrate innovative IT applications for education

Illustrative technical thrusts of SEW programs are:

- Interactions and complex interdependencies of information systems and social systems

- Collaborative knowledge environments for the management of dynamic information and tools for social-network analysis
- Application of information technology to law and regulation
- Technologies and tools to facilitate large-scale collaboration through distributed systems
- Technologies in and theories of e-business, supply chains, economics of IT, productivity, and related areas
- Innovation in computational modeling and simulation in research and education
- Advanced graduate training in the strategically important IT fields of bioinformatics and computational science
- Efforts to eliminate barriers to IT workforce participation for women and minorities
- Experimentation with cutting-edge networked applications for engineering training and K-14 science and mathematics education

7.3   SEW CG ACTIVITIES

The SEW CG has two related but distinct components: (1) education and workforce development activities and (2) activities involving the socioeconomic implications of IT. NSF is the sole NITRD agency pursuing research in the latter area, while the other SEW agencies' investments lie in the former. Because of the breadth of this portfolio, the SEW Coordinating Group (CG) has taken on a character somewhat different from those of the CGs devoted to IT research topics that engage multiple agencies. The SEW CG has developed a program of briefings on themes of interest to agencies beyond the ITR&D community. Subjects have included intellectual property issues in open source software, issues in creating a national health information infrastructure, and trends in IT workforce demographics and their implications for education and training.

Since FY 2002, the CG has also supported, through its Universal Accessibility Team, the development of a new program of workshops sponsored by GSA and the Federal CIO Council to foster collaboration among government and community implementers of IT and to demonstrate promising IT capabilities emerging from Federal research.

Each of these evolutionary directions has sought to position the SEW CG as a communications link between IT researchers and policymakers and implementers of IT applications. In FY 2004, the SEW CG's principal activity is an examination of how its role and structure have changed since the PCA's inception.

7.4   SEW UNIVERSAL ACCESSIBILITY TEAM ACTIVITIES

The monthly Collaboration Expedition Workshops,[150] completing their third year in FY 2004, bring together a diverse group of IT researchers, developers, and implementers representing such fields as emergency preparedness and response, healthcare, environmental protection, and citizen services. Drawing between 60 and 100 participants each month, the workshops also assist Federal program managers in coordinating necessary steps to implement the Administration's Federal Enterprise Architecture (FEA) Program in their agencies.

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[150] http://ua-exp.gov/

The workshops have developed into a crossroads for software and system developers, IT managers and implementers, and public service practitioners across all levels of government, in the private sector, and in local communities. Each monthly meeting includes demonstrations of emerging technologies and prototype applications for developing intergovernmental "citizen-centric" services, and discussions of barriers and opportunities in applying technologies to enhance citizen-government interactions. The goal is to accelerate multi-sector partnerships around IT capabilities that help government work better on behalf of all citizens. Sample meeting topics are:

- Taxonomies and the Semantic Web (XML and XML Schema, Resource Description Framework/Schema [RDF/S], DARPA Agent Markup Language [DAML]+Ontology Inference Layer [OIL] and the new Web Ontology Language OWL, derived from DAML+OIL)
- Extensible Federal Enterprise Architecture components that transcend "stove-piping" through open standards technologies
- Realistic citizen-service scenarios for benchmarking performance
- Audio e-book technology
- Multi-channel communication and information services, including dynamic knowledge repositories
- Web-based collaboration

7.5 SEW AGENCY ACTIVITIES

7.5.1 NSF

NSF's SEW portfolio encompasses a broad range of efforts, from studies of the socioeconomic implications of the ongoing digital revolution, to explorations of how IT can enhance government-citizen interactions, to research on ways to expand and better prepare the Nation's IT workforce, to R&D on innovative applications of information technologies in education and training. In FY 2004, these elements of SEW research are supported under a variety of programs, as follows:

7.5.1.1 Information Technology Research (ITR) Program

The ITR program, a major foundation-wide interdisciplinary initiative, began its fifth and final year of grant awards in FY 2004. The program's new focus for FY 2004 – Information Technology Research for National Priorities – emphasizes R&D areas of interest to SEW. For example, the FY 2004 ITR solicitation calls for proposals that integrate research and education activities or foster the development of a diverse IT workforce.

In addition, the solicitation calls for SEW research related to the following National Priorities:[151]

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[151] These National Priorities, NITRD Program Grand Challenges, and IT Hard Problem Areas are described in *"Grand Challenges: Science, Engineering, and Societal Advances Requiring Networking and Information Technology Research and Development."*

- Advances in Science and Engineering (ASE), which could include research on technologies and tools to facilitate large-scale collaborative research through distributed systems

- Economic Prosperity and Vibrant Civil Society (ECS), which seeks projects that investigate the human and socio-technical aspects of current and future distributed information systems for economic prosperity and a vibrant civil society. Examples of topics include human and social aspects of distributed information systems for innovation, business, work, health, government, learning, and community, and their related policy implications.

- National and Homeland Security (NHS), which includes research on critical infrastructure protection and technologies and tools for understanding threats to national security

Under the overarching FY 2004 theme, ITR proposals must address one or more of four specified technical focus areas. The following two of the four directly address SEW research interests:

- Interactions and complex interdependencies of information systems and social systems
- Innovation in computational modeling or simulation in research or education

In addition, a total of about 100 ITR grants awarded in prior fiscal years for SEW-related research are continuing in FY 2004.

7.5.1.2 CISE Directorate

In the new FY 2004 divisional reorganization of the CISE Directorate,[152] a substantial portion of SEW-related research is housed in the Systems in Context cluster of the Division of Information and Intelligent Systems (IIS),[153] under the following programs: Digital Government; Digital Society and Technologies (DST); and Universal Access.

As part of the CISE Directorate's overarching FY 2004 emphasis on education and workforce issues, SEW-related research in educational technologies and IT workforce development is also supported under the Combined Research and Curriculum Development and Educational Innovation Program and the Information Technology Workforce Program. These two programs reside in the Education and Workforce Cluster[154] of the Division of Computer and Network Systems (CNS).[155]

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[152] http://www.cise.nsf.gov/
[153] http://www.cise.nsf.gov/div/index.cfm?div=iis
[154] http://www.cise.nsf.gov/priority_areas/educ_and_work.cfm
[155] http://www.cise.nsf.gov/div/index.cfm?div=cns

7.5.1.2.1   CISE/IIS Division

SEW-related research is conducted in the Digital Government, Digital Society and Technologies, and Universal Access thrusts of the IIS Division's "Systems in Context" Cluster. In FY 2004, the Digital Government thrust supports research that advances IT applied to governmental missions and/or research that enhances our understanding of the impact of IT on the structures, processes, impact, and outcomes within government, both from the perspective of government agencies and from the viewpoint of the citizenry at large. Sample research topics include the capture of government decision-making processes; the application of information technology to law and regulation; software engineering of large-scale government projects; on-line campaigning and e-voting; new forms of civic engagement and interaction enabled by IT; failures and successes of IT adoption in government; disintermediation – direct citizen-agency interaction and services; implications and impact of IT on democracy and forms of governance; and the impact of more transparent and understandable government processes and decision making enabled by IT.

In FY 2004, the Digital Society and Technologies thrust is emphasizing:

- *Universal Participation in a Digital Society* – Research seeking to understand the underlying processes by which IT shapes and transforms society and society simultaneously shapes and transforms new IT, and how these transformations impact the goal of universal participation in our democratic society. Areas of study include e-commerce, digital science, the IT workforce, community networking, and digital governance.

- *Collaborative Intelligence* – This area includes theories, models, and technologies for distributed, intelligent, collective action among humans, agents, robots, and other embedded devices. The focus is on:

    o The science of collaboration (design principles, mixed initiative and adjustable autonomy problems, and implicit and explicit, affective and instrumental human-machine interactions)
    o Distributed intelligence (knowledge representation, management and fusion, science of coordination, and division of labor)
    o Systems for managing trust, reputation, and other critical elements in heterogeneous, dynamic, distant relationships

- *Management of Knowledge Intensive Enterprises* – Research to understand how structured, global collections of knowledge can be brought to bear on complex decision-making processes so that processes can rapidly reconfigure and re-schedule resources while the enterprise remains stable enough to carry out routine processes and achieve high levels of performance. The focus is on:

    o Adaptive scheduling and control of product dynamics, rapid reconfiguration and rescheduling of human and machine resources
    o Learning hidden workflow rules to optimize workflow

- o Distributed decision-making and appropriate schemes for distributing decision authority throughout hierarchies, and understanding how information is shared, partitioned, and flows to the right places
- o How we measure the productivity of dynamically re-configuring business processes and local vs. global problems such as performance across levels of analysis
- o Collaborative knowledge representation, acquisition, retrieval, and inference

- *Knowledge Environments for Science and Engineering* – Research focused on:

  - o Identifying the requirements of distributed scientific practices and how scientific practices are changing (for example, due to more complex data sets or more interdisciplinary teams) and to what consequence
  - o Understanding barriers to adoption and use and building trust across geographic boundaries and on how resources can be shared
  - o Understanding the governance issues related to distributed work practices, facilities, and shared resources
  - o Understanding copyright restrictions, information privacy, and open source software issues related to collecting and harvesting knowledge across geographic and social boundaries

- *Transforming Enterprise* – Research focused on:

  - o Technologies and theories of electronic business, supply chains, economics of IT, productivity, etc.
  - o Technologies and theories of collaborative and distributed work, including the development and use of collective knowledge representations and open source software development of human and machine resources
  - o Understanding the various legal, social, and cultural issues when information, software, and autonomous proxies flow across boundaries
  - o Understanding how to value information and evaluate risks and reputations in transactions with distant strangers
  - o Understanding and mitigating information balkanization

In FY 2004, the third thrust emphasizes Universal Access, which will develop new knowledge about how IT can empower people with disabilities, young children, seniors, and members of other traditionally under-represented groups to participate fully in the digital society.

7.5.1.2.2   CISE/CNS Division

CNS's Workforce and Education cluster supports projects that integrate research and education across CISE, study the causes of the current lack of diversity in the IT workforce, and lead to a broadening of participation by all under-represented groups. The cluster works closely with all CISE Divisions to achieve these goals. It also coordinates the participation by CISE in a portfolio of NSF-wide education and workforce programs.

FY 2004 SEW-related projects in the Information Technology Workforce Program seek to develop and implement promising strategies to reverse the underrepresentation of women and minorities in IT education and careers.

SEW-related efforts in the CISE Combined Research and Curriculum Development and Educational Innovation Program for FY 2004 focus on the design, development, testing, and dissemination of innovative IT approaches for increasing the effectiveness of educational experiences, including integration of research results into courses and curricula.

7.5.2   NIH

NIH's National Library of Medicine (NLM)[156] is the pioneer supporter of advanced training in bioinformatics, whose practitioners bring both high-end computer science and medical expertise to the healthcare arena. The need for bioinformatics skills spans biomedical research applications, telemedicine, and large-scale healthcare 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 practitioners.

Training efforts in FY 2004 include:

- *Institutional Grants*: NLM supports training grants in medical informatics at ten major universities. They are intended to train predoctoral and postdoctoral students for research in medical informatics. Some offer special track training in such informatics-intensive fields as radiation oncology and biotechnology.[157]

- *Individual Fellowships*: Informatics Research Training. Post-doctoral health science workers who identify a mentor, institution, research project, and curriculum are eligible to compete for these fellowships. They complement the institutional programs (described above) by making it possible for students to enter informatics training at any institution with appropriate mentor and facilities.[158]

- *Applied Informatics*. These fellowships support training for those who will design or manage large information systems, or adapt applications developed by research workers to actual use in a clinic setting, classroom, laboratory, library, or office. Although many applicants will have doctorates, nurses, librarians, and other health professionals without doctoral degrees are encouraged to apply.[159]

- *IAIMS*: Over the last decade, NLM has supported the development of Integrated Academic Information Management Systems in selected major medical centers. The experience gained by those who, through on-the-job training, have developed and

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[156] http://www.nlm.nih.gov/, http://www.nlm.nih.gov/pubs/factsheets/trainedu.html
[157] A description of the programs, with fields of emphasis, is available from NLM Extramural Programs (EP) at (301) 496-4621.
[158] Further details are available at EP at (301) 496-4621.
[159] Further details are available at EP at (301) 496-4621.

implemented complex integrated information systems, will now be systematically exploited through designated training slots at IAIMS sites.[160]

- *Biotechnology*: For recent doctoral graduates, the National Research Council Research Associateship Program provides an opportunity for concentrated research in association with selected members of the National Center for Biotechnology Information (NCBI) scientific staff.[161]

- *Woods Hole*: The Marine Biological Laboratory at Woods Hole, Massachusetts, conducts an annual NLM-sponsored one-week course in Medical Informatics. Thirty trainees are selected from applicants in health professions, research, and librarianship. They receive intensive hands-on experience with a variety of medical information systems, including medical informatics, expert systems, and molecular biology databases. Trainees have most costs covered.[162]

- *HBCU Toxicology Information Outreach*: NLM's Toxicology Information Program (TIP) supports projects designed to strengthen the capacity of Historically Black Colleges and Universities (HBCUs) to train medical and other health professionals in the use of toxicological, environmental, occupational, and hazardous wastes information resources developed at NLM. A number of HBCUs with schools of medicine, pharmacy, and nursing participate in the program, which includes training and free access to NLM's databases.[163]

- *Medical Informatics Elective*: The Computer Science Branch, Lister Hill National Center for Biomedical Communications (LHNCBC), conducts an eight-week elective in Medical Informatics, as part of NIH's Clinical Electives Program. Each spring this elective combines an extensive seminar series by senior figures in the field with an independent research project under the preceptorship of an LHNCBC professional. Eight to fourteen fourth-year medical students are admitted each year.[164]

- *Medical Informatics Training Program*: LHNCBC conducts a Medical Informatics Training Program to provide support for faculty members, postdoctoral scientists, graduate students, and undergraduate students for research participation at the Center through visits of a few months to several years.[165]

7.5.3   NASA

The Learning Technologies Project (LTP), NASA's educational technology incubator, funds activities and collaborates with endeavors that incorporate NASA content with revolutionary technologies or innovative use of entrenched technologies to enhance education at all levels in

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[160] Further details are available at EP at (301) 496-4261.
[161] Further details are available by contacting David Lipman, M.D., NCBI, NLM, at (301) 496-2475.
[162] Further details are available by contacting Ms. Catherine N. Norton, Director, Information Technology, Marine Biological Lab, Woods Hole, MA 02543 at (508) 548-3705 x341.
[163] Further details are available by contacting Gale Dutcher, TIP, NLM, at (301) 496-3147.
[164] Further details are available by contacting May Cheh, LHNCBC, at (301) 435-3193.
[165] Further details are available by contacting May Cheh, LHNCBC, at (301) 435-3193.

the areas of science, technology, engineering, and mathematics (STEM). LTP's mission is to efficiently develop world-class educational products that:

- Are poised for the widest possible market diffusion that inspire and educate.
- Use innovative methods or emerging technologies.
- Address educational standards utilizing NASA data. These products account for diverse learning environments whenever applicable and wherever possible.

FY 2004 projects include:

- *Animated Earth* – developing IT capabilities to provide Internet-accessible animated visualizations of important Earth Science processes, events, and phenomena to students, educators, and the public, using NASA remote sensing and model data; includes work to determine which standards and protocols will be adopted to convey these visualizations over the Internet and to implement and document a public server-side infrastructure to deliver these visualizations using the chosen standards and protocols

- *Information Accessibility Lab* – research aiming to provide software tools that enable development of assistive instructional software applications for sensorily impaired K-12 students; use a combination of graphing, sonification, and mathematical analysis software to represent mathematical and scientific information; and provide unique NASA-technology teaching tools that enhance STEM education for sensorily impaired students

- *What's the Difference?* – research to develop a simple-to-use software component that uses richly visual and highly interactive comparisons to teach science and math concepts; design the component so that additional information and new information sets can be developed and easily added by curriculum developers; enable developers of educational software applications to use the visual comparison componentry and information in their applications; provide information sets and tool capabilities beyond those delivered for this project's phase 1 effort

- *Virtual Lab* – R&D to provide students and their educators with virtual but realistic software implementations of sophisticated scientific instruments commonly used by NASA scientists and engineers; design and implement the virtual instruments such that additional specimens can be added easily and additional instruments can be used to study the same specimens; build on the LTP Phase 1 Virtual Lab by expanding the set of specimens for the Virtual Scanning Electron Microscope; provide mechanisms to enable independent applications to invoke and contain the virtual instruments

7.5.4   DOE/NNSA

Academic Strategic Alliance Program (ASAP):[166] Through partnerships with universities, this element of the Advanced Simulation and Computing (ASC) Program pursues advances in the

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[166] http://www.llnl.gov/asci/alliances/alliances.html

development of computational science, computer systems, mathematical modeling, and numerical mathematics important to the ASC effort. By supporting student involvement in these research efforts, ASAP aims to strengthen education and research in areas critical to the long-term success of ASC and the Stockpile Stewardship Program (SSP).

7.5.5   DOE/NNSA and DOE/SC

DOE Computational Science Graduate Fellowship (CSGF):[167] Funded by the Office of Defense Programs and Office of Science, this program works to identify and support some of the very best computational science graduate students in the Nation. This fellowship has supported more than 120 students at approximately 50 universities. The fellowship program is administered by the Krell Institute in Ames, Iowa.

7.5.6   GSA

GSA's Office of Intergovernmental Solutions and the Federal CIO Council's Emerging Technology Subcommittee sponsor the Expedition Workshop Series of monthly open workshops for representatives of Federal, State, and local government, community organizations, and the private sector to explore how to create a citizen-centric governance infrastructure supported by new technologies. Expedition Workshop objectives are to:

- Accelerate mutual understanding of the FEA initiative and commitments toward intergovernmental collaboration practices needed to implement the E-government Act of 2002 (P.L. 107-347)
- Accelerate maturation of candidate technologies
- Expand intergovernmental collaboration and facilitate development of communities of practice
- Provide a forum for discussion of and experimentation with new IT capabilities and "best practices" in IT applications and deployment

By bringing IT developers and researchers together with practitioners across a broad range of government and citizen service sectors, the workshops are developing a collaborative "incubator" process to facilitate emergence of a lasting enterprise architecture by providing:

- Realistic citizen-service scenarios for benchmarking performance
- Innovation practitioners with multilateral organizing skills
- Faster maturation and transfer of validated capabilities among intergovernmental partners
- Extensible e-gov components that transcend "stove-piping" through open standards technologies

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[167] http:// www.krellinst.org

Appendix A: Overview of NITRD Agency Missions

This appendix is a contextual overview of the missions of the NITRD agencies. Much of this material is from agency Web sites.

A.1. National Science Foundation (NSF)

NSF,[168] established in 1950, has the mission of promoting the progress of science; advancing the national health, prosperity, and welfare; and securing the national defense. NSF is authorized to engage in the following activities:

- Initiate and support, through grants and contracts, scientific and engineering research and programs to strengthen scientific and engineering research potential and education programs at all levels, and appraise the impact of research upon industrial development and the general welfare
- Award graduate fellowships in the sciences and in engineering
- Foster the interchange of scientific information among scientists and engineers in the United States and in foreign countries
- Foster and support the development and use of computers and other scientific methods and technologies, primarily for research and education in the sciences
- Evaluate the status and needs of the various sciences and engineering and take into consideration the results of NSF evaluations in correlating its research and educational programs with other Federal and non-Federal programs
- Provide a central clearinghouse for the collection, interpretation, and analysis of data on scientific and technical resources in the United States, and provide a source of information for policy formulation by other Federal agencies
- Determine the total amount of Federal money received by universities and appropriate organizations for the conduct of both basic and applied (excluding developmental research) scientific and engineering research and the construction of facilities where such research is conducted, and report annually thereon to the President and the Congress
- Initiate and support specific scientific and engineering activities in connection with matters relating to international cooperation, national security, and the effects of scientific and technological applications upon society
- Initiate and support scientific and engineering research, including applied research, at academic and other nonprofit institutions and, at the direction of the President, support applied research at other organizations
- Recommend and encourage the pursuit of national policies for the promotion of basic research and education in the sciences and engineering. Strengthen research and education innovation in the sciences and engineering, including independent research by individuals, throughout United States.
- Support activities designed to increase the participation of women, minorities, and others under-represented in S&T

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[168] http://www.nsf.gov

Information Technology's importance to furthering NSF's scientific and engineering mission is evident in many of the Foundation's disciplinary and crosscutting research programs. However, most of the ITR&D is carried out in the Directorate for Computer and Information Sciences and Engineering (CISE).[169] CISE promotes basic research and education in the computer and information sciences and engineering and helps maintain the Nation's preeminence in these fields.

In December 2003, CISE was reorganized into four divisions: the Division of Computing and Communication Foundations (CCF); the Division of Computer and Network Systems (CNS); the Division of Information and Intelligent Systems (IIS); and the Division of Shared Cyberinfrastructure (SCI). Each division is organized into a small number of clusters that are responsible for managing a portfolio of grant and proposal competitions within a broad area of research and education. While individual program directors may be designated as the point of contact for specific sub-disciplines, collaboration will take place within each cluster, across each division, and between divisions and directorates.

NSF also has identified a number of crosscutting CISE emphases for FY 2004 that require multidisciplinary collaboration and directorate- and/or NSF-wide involvement. These are Cyber Trust, the Science of Design, Information Integration, and Education and Workforce. The goal is to create a broad portfolio of awards (individual, group and, in some cases, center) within each of these areas.

NSF NITRD programs cover all seven PCAs.

A.2. National Institutes of Health (NIH)

Founded in 1887, NIH[170] is the Federal focal point for medical research in the United States. Comprising 27 separate institutes and centers, NIH is one of eight health agencies of the Public Health Service that is part of the U.S. Department of Health and Human Services.

The goal of NIH research is to acquire new knowledge to help prevent, detect, diagnose, and treat disease and disability. The NIH mission is to uncover new knowledge that will lead to better health for everyone. NIH works toward that mission by conducting research in its own laboratories; supporting the research of non-Federal scientists in universities, medical schools, hospitals, and research institutions throughout the country and abroad; helping in the training of research investigators; and fostering communication of medical and health sciences information.

NIH programs cut across all seven NITRD PCAs and across many of NIH's 27 institutes and centers.

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[169] http://www.cise.nsf.gov/
[170] http://www.nih.gov

A.3. National Aeronautics and Space Administration (NASA)

NASA was established in 1958. The NASA vision is to improve life here, extend life there, and find life beyond. Its mission is to:
- Understand and protect our home planet
- Explore the universe and search for life
- Inspire the next generation of explorers

Until recently, NASA accomplished its mission through seven strategic enterprises:[171]

- Earth Science
- Space Science
- Biological and Physical Research
- Aeronautics
- Exploration Systems
- Space Flight
- Education

NASA NITRD programs are found primarily in the NASA Research and Education Network,[172] Computing Networking Information and Communications Technologies Program,[173] Engineering for Complex Systems,[174] and Earth Science Technology Office.[175] These programs cut across all seven NITRD PCAs.

A.4. Defense Advanced Research Projects Agency (DARPA)

DARPA[176] was established in 1958 as the first U.S. response to the Soviet launching of Sputnik. Since that time DARPA's mission has been to assure that the United States maintains a lead in applying state-of-the-art technology for military capabilities and to prevent technological surprises from its adversaries. The DARPA organization is unique, reporting directly to the Secretary of Defense and operating in coordination with, but completely independent of, the military R&D establishment.

The DARPA mission is to develop imaginative, innovative, and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches, and to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems.

Most of DARPA's NITRD activities are found in the Information Processing Technology Office (IPTO) and cut across the following PCAs: HEC R&D, HCI&IM, LSN, SDP, and HCSS.

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[171] Future documentation will be consistent with NASA's new organizational structure.
[172] http://www.nren.nasa.gov
[173] http://www.cict.nasa.gov
[174] http://www.ecs.arc.nasa.gov
[175] http://www.esto.nasa.gov
[176] http://www.darpa.mil/index.html

A.5. Department of Energy (DOE)

DOE[177] was established in 1977 under the Department of Energy Organization Act. Its overarching mission is to advance the national, economic, and energy security of the United States to promote scientific and technological innovation in support of that mission and to ensure the environmental cleanup of the national nuclear weapons complex.

The Department has four strategic goals toward achieving this mission:

- *Defense Strategic Goal*: To protect U.S. national security by applying advanced science and nuclear technology to the Nation's defense
- *Energy Strategic Goal*: To protect U.S. national and economic security by promoting diverse supply and delivery of reliable, affordable, and environmentally sound energy
- *Science Strategic Goal*: To protect our national and economic security by providing world-class scientific research capacity and advancing scientific knowledge
- *Environment Strategic Goal*: To protect the environmental legacy of the Cold War and by providing for the permanent disposal of the Nation's high-level radioactive waste

The ITR&D elements of DOE are carried out in two organizations – DOE's Office of Science (DOE/SC)[178] and the National Nuclear Security Administration[179] (DOE/NNSA).

A.5.1 DOE/Office of Science (DOE/SC)

DOE/SC is the single largest supporter of basic research in the physical sciences in the United States – providing more than 40 percent of total funding – and is the principal Federal funding agency of the Nation's research programs in high-energy physics, nuclear physics, and fusion energy sciences.

The Office of Science manages fundamental research programs in basic energy sciences, biological and environmental sciences, and computational science. In addition, the Office of Science is the Federal Government's largest single funder of materials and chemical sciences. It supports unique and vital parts of U.S. research in climate change, geophysics, genomics, life sciences, and science education.

Most of the DOE/SC NITRD programs are found in the Advanced Scientific Computing (ACSR) program and are carried out by the Mathematical, Information, and Computational Sciences (MICS) subprogram. The mission of ASCR is to discover, develop, and deploy the computational and networking tools that enable researchers in the scientific disciplines to analyze, model, simulate, and predict complex phenomena important to DOE. To accomplish this mission the program fosters and supports fundamental research in advanced scientific computing – applied mathematics, computer science, and networking – and operates supercomputer, networking, and related facilities. The applied mathematics research efforts

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[177] http://www.doe.gov
[178] http://www.sc.doe.gov
[179] http://www.nnsa.doe.gov

provide the fundamental mathematical methods to model complex physical and biological systems. The computer science research efforts enable scientists to efficiently run these models on the highest performance computers available and to store, manage, analyze, and visualize the massive amounts of data that result. The networking research provides the techniques to link the data producers (for example, supercomputers and large experimental facilities) with scientists who need access to the data. The research programs of ASCR have played a critical role in the evolution of high performance computing and networks.

DOE/SC NITRD programs are part of the HEC I&A, HEC R&D, HCI&IM, LSN, and SEW PCAs.

A.5.2   DOE/National Nuclear Security Administration (DOE/NNSA)

The mission of NNSA is to:

- Enhance U.S. national security through the military application of nuclear energy
- Maintain and enhance the safety, reliability, and performance of the U.S. nuclear weapons stockpile, including the ability to design, produce, and test, in order to meet national security requirements
- Provide the U.S. Navy with safe, militarily effective nuclear propulsion plants and to ensure the safe and reliable operation of those plants
- Promote international nuclear safety and nonproliferation
- Reduce global danger from weapons of mass destruction
- Support U.S. leadership in science and technology

DOE/NNSA NITRD programs cut across the HEC I&A, HEC R&D, LSN, SDP, and SEW PCAs.

A.6. Agency for Health Research and Quality (AHRQ)

AHRQ[180] is a part of the U.S. Department of Health and Human Services and is the lead agency charged with supporting research designed to improve the quality of healthcare, reduce its cost, improve patient safety, decrease medical errors, and broaden access to essential services. AHRQ sponsors and conducts research that provides evidence-based information on healthcare outcomes; quality; and cost, use, and access. The information helps healthcare decisionmakers – patients and clinicians, health system leaders, and policymakers – make more informed decisions and improve the quality of healthcare services. It was reauthorized from the Agency for Healthcare Policy and Research (AHCPR) by the Healthcare Research and Quality Act of 1999 (P.L. 106-129).

The Act affirms the agency's existing goals and research priorities:

- Support improvement in health outcomes
- Strengthen quality measurement and improvement

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[180] http://www.ahrq.gov

- Identify strategies to improve access, foster appropriate use, and reduce unnecessary expenditures

More specifically, the legislation directs AHRQ to:

- Improve the quality of healthcare by:

  - Coordinating, conducting, and supporting research, demonstrations, and evaluations related to the measurement and improvement of healthcare quality
  - Developing annual reports to the Nation on trends in healthcare quality and trends in healthcare disparities
  - Disseminating scientific findings about what works best and facilitating public access to information on the quality of and consumer satisfaction with healthcare

- Promote patient safety and reduce medical errors by:

  - Developing research and building partnerships with healthcare practitioners and healthcare systems to reduce medical errors
  - Establishing the Centers for Education and Research on Therapeutics (CERTs) as a permanent program. This initiative helps reduce adverse drug events by conducting state-of-the-art clinical and laboratory research to increase awareness of both the uses and risks of new drugs and drug combinations, biological products, and devices as well as of mechanisms to improve their safe and effective use. The CERTs initiative was originally established as a short-term demonstration program under the Food and Drug Modernization Act of 1997.[181]

- Advance the use of information technology for coordinating patient care and conducting quality and outcomes research by:

  - Promoting the use of information systems to develop and disseminate individual provider- and plan-level comparative performance measures
  - Creating effective linkages between various sources of health information to enhance the delivery and coordination of evidence-based healthcare services
  - Promoting the protection of individually identifiable patient information used in health services research and healthcare quality improvement

- Expand the agency's existing commitment to research on the cost and use of healthcare services and access to services by:

  - Establishing an Office of Priority Populations to ensure that the needs of these populations are addressed throughout the agency's intramural and extramural research portfolio
  - Supporting research on the cost and utilization of and the access to healthcare

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[181] http://www.fda.gov/cdrh/modact.pdf

      o   Maintaining a Center for Primary Care Research and supporting the work of the U.S. Preventive Services Task Force

AHRQ participates in the HCI&IM and LSN PCAs.

A.7. National Security Agency (NSA)

Established in 1951, NSA[182] recently celebrated its 50th anniversary. NSA has two missions:

- An information assurance mission to provide the solutions, products, and services and to conduct defensive information operations to achieve information assurance for information infrastructures critical to U.S. national security interests
- The foreign signals intelligence or SIGINT mission to allow for an effective, unified organization and control of all the foreign signals collection and processing activities of the United States

Most of the NITRD work in which NSA participates is located in the Information Assurance arena. This research is carried out primarily in the Laboratory for Telecommunications Research and the Information Assurance Research Group and covers the HEC R&D, LSN, and HCSS PCAs.

A.8. National Institute of Standards and Technology (NIST)

Founded in 1901, NIST[183] is a non-regulatory Federal agency within the U.S. Commerce Department's Technology Administration.[184] NIST's mission is to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life. NIST carries out its mission in four cooperative programs:

- NIST Laboratories that conduct research to advance the Nation's technology infrastructure and research needed by U.S. industry to continually improve products and services

- Baldridge Quality Program, which promotes performance excellence among U.S. manufacturers, service companies, educational institutions, and healthcare providers; conducts outreach programs and manages the annual Malcolm Baldrige National Quality Award that recognizes performance excellence and quality achievement

- Manufacturing Extension Partnership, a nationwide network of local centers offering technical and business assistance to smaller manufacturers

- Advanced Technology Program, which accelerates the development of innovative technologies for broad national benefit

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[182] http://www.nsa.gov/about/index.cfm
[183] http://www.nist.gov
[184] http://www.technology.gov/

NIST NITRD activities are found primarily in NIST Laboratories, and specifically within the Divisions of Information Access, Software Diagnostics and Conformance Testing, Computer Security, and Advanced Network Technologies in the Information Technology Laboratory[185] and the Manufacturing Systems Integration Division in the Manufacturing Engineering Laboratory.[186]

NIST participates in the HEC I&A, HCI&IM, LSN, SDP, and HCSS PCAs.

A.9. National Oceanic and Atmospheric Administration (NOAA)

NOAA's[187] vision is to move NOAA into the 21st century scientifically and operationally, in the same interrelated manner as the environment that is observed and forecasted, while recognizing the link between the global economy and the planet's environment.

NOAA's mission is to understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet U.S. economic, social, and environmental needs. NOAA's role, in facing the challenges of the environment, the economy, and public safety, is to assess and predict environmental changes, protect life and property, provide decision makers with reliable scientific information, manage the Nation's living marine and coastal resources, and foster global environmental stewardship.

To achieve its mission, NOAA's focus through 2008 will be on four mission goals:

- Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management
- Understand climate variability and change to enhance society's ability to plan and respond
- Serve society's needs for weather and water information
- Support the Nation's commerce with information for safe, efficient, and environmentally sound transportation

NOAA's NITRD activities are supported through the Office of the Chief Information Officer and High Performance Computing and Communications (CIO/HPCC).[188] The functions of the CIO/HPCC are to:

- Lead NOAA's principal IT research through the NOAA High Performance Computing and Communications (HPCC) program
- Provide advice to NOAA management on information resources and information systems management
- Promote and shape an effective strategic and operational IT planning process for NOAA
- Coordinate the preparation of NOAA's IT budget and associated materials

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[185] http://www.itl.nist.gov/
[186] http://www.mel.nist.gov/
[187] http://www.noaa.gov
[188] http://www.cio.noaa.gov/

- Oversee selected NOAA-wide operational IT systems and services
- Oversee other assigned programs that are interagency and/or international in scope

NOAA participates in the HEC I&A, HEC R&D, HCI&IM, LSN, and SDP PCAs.

A.10. Environmental Protection Agency (EPA)

EPA's[189] mission is to protect human health and to safeguard the natural environment upon which life depends.

EPA's purpose is to ensure that:

- All Americans are protected from significant risks to human health and the environment where they live, learn, and work.

- National efforts to reduce environmental risk are based on the best available scientific information.

- Federal laws protecting human health and the environment are enforced fairly and effectively.

- Environmental protection is an integral consideration in U.S. policies concerning natural resources, human health, economic growth, energy, transportation, agriculture, industry, and international trade, and these factors are similarly considered in establishing environmental policy.

- All parts of society – communities, individuals, business, state and local governments, tribal governments – have access to accurate information sufficient to effectively participate in managing human health and environmental risks.

- Environmental protection contributes to making our communities and ecosystems diverse, sustainable, and economically productive.

- The United States plays a leadership role in working with other nations to protect the global environment.

EPA participates in the HEC I&A and HCI&IM PCAs through its Office of Research and Development.

A.11. Air Force Research Laboratory (AFRL)

AFRL's[190] mission is to lead the discovery, development, and integration of affordable war fighting technologies for U.S. air and space forces. The AFRL mission is executed by nine

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[189] http://www.epa.gov/history/org/origins/mission.htm
[190] http://www.afrl.af.mil/

technology directorates located throughout the United States, the Air Force Office of Scientific Research, and AFRL central staff. It supports Air Force major commands.

AFRL is a full spectrum laboratory responsible for planning and executing the Air Force's entire S&T budget in basic research, applied research, and advanced technology development.

AFRL participates in the HCSS CG.

A.12. Department of Defense/High Performance Computing Modernization Program Office (DoD/HPCMPO)

DoD/HPCMPO[191] was initiated in 1992 in response to congressional direction to modernize the Department of Defense (DoD) laboratories' high performance computing (HPC) capabilities. DoD/HPCMPO was assembled out of a collection of small high performance computing departments, each with a rich history of supercomputing experience that had independently evolved within the Army, Air Force, and Navy laboratories and test centers.

The DoD/HPCMPO provides the supercomputer services, high-speed network communications, and computational science expertise that enables the Defense laboratories and test centers to conduct a wide range of focused research, development, and test activities. This partnership puts advanced technology in the hands of U.S. forces more quickly, less expensively, and with greater certainty of success. Today's weapons programs, such as the Joint Strike Fighter, Unmanned Aerial Vehicles, Medium Tactical Vehicle Replacement, and the Javelin Missile program, have benefited through innovative materials, advanced design concepts, improved and faster modification programs, higher fidelity simulations, and more efficient tests. Future weapons systems, such as radio frequency weapons, the airborne laser, and the Army's future combat system, are benefiting through basic and applied research in plasma physics, turbulence modeling, molecular engineering, high-energy materials, and advanced signal processing.

DoD/HPCMPO is organized into three components to achieve its goals. These components are: HPCMP HPC Centers, Networking, and Software Application Support. This program is under the cognizance of the Deputy Under Secretary of Defense (Science and Technology) (DUSD(S&T)).

DoD/HPCMPO participates in the HEC CG.

A.13. Federal Aviation Administration (FAA)

FAA's[192] mission is to provide a safe, secure, and efficient global aerospace system that contributes to national security and the promotion of U.S. aerospace safety.

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[191] http://www.hpcmo.hpc.mil/
[192] http://www.faa.gov

FAA NITRD Program interests lie primarily in the Office of the Assistant Administrator for Information Services and Chief Information Officer (AIO).[193] FAA participates in the HCI&IM, SDP, and HCSS CGs.

A.14. Food and Drug Administration (FDA)

FDA[194] is a part of the Department of Health and Human Services and is responsible for protecting the public health by assuring the safety, efficacy, and security of human and veterinary drugs, biological products, medical devices, the Nation's food supply, cosmetics, and products that emit radiation. The FDA is also responsible for advancing public health by speeding innovations that make medicines and foods more effective, safer, and more affordable; and helping the public get the accurate, science-based information they need to use medicines and foods to improve their health.

The FDA participates in the NITRD HCSS CG primarily through its Center for Devices and Radiological Health (CDRH),[195] which assures that new medical devices are safe and effective before they are marketed.

A.15. General Services Administration (GSA)

GSA[196] secures the buildings, products, services, technology, and other workplace essentials Federal agencies need. About 13,000 GSA employees support over one million Federal workers located in 8,000 government-owned and leased buildings in 2,000 U.S. communities and overseas. GSA personnel:

- Provide superior workplaces for Federal workers
- Facilitate procurement of state-of-the-art commercial products and a wide range of services
- Offer best value and innovative solutions on IT products and services
- Develop and implement government-wide policies

GSA participates in the SEW CG.

A.16. Office of Naval Research (ONR)

ONR[197] coordinates, executes, and promotes the S&T programs of the U.S. Navy and Marine Corps through schools, universities, government laboratories, and nonprofit and for-profit organizations. It provides technical advice to the Chief of Naval Operations and the Secretary of the Navy and works with industry to improve technology manufacturing processes.

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[193] http://www.faa.gov/aio/
[194] http://www.fda.gov
[195] http://www.fda.gov/cdrh/index.html
[196] http://www.gsa.gov/Portal/gsa/ep/home.do?tabId=6
[197] http://www.onr.navy.mil

ONR participates in the HCI&IM, HCSS, SDP, and SEW PCAs through the Program on Cognitive, Neural, and Social Science and Technology.

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Appendix E: Glossary and List of Acronyms

3D
>Three dimensional

3MRA
>EPA's Multimedia, Multipathway, Multireceptor Risk Assessment modeling system

6TAP
>IPv6 Transit Access Point

A

AAAI
>American Association for Artificial Intelligence

AAMP
>Advanced Architecture MicroProcessor

AAMP7
>Latest member of the Advanced Architecture MicroProcessor family that supports high-assurance application development exploiting intrinsic partitioning

ACE
>NIST's Automatic Content Extraction program

ACM CHI
>Association for Computing Machinery Computer Human Interaction

ACRT
>DOE/SC's Advanced Computing Research Testbeds activity

ADAPT
>NASA's Automatic Data Alignment and Placement Tool

ADCs
>DoD/HPCMPO's Allocated Distributed Centers

AEDC
>Arnold Engineering Development Center, a DoD/HPCMPO DDC

AeroDB
>Aeronautical Database

AEX
>NIST's Automating Equipment Information Exchange project

AFOSR
>Air Force Office of Scientific Research

AFRL
>Air Force Research Laboratory

AFRL/IF
>AFRL's Information Directorate, a DoD/HPCMPO DDC

AFWA
>Air Force Weather Agency, a DoD/HPCMPO DDC

AHRQ
>Agency for Healthcare Research and Quality

AHPCRC
>Army High Performance Computing Research Center, a DoD/HPCMPO ADC

AI&CS
>NSF/CISE's Artificial Intelligence and Cognitive Science program

AID-N
>Advanced Health and Disaster Aid Network

AIO
>FAA's Office of the Assistant Administrator for Information Services and CIO

AIST
>Japan's National Institute of Advanced Industrial Science and Technology

AITP
>NOAA's Advanced Information Technology Program

ALU
>Arithmetic-logic unit

ANL
>DOE's Argonne National Laboratory

ANSI
American National Standards Institute

ANTD
NIST's Advanced Network Technologies
Division

API
Application Program Interface

AQMA
NIST's Air Quality Modeling Applications

AQUAINT
NIST/NSA's Advanced Question and
Answering for Intelligence program

ARDA
NSA's Advanced Research and
Development Activity

ARL
Army Research Laboratory, a
DoD/HPCMPO MSRC

ARO
Army Research Office

ARSC
Arctic Region Supercomputing Center, a
DoD/HPCMPO ADC

ASC
Advanced Scientific Computing

ASC
Aeronautical Systems Center, a
DoD/HPCMPO MSRC

ASC
DOE/NNSA's Advanced Simulation and
Computing program

ASCI
DOE/NNSA's Accelerated Strategic
Computing Initiative (now ASC)

ASCR or OASCR
DOE/SC's Office of Advanced Scientific
Computing Research

ASE
Advances in Science and Engineering

ASAP
DOE/NNSA's Academic Strategic Alliance
Program

ATDnet
DoD's Advanced Technology
Demonstration network

ATM
Asynchronous transfer mode

B

BECON
NIH's Bioengineering Consortium

BGP
Border gateway protocol

BIO
NSF's Biological Sciences Directorate

BioAPI
Biometric API

BISTI
NIH's Biomedical Information Science and
Technology Initiative

BISTIC
NIH's BISTI Initiative Consortium

BLAS
Basic linear algebra subroutines

BOSSnet
BoSton-South NETwork, MIT's Boston to
Washington, DC fiber optic network

C

CAD
computer-aided design

CAIB
NASA's Columbia Accident Investigation
Board

CalREN2
California Research and Education
Network 2

Caltech
California Institute of Technology

Canarie2
Canadian Network for the Advancement of Research, Industry, and Education 2

CAPO
NASA's Computer-Aided Parallelizer and Optimizer

CAST
DARPA's Compact Aids for Speech Translation program

CBEFF
Common Biometric Exchange File Format

CBP
DHS's Customs and Border Protection

CCAMP
Common Control and Measurement Plane

CCF
NSF/CISE's Computing and Communications Foundations Division

CCM
DoD/HPCMPO's Computational Chemistry and Materials Science CTA

CDRH
FDA's Center for Devices and Radiological Health

CDROM
Compact Disc Read-Only Memory

CEA
DoD/HPCMPO's Computational Electromagnetics and Acoustics CTA

CEN
DoD/HPCMPO's Computational Electronics and Nanoelectronics CTA

CERN
European Laboratory for Particle Physics

CERTs
AHRQ's Centers for Education and Research on Therapeutics

CEV
NASA's Crew Exploration Vehicle

CFD
computational fluid dynamics

CFD
DoD/HPCMPO's Computational Fluid Dynamics CTA

CG
Coordinating Group

CHEETAH
NSF/CISE's Circuit-switched High-Speed End-to-End Transport ArcHitecture project

CHSSI
DoD/HPCMPO's Common High Performance Computing Software Initiative

CI
Cyberinfrastructure

CIAPP
NASA's Computational Intelligence for Aerospace Power and Propulsion systems

CICT
NASA's Computing, Information, and Communications Technology Program

CIF
NIST's Common Industry Format

CIO
Chief Information Officer

CIOC
Federal CIO Council

CIP
Critical Infrastructure Protection

CISE
NSF's Computer and Information Science and Engineering Directorate

CMAQ
EPA's Community Multi-Scale Air Quality modeling system

CMM
Carnegie Mellon University's Software Engineering Institute's Capability Maturity Model

CMS
HHS's Centers for Medicare and Medicaid Services

CNIS
NASA's Computing, Networking, and Information Systems project

CNS
NSF/CISE's Computer and Networking Systems Division

CONUS
Continental United States

CORBA
Common Object Request Broker Architecture

COTS
commercial-off-the-shelf

CPU
Central Processing Unit

CRA
Computing Research Association

CSD
NIST/ITL's Computer Security Division

CSGF
DOE/NNSA's and DOE/SC's Computational Science Graduate Fellowship program

CSM
DoD/HPCMPO's Computational Structure Mechanics CTA

CSTB
Computer Science and Telecommunications Board of the National Academies' National Research Council

CSTL
NIST's Chemical Science and Technology Laboratory

CSTP
Japan's Council for Science and Technology Policy

CTAs
DoD/HPCMPO's Computational Technology Areas

D

DAML
DARPA Agent Markup Language program

DARPA
DoD's Defense Advanced Research Projects Agency

DCE
DOE/NNSA's Distributed Computing Environment

DDCs
DoD/HPCMPO's Dedicated Distributed Centers

DETER
NSF's cyber Defense Technology Experimental Research network

DG
NSF/CISE's Digital Government program

DHS
Department of Homeland Security

DIA
Defense Intelligence Agency

DiffServ
Differentiated Services

DISA
DoD's Defense Information Systems Agency

DisCom
DOE/NNSA's Distance Computing program

DiVAs
DOE/SC's Distributed Visualization Architecture workshops

DIVERSE
NIST and NSF Device Independent Virtual Environments – Reconfigurable, Scalable, Extensible

DLMF
NIST and NSF Digital Library of Mathematical Functions

DMTF
Distributed Management Task Force

DNS
Domain Name System

DOC
Department of Commerce

DoD
Department of Defense

DoD/HPCMPO
DoD/High Performance Computing Modernization Program Office

DoD/OSD
DoD/Office of the Secretary of Defense

DOE
Department of Energy

DOE/NNSA
DOE/National Nuclear Security Administration

DOE/SC
DOE/Office of Science

DOJ
Department of Justice

DOL
Department of Labor

DRAGON
NSF/CISE's Dynamic Resource Allocation for GMPLS Optical Networks project

DREN
DoD's Defense Research and Engineering Network

DSC
DoD's Distributed Systems and Compilers

DST
NSF/CISE's Digital Society and Technologies program

DTC
NOAA's Development Test Center

DUC
NIST's Document Understanding Conference

E

EARS
DARPA's and NIST's Effective Affordable Reusable Speech-To-Text program

ebXML
electronic business Extensible Markup Language

ECCO
Estimating the Circulation and Climate of the Ocean consortium

ECEI
NIST's Electronic Commerce for the Electronics Industry

ECS
NASA's Engineering for Complex Systems program

ED
Department of Education

EDRAM
Erasable Dynamic Random Access Memory

EHR
NSF's Education and Human Resources Directorate

EHRS
Electronic Health Record System

EHS
Embedded and Hybrid Systems

EINs
NSF's Experimental Infrastructure Networks

ENG
NSF's Engineering Directorate

EPA
Environmental Protection Agency

EQM
DoD/HPCMPO's Environmental Quality Modeling and Simulation CTA

ERDC
U.S. Army's Engineering Research and Development Center, a DoD/HPCMPO MSRC

ESRDC
Japan's Earth Simulator Research and Development Center

ESCHER
DARPA's and NSF's Embedded Systems Consortium for Hybrid and Embedded Research

ESMF
Earth System Modeling Framework

ESnet
DOE/SC's Energy Sciences network

ESSC
Esnet Steering Committee

ESTO
NASA's Earch Sciences Technology Office

ETF
Extensible Terascale Facility

ETHR
Education, Training, and Human Resources

EU
European Union

F

FAA
Federal Aviation Administration

FBI
Federal Bureau of Investigation

FDA
Food and Drug Administration

FEA
OMB's Federal Enterprise Architecture program

FMS
NOAA's Flexible Modeling System

FMS
DoD/HPCMPO's Forces Modeling and Simulation CTA

FNMOC
U.S. Navy's Fleet Numerical Meteorology and Oceanography Center, a DoD/HPCMPO DDC

ForCES
Forwarding and Control Element Separation

FPGA
Field Programmable Gate Array

FpVTE
fingerprint vendor technology evaluation

FSL
NOAA's Forecast Systems Laboratory

FTP
file transfer protocol

G

Gbps
Gigabits or billions of bits per second

GEO
NSF's Geosciences Directorate

GFDL
NOAA's Geophysical Fluid Dynamics Laboratory

Gflops
Gigaflops or billions of floating point operations per second

GGF
Global Grid Forum

GGMAO
NASA's Goddard Global Modeling and Assimilation Office

GHz
Gigahertz

GigE
Gigabit Ethernet

GIPS
Giga integers per second

GIS
geographic information system

GISS
NASA's Goddard Institute for Space Studies

GLASS
NIST's GMPLS/Optical Simulation Tool

GLIS
NASA's Goddard Land Information Systems project

GMPLS
Generalized Multi-Protocol Label Switching

GOPS
Giga operations per second

GSA
General Services Administration

GSFC
NASA's Goddard Space Flight Center

GUI
Graphical user interface

GUPS
Giga updates per second

H

H-ANIM
Human Animation

HARD
NIST's High Accuracy Retrieval from Documents program

HBCUs
Historically Black Colleges and Universities

HBM
Haskell on Bare Metal

HCI&IM
Human Computer Interaction and Information Management, a NITRD Program PCA and CG

HCSS
High Confidence Software and Systems, a NITRD Program PCA and CG

HDCCSR
NASA's and NSF's Highly Dependable Computing and Communications Systems Research program

HDCP
NASA's Highly Dependable Computing Platform

HEC
High-End Computing, a NITRD Program CG

HEC I&A
HEC Infrastructure and Applications, a NITRD Program PCA

HEC R&D
HEC Research and Development, a NITRD Program PCA

HECRTF
High-End Computing Revitalization Task Force

HEC-URA
DARPA's, DOE/SC's, and NSF's HEC University Research Activity

HHS
Department of Health and Human Services

HIT
AHRQ's Patient Safety Health Information Technology Initiative

HL-7
Health Level Seven

HP
Hewlett Packard

HPC
High Performance Computing

HPCC
High Performance Computing and Communications

HPCMPO
DoD's High Performance Computing Modernization Program Office

HPCS
DARPA's High Productivity Computing Systems program

HRI
Human Robot Interaction

HSAIs
DoD/HPCMPO's High Performance Computing Software Applications Institutes

HTML
HyperText Markup Language

HuCS
Human Centered Systems

HVAC
heating, ventilation, and air conditioning

HVAC/R
Heating, ventilation, air conditioning, and refrigeration

I

IA
Information Assurance

IAD
NIST's Information Access Division

IAFIS
FBI's Integrated Automated Fingerprint Identification System

IAIMS
NIH/NLM's Integrated Academic Information Management Systems

IARG
NSA's Information Assurance Research Group

IBM
International Business Machines

IC
Intelligence Community

ICAT
NIST/ITL/CSD's searchable index of information on computer vulnerabilities

ICDE
International Conference on Data Engineering

ICR
NITRD Program's Interagency Coordination Report

IDC
A global market intelligence and advisory firm

IDM
NSF/CISE's Information and Data Management program

IDS
NIST's Intrusion Detection System

IEEE
Institute of Electrical and Electronics Engineers

IETF
Internet Engineering Task Force

IIS
NSF/CISE's Information and Intelligent Systems Division

IJCAI
International Joint Conference on Artificial Intelligence

IMPI
NIST's Interoperable Message Passing Interface

IMT
DoD/HPCMPO's Integrated Modeling and Test Environments CTA

INCITE
DOE/SC's Innovative and Novel Computational Impact on Theory and Experiment program

INCITS
International Committee for IT Standards

Internet2
University-led effort to develop advanced network applications and the network technologies needed to support them

I/O
Input/Output

IP
Internet Protocol

IPG
NASA's Information Power Grid (now the NASA Grid)

IPSec
IP Security

IPTO
DARPA's Information Processing Technology Office

IPv6
Internet Protocol, version 6

IRNC
International Research Network Connections

IS
Information Security

IS
NASA's Intelligent Systems Division

ISD
NIST/MEL's Intelligent Systems Division

ISICs
DOE/SC's Integrated Software Infrastructure Centers

ISO
International Organization for Standardization

ISPAB
NIST's Information Security and Privacy Advisory Board

IT
Information Technology

ITL
NIST's Information Technology Laboratory

ITR
NSF's Information Technology Research program

ITR&D
Information Technology Research and Development

ITSR
NASA's Information Technology Strategic Research program

IU
Indiana University

IUSR
Industry USability Reporting project

IV&V
Independent Verification and Validation

IWG
Interagency Working Group

IXO
DARPA's Information Exploitation Office

J

JAMSTECH
Japan Marine Science and Technology Center

JAERI
Japan Atomic Energy Research Institute

Java
 A network-oriented programming language developed by Sun Microsystems

Javaspaces
A service specification that provides a distributed persistence and object exchange mechanism for Java objects and can be used to store the system state and implement distributed algorithms

JAXA
Japan's Aerospace Exploration Agency

JDCL
Joint Conference on Digital Libraries

JES
Japanese Earth Simulator

JET
LSN's Joint Engineering Team

JETnets
Federal research networks supporting networking researchers and advanced applications development

JFCOM
U.S. Joint Forces Command, a DoD/HPCMPO DDC

Jini
Jini is a set of APIs and runtime conventions that facilitate the building and deploying of distributed systems.

JLAB
Thomas Jefferson National Accelerator Facility

JPL
NASA's Jet Propulsion Laboratory

K

Ka-band
(Kurtz-above band) is a portion of the K band of the microwave band of the electromagnetic spectrum that roughly range from 18 to 40 GHz

KEK
Japan's High Energy Accelerator Research Organization

L

LANL
DOE's Los Alamos National Laboratory

LBNL or LNL
DOE's Lawrence-Berkeley National Laboratory

LHNCBC
NIH/NLM's Lister Hill National Center for Biomedical Communications

LSN
Large Scale Networking, a NITRD Program PCA and CG

LSTAT
FDA's Life Support for Trauma and Transport

LTP
NASA's Learning Technologies Project

LTS
NSA's Laboratory for Telecommunications Sciences

M

MAA
EPA's Multimedia Assessments and Applications framework

MAGIC
LSN's Middleware and Grid Infrastructure Coordination team

MAX
Mid-Atlantic Exchange

Mbps
Megabits (millions of bits) per second

MDS
NASA's Mission Data Systems program

MEL
NIST's Manufacturing Engineering Laboratory

METI
Japan's Ministry of Economy, Trade, and Industry

MEXT
Japan's Ministry of Education, Culture, Sports, Science, and Technology

MHPCC
Maui High Performance Computing Center, a DoD/HPCMPO ADC

MHz
Megahertz

MICS
DOE/SC/OASCR's Mathematical, Information, and Computational Sciences subprogram

MIT
Massachusetts Institute of Technology

MLP
multi-level parallelism

MobiDE
International Workshop on Data Engineering for Wireless and Mobile Access

MoBIES
DARPA's Model-Based Integration of Embedded Systems program

MOU
Memorandum of Understanding

MPEG-7
Moving Picture Experts Group's Multimedia Content Description Interface

MPI
Message Passing Interface

MPICH
freely available, high performance portable implementation of MPI

MPLS
Multi Protocol Label Switching

MPS
NSF's Mathematical and Physical Sciences Directorate

MREFC
NSF's Major Research Equipment and Facilities Construction account

MSID
NIST's Manufacturing Systems Integration Division

MSRCs
DoD/HPCMPO's Major Shared Resource Centers

MT
NIST's Machine Translation program

MTBF
Mean Time Between failures

MTU
Message Text Unit

N

NAACL
North American chapter of the Association for Computational Linguistics

NAP
Network Access Point

NAREGI
Japan's National Research Grid Initiative

NASA
National Aeronautics and Space Administration

NAVO
U.S. Navy's Naval Oceanographic Office, a DoD/HPCMPO MSRC

NAWCAD
Naval Air Warfare Center Aircraft Division, a DoD/HPCMPO DDC

NCAR
NSF-supported National Center for Atmospheric Research

NCBI
NIH/NLM's National Center for Biotechnology Information

NCEP
NOAA's National Center for Environmental Prediction

NCO
National Coordination Office for Information Technology Research and Development

NCSA
NSF-supported National Center for Supercomputing Applications

NDML
Numerical Data Markup Language

NERSC
DOE/SC's National Energy Research Supercomputing Center

NESC2
National Environmental Scientific Computing Center

NEST
DARPA's Networked Embedded Systems Technology program

NEXRAD
Next Generation Weather Radar System

NGI
Next Generation Internet

NGIX
Next Generation Internet Exchange point

NGS
NSF's Next Generation Software Program

NHII
National Health Information Infrastructure

NHS
National and Homeland Security

NIAP
NIST's and NSA's National Information Assurance Partnership

NICs
Network Interface Cards

NIFS
Japan's National Institute for Fusion Science

NIGMS
NIH's National Institute of General Medical Sciences

NIH
National Institutes of Health

NIJ
DOJ's National Institute of Justice

NIMD
NIST's Novel Intelligence for Massive Data project

NISN
NASA's Integrated Services Network

NIST
National Institute of Standards and Technology

NITRD
Networking and Information Technology Research and Development

NLM
NIH's National Library of Medicine

NLR
National LambdaRail

NMI
NSF Middleware Initiative

NMR
Nuclear magnetic resonance

NMS
DARPA's Network Modeling and Simulation program

NNLM
NIH/NLM's National Network of Libraries of Medicine

NOAA
National Oceanic and Atmospheric Administration

NPACI
NSF-supported National Partnership for Advanced Computational Infrastructure

NREN
NASA's Research and Education Network

NRL-DC
Naval Research Laboratory-Washington, D.C., a DoD/HPCMPO DDC

NRNRT
National radio network research testbed

NRO
National Reconnaissance Office

NRT
LSN's Networking Research Team

NRT
NSF/CISE's Networking Research Testbed program

NSA
National Security Agency

NSF
National Science Foundation

NSRC
Network Startup Resource Center

NSRL
NIST's and DOJ/NIJ's National Software Reference Library

NSTC
White House National Science and Technology Council

NWS
NOAA's National Weather Service

O

OASCR or ASCR
DOE/SC's Office of Advanced Scientific Computing Research

OAV
Organic Air Vehicle

OC-x
Optical Carrier rate, an optical network transmission standard. The base rate (OC-1) is 51.84 Mbps; higher transmission speeds such as OC-3 or OC-48 are multiples

OCONUS
Outside the Continental United States

ODDR&E
DoD's Office of the Director, Defense Research and Engineering

OIL
Ontology Inference Layer

OMB
White House Office of Management and Budget

ONR
DoD's Office of Naval Research

ONT
Optical Networking Testbed

OOF
NIST's -Object-Oriented Finite Element Modeling of Material Microstructures

OOMMF
NIST's Object-Oriented MicroMagnetic Computing Framework

OpenMP
An open message-passing standard

OPP
NSF's Office of Polar Programs

ORNL
DOE's Oak Ridge National Laboratory

OSCAR
open source toolkit for managing Linux clusters

Osker
Oregon Separation Kernel

OSPF
Open Shortest-Path First, an Interior Gateway Protocol

OSS
Open source software

OSTP
White House Office of Science and Technology Policy

OWL
Web Ontology Language derived from DAML + OIL

P

PCA
DARPA's Polymorphous Computing Architectures

PCAs
NITRD Program Component Areas

PCMon
PC-based network traffic monitoring, a monitoring and measurement tool that enables detailed analysis of individual traffic flows

PDE

DOE/SC's Algorithmic and Software Framework for Applied Partial Differential Equations ISIC

PDEs

partial differential equations

PE

Processing element

PerMIS

NIST's Performance Metrics for Intelligent Systems workshops

PET

DoD/HPCMPO's Programming Environment and Training program

Petaflops

10^{15} floating point operations per second

PHAML

Parallel Hierarchical Adaptive Multilevel Grid refinement multigrid code for PDEs

PI

Principal investigator

PIM

Processor in memory

PITAC

President's Information Technology Advisory Committee

PKI

public key infrastructure

PMEL

NOAA's Pacific Marine Environmental Laboratory

PNNL

DOE/SC's Pacific Northwest National Laboratory

POS

Packet Over SONET

POSIX

Portable Operating System Interface

PSC

NSF-supported Pittsburgh Supercomputing Center

PSE

Patient Safety Event

PSE

DOE/NNSA's Problem Solving Environment thrust

PVM

Parallel Virtual Machine

Q

QCD

Quantum ChromoDynamics

QoS

Quality of Service

R

R&D

Research and Development

R&E

Research and Engineering

RAiN

NIST's Resilient Agile Networking program

RAMAS

NASA's Resource Allocation, Measurement and Adjustment System

RAW

DARPA's Reconfigurable Architecture Workstation

RDF/S

Resource Description Framework/Schema

RFI

request for information

RFP

request for proposals

RIKEN

Japan's Institute of Physical and Chemical Research

RIST
Japan's Research Organization for Information Science and Technology

RLV
NASA's Reusable Launch Vehicle

RMS
DARPA's Rapid Multilingual Support

RONs
Regional Operational Networks

RSS
NOAA's Really Simple Syndication

RTTC
Redstone Technical Test Center, a DoD/HPCMPO DDC

S

S&T
Science and technology

SAP
NASA's Software Assurance Program

SAPP
DOE/SC's Scientific Applications Pilot Program

SAS
DoD/HPCMPO's Software Applications Support

SBE
NSF's Social, Behavioral, and Economic Sciences Directorate

SCADA
Supervisory Control and Data Acquisition

SCALES
DOE/SC's Science Case for Large Scale Simulation

SCI
NSF/CISE's Shared Cyberinfrastructure Division

SciDAC
DOE/SC's Scientific Discovery through Advanced Computing program

SCS
DOE/NNSA's Simulation and Computer Science thrust

SDCTD
NIST/ITL's Software Diagnostics and Conformance Testing Division

SDSC
NSF-supported San Diego Supercomputing Center

SDP
Software Design and Productivity, a NITRD Program PCA and CG

SEC
DARPA's Software Enabled Control program

SEI
NASA's Software Engineering Initiative

SEL
NSF/CISE's Software Engineering and Languages program

SEW
Social, Economic, and Workforce Implications of IT and IT Workforce Development, a NITRD Program PCA and CG

SGI
Silicon Graphics, Inc.

SI
NSF/CISE's System Integrator awards

SIGINT
NSA's foreign Signals Intelligence mission

SIMA
NIST's Systems Integration for Manufacturing Applications program

SIMAF
Simulation and Analysis Facility, a DoD/HPCMPO DDC

SIP
NIST's Session-Initiated Protocol program

SIP
DoD/HPCMPO's Computational Signal/Image Processing CTA

SMART
NIH/NLM's Scalable Medical Alert and Response Technology project

SMDC
U.S. Army Space and Missile Defense Command, a DoD/HPCMPO ADC

SMP
Symmetric Multiprocessing

SODA
Service Oriented Data Access

SONET
synchronous optical network

SP
IBM's Supercomputing Processor system

SPC
DoD/HPCMPO's Software Protection Center

SRM
NIST's Standard Reference Model

SRS
Self-Regenerative Systems

SSCSD
SPAWAR Systems Center, San Diego, a DoD/HPCMPO DDC

SSI
single system image

SSP
DOE/NNSA's Stockpile Stewardship Program

StarLight
NSF-supported international optical network peering point in Chicago

START
NSF/CISE's Strategic Technology Astronomy Research Team collaboratory

STEM
Science, technology, engineering, and mathematics

STI
NSF's Strategic Technologies for the Internet program

STM1
Synchronous Transport Mode 1 (155 Mbps)

STT
Speech-to-text

SUNMOS
Sandia University of New Mexico Operating System

SuperNet
A wide-area, advanced networking testbed supported by the NGI program

SV2
A Cray, Inc. scalar-vector supercomputer

T

T&E
Test and evaluation

TACC
Texas Advanced Computing Center

TCO
Total Cost of Ownership

TCP/IP
Transmisson Control Protocol/Internet Protocol

TCS
NSF-supported Terascale Computing System at the University of Pittsburgh

TDT
NIST's Topic Detection and Traction program

Tera-
Trillions

TES
NASA/NREN's Transportable Earth Station

TIDES
DARPA's and NIST's Translingual Information Detection, Extraction and Summarization program

TIP
NIH/NLM's Toxicology Information Program

TLG
NITRD Program's Temporary Linkages Group

TNT
NIST's Template Numerical Toolkit

TOPS
DOE/SC's Terascale Optimal PDE Solvers ISIC

TREC
DARPA's and NIST's Text Retrieval Conference

TRIPS
DARPA Polymorphous Computing Architecture's Tera-op Reliable Intelligently Adaptive Processing System-x

TRL
NASA's Technology Readiness Level

TSTT
DOE/SC's Terascale Simulation Tools and Technologies ISIC

U

UA
NIST's Uncertainty Analysis framework

UA
Universal Access

UAV
Unmanned Air Vehicle

UCAID
University Consortium for Advanced Internet Development

UCAR
University Corporation for Atmospheric Research

UltraScience Net
DOE/SC's experimental research network

UnitsML
An XML schema for encoding measurement units

UPC
NSA's Unified Parallel Compiler

USAR
urban search and rescue

USGS
U.S. Geological Survey

US VISIT
DHS's United States Visitor and Immigrant Status Indicator Technology

UWB
UltraWide Band

V

V&V
Verification and Validation

VACE
ARDA's and NIST's Video Analysis and Content Extraction program

vBNS+
NSF's very high performance Backbone Network Services plus

VIEWS
DOE/NNSA's Visual Interactive Environment for Weapons Simulation

VPN
Virtual Private Network

VRML
Virtual Reality Modeling Language

W

W3C
World Wide Web Consortium

WAN
Wide area network

Web3D

Communicating with real-time 3D across applications, networks, and XML Web services

WIISARD

NIH/NLM's Wireless Internet Information System for Medical Response in Disasters project

WPAN

Wireless Personal Area Networks

WRF

NOAA's and NSF's Weather Research and Forecast program

WSMR

White Sands Missile Range, a DoD/HPCMPO DDC

WTEC

World Technology Evaluation Center, Inc

X

X1

Cray, Inc. scalable, hybrid scalar-vector high-end computing system developed with support from NSA and ODDR&E

X1e

NSA-supported next generation of Cray X1 known as Black Widow; under development now, is expected to be available in 2006

X3D

An extensible open file format standard for 3D visual effects, behavioral modeling, and interaction

XCP

eXplicit Congestion control Protocol

XML

Extensible markup language that is more generalized than HTML and can be used for tagging data streams more precisely and extensively

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