NEES

Information Technology within the George E. Brown, Jr. Network for Earthquake Engineering Simulation: *A Vision for an Integrated Community*

Task Group on Information Technology Vision
of the Board of Directors of NEES, Inc.

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The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)

The mission of the Network for Earthquake Engineering Simulation (NEES) is to enable collaboration and transformative research to reduce seismic risk by providing world-class community infrastructure.

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April 2007

A VISION FOR INFORMATION TECHNOLOGY IN THE GEORGE E. BROWN, JR. NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION

EXECUTIVE SUMMARY

The power of information technology is revolutionizing research and practice in earthquake engineering as the entire community strives to achieve comprehensive, innovative, and cost-effective solutions for mitigating the devastating effects of earthquakes and tsunamis in the United States and around the world. Advanced simulation tools, content-rich web-accessible databases coupled with powerful mining techniques, graphical and visual information systems, and multi-media-based tools for real-time collaboration are opening new opportunities for creativity and productivity across the field of earthquake engineering.

To enable the development of transformative technologies through the creation of the next generation of experimental and computational facilities for the earthquake engineering research and education community, the National Science Foundation (NSF) launched the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) in 1999. NSF envisioned that the creation of NEES would "shift the emphasis of earthquake engineering research from current reliance on physical testing to integrated experimentation, computation, theory, databases, and model-based simulation." This provides a new paradigm in which earthquake engineering research and education within the NEES consortium becomes a collaborative effort among the community rather than a collection of loosely coordinated research and education projects by individuals, and it provides mechanisms for broadening participation in earthquake engineering by allied disciplines. To this end, the NEES community has initiated the development of technologies for collaborative on-site and remote research, data sharing, distributed testing, and model-based simulation, with emphasis on providing real-time experiment-simulation interaction capabilities. Building off of this prior experience, now is an opportune time to take stock of the vision and strategies for information technology (IT) within NEES to ensure future activities are in keeping with the needs of the global user community, to harness new ideas at the interface between earthquake engineering and cyber technologies, and to position NEES to take advantage of the rapidly advancing world of IT. Information Technology within the George E. Brown, Jr. Network for Earthquake Engineering Simulation: A Vision for an Integrated Community presents a vision for IT within NEES and a strategy for accomplishing the vision.

VISION FOR NEES INFORMATION TECHNOLOGY

The vision of NEES Information Technology is to drive innovation in earthquake engineering through transformative technologies that will enable the creation and integration of knowledge leading to pioneering solutions for protecting society from the catastrophic effects of earthquakes and tsunamis.

This vision is both broad and aggressive in scope, but is realistic and focused on the goals of the NEES program. The resulting strategy takes a high-level view of the major components and approaches for developing information technology for NEES to meet the diverse needs of all earthquake engineering users: researchers, practitioners, educators, students, and stakeholders. The vision and strategy provide guidance to the NEES Board of Directors and NEES Inc. on strategic choices that will lead to an implementation and execution plan. In addition, this plan:

- Seeks to engage the NEES community of researchers and practitioners regarding the powerful capabilities achievable through synergistic activities between earthquake engineering and IT;
- Motivates researchers and practitioners involved in other engineering domains, such as wind, blast, and infrastructure management, to use, adapt, and contribute to applications and services that are being developed by the NEES community;

- Defines IT-based approaches for integrating education and training with research and practice in earthquake engineering;
- Provides recommendations for partnerships with stakeholders from earthquake engineering communities worldwide, and from other science and engineering communities within the United States that benefit from coordinated activities with NEES; and
- Conveys the users needs for earthquake engineering to IT professionals and those involved in developing the national cyberinfrastructure in accordance with the cyberinfrastructure vision of the National Science Foundation.

The elements of the IT vision, which tie in closely with the overall mission of NEES, are a concise statement that the NEES community can use to guide its strategy into the near and more distant future. The vision sets IT innovations within the context of a core objective of the NEES program, protecting society from the catastrophic effects of earthquakes. These vision elements focus on how IT within NEES can drive innovation to lead to transformative technologies for earthquake engineering. The vision elements identify how IT innovations enhance the opportunities for creation and integration of knowledge to allow the NEES community to forge pioneering solutions to reduce the societal risk to earthquakes.

The strategic plan focuses on the earthquake engineering user needs for applications and services necessary to realize the IT vision. This plan outlines the current state-of-the-art IT capabilities that are integrated within NEES, and provides an overview of the user needs and functionality in seven core areas, including: Community Data Sharing; Computational Modeling and Simulation; Visualization; Integrated Computational, Experimental, and Field Simulations; Collaboration; Knowledge Capture and Dissemination; and Integrated Teaching and Learning Environment. Both leveraging opportunities and research and development needs are identified. The applications and services in the strategic plan are prioritized, and within each application, the functionalities and user needs are prioritized with expected time frames needed for completion. Critical IT processes and technologies are also summarized to highlight fundamental approaches that are recommended for implementation of the strategies.

The strategic plan calls for completion of near-term objectives in the next one to two years and long-range strategic objections in five years. The plan is designed to continue the vision beyond five years by increasing the capacity of the NEES community to take advantage of the continuing revolution in information technology and development of the national cyberinfrastructure.

Success in accomplishing the vision and strategy will provide a vital underpinning for the earthquake engineering community in understanding seismic hazards, assessing earthquake impacts, reducing earthquake impacts, enhancing community resilience, and expanding education and public outreach, all of which have been identified as key programs for achieving the national goal of securing society from catastrophic earthquake and tsunami losses. The successful implementation of the strategic plan will transform how engineers design structural and geotechnical systems, how stakeholders manage earthquake risks, how students learn about earthquakes and their effects on structures, and how the public learns about the impacts of earthquakes on their lives.

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The power of information technology is revolutionizing research and practice in earthquake engineering as the research community and the profession strive to achieve comprehensive, innovative, and cost-effective solutions for mitigating the devastating effects of earthquakes and tsunamis in the United States and around the world. Advanced simulation tools, content-rich web-accessible databases coupled with powerful mining techniques, graphical and visual information systems, and multimedia-based tools for real-time collaboration are opening new opportunities for creativity and productivity across the field of earthquake engineering.

VISION FOR NEES INFORMATION TECHNOLOGY

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This report presents a vision for information technology (IT) within the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) and a strategy for accomplishing the vision. The vision is both broad and aggressive in scope, but is realistic and focused on the goals of the NEES program. The strategy takes a high-level view of the major components and approaches for developing information technology for NEES to meet the diverse needs of all earthquake engineering users: researchers, practitioners, educators, students, and stakeholders. Success in accomplishing the vision and strategy will provide a vital underpinning for the earthquake engineering community in understanding seismic hazards, assessing earthquake impacts, reducing earthquake impacts, enhancing community resilience, and expanding education and public outreach, all of which have been identified as key programs for achieving the national goal of securing society from catastrophic earthquake and tsunami losses (EERI, 2003). The IT plan will transform how engineers design structural and geotechnical systems, how stakeholders manage earthquake risks, how students learn about earthquakes and their effects on structures, and how the public learns about the impacts of earthquakes on their lives.

The vision and strategy provide guidance to the NEES Board of Directors and NEES Inc. on strategic choices that will lead to an implementation and execution plan. In addition, the plan:

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- Conveys the user needs for earthquake engineering to IT professionals and those involved in developing the national cyberinfrastructure.

1. INTRODUCTION

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) was initiated by the National Science Foundation (NSF) in 1999 to enable the development of transformative technologies through the creation of the next generation of experimental and computational facilities for the earthquake engineering research and education community. As stated in the request for proposals during the Major Research Equipment and Facilities Construction (MREFC) phase of NEES, NSF envisioned that the creation of NEES would "shift the emphasis of earthquake engineering research from current reliance on physical testing to integrated experimentation, computation, theory, databases, and model-based simulation." NEES provides new paradigm in which earthquake engineering research and education within the NEES consortium becomes a collaborative effort among the community rather than a collection of loosely coordinated research and education projects by individuals, and it provides mechanisms for broadening participation in earthquake engineering by allied disciplines. To this end, the System Integrator award to the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign during the MREFC phase of NEES and, more recently, NEESit (i.e., the NEES cyberinfrastructure center) at the San Diego Supercomputing Center at the University of California, San Diego during the operations and maintenance phase of NEES have developed technologies for collaborative on-site and remote research, data sharing, distributed testing, and model-based simulation, with emphasis on providing real-time experiment-simulation interaction capabilities.

Since October 2004, NEES is now in full operation and NEESit is in the process of adapting, integrating, and extending the Information Technology infrastructure for the NEES research community. Now is an opportune time to take stock of the vision and strategies for IT within NEES to ensure future activities are in keeping with the needs of the global user community, to harness new ideas at the interface between earthquake engineering and cyber technologies, and to position NEES to take advantage of the rapidly advancing world of IT. To attain this vision, it is essential that the NEES earthquake engineering community have a view of and embrace next-generation information technologies necessary to address the scientific and engineering goals and challenges associated with seismic hazard mitigation.

NEES PROVIDES A NEW PARADIGM FOR COLLABORATION IN RESEARCH AND EDUCATION
NEES provides new paradigm in which earthquake engineering research and education within the NEES consortium becomes a collaborative effort among the community rather than a collection of loosely coordinated research and education projects by individuals.

There are numerous challenges and opportunities to enabling the vision for IT in NEES laid out in this document. While the system of tools and technologies developed by the NEES IT community should present a unified and consistent model of use and function for earthquake engineering users, each type of user and stakeholder will benefit differently from the advances made in IT since each has its own unique set of needs and requirements. For example, NEES began and will continue in the short term to be researcher centric. As NEES matures, both as a program and by the products and services (IT and others) it provides, the designed target emphasis for the IT deliverables will broaden to practitioners, educators, students, and the broader public community. Also, IT is developing rapidly and new cybercommunities are being formed that can both contribute to and learn from NEES. Through the strategic execution of the vision laid out in this document, the NEES community will harness these new information technology capabilities in their drive to mitigate risk from earthquakes and tsunamis.

The Transformative Potential of Information Technology in NEES

Performing high-fidelity simulations and physical experimentation of realistic engineering systems and components is a complex process that requires the collaboration of individual researchers located at different sites, accessing and sharing extensive amounts of data and conducting their activities in a highly coordinated fashion, in some cases in real time. The required advances in information technology and their application to NEES research cannot be attained for each activity in isolation. A concerted approach to advancing IT within NEES is required that takes into consideration the overall earthquake engineering objectives, specific applications for which the information technology is intended, and the interrelationship between the IT system components. The National Research Council issued a report in 2003 (NRC, 2003) on grand challenges in earthquake engineering and a long-range research agenda for NEES. That report indicated "This will require major advances in information and communication technology within the earthquake engineering community, including data sharing and interoperability; effective collaboration across disciplines and subdisciplines; hybrid simulation; accuracy and computational performance of large-scale simulation; coupling between multiple computational models; and knowledge-based and geographic information systems (GIS) to support decision making by policy makers and planners" (NRC, 2003).

The transformative power of IT in NEES is best harnessed by:

- Providing a world-class set of IT tools for the NEES community to conduct research in earthquake engineering that can lead to comprehensive, innovative, and cost-effective earthquake mitigation and response strategies.
- Establishing a cohesive, long-term relationship between the NEES community, earthquake engineering stakeholders, and the cyberinfrastructure community to facilitate sharing and opportunities for future growth, development, and increased efficiency.
- Establishing a strong base of IT capabilities to contribute to the ongoing dialogue worldwide about incorporating IT into earthquake engineering research, education, and practice for collaborative activities.
- Educating and energizing the NEES community to incorporate information technology cohesively into their own work and to seek new opportunities that build on the vision outlined in this document.
- Customizing and deploying IT tools to create and disseminate education, outreach and training learning objects and conduct distributed learning sessions for all audiences.
- Broadening the cross-disciplinarity of earthquake engineering to incorporate new knowledge and technology from allied (and related) fields.

The vision and strategy for IT in NEES laid out in this report are designed to leverage technology, the NEES community, and international collaborators in a genuine transformation of earthquake engineering towards integrated experimentation, computation, theory, databases, and model-based simulation to enable new approaches for earthquake engineering research, education, and practice. A well-executed strategy will facilitate the creation of new approaches to and opportunities for research, education, and practice in earthquake engineering and will produce services to support the needs of NEES stakeholders. Illustrative, but certainly not exhaustive, examples of the possibilities are as follows:

> **HARNESSING THE POWER OF IT IN NEES**
> *Harnessing powerful IT tools permits current activities within the NEES community to occur better and faster, facilitates new interactions, encourages new ways to think about problems, exposes innovative ways to solve these problems, and ultimately enables researchers to tackle new, previously unfathomable challenges.*

- An engineering student will be able to search databases of experimental, field, and reconnaissance data. This is first used to compare empirical or design-code relationships with the data, and then to build computational models of the experiments, and investigate the range of validity of the models.
- An earthquake engineering research team will be able to conduct a series of experiments on components; compare computational models with the experimental results; refine the computational models based on the data; develop a prototype system simulation model; conduct a hybrid simulation to improve the understanding of how the component performs within the system and how the system performs through all phases of response including collapse; and create visualizations of the system to explain the performance to students and stakeholders.
- A U.S. research team will be able to collaborate with colleagues internationally through document sharing, streamlined access to distributed content and resources, and coordinated multi-site simulations.
- A faculty member teaching a course will be able to provide an education portal that provides online access to primary source material for the course, including articles from E-journals, synthesized results from seminal simulations, and easy access to simulation tools and data that may be used by the students for assignments.
- An engineering practitioner will be able to search online E-journal papers for information needed to analyze and design a particular system. The e-paper will provide links to the data sources and models developed for understanding the performance of the system. The engineer can then verify that the information is relevant to the problem at hand, and select model parameters for simulating or assessing performance. The engineer may need to conduct a number of parametric studies to understand the sensitivity of the response; to accomplish this efficiently, she or he will have access, as needed, to high-performance computers that can run large parameter studies efficiently through a portal.
- Researchers developing simulation solutions for policy makers in charge of implementing seismic mitigation and response strategies will be able to access software tools and data that provide a range of capabilities that include hazard mapping, inventory assessment, damage assessment, resulting social and economic loss, and decision support engines.
- Engineering and computer science researchers and developers will be able to harness a well-managed set of core capabilities in the NEES cyberinfrastructure for the purpose of providing the ability to include new data sources and tools (from local projects or other national/international projects) to explore beyond the original science plan and contribute to scientific capabilities in other fields. New and developing cyberinfrastructure technologies enable harnessing this powerful mix of current and future functionality.

This vision encompasses more than the direct needs of the research community in earthquake engineering. IT can assist in lowering or eliminating barriers to collaboration, information sharing and knowledge transfer. The need to excite, educate and transfer knowledge to researchers, practitioners, educators, students, and policymakers is a high priority of NEES; the IT vision is designed to facilitate and enhance this process. Harnessing powerful IT tools permits current activities within the NEES community to occur better and faster, facilitates new interactions, encourages new ways to think about problems, exposes innovative ways to solve these problems, and ultimately enables researchers to tackle new, previously unfathomable challenges.

This vision is realistic and achievable with the full support of the NEES community and its constituencies. NEES has the opportunity to take a strong leadership role in transformative power of information technology in engineering research and education. Success will require the commitment of the NEES community, securing resources through partnerships with a variety of funding sources, a clear articulation of the strategy, and a focused execution that combines assessment of user needs, research and development, and integration of existing and new technological approaches.

Context and Background

Information technology has transformed every field of engineering and science field. The exponential increases in the power of computers, network communications, and enterprise software systems have been breathtaking. High-performance computing has revolutionized the understanding of fundamental physics, chemistry, biology, astronomy, and earth science. In engineering, highly scalable parallel computing has fueled the development of high-fidelity simulations of engineering systems, as described in a 2006 report by a blue-ribbon panel on simulation-based engineering science (NSF, 2006a). Embedded computing, sensors, and control systems are prevalent in such everyday items as cell phones, automobiles, traffic control in urban areas, and electric power transmission and distribution. Advanced databases have allowed the search (or mining) for information, and communication networks are facilitating virtual teaming and collaboratories. In the hazards arena, information technology is a key component for improving the nation's ability to respond to disasters (NRC, 2007). Building on these significant developments in IT, NSF has recently developed a cyberinfrastructure vision that includes plans for (i) high-performance computing, (ii) data analysis and visualization, and (iii) and virtual organizations for distributed communities (NSF, 2007).

The impact of each of these cyberinfrastructure areas has been recognized in earthquake engineering. Notwithstanding the significant strides made in recent years by the earthquake engineering community, substantive progress towards the long-term goal of preventing earthquake disasters will require, to quote the NRC report (NRC, 2003) on grand challenges within NEES, "multidisciplinary research studies of unprecedented scope and scale. In particular, major advances will be required in many areas, from the computational simulation of seismic events, wave propagation, and site effects on ground motion, to the simulation of the performance of buildings, bridges, their foundations, and other infrastructure, including their dynamic interactions, due to such earthquakes—all of which will rely on extensive physical testing or observation for validation of the computational models." The 2003 NRC report identifies the major advances in information technology that are essential for pursuing challenging, high-impact research: (i) Accuracy and computational performance of large-scale simulations, including coupling of multiple analytical models and hybrid simulation of experimental and analytical models, (ii) visualization for experimental, computational, and hybrid simulations, (iii) data sharing and interoperability, (iv) collaboration, and (v) knowledge-based and geographical information systems (GIS). The report concludes that managing, curating, and sharing of data are essential for multidisciplinary research in earthquake engineering. Furthermore, IT tools are needed to develop true collaborative systems with visualization, communication, and knowledge discovery. These initiatives also corroborate well with the more recently released broad assessment of grand challenges for disaster reduction from the National Science and Technology Council (NSTC, 2005).

Also in 2003, the Earthquake Engineering Research Institute developed a research and outreach plan for earthquake engineering (EERI, 2003) to achieve the goal of securing society against catastrophic earthquake losses. An important recommendation of the EERI report was that information technology has a critical role in achieving the goal of preventing catastrophic losses by increasing knowledge of earthquake hazards, assessment of impacts, and impact reduction programs, both before and after an earthquake. Three major categories of technology are identified: (i) high-performance computing for computational and hybrid simulation, (ii) sensor networks and communications, and (iii) information management and visualization. The IT development and deployment in NEES was expected to provide a revolutionary resource for conducting advanced experiments, collecting data, and collaborating in experimental and computational simulations of earthquake engineering systems.

Establishing a vision regarding IT in earthquake engineering and the NEES program occurs in a national context of developing a cyberinfrastructure for science and engineering. The concept of cyberinfrastructure was introduced by the President's Information Technology Advisory Committee (PITAC, 1999). In 2002, the National Science Foundation formed an advisory committee with the leading information technology and application researchers in the country to develop a roadmap for cyberinfrastructure (Atkins, 2003). The National Science Foundation has a central role with its vision of leading the "development and support of a comprehensive cyberinfrastructure essential to the 21st century advances in science and engineering research and education" (NSF, 2006b).

Since these landmark reports, NSF has worked with a broad range of science and engineering communities to define information technology needs for transformative research and education. These have been critically important efforts to abstract the common infrastructure components, examine specific application needs, and define processes for taking advantage of the exponential increases in computing and communications power. In the sciences, high-performance computation is driving many of the discoveries, particularly in physics (McCurdy et al., 2002); chemistry (Head-Gordon et al., 2004); and biology (Wooley, 2003). Some common themes that emerge from the science communities are that capabilities of high-performance computing often define the limits of what can be explored computationally, such as the complexity of molecular structures, and the spatial and temporal resolution of phenomena based on fundamental principles. There is considerable research needed on scalable and tunable algorithms as computing moves from teraflops to petaflops; data management and visualization of data are essential for understanding phenomena and validating models; IT developments need to be flexible to respond to changes in user needs as knowledge is gained and as computers, communications, and software increases in power and capability; and a layered software infrastructure is necessary for progress in utilizing cyberinfrastructure for new application (NSF, 2004).

Several examples are available within various disciplines of science and engineering of how significant advances in IT are changing the way in which work is conducted within the field. For example, the geological sciences have developed a sophisticated approach to cyberinfrastructure in GEON (2006) (http://www.geongrid.org/). GEON provides a web portal for accessing a rich array of data, web services, and tools related to geosciences. Similarly, nanoHub (2006) (http://www.nanohub.org/) is a collaborative community web portal related to nanotechnology that provides flexible access to interactive tools, simulation results, shared documents, learning modules, news, and other features. Members of the community can upload information and use the space for collaborative activities within their project team.

In engineering, a notable program to utilize cyberinfrastructure is the Water and Environmental Research Systems (WATERS) Network (http://cleaner.ncsa.uiu.edu). The goal of WATERS is to develop an advanced, distributed research and education network for complex environmental systems. The plan is to fuse environmental sensing with databases, visualization, and modeling and simulation (Haas et al., 2006). Pilot projects in this area are already demonstrating advanced capabilities such as real-time monitoring of sensors and community sharing of computation workflow descriptions.

> ***NEES IS A SHOWCASE FOR IT WITHIN ENGINEERING***
>
> *With the significant investment from NEES in components of cyberinfrastructure and its community processes in place, it is well-positioned to be an IT showcase for driving innovation to pioneer new engineering solutions.*

The Open Science Grid (OSG , 2006) (http://www.opensciencegrid.org/) and Teragrid (http://www.teragrid.org/) operate cyberinfrastructure for providing distributed computing resources for petascale computing. A number of different fields of science tap into the large-scale computing capabilities offered by these national grid systems.

Information Technology will also provide NEES Education, Outreach, and Training activities with the resources to create activities with large-scale and cost-effective impact. Beyond single activities, IT integration will allow for indexing activities within NEES and in broader collections such as the National Science Digital Library (NSDL, http://nsdl.org/). The NEES Education, Outreach and Training (EOT) Strategic Plan (Anagnos et al., 2005) and NEES EOT Execution Plan (NEES, 2006) are both anchored within a robust cyberinfrastructure.

NEES is a showcase for information technology within engineering, as described in NSF (2007). Building upon the ongoing investment in IT in NEES, a coherent vision and strategy will accelerate the advance of information technology within NEES. The earthquake engineering community supports the goals and strategies for NSF's cyberinfrastructure landscape (NSF, 2006b, 2007) and, conversely, advances in earthquake engineering will provide a significant impetus for engineering contributions to inform and reach NSF's goals for its use of information technologies. With the significant investment from NEES in components of cyberinfrastructure and its community processes in place, it is well-positioned to showcase the "innovation loop" process described in a recent report on maximizing the engineering impact of cyberinfrastructure (Berman et al., 2006).

Scope of the Report

This document is divided into the following sections:

Vision: Section 2 of this report presents the vision for information technology within the NEES program. The elements of the IT vision, which tie in closely with the overall mission of NEES, are a concise statement that the NEES community can use to guide its strategy into the near and more distant future. This discussion highlights for earthquake engineers how integration of IT will transform research, education, outreach, and technology transfer in the field, and highlights for the IT community the most critical elements of what is needed within earthquake engineering related to IT.

Strategic Plan: The strategic plan for information technology in NEES is given in Section 3 of this report. The plan focuses on the applications and services necessary to realize the IT vision. This section also outlines for earthquake engineers the current state-of-the-art IT capabilities that will be integrated within NEES, and provides a high-level view of the user needs and functionality. The strategic plan is intended to guide the NEES community towards achieving the vision, and recommendations are made for both short- and long-term priorities over a five year time frame. An important aspect of the strategic plan is to increase the capabilities of the NEES community to leverage with cyberinfrastructure communities for sustained development activities beyond the five-year time frame.

Conclusion: Conclusions from this report are presented in Section 4.

Appendices: Three appendices provide details of the applications and services, processes, and technologies needed to achieve the vision and strategic plan laid out in this report.

2. A VISION FOR INFORMATION TECHNOLOGY IN NEES

A vision statement communicates the aspirations of a community to its constituencies. The ultimate goal of the earthquake engineering community for more than half a century has been to reduce the loss of human life and economic vitality of our society caused by large earthquakes. On the geological time scale that earthquakes and tsunamis occur, fifty years is a short time and enormous challenges face the earthquake engineering community as it strives to achieve this goal. NEES, as authorized under the National Earthquake Hazards Reduction Program (NEHRP) (http://www.nehrp.gov/), is a major milestone in earthquake hazard mitigation because it provides the facilities, research opportunities, education, collaborative tools, and outreach that are essential for creating knowledge and innovative technologies and enabling solutions to be used in engineering practice. And within NEES, a key ingredient for success is deployment of modern information technology to accelerate and increase the effectiveness of knowledge creation, integration, and implementation. The vision statement for information technology within NEES captures this goal:

The vision of NEES Information Technology is to drive innovation in earthquake engineering through transformative technologies that will enable the creation and integration of knowledge leading to pioneering solutions for protecting society from the catastrophic effects of earthquakes and tsunamis.

The purpose of this section is to discuss the key elements of the vision statement and to lay the groundwork for developing a strategy for information technology in NEES.

Protecting Society from the Catastrophic Effects of Earthquakes

As presented in the 2003 EERI report (EERI, 2003), earthquakes are a major threat worldwide. The United States is not immune to disasters that can occur as a result of an earthquake. A large earthquake in the U.S. could cause more than $100 billion damage and result in large numbers of human casualties. The 1994 Northridge earthquake was not large, yet it caused 57 fatalities, economic losses in excess of $40 billion, and it overwhelmed the San Fernando region of Los Angeles for months even though it occurred in a region where seismic deign has been practiced for many years. A large earthquake striking a major U.S. city is expected to cause significantly more damage than the Northridge event, and depending on the location and time of day, the casualties will be significantly greater than the relatively few deaths and injuries in U.S. earthquakes over the past 50 years. The NEES program and other earthquake engineering research efforts are making progress towards protecting society from the effects of earthquakes through cutting edge research involving experimental methods and simulation, improved education at all levels, and outreach to the practicing engineers, public policy makers, and the general public. The vision for IT is to directly enable and support these initiatives, initially within the NEES program, and later within the larger community.

Drive Innovation

The IT vision for NEES states that new technologies will accelerate the development of innovative solutions that will reduce the risks to the built environment from devastating earthquakes and tsunamis. Advances in data tools, high-performance computing, visualization, communication and high-performance networks, middleware, cybersecurity, sensor acquisition and distribution, and portal frameworks that are emerging in the rapidly advancing cyberinfrastructure coupled with the unique facilities of NEES are expected to accelerate these developments.

Transformative Technologies for Earthquake Engineering

Robust developments related to IT in earthquake engineering will support the development of transformative earthquake engineering technology to enable faster and more effective solutions similar to innovations that have revolutionized many other fields of engineering. In earthquake engineering, faster means speeding up the cycle for risk mitigation strategies to be used in retrofit and new construction and response strategies to be used after a seismic event. More effective means improved earthquake engineering performance, often for the same or lower cost. IT tools for collaboration, data, management, computational simulation, and hybrid simulation will be essential for researchers to develop these new solutions and verify them using one or more NEES equipment sites. Many of these same tools can be adopted for use in education, outreach and training, thereby dramatically expanding the scope and impact of these activities.

There is already an extensive history of disciplines within earthquake engineering utilizing and integrating IT. For example, the linkages between a variety of these core capabilities are traced in Figure 1. Starting in the upper left with Figure 1a, seismological monitoring is now ubiquitous through most of the world (e.g., IRIS , 2006) . Early, if not instant, access to earthquake accelerograms, seen now for example in the form of shake maps generated within minutes of an event (e.g., Caltrans, 2006), can fuel new areas of research related to coordinated response through understanding of seismic excitation across a region. The COSMOS virtual database also provides access to a wide range of strong motion information from a number of data providers (COSMOS , 2006). Moving down to Figure

TRANSFORMATIVE TECHNOLOGIES FOR EARTHQUAKE ENGINEERING

Robust developments related to IT in earthquake engineering will support the development of transformative earthquake engineering technology to enable faster and more effective solutions.

1b, GIS-based tools (e.g., Anselin et al., 2006), coupled with terrain-rendering engines such as Google Earth (2006) then enable the seismic event to be mapped across the region so that interdependent effects of the hazard may be ascertained. Regional or localized damage assessments, mapped onto these GIS tools, may then be conducted (Figure 1c) via the use of fragility curves and other statistical means, or via direct simulation, to estimate damage of a population of structures and systems across a region (e.g., Spencer et al., 2005; MAEviz, 2006; HAZUS, 2006; Huyck et al., 2006). These IT tools also serve as asset management tools in which detailed characteristics of the structure (e.g., attributes, drawings, simulation results) may be stored and manipulated (e.g., through the use of Building Information Models) (Figure 1d). The technical basis for these damage estimates, in turn, plug into the rich world of component and system experimentation and simulation (Figure 1e) that is at the heart of current NEES activities. Through digitization (Figure 1f) not only of simulations of experimental tests (French et al., 2005) but of the experimental specimens themselves (Xu and Chen, 2004), coordinated exploration of experimental and computational simulations offer a new generation of data analysis capabilities and augmented reality visualizations (local and remote, live and archived) (Figure 1g) (Henry et al., 1998), and thus a combined richer understanding of the response of the built environment to extreme events.

In the field of computational simulation, a recent NSF workshop examined computational and visualization environments for NEES (Roddis, 2003). For example, OpenSees has demonstrated that community software development enabled by an open-source development process, modern software engineering and high-performance computing enables sophisticated modeling and simulation of structural and geotechnical systems (OpenSees , 2006). There are many compelling examples of very large-scale simulation models used to investigate the earthquake ground motion in large sedimentary basins, and seismic performance of complex structural and geotechnical systems. Combining experimental and computational approaches, hybrid simulation methods (e.g., OpenFresco , 2006; SimCor , 2006) have recently been developed using software and communication tools that were not available when the original pseudo-dynamic test method was developed. Hybrid simulation is an excellent example of transformative information technologies that directly apply to NEES, allowing researchers and practitioners to simulate a system through integrated use of multiple NEES equipment sites.

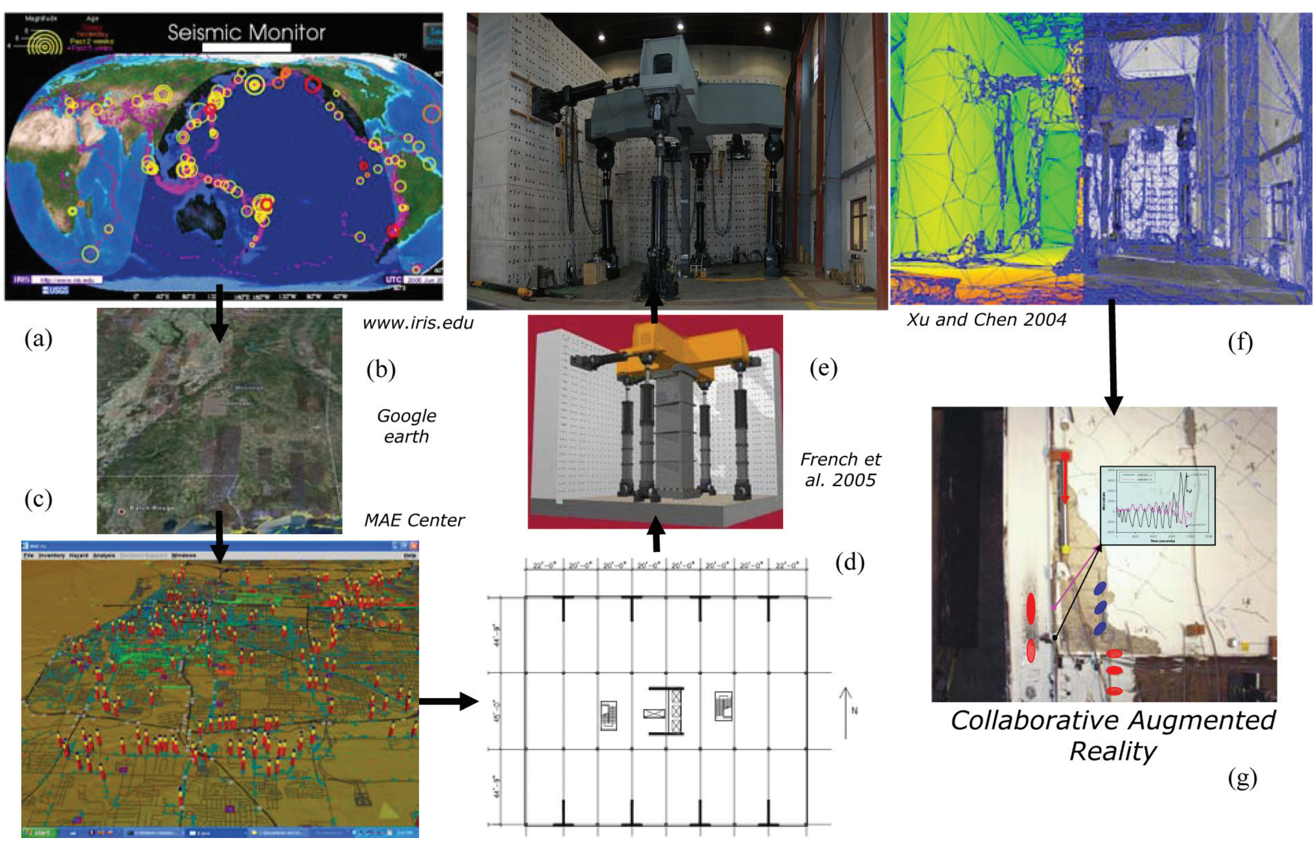


Figure 1. Multi-Layered Information Technology within Earthquake Engineering

Creation and Integration of Knowledge

Information technology is essential for supporting the creation and integration of knowledge of, in this case, earthquake engineering. Information technology provides a virtuous cycle where researchers from earthquake engineering and allied fields and practitioners alike can extract information and data, use it, contribute to it, and add back into the knowledge base. The NEES community has an ambitious set of objectives and is defining a challenging research agenda that combines experiments and simulations in earthquake engineering research. Key elements of information technology needed for creating and integrating knowledge for NEES are:

- Universal access to data and metadata; ability to query and mine information in federated data systems using flexible criteria for different users with a range of expertise and data needs;
- Establishing and tracking the curation and provenance of information, accuracy of the data, and links to other uses of the data;
- Tools for utilizing simulation software to develop, validate, and calibrate models; access to high-performance computing resources and optimized software;
- Advanced hybrid simulation methods to provide the ability to couple computation and physical modeling across multiple NEES, non-NEES, and international equipment sites;
- Visualization tools to turn data into knowledge; ability to use visualizations to investigate rich data sets from experiments and simulations and make comparisons between the two;
- Software tools to dramatically improve the process of knowledge creation and integration, such as flexible portals for collaboration and access to data, experimental, and computational resources; workflow tools that will greatly improve the process of inquiry and transfer of research results into practice;
- Advanced collaboration tools that facilitate integrated work of project teams at distributed locations nationally and internationally, including remote telepresence in real-time for experimental and computational simulations, document sharing, and collaborative community portals; these collaborative tools will harness core IT technologies related to high performance networks domestically and internationally;
- Robust middleware software and services that would provide many benefits of building upon work in other engineering and science communities and providing interoperability with the cyberinfrastructure for other communities; and
- Attractive and functional portals for educating the next generation of earthquake engineers, motivating students about challenging problems in earthquake engineering, and educating the public about how earthquake engineers help protect society from catastrophic losses.

PIONEERING SOLUTIONS IN EARTHQUAKE ENGINEERING

Innovation, transformative technologies, and new knowledge must be marshaled together for truly pioneering solutions to reduce the societal risk to earthquakes. This is where the IT comes together with the promise of NEES by unleashing creative researchers to revolutionize earthquake engineering and advance the goal of reducing the risk to society of major earthquakes.

Pioneering Solutions

Innovation, transformative technologies, and new knowledge must be marshaled together for truly pioneering solutions to reduce the societal risk to earthquakes. This is where the IT comes together with the promise of NEES by unleashing creative researchers to revolutionize earthquake engineering and advance the goal of reducing the risk to society of major earthquakes. Examples of current earthquake engineering research where IT can have significant impact include large-scale ground motion modeling; high-performance structural systems; damage tolerant foundations; new techniques to protect non-structural equipment from damage; improved understanding of damage mechanisms and collapse of buildings, bridges, and other infrastructure; smart materials and systems; and regional loss simulation and estimation. Information technology within NEES will also improve the transfer of knowledge into practice through accessible and user-friendly tools to provide better access to data, examples, and research that forms the basis of building code specifications and guidelines. International collaboration with researchers and practitioners in other countries will be improved considerably with better IT tools. Finally, information technology within NEES will improve outreach to students, public policy makers, and the public by communicating information in an exciting, up to date, and relevant manner for each constituency. These examples are representative of the earthquake engineering capabilities, accelerated by IT tools, that detail the overall transformative vision for NEES.

3. *A STRATEGIC PLAN FOR INFORMATION TECHNOLOGY IN NEES*

From the formative days of NEES, it was recognized that information technology has the potential for fundamentally transforming earthquake engineering research, practice, and education (EERI, 2003; NRC, 2003). Information technology has a crucial role for NEES to accomplish its mission and achieve its goals by providing researchers, practitioners, educators, and students access to applications and services for data, simulation, visualization, collaboration, and information. These applications and services will, in turn, be continuously improved and extended as NEES takes advantage of national trends in information technology and the growing cyberinfrastructure (NSF, 2007).

Building upon the vision for information technology in Section 2, this section defines a broad strategic plan that will maximize the transformative potential of information technology in NEES. The strategic plan has been developed to provide guidance on choices between alternatives and for setting priorities in support of the overall goals and measures of success for NEES to achieve the vision for information technology.

In defining the strategic plan, it must be recognized that NEES faces many challenges in building an effective state-of-the-art cyberinfrastructure for earthquake engineering users. The applications and services are driven by the context of both current and anticipated future community practices, interests, and user needs in earthquake engineering. They must be built cost-effectively and balance current functionality with future scalability and extensibility. The IT functionality required by the NEES users is often at or beyond the state-of-the-art; in planning, NEES must avoid both under- and over-engineered IT solutions. Applications and services can become obsolete quickly as technology improves and user expectations and needs change. Conversely, applications built with options and performance levels for future use-cases can end up being too complex and too costly to use and maintain and may never be adopted. The need to achieve a workable balance between current and future utility argues strongly for agile, modular, use-case driven development strategies. Scalability, evolvability, and a clear forward-migration path should be emphasized, rather than aiming for an all-encompassing scale and scope at one point in time.

Central to the NEES IT strategic plan is that it does not begin and end with earthquake engineering applications and services for users, but rather it balances application development with increasing the capacity of existing cyberinfrastructure to reduce the cost of future developments and enhance the ability for the applications to evolve in response to new user needs. Therefore, the strategic plan for information technology recognizes that the NEES community must design, develop, and leverage the resources required to address the issues driving the science and engineering goals. NEES will not be the sole driver of advancements but will take advantage of, where appropriate, software developed in other national IT efforts and commercial-off-the-shelf software (COTS). Finally, it must be recognized that NEES must provide high quality service, support, access to resources, and training to achieve the strategic goals for all users: researchers, practicing engineers, educators, and students.

With this background, the strategic decisions for IT within NEES define the applications and services to meet the needs of NEES users. Most users will see the benefits of the NEES cyberinfrastructure through the capabilities, quality, and robustness of the applications and services. To achieve the strategic plan we address the technologies needed for the applications and services, such as data systems, high-performance computing, visualization, high-performance networks, and middleware services such as portals. The technology choices will have a large impact on the functionality, reliability, and long-term extensibility of the NEES systems, and the choices must allow for rapidly changing and improving technology. Finally, another set of strategic decisions is related to the processes that will be used and developed for creating, maintaining, and adapting NEES applications and services. The processes used in executing the strategic plan are critical determinants that will increase the capacity NEES has for continual improvement of the technology and for leveraging and contributing to the larger scientific cyberinfrastructure.

> ***STRATEGIC OBJECTIVE: BUILD CAPACITY FOR IT IN EARTHQUAKE ENGINEERING***
> *Central to the NEES IT strategic plan is that it does not begin and end with earthquake engineering applications and services, but rather it balances application development with increasing the capacity of existing cyberinfrastructure to reduce the cost of future developments and enhance the ability for the applications to evolve in response to new needs.*

Throughout the development of this strategic plan for applications, technologies, and processes, four key elements were deemed fundamental to acquiring and disseminating new earthquake engineering knowledge effectively and efficiently through the use of information technology. The four elements are: Discover new technologies to bring into the IT systems of NEES; Produce new and adapt existing applications through research and development; Serve the NEES community by providing high-quality support in the development and use of

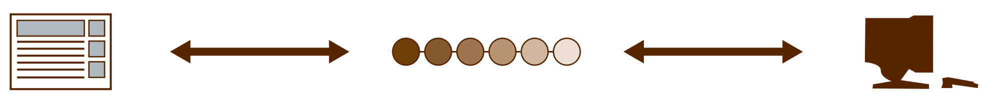
IT applications; and Educate the NEES community to use information technologies for earthquake engineering applications and provide education resources for earthquake engineering. The relationships between the strategic decisions on applications and services in relation to the technologies and processes are illustrated in Figure 2.

> ***STRATEGIC OBJECTIVE: BUILD SCALABLE AND EVOLVABLE IT APPLICATIONS AND SERVICES FOR EARTHQUAKE ENGINEERING***
>
> *The strategic plan for applications and services defines the tools needed by the NEES community for research, education, and engineering practice. Scalability, evolvability, and a clear forward-migration path should be emphasized, rather than aiming for an all-encompassing scale and scope at one point in time.*

3.1. Applications and Services Overview

The NEES community is expanding to encompass facilities and researchers at institutions throughout the United States. It also seeks to partner with earthquake engineering organizations worldwide that are embarking on similar endeavors at harnessing transformative technologies to accelerate earthquake engineering discoveries. The NEES user community is geographically distributed, multi-disciplinary, and located at institutions ranging from large universities to small colleges to government organizations to private companies and small firms. The community is diverse in its needs, interests, and level of IT expertise and so the applications and services need to account for this diversity. Users range from active researchers creating data through the use of NEES facilities and model-based simulations, to users of the data and other information throughout the world. Success at integration of IT within NEES demands first-rate applications and services.

The strategic plan for applications and services defines the tools needed by the NEES community for research, education, and engineering practice. Table 1 is an overview of the categories



	Applications and Services	Processes	Technologies
DISCOVER	New applications for advancing earthquake engineering research frontiers through IT	Leveraged processes and tools for cyberinfrastructure developed worldwide to expand NEES resources and capabilities	New IT technologies to improve cyberinfrastructure-based needs in earthquake engineering
PRODUCE	New, high-quality NEES applications and tools	New approaches for extensible applications and services	New IT technologies to improve cyberinfrastructure-based needs in earthquake engineering
SERVICE	Operation and support for NEES tools and resources	Processes for responsive support and prioritization of new services for IT in earthquake engineering	Technologies that enable scalable, robust support for development and use of IT across NEES
EDUCATE	Students, practitioners, researchers, and the general public through new and customized applications that use IT to teach earthquake engineering to students, practitioners, researchers, general public	NEES IT developers to create new approaches methods to produce and distribute educational resources	NEES users and IT developers about new and existing technologies that can be accessed easily by researchers, practitioners, educators, and students

Figure 2. Relationship between Strategic Choices and Key Elements of Strategy for Information Technology in NEES

of IT applications and services to meet NEES user needs. With limited resources, prioritization is necessary for NEES to develop an execution plan that is responsive to the community needs and balances the current needs with long-term capacity building. The applications and services listed in Table 1 are in an approximate prioritized order with the highest priority items near the top of the table.

For each application and service listed in Table 1, the high-level functionality is summarized and the transformative potential is identified. The development of truly transformative applications and service needs to be based on user scenarios. Thus, Table 1 is the first step for defining the requirements traceability matrix (RTM) that captures user needs and refines them into specific application and service requirements and ultimately validation test cases. Sophisticated approaches for gathering user requirements for software applications have been developed for a number of IT initiatives to date. With the diverse community represented within NEES, establishing specific use-case studies that facilitate frequent communication and integral collaboration between those designing and developing IT components and those using IT components enables detailed assessment of complex user needs and performance metrics for applications and services. The NEES vision addresses the future of earthquake engineering and a true partnership in which all involved commit to addressing the necessary advances in technology and in earthquake engineering research and education practice, guided by use cases, RTMs, and frequent collaborative interaction, must be a core element of the IT strategy.

Since there is ongoing development in all the application and service areas, the next row in each sub-table of Table 1 summarizes how NEES can leverage completed and ongoing work and integrate it into the NEES IT systems. An important set of decisions is associated with whether to base development of applications and underlying services on open-source software or commercial off-the-shelf software. Well-designed open-source software has a very good track record of functionality, extensibility, and scalability, which are the attributes discussed previously for the long-term success of the NEES cyberinfrastructure. There are also many COTS that provide useful functionality at a given point in time. To the extent that COTS utilize industry-standard application program interfaces (API), they will continue to play a crucial role within NEES.

Although many of the NEES applications and services listed in Table 1 can benefit from leveraging other existing IT solutions, it must be recognized that a significant investment in research and development is necessary to meet fully the needs of NEES users and earthquake engineers. The last rows in the Table 1 sub-tables summarize the research and development necessary to move beyond general software for the application and services and provide users with transformative solutions. To produce the suite of applications and services identified in Table 1, it will be necessary to marshal the resources required to bring these research and development objectives to fruition. A vigorous and focused IT research and development program integrated with the NEES engineering research program will not only improve earthquake engineering knowledge and practice, realizing the transformative potential of information technology, but will also contribute to the goals of building capacity for future work in earthquake engineering, educating students in modern information technology and its applications in science and engineering, and positioning earthquake engineering as a supplier of knowledge and capability for the national cyberinfrastructure initiatives.

Table 1. NEES Information Technology Applications and Services: Functionality, Opportunities, and Needs

Table 1a. Functionality, Opportunities, and Needs for Community Data Sharing

Application and Service	CDS: Community Data Sharing
Functionality	Researchers, educators, practitioners, and students will have access to curated data for a wide range of uses.
Transformative Potential	Transformative Potential Sharing, searching, mining, and viewing experimental, reconnaissance, field, and computational data.
Leveraging Opportunities	Extensive applications in distributed data services, database federation, and content management, as well as solutions for providing persistent URL references/global identifiers.
Research and Development Needs	Metadata models and dictionaries for earthquake engineering applications. Interfaces for human and programmatic interaction (e.g. at equipment sites and from within computational engines).

Table 1b. Functionality, Opportunities, and Needs for Computational Modeling and Simulation

Application and Service	CMS: Computational Modeling and Simulation
Functionality	Model-based simulation to facilitate engineering design: model processes to enable multi-physics, multi-scale predictions of behavioral assessment, optimized engineering design, policy planning, and decision support, such as: simulate causes and effects of seismic excitation; predict component or system damage and collapse due to earthquakes; explore new materials for earthquake engineering applications; predict losses within systems or regions due to seismic damage.
Transformative Potential	Create simulation models of experimental systems, and prototype systems, geographic regions, or processes. Perform simulation of response for geophysical, soil, and structural systems. Use high-performance computing resources for simulation, as needed.
Leveraging Opportunities	Wide range of modeling and simulation software, including geophysical, soil, and structural system response, tsunami simulation, regional modeling and decision support, and optimization and design applications.
Research and Development Needs	New approaches to simulation across different scales and materials to understand and predict system performance. Interfaces to NEES cyberinfrastructure.

Table 1c. Functionality, Opportunities, and Needs for Visualization

Application and Service	VIZ: Visualization
Functionality	Provide interactive graphical interfaces for model creation and interpretation, including geophysical, soil, and structural models, building information models, visualizations for geographic information systems, and image synthesis applications.
Transformative Potential	Create new models for all types of simulation. Create digitized representations of experiments or objects associated with field studies. Visualize real-time data from experimental and computational models, including three-dimensional graphical representations, image- and video-based visualizations, and augmented reality. Compare multiple data sets from repositories.
Leveraging Opportunities	Significant development in scientific visualization for experimental and computational applications. Existing applications for building information models, geographic information systems, image synthesis, and augmented reality.
Research and Development Needs	Synthesized visualization tools linking computational visualizations, digitized renderings of experimental or field specimens, images, and audio. Development of visual metaphors appropriate for wide range of earthquake engineering problems. Tools for community-driven vocabulary and data model development.

Table 1d. Functionality, Opportunities, and Needs for Integrated Computational, Experimental, and Field Simulations

Application and Service	CEF: Integrated Computational, Experimental, and Field Simulations
Functionality	Enable three-dimensional exploration, visualization, and manipulation of experimental specimen or field response based on predictive models calibrated iteratively from experimental or field results. Create new approaches for system identification. Simulate systemic response across systems or regions based upon measured damage.
Transformative Potential	Perform hybrid simulations that combine experimental and computational models at different time scales. Link field measurements to computational models to simulate effects of earthquakes.
Leveraging Opportunities	Limited tools for model calibration and validation. Ongoing work in hybrid simulation to integrate with NEES cyberinfrastructure.
Research and Development Needs	Wide-ranging applications linking computational, experimental, and field simulations for damage prediction, planning, optimization, system identification, and loss prediction.

Table 1e. Functionality, Opportunities, and Needs for Collaboration

Application and Service	COL: Collaboration
Functionality	Facilitate project planning and execution for collaborators at different locations worldwide. Enable coordinated simultaneous work on documents or processes.
Transformative Potential	Workflow systems for virtual project teams working in a global environment using NEES resources and capabilities.
Leveraging Opportunities	Web portals for collaborative interaction including text, images, audio, and video. Cybersecurity tools for remote collaboration. Calendar for resource allocation. Applications for streaming telepresence.
Research and Development Needs	Integrated interfaces for collaboration including common work spaces and heterogeneous communication vehicles. Tools to facilitate domestic and international collaboration.

Table 1f. Functionality, Opportunities, and Needs for Knowledge Capture and Dissemination

Application and Service	KCD: Knowledge Capture and Dissemination
Functionality	Provide up-to-date and accurate information to researchers, educators, practitioners, and the public. Enable information exchange via knowledge-based systems.
Transformative Potential	E-journals and documentation, online specifications and guidelines, and education and training materials. Incorporation of building information models and geographic information systems into communication and management of information across NEES projects.
Leveraging Opportunities	Interactive portals for user communities. Document repository software. Existing applications for building information models and geographic information systems.
Research and Development Needs	E-journal linked to existing publication vehicles for earthquake engineering community. Document repositories integrated with data repositories. Web-enabled knowledge-based systems for information retrieval and manipulation.

Table 1g. Functionality, Opportunities, and Needs for Integrated Teaching and Learning Environment

Application and Service	TLE: Integrated Teaching and Learning Environment
Functionality	Provide single point of access to research tools and learning objects for use in a teaching and learning context. Provide framework to create new learning objects incorporating materials developed through NEES research.
Transformative Potential	Integration of research into teaching contexts, increased impact of education, outreach and training activities and innovations in teaching and learning in earthquake engineering.
Leveraging Opportunities	Web portals and learning management systems with targeted content based upon user specifications.
Research and Development Needs	Middleware and library development to integrate applications developed independently into a cohesive teaching and learning environment

3.2. Strategic Plan for Applications and Services

This section provides definitions of the applications and services identified in Table 1. In addition, for each application and service, Table 2 lists the functionality and user needs that have been identified as essential for the strategic plan. This provides further refinement, although still at a high-level, of the traceability matrix for user requirements (an example of a more detailed requirements traceability matrix for implementation of NEES applications may be found in Finholt et al., 2003). The functionalities are identified with an expected time frame for completion of less than 1 year, 1-2 years, 3-4 years, or 5 or more years, based on a starting time of publication of this document.

As discussed in Section 3.1, the strategic plan focuses on the earthquake engineering user needs through applications and services. The applications and services are built upon technologies, using IT design processes, design patterns, and frameworks to ensure flexible and scalable results. For each application and service, Table 2 identifies the associated key processes and technologies, which are summarized below:

NEES Information Technology Processes and Technologies

Processes	Technologies
P-CM: Distributed Content Management	T-DB: Data Management Systems
P-PM: Distributed Process Management	T-HC: High-Performance Computing
P-VO: Virtual Organization-Based Management	T-VZ: Visualization
P-RV: Resource Virtualization	T-HN: High-Performance Networks
P-CO: Composable Interfaces	T-MW: Middleware
P-QC: Quality Control	T-CY: Cybersecurity
	T-PF: Portal Frameworks
	T-SA: Sensor Acquisition and Distribution

Additional technical details about the information provided in Tables 1 and 2 are included in the appendices. Appendix A provides descriptions of each application and service area, including further discussion of the short-term and long-term functionality and user needs, key technologies, key processes, leveraging opportunities, and needs for research and development pertinent to the application and service. Appendix B has an extensive discussion of the IT processes needed to build a flexible and robust cyberinfrastructure in NEES, and Appendix C describes the information technologies appropriate for consideration within NEES.

3.2.1. Community Data Sharing

All NEES users and the broader community depend on a highly functional, curated data management system. Implementation of this system is the highest priority strategic thrust for IT within NEES. The basic functionality includes upload, download, query and search, view, and compare data for experimental specimens, field simulations and observations, and computational models and simulations using the data services in the NEES cyberinfrastructure. The data system should provide users access from web browsers, collaborative portals, and from within applications, and users should only need to be concerned with the logical structure of the data and not its physical format or location. The community data systems should support collaborative curation processes so that the community can define and automatically apply validation and review procedures to the data, which then becomes part of the overall provenance record. The system should be highly secure, assure the long-term preservation of NEES data assets, and enable robust, efficient access. It should be a resource not only for researchers, but for practitioners and students as well.

Table 2. NEES Information Technology Strategic Priorities

Table 2a. Strategic Priorities for Community Data Sharing

CDS: Community Data Sharing Key Processes: Distributed Content Management (P-CM), Distributed Process Management (P-PM), Virtual Organization-Based Management (P-VO), Resource Virtualization (P-RV), Composable Interfaces (P-CI), Quality Control (P-QC) Key Technologies: Database Management Systems (T-DB), Middleware (T-MW), Cybersecurity (T-CY), Portal Frameworks (T-PF)	
Functionality and User Needs	**Time Frame**
CDS-1. Capture NEES data, organize it, and make it available as a long-term community resource.	< 1 year
CDS-2. Reduce effort for uploading and annotating data and automate flow of data, metadata, and provenance from local systems.	< 1 year
CDS-3. Support dynamic addition of new data types/formats and new metadata to the system by individual users and groups	1-2 years
CDS-4. Support integration of externally managed data into NEES (through database federation, metadata harvesting, etc.)	1-2 years
CDS-5. Support dynamic addition of new data viewers and translators.	1-2 years

CDS-6. Mechanisms for individuals and groups to directly manage and customize their view of community data by selecting the compliment of viewers, translators, data types and meta-data elements that are required, preferred, or allowed by their sub-community.	3-4 years
CDS-7. Mechanisms to associate processes with data uploads and to trigger processes.	3-4 years
CDS-8. Support for advanced preservation such as system mechanisms and operational processes for archiving to write-only media, maintaining mirror sites, assuring data integrity over time through checksums/signatures, recording details of data formats and meaning and assuring a means for future reading of data after programs are obsolete	3-4 years

3.2.2. *Computational Modeling and Simulation*

Computational modeling and simulation are central to the vision of NEES to transform the development of new earthquake engineering solutions from being primarily based on experiments to a balanced use of simulation and experimentation using computational models validated by experimental and field data. A close integration of modern computational models and simulation software with other NEES applications and services will provide the earthquake engineering community and practitioners with new capabilities for developing innovative and cost-effective solutions. Simulation software related to structural and geotechnical systems should provide the capability for representing the nonlinear behavior of material and the large displacements associated with collapse. Furthermore, the software should have the capability to model coupled structural systems and geotechnical systems since soil-foundation-structure interaction has a significant impact on earthquake performance and is the subject of much of NEES research. Expanded mechanistic models could also simulate processes such as fluid-structure interaction that is critical for modeling the impact of tsunamis, impact of deteriorating infrastructure on seismic vulnerability, or multi-hazard events such as the effect of floods, fires, or hazardous spills caused by seismic events. Long range, modeling and simulation of entire urban regions to assess damage, lifeline network performance, losses, and response and recovery operations will open new horizons in systematic approaches to seismic resilience of communities. The integration of computational modeling and simulation with other NEES IT applications, such as the community data services, visualization, and collaboration tools will provide unprecedented capabilities for researchers, engineering practitioners, and students.

Table 2b. Strategic Priorities for Computational Modeling and Simulation

CMS: Computational Modeling and Simulation Key Processes: Distributed Process Management (P-PM), Virtual Organization-Based Management (P-VO), Resource Virtualization (P-RV) Key Technologies: Database Management Systems (T-DB), High-Performance Computing (T-HC), Visualization (T-VZ), High-Performance Networks (T-HN)	
Functionality and User Needs	**Time Frame**
CMS-1. Tools for creating computational models of experimental specimens	1-2 years
CMS-2. Robust software for nonlinear analysis of experimental specimens and associated prototype soil-structure systems for pre-experiment analysis and post-experiment validation and study.	1-2 years
CMS-3. Seamless access to the NEES database systems for models and simulation results.	1-2 years
CMS-4. Extensible software in terms of material models, system models, and solution algorithms since future research will pursue increasingly refined and higher-fidelity simulation	3-4 years
CMS-5. Scalable simulation software in terms of model size and complexity; have the ability to efficiently use hardware from laptop personal computers to high-performance computers depending on the computational needs of the simulation	3-4 years
CMS-6. Optimization methods for geotechnical and structural system design integrated with NEES data and visualization tools.	3-4 years
CMS-7. Lifeline or traffic network flow functionality modeling due to damage from earthquakes.	3-4 years
CMS-8. Simulation tools for response operations and logistics after an earthquake.	3-4 years
CMS-9. Simulation of short- and long-term economic or social losses per structure and across regions due to damage from earthquakes to interdependent systems	5+ years
CMS-10. Decision support engines for prioritizing use of limited resources for targeted retrofit and rebuilding in seismic zones across the country.	5+ years

3.2.3. Visualization

The visualization tools for the NEES cyberinfrastructure should provide users a wide range of visualization methods and opportunities to use devices, from relatively low-resolution such as web portals to very high-resolution such as PowerWalls and immersive visualization environments. Visualization will assist in understanding the large amounts of data collected in an experiment, relating various types of data, and providing a virtual view of an experiment for remote users and teleobservers. For computational simulation, visualization is an essential tool for interpreting the enormous amount of generated output. One high impact opportunity in visualization is to integrate experiments or field data and computation by combining data from the two for a comprehensive view of a simulation. Visualization tools provide an ideal framework for the verification and validation of computational models using experimental data. Visualization methods and tools are also an excellent approach to integrating data about specific components and subsystems into entire systems, such as Building Information Modeling (BIM) systems, and geographic models using Geographical Information Systems (GIS).

Table 2c. Strategic Priorities for Visualization

VIZ: Visualization Key Processes: Virtual Organization-Based Management (P-VO), Resource Virtualization (P-RV), Composable Interfaces (P-CI) Key Technologies: Visualization (T-VZ), High-Performance Networks (T-HN), Middleware (T-MW)	
Functionality and User Needs	**Time Frame**
VIZ-1. Interactive graphical interfaces for model creation and interpretation, including geophysical, soil, and structural models	1-2 years
VIZ-2. Web-based digitized representations and visualization of experimental data or objects associated with field data.	1-2 years
VIZ-3. Web-based visualization of computational simulation and comparison with experiments	1-2 years
VIZ-4. High-resolution visualization of three-dimensional experimental and computational data and video-based visualizations using standard PC graphics technology.	3-4 years
VIZ-5. Highly-scalable visualization of experimental and computational data from single PC to PowerWall type displays and immersive displays to enable knowledge discovery through augmented reality	3-4 years
VIZ-6. Integration of visualization applications for individual buildings with building information management systems at one end and regional and GSI tools at the other end to allow a user, for example, to zoom from a regional view to the detail of a structural joint and access models and experimental data	5+ years

3.2.4. Integrated Computational, Experimental, and Field Simulations

A critical set of tools to achieve new discoveries through earthquake engineering research involves combining computational, experimental, and field simulations in new ways to investigate complex system performance. Hybrid simulation is an important example of this application and service. Other tools involve validating and calibrating parameterized simulation models using experimental data, creating new approaches for system identification and damage assessment, and simulating systemic response across systems or regions based upon measured damage. Users should be able to access a library of deterministic and probabilistic calibration and validation methods, and have the capability to extend and develop new methods.

Table 2d. Strategic Priorities for Integrated, Computational, Experimental, and Field Simulations

CEF: Integrated, Computational, Experimental, and Field Simulations Key Processes: Distributed Content Management (P-CM), Distributed Process Management (P-PM), Quality Control (P-QC) Key Technologies: Data Management Systems (T-DB), High-Performance Networks (T-HN), Middleware (T-MW), Cyber-security (T-CY), Sensor Acquisition and Distribution (T-SA)	
Functionality and User Needs	**Time Frame**
CEF-1. Perform hybrid simulations that combine experimental and computational models.	1-2 years
CEF-2. Near real-time hybrid simulation.	3-4 years
CEF-3. Enable three-dimensional exploration, visualization, and manipulation of experimental specimen response based on predictive models calibrated iteratively from experimental results.	3-4 years
CEF-4. Link field measurements to computational models to simulate effects of earthquakes.	3-4 years
CEF-5. Simulate systemic response across systems or regions based upon damage predictions	3-4 years

3.2.5. *Collaboration*

Collaboration tools allow users to aggregate information, including developing links and threads with other users. One of the key pioneering concepts for the creation of NEES is that it is a collaboratory, and collaboration tools are at the core of ensuring successful broad access to NEES facilities and cohesive partnerships throughout the NEES community and with communities worldwide. The collaboration tools, such as portals, will allow users to integrate the rich array of NEES IT services for specific problems and will enable community approaches to problem solving.

Table 2e. Strategic Priorities for Collaboration

COL: Collaboration Key Processes: Virtual Organization-Based Management (P-VO), Resource Virtualization (P-RV), Composable Interfaces (P-CI), Quality Control (P-QC) Key Technologies: Visualization (T-VZ), High-Performance Networks (T-HN), Middleware (T-MW), Cybersecurity (T-CY), Portal Frameworks (T-PF), Sensor Acquisition and Distribution (T-SA)	
Functionality and User Needs	**Time Frame**
COL-1. Video-teleconferencing and internet-based collaborative technologies for real-time sharing of documents and other resources.	<1 year
COL-2. Remote telepresence, including viewing of asynchronous data in near real-time and synchronized data in playback mode for experimental, field, and computational simulations.	1-2 years
COL-3. Initiation of collaborative community resource portals that enable sharing of both curated and non-curated information between project teams or the general public.	1-2 years
COL-4. Advanced visualization and collaboration services that integrate sensor networks and mapping	3-4 years
COL-5. Tools for coordinated simultaneous work on documents or processes.	3-4 years
COL-6. Workflow systems for virtual project teams working in a global environment using NEES resources and capabilities	3-4 years

3.2.6. *Knowledge Capture and Dissemination*

Knowledge management is tied to the capability for sharing data. In the NEES vision, the ideas of capturing and disseminating knowledge are interwoven with plans in many areas including data sharing, collaboration, and coupling experiments and modeling. The functionality in this application focuses on the means by which cyberinfrastructure will support the evolution of knowledge-centric capabilities, contribute to the dissemination of best practices and training, and enhance the automation of knowledge transfer within and across communities.

Table 2f. Strategic Priorities for Knowledge Capture and Dissemination

KCD: Knowledge Capture and Dissemination Key Processes: Distributed Content Management (P-CM), Distributed Process Management (P-PM), Virtual Organization-Based Management (P-VO), Resource Virtualization (P-RV), Composable Interfaces (P-CO), Quality Control (P-QC) Key Technologies: Data Management Systems (T-DB), Visualization (T-VZ), Middleware (T-MW), Cybersecurity (T-CY), Portal Frameworks (T-PF)	
Functionality and User Needs	**Time Frame**
KCD-1. Provide up-to-date and accurate information to researchers, educators, practitioners, and the public.	<1 year
KCD-2. Operation of a general website describing NEES and its capabilities and providing training material related to use of NEES facilities and software as well as earthquake engineering educational material.	<1 year
KCD-3. An electronic journal providing short descriptions of simulations and their conclusions in the style of the general scientific literature, linked to the more detailed data and metadata.	1-2 years
KCD-4. Collaboration tools for information federation and exchange via knowledge-based systems.	3-4 years
KCD-5. Incorporation of building information models and geographic information systems into communication and management of information across NEES projects	3-4 years

3.2.7. *Integrated Teaching and Learning Environment*

The array of IT tools developed by NEES, learning materials created by researchers and others throughout the NEES community, and the documented methods of use of the tools and resources to further understanding of earthquake engineering, may be made accessible to the broad range of constituency groups identified in the NEES Education, Outreach and Training (EOT) Strategic Plan (Anagnos et al., 2005), through a single web presence. The online collection will include applications (including those that support the development of learning objects), as well as research findings, simulations, visualization, experimental data, videos and photos taken during research that may be classified through the metadata model, indexed, and made available to users depending upon interest criteria.

Table 2g. Strategic Priorities for Integrated Teaching and Learning Environment

TLE: Integrated Teaching and Learning Environment Key Processes: Distributed Content Management (P-CM), Virtual Organization-Based Management (P-VO), Resource Virtualization (P-RV), Composable Interfaces (P-CI) Key Technologies: Data Management Systems (T-DB), Visualization (T-VZ), Middleware (T-MW), Portal Frameworks (T-PF)	
Functionality and User Needs	**Time Frame**
TLE-1. Single sign-on web portal application for teaching and learning.	1-2 years
TLE-2. Educational versions of visualization, simulation, other research tools with detailed documentation for effective teaching and learning activities..	1-2 years
TLE-3. Digital Library with access to educational objects created throughout the NEES network and federated with other digital libraries (e.g. via the National Science Digital Library (NSDL)).	1-2 years
TLE-4. Support multimedia learning object authoring and inclusion	3-4 years
TLE-5. Create advanced interactive learning environment with self-directed student activities.	3-4 years

3.3 Success of the Strategic Plan

The strategic plan represents a unified and comprehensive approach to IT within NEES. Each application and service has been identified to contribute to the entire vision for information technology in NEES with the overall goal of securing society from the catastrophic effects of earthquakes and tsunamis. Success in IT endeavors within NEES are primarily measured by the development of the applications and services and the adoption and use by the NEES community, students, the broader earthquake engineering community, and the public, within the framework of the prioritizations and timetables recommended in this report. True success in the earthquake engineering arena will be achieved when researchers, practitioners, and students use information technology for solving new problems in creative ways. Since the strategic plan calls for a two-way relationship between the earthquake engineering and the cyberinfrastructure communities, a final metric of success is that earthquake engineering has had an impact on the development of the national cyberinfrastructure.

4. CONCLUSION

This document presents recommendations and priorities for the vision and strategic plan for Information Technology within NEES. Transforming research, education, and practice in earthquake engineering through the use of information technologies will require a concerted effort by the NEES community over an extended period of time. Success will be achieved through a balance between strategic planning and execution, updated periodically to stay current with the fast-paced field of information technology, coupled with a flexible approach that allows critical fresh ideas to be integrated into the NEES IT system. From its inception to its culmination, NEES spans a period of nearly two decades, representing a half a generation in the working career of many of those involved. This vision and recommendations have been developed cognizant of the lessons learned during the initial years of the NEES consortium and first phase of NEES research. With this experience, now is an ideal time to define the IT vision within NEES and mobilize the support and initiative of the broad NEES community in a strategy that will accelerate the transformation of earthquake engineering.

Successful execution of the vision laid out in this document may be viewed via the elements of the vision statement itself: developing transformative technologies, driving innovation, creating new knowledge, and pioneering solutions for the purpose of protecting society from the catastrophic effects of earthquakes and tsunamis. To achieve this vision, the NEES community will partner with other disciplines within the U.S. and with communities worldwide to harness the most appropriate technologies available. However, transforming the practice of earthquake engineering also provides new opportunities and challenges and requires community involvement as well as adequate resources for research and development that can greatly expand the range of IT solutions now available to earthquake engineering researchers and practitioners. The future of information technology within NEES will thus be linked through the determined effort of the community and the availability of resources, available through partnerships from a variety of funding sources, necessary to transform the field of earthquake engineering.

APPENDIX A

INFORMATION TECHNOLOGY APPLICATIONS AND SERVICES IN NEES

This appendix provides summary descriptions of the applications and services central to achieving the vision for IT in NEES laid out in this report. The applications and services, highlighted in Section 3 of this document, are listed in approximate priority order, with the most important application listed first. For each, following a description of the key characteristics of the application and service, short and long-term priorities are identified, key processes and technologies are listed (refer to Appendices B and C for further descriptions of the processes and technologies), and leveraging opportunities and research and development needs are discussed.

CDS: COMMUNITY DATA SHARING

A bedrock application for NEES is a robust, highly functional curated data management system. Implementation of this system is the highest priority strategic thrust for IT within NEES. Minimally, a user should be able to upload, download, query and search, view, and compare data for experimental specimens and computational models and simulation using the data services in the NEES cyberinfrastructure. Beyond this basic capability, there is a wide range of capabilities such a system should ultimately have. The data system should provide users access from web browsers, collaborative portals, and from within applications, and users should only need to be concerned with the logical structure of the data and not its physical format or location. Rich metadata focused around common vocabularies, essential for users to be able to perform effective searches within the community's data resources, should expand to capture a systematic, consensus view of the structure of knowledge in earthquake engineering. Metadata should also be extensible by any researcher, enabling the knowledge from new findings to be reflected in the community data system. The data system must also recursively track the provenance of data (who created it, how, when, and why) to enable effective assessment of data quality. It should also directly support collaborative curation processes so that the community can define and automatically apply validation and review procedures to the data, which then becomes part of the overall provenance record. The system should be highly secure, assure the long-term preservation of NEES data assets, and enable robust, efficient access. It should be a resource not only for researchers, but for practitioners and students as well. Given the breadth of information needed to support such a diverse user base, the data system should not assume that all information of interest will be owned and/or hosted by NEES. Thus, it must support federation with external data sources and map the data formats, metadata, and provenance of the source into the NEES model.

Short-Term Functionality and User Needs

Short-term functionality needs in community data sharing include:

- *CDS-1. Capture NEES data, organize it, and make it available as a long-term community resource:* Supporting the basic cycle of capturing NEES data, organizing it, and making it available to users is the highest priority in NEES. Significant capability already exists in this domain: web-based forms for uploading data and annotating it with metadata, a repository organized using a community-developed data model, and web-based search, browse, and download capabilities have been developed. Adding support for persistent references that are guaranteed not to change would be a key extension that would enable NEES data to be linked with the literature and external information (minimally through the use of URL conventions (W3C Style, 2006) or more robustly by leveraging emerging persistent identifier mechanisms such as Handles (2006), life science identifiers (LSID, 2004), or archival resource keys (ARK) (Kunze, 2003)).
- *CDS-2. Reduce effort for uploading and annotating data and automate the flow of data, metadata, and provenance from local systems:* A key short-term goal would be to enhance this system to reduce the effort required to upload and annotate new data and to enhance the value of captured information. Enhancements should be evaluated based on their potential to eliminate duplicate entry of information (i.e., into a local system used before entering data into the community system), to automate the flow of data, metadata, and provenance from local systems to the shared data store, and their direct value to current laboratory operations. For example, programmatic interfaces could allow direct submission of data from data acquisition systems and eventually enable parameters from stored experiments to be re-loaded as a template for new work. Electronic notebooks (Myers et al., 2003; CENSA, 2006) with knowledge of the NEES data model could help structure work and primary annotation to greatly reduce or eliminate the burden of repackaging information for community submission. Enhanced laboratory applications that, for example, use the configuration of a current and planned experiment to generate a task list of the changes needed to prepare for new work, could also enhance the direct benefit to researchers of submitting their information routinely and assuring its accuracy.
- *CDS-3. Support dynamic addition of new data types/formats and new metadata to the system by individual users*

and groups.

- *CDS-4 Support integration of externally managed data into NEES (through database federation, metadata harvesting, etc.)*
- *CDS-5. Support dynamic addition of new data viewers and translators.*

Long-Term Functionality and User Needs

Central to the longer-term vision for advanced functionality related to community data is the recognition that the definition of appropriate data and metadata structures is an earthquake engineering community-wide activity that should not be controlled through software. Recognizing that data, metadata, and provenance encode knowledge and that evolving the information captured represents an intellectual contribution that parallels more traditional publication mechanisms such as scientific papers is critical both for the community and to properly architect a community data system. Further, it must be recognized that significant amounts of information of interest in NEES will be managed by other organizations and/or international partners and the data system must support federation of independently controlled data systems.

This conceptual framework also clarifies that the overall system that will be required is not simply a large database. Mapping from the high-level long-term requirements outlined above to lower-level capabilities as listed below can help guide architecture and implementation and operation plans. Thus, building an effective community data system that fully supports the long-term collaboration, federation, knowledge management, curation, and preservation needs in the context of a larger cyberinfrastructure, which provides additional data and computational resources beyond the control of NEES, requires the development of the following enabling capabilities:

- *CDS-6. A mechanism for individuals and groups to directly manage and customize their view of community data by selecting the compliment of viewers, translators, data types and metadata elements that are required, preferred, or allowed by their sub-community.*
- *CDS-7. Mechanisms to associate processes with data uploads and to trigger processes (from email alerts to peer-review processes to large-scale simulations).*
- *CDS-8. Support for advanced preservation such as system mechanisms and operational processes for archiving to write-only media, maintaining mirror sites, assuring data integrity over time through checksums/signatures, recording details of data formats and meaning and assuring a means for future reading of data after programs are obsolete.*

Additional discussion of how these capabilities within the data system can support the higher-level vision are provided in the sections in Appendix A on Collaboration and Knowledge Capture and Dissemination.

Key Processes

Much of the more advanced functionality outlined above will, by necessity, be delivered incrementally over the years, and its development will require the use of patterns that support evolution of data structures (distributed content management) and processes (distributed process management) applied to data. Virtualization to limit the exposure of tools to the specifics of where data is stored and processed and how it is physically formatted will be required to limit the system-wide costs of upgrading the community data system. Similarly, composable interfaces and virtual organization-based management will enable groups of researchers to easily develop and prototype new tools and to extend data models beyond the current baseline capabilities in a straightforward manner with a clear mechanism for making advances available to the larger community.

Key Technologies

Scalable and federated database, metadata catalog, and content management system technologies are directly relevant to the capabilities outlined above. Persistent globally unique identifier mechanisms such as those noted above are also relevant. Middleware for wrapping this functionality as services, within programming libraries, and as web-accessible functionality will also be required. In the longer-term, technologies for knowledge management including capabilities related to the semantic web/semantic grid are also extremely relevant.

Leveraging Opportunities

The larger cyberinfrastructure community is developing a wide range of middleware and data/metadata/provenance systems that can be leveraged, either through direct integration of software or through the adoption of designs and standard APIs and protocols. These activities are occurring within the business community (i.e., through specification of the Java Content Repository (JCR) API (JSR 170, JSR 286)), in grid computing (standards such as OGSA-DAI, metadata catalogs, replica services, and preservation systems (OGF, 2006)), and in the semantic web (ontology development tools (Protégé, 2006), scalable RDF metadata repositories (Mulgara, 2006), the SPARQL query language (SPARQL, 2006), and semantic data integration capabilities).

Required Research and Development

While the short term requirements are well supported by current technologies and can be approached as an integration/customization based on existing open-source/commercial technologies, it is unclear that any existing system successfully targets the full range of functionality outlined. Thus, tackling the overall vision for a community data system should be approached as an R&D effort. NEES requirements are clearly shared by many communities and thus there are significant opportunities for shared/coordinated developments. Having relevant expertise in the technology areas noted above and maintaining an active role in these communities (through publications and participation in relevant conferences, workshops, and standards efforts) will be critical for NEES to be able to effectively leverage new developments and to deliver a working, state-of-the-art system to the NEES community.

The software developments outlined here should be complimented by ongoing community efforts to standardize data and metadata formats and to form consensus around tools and processes that should be maintained/extended by NEES on behalf of the community.

CMS: COMPUTATIONAL MODELING AND SIMULATION

Computational modeling and simulation is central to the vision of NEES to transform the development of new earthquake engineering solutions from being primarily based on experiments to a balanced use of simulation and experimentation using computational models validated by experimental data. A close integration of modern computational models and simulation software with other NEES applications and services will provide the earthquake engineering community, and broad engineering users, new capabilities for developing innovative and cost-effective solutions.

For NEES to be successful in improving the capability of simulation for estimating the earthquake performance of structure and geotechnical systems the software needs to go well beyond the lumped plasticity models typically used in practice for buildings and equivalent linearized models used for soils. Simulation software should provide the capability for representing the nonlinear behavior of material and the large displacements associated with collapse. Furthermore the software should have the capability to model both structural systems and geotechnical systems since soil-foundation-structure interaction has a significant impact on earthquake performance and is the subject of much of NEES research. Expanded mechanistic models could also simulate processes such as fluid-structure interaction that is critical for modeling the impact of tsunamis, impact of deteriorating infrastructure on seismic vulnerability, or multi-hazard events such as the effect of floods, fires, or hazardous spills caused by seismic events. A broader scope for earthquake engineering analysis includes modeling and simulation of urban regions to assess damage, network functionality, losses, and response and recovery operations.

Short-term functionality and user needs

In the short term, the high-priority need for IT within NEES is to provide simulation capability to earthquake engineering researchers and practitioners that is integrated with NEES data, visualization, collaboration, and hybrid simulation applications and services. The key needs are:

- *CMS-1. Tools for creating computational models of an experimental specimen.*
- *CMS-2. Robust software for nonlinear analysis of experimental specimens and associated prototype soil-structure systems for pre-experiment analysis and post-experiment validation and study.*
- *CMS-3. Seamless access to the NEES database systems for models and simulation results.*

Long-range functionality and user needs

In the long-term, substantial research and development is needed for model-based simulation of systems, ranging from individual buildings to entire urban regions, for high confidence estimates of earthquake performance. Model-based simulation has tremendous potential to facilitate engineering design through multi-physics, multi-scale predictions of behavioral assessment, optimized engineering design, policy planning, and decision support. User needs include the ability to simulate causes and effects of seismic excitation, predict component or system damage due to earthquakes, explore new materials for earthquake engineering applications, and predict losses within systems or regions due to seismic damage

It is also important for NEES applications to encompass a broader range of computational simulation capabilities, expanding from a base that is tied closely to experimental testing of geotechnical and structural systems to a broader set of capabilities for simulation of processes that target improved solutions to earthquake engineering problems. These expanded applications could use the experimental testing sites as testbed for process validation, and, for example, through the Grand Challenge projects within NEES, may be linked directly to damage studies that are at the core of NEES research. Long terms user needs for simulation include:

- *CMS-4. Extensible software in terms of material models, system models, and solution algorithms since future research will pursue increasingly refined and higher-fidelity simulation.*
- *CMS-5. Scalable simulation software in terms of model size and complexity and have the ability to efficiently use hardware from laptop personal computers to high-performance computers depending on the computational needs of the simulation.*
- *CMS-6. Optimization methods for geotechnical and*

structural system design

- *CMS-7. Lifeline or traffic network flow functionality modeling due to damage from earthquakes*
- *CMS-8. Simulation of response operations and logistics after an earthquake*
- *CMS-9. Simulation of short- and long-term economic or social losses per structure and across regions due to damage from earthquakes to interdependent systems*
- *CMS-10. Decision support engines for prioritizing use of limited resources for targeted retrofit and rebuilding in seismic zones across the country.*

Key processes

Distributed process management is important for computational modeling and simulation in order to allow researchers to share and distribute models and simulation procedures. Virtual organization-based management and resource virtualization will allow users to compose simulation models and procedures for their application using available compute resources. Content management is also relevant, particularly as expressed in CDS-3 as the ability to dynamically add new types of data and metadata to the community data sharing system.

Open-source software is particularly useful in the simulation area because it provides NEES researchers with the opportunity to build-upon each other's work and leverage developments in modeling of nonlinear components and systems, algorithms, and high-performance computing. This has become common in the IT area with SourceForge (2006). NEES has adopted a similar system with NEESforge . NEES is strongly encouraged to adopt open standards and interoperability of software for simulation models and software so that individual research efforts can be shared and that a robust community-based approach evolves.

Key technologies

Integration with database management systems is important to preserve seminal simulations and to facilitate exchange of information. High-performance computing will enable a substantial increase in the fidelity of simulations, which will be essential for improving the robustness of models. Integrated visualization services are needed to interpret and understand simulations and for comparing experimental and computational simulation. For large models, high performance networks are necessary for communicating computational data for visualization, data storage, and collaboration.

Leveraging opportunities

There are a wide range of modeling and simulation software, including geophysical, soil, and structural system response, tsunami simulation, regional modeling and decision support, and optimization and design applications that are available for leveraging in the efforts related to computational modeling and simulation.

Required research and development

Required research and development in the field of computational modeling and simulation remains vast to achieve the NEES IT vision. New approaches to simulation across different scales and materials are required to understand and predict system performance, and interfaces to the NEES cyberinfrastructure are required to enable effective use of the simulation tools. Examples of the required research include:

- Definition of community-based API's for modeling and simulation, for highly nonlinear structural, geotechnical, and tsunami problems.
- Methods for providing optimized and scalable computation across a range of computing platforms depending on user requirements and computational demands.
- A broad model-simulation research program to fuel major advances in transforming earthquake engineering from reliance on testing to balanced computational and experimental approaches.
- Integration of modeling and simulation for regional-scale applications to assess performance in earthquakes, emergency response, and economic and public policy impacts.

VIZ: VISUALIZATION

The human eye is the highest bandwidth perceptional sense, and hence visualization tools are essential for users to understand and improve insight using the immense amount of data generated by NEES researchers. The visualization tools for the NEES cyberinfrastructure should provide users a wide range of visualization methods and opportunities to use devices from relatively low-resolution such as web portals to very high-resolution up to PowerWalls and immersive visualization environments.

Considering first experimentation, visualization will assist in understanding the large amounts of data collected in an experiment, relating various types of data, and providing a virtual view of an experiment for remote users and teleobservers. For computational simulation, visualization is an essential tool for interpreting the enormous amount of generated output. The most intriguing aspect of visualization is to integrate experiments or field data and computation by combining data from the two for a comprehensive view of a simulation. Visualization tools provide an ideal framework for the verification and validation of computational models using experimental data.

Thinking more broadly, visualization methods and tools are an excellent approach to integrating data about specific components and subsystems into entire systems. This is readily apparent through the use of Building Information Management systems (BIM) that are now available in commercial products such as AutoDesk REVIT. BIM systems can provide a visualize interface to a simulation or experiment, and can also be used for fly-throughs that could eventually be extended to examine, for example, the estimated damage to a building during an earthquake.

Extending this concept further to entire cities or regions, linked through Geographic Information Systems (GIS), the vision of investigating how regions would be affected by an earthquake is achievable with visualization as the primary integration tool.
Short-term functionality and user needs
Short-term functionality needs in visualization include:

- *VIZ-1. Interactive graphical interfaces for model creation and interpretation, including geophysical, soil, and structural models*
- *VIZ-2. Web-based digitized representations and visualization of experimental data or objects associated with field data.*
- *VIZ-3. Web-based visualization of computational simulation and comparison with experiments*

Long-term functionality and user needs
Long-term functionality needs in visualization include:

- *VIZ-4. High-resolution visualization of three-dimensional experimental and computational data and video-based visualizations using standard PC graphics technology*
- *VIZ-5. Highly-scalable visualization of experimental and computational data from single PC to PowerWall type displays and immersive displays to enable knowledge discovery through augmented reality.*
- *VIZ-6. Integration of visualization applications for individual buildings with building information management systems at one end and regional and GIS tools at the other end to allow a user, for example, to zoom from a regional view to the detail of a structural joint and access models and experimental data.*

Key processes
Virtual organization-based management and resource virtualization will allow users to harness multi-media visualization solutions via distributed resources with features targeted for the application needs. Composable interfaces will facilitate development of customized, high-quality visualization tools.

Key technologies
Visualization hardware and displays, scalable rendering methods, model and video integration are key technologies related to visualization. High-performance networks are also required if the large data sets are being visualized.

Leveraging opportunities
There are significant developments in visualization software created for other applications, e.g., as developed by national supercomputing centers, national laboratories, and other organizations. Much of this will require significant adaptation to be useful for earthquake engineering applications. Building information models, such as Autodesk REVIT, and geographic information systems (both open-source and COTS software systems are available), provide outstanding opportunities for leveraging the rich array of features being developed within these data manipulation tools.

Required research and development
Research and development needs for visualization within NEES include the following:

- Synthesized visualization tools linking computational visualizations, digitized renderings of experimental or field specimens, images, and audio.
- Real-time scalable visualization display systems with data streams from simulations, experiments, video, and remote sensing, including the ability to zoom through regions of interests from orders of kilometers to orders of millimeters.
- Development of visual metaphors appropriate for wide range of earthquake engineering problems.

CEF: INTEGRATED COMPUTATIONAL, EXPERIMENTAL, AND FIELD SIMULATIONS
A critical set of tools in the short-term are for validating and calibrating parameterized simulation models using experimental data. An important strategic thrust is to have close integration of data, simulation, and visualization tools for validating models (Oberkampf et al. 2002). Users should be able to access a library of deterministic and probabilistic calibration and validation methods, and have the capability to extend and develop new methods.

Short-Term Functionality and User Needs

Short-term functionality needs in visualization include:

- *CEF-1. Perform hybrid simulations that combine experimental and computational models:* Following the theme of integration of physical and computational simulation, hybrid simulation allows more sophisticated experiments on systems by representing a portion of the system computationally and one or more other parts experimentally. This allows testing of components as if they were part of a system responding dynamically to an earthquake ground motion without having to construct and test dynamically a complete model on a shaking table or centrifuge. This is a common approach, called 'hardware in the loop' for testing of mechanical systems, particularly for vehicle control systems, and embedded computing systems. There has been substantial progress within NEES on hybrid simulation for structural systems (SimCor , 2006; OpenFresco , 2006), which will serve as a base technology for robust, scalable, and extensible hybrid simulation tools. Initial implementations should focus on linking experiments executed at quasi-state testing rates with computational simulations within one site and across sites located nationally and internationally. Future work will involve near real-time hybrid simulation, building upon substantial work that is underway within NEES. Developing a flexible, scalable protocol and interface for data communication for hybrid simulation will facilitate cohesive expansion of capabilities so that diverse users of NEES sites can benefit from the advances in hybrid simulation and provide a uniform set of services for users.

Long-Term Functionality and User Needs

Long-term functionality needs in visualization include:

- *CEF-2. Near real-time hybrid simulation:* Models developed in the short-term for hybrid simulation of quasi-static testing should be extended to incorporate near real-time and real-time hybrid simulation through the use of secure, high bandwidth communication protocols and coordinated data exchanges.
- *CEF-3. Enable three-dimensional exploration, visualization, and manipulation of experimental specimen response based on predictive models calibrated iteratively from experimental results.* Strategies geared towards enhancing predictive modeling through active acquisition of knowledge during an experiment can help drive a new generation of simulation model development that are at the core of model-based simulation strategies.
- *CEF-4. Link field measurements to computational models to simulate effects of earthquakes.* The scale and breadth of NEES facilities provide special new opportunities for creating integrated links between field measurements and computational simulations for topics such as structural health monitoring, system identification, and damage detection.
- *CEF-5. Simulate systemic response across systems or regions based upon damage predictions:* Advanced approaches for integration of experimental and computational simulations can include development of better predictive algorithms for regional loss modeling, risk management, response planning, and decision support that link, for example, shake maps generated directly from measurements of seismic activity, damage detection from sensors in the field coupled with image synthesis, and regional loss modeling algorithms based on fragility assessment coupled with social and economic loss models and updated based on up the collected seismic and field data.

Key Processes

Design patterns related to distributed content management and distributed process management will be particularly useful to establish when developing integrated simulation systems within NEES, as these simulations commonly link heterogeneous sites nationally and internationally.

Key Technologies

Integrated simulation is a data-centric procedure in which disparate types of data are communicated between heterogeneous systems. Database management systems and associated can facilitate cohesive exchange of information. High performance networks including quality of service and bounded latency are crucial for integrated simulations. Cybersecurity solutions should also be leveraged particularly for multi-site testing. Sensor acquisition and distribution is at the core of achieving experimental or field results with sufficient accuracy to ensure the reliability of the results.

Leveraging Opportunities

There are presently limited tools for integrated model calibration and validation. Existing applications for automated model calibration and validation within earthquake engineering provide a starting point for more sophisticated. Major efforts internationally in hybrid simulation, building on years of research in pseudo-dynamic testing, provide building blocks for future research in this field.

Research and Development Opportunities

Wide ranging applications linking computational, experimental, and field simulations for damage prediction, planning, optimization, and system identification: Integration of computational, experimental, and field simulations is a core activity to achieve the transformative vision set forth within NEES. Adequate resources are needed to enable the development of long-range applications that harness the power of IT to integrate simulations that can lead to the development of new and powerful predictive processes.

COL: COLLABORATION

Collaboration tools allow users to aggregate information, including developing links and threads with other users. One of the key pioneering concepts for the creation of NEES is that it is a collaboratory, and collaboration tools are at the core of ensuring successful broad access to NEES facilities and cohesive partnerships throughout the NEES community and with communities worldwide.

Short-Term Functionality and User Needs

NEES should continue to harness and develop opportunities to facilitate collaboration through IT, including the following functionality and user needs:

- *COL-1. Video-teleconferencing and internet-based collaborative technologies for real-time sharing of documents and other resources.*
- *COL-2. Remote telepresence, including viewing of asynchronous data in near real-time and synchronized data in playback mode for experimental, field, and computational simulations.* Initial telepresence capabilities have appropriately focused primarily on remote teleobservation and teleoperation of experimental simulations. While current capabilities have concentrated on telepresence of data from common sensor types (strain gages, video, still images), integration of advanced sensor data within the telepresence environments should be enabled in the short-term through protocols that facilitate user-based extensibility for remote viewing and data exchange. Additional capabilities to support collaborative telepresence of integrated experimental, computational, and field simulations, meshing with new visualization technologies, may then be developed as integrated simulation tools are created (as discussed in the section of Appendix A on Visualization).
- *COL-3. Initiation of collaborative community resource portals that enable sharing of both curated and non-curated information between project teams or the general public.* Collaborative portals provide access and management interfaces for capabilities listed in other sections (including data sharing, visualization, web conferencing)within an overall framework for managing groups and their context (security policies, preferences, resource allocations). They also incorporate traditional tools such as discussion lists and calendars with access to data and grid resources. Increasingly, they also include newer tools such as blogs and wikis and social tagging.

Communities related to earthquake engineering internationally are harnessing collaboration technologies. NEES should work with these communities to adopt and develop shared technologies, as this will provide a key first step towards fostering richer international partnerships within earthquake engineering.

Long-Term Functionality and User Needs

- *COL-4. Advanced visualization for collaborative environments:* Advanced sensors are being used increasingly within the NEES community. Several types of sensors, such as lasers used to create data clouds that digitize experimental test specimens, can be harnessed to enable a variety of enhanced telepresence functionality, such as three-dimensional interactive immersion environments, or integrated mapping between computational and experimental simulations.
- *COL-5. Tools for coordinated simultaneous work on documents or processes:* Applications are increasingly permitting shared editing of documents or collaborative development of processes. This functionality will greatly enhance opportunities for in-depth collaboration.
- *COL-6. Workflow systems for virtual project teams working in a global environment using NEES resources and capabilities:* The onset of collaborative community resource portals enables a wide array of options for project teams to share and operate on resources in a flexible but structured environment for both research and education.

Key Processes

Collaboration environments will utilize several of the processes highlighted in Section 3.2. Virtual organization-based management, resource virtualization, and composable interfaces are all at the core of functional collaboration tools. Desirable features from these adopted processes include enabling extensibility of the telepresence and collaborative portal interfaces for new sensors and new types of simulation technologies.

Key Technologies

High-performance networks and visualization systems are vital for the successful performance of collaboration functionality, as large amounts of information (particularly from video) must be transmitted to enable telepresence or document sharing. Collaborative community portals within a secure environment are an evolving technology for this type of information aggregation and collaboration that are a key strategic thrust for the NEES cyberinfrastructure. New sensor technologies will also create challenges and opportunities for enhanced telepresence capabilities.

Leveraging Opportunities

There are existing web portals for collaborative interaction including text, images, audio, and video that may be leveraged for use within NEES. Early examples of collaborative community portals such as nanoHub (http://www.nanohub.org) highlight the range of capabilities enabled by these portals. In addition, a variety of related tools for cybersecurity (single sign-on) are becoming available that will be required for implementation of collaboration applications. Web 2.0 technologies, which offer a richer interface than earlier web portals and which focus more directly on supporting user generated content and use of social controls (as discussed more fully in the Knowledge Capture and Dissemination section below), are likely to be increasingly relevant as they mature. Resource allocation and scheduling is an important ongoing problem within NEES that may be facilitated through leveraging existing applications for shared calendars and resource allocation. Existing streaming technologies may also be adapted to the needs of collaboration within NEES, particularly for remote telepresence.

Required Research and Development

Research and development needs for collaboration within NEES include the following:

- Integrated interfaces for collaboration including common work spaces and heterogeneous communication vehicles are needed within NEES. The complex geometry of geo and structural prototypes and specimens, the heterogeneity of new advanced instrumentation, and the complexity of integrating, streaming, and visualizing data from experimental, field, and computational simulations, lead to specific challenges in developing collaboration tools that limit direct use of COTS software.
- Tools to facilitate domestic and international collaboration will greatly enhance the ability to collaborate with partners internationally. Collaboration with the earthquake engineering community, IT community, and other communities within the U.S. and internationally will require establishing specific protocols and applications so as to mesh communities that are different stages of incorporation of collaboration tools.

KCD: KNOWLEDGE CAPTURE AND DISSEMINATION

Knowledge capture and dissemination are linked to several key concepts introduced in this document, including community data sharing, integrated simulations, and collaboration. This section concentrates less on the direct capabilities encompassed in these other applications and more on the means by which cyberinfrastructure will support the evolution of knowledge-centric capabilities, contribute to the dissemination of best practices and training, and lower the barriers to and increase the automation of knowledge transfer within and across communities.

Short-Term Functionality and User Needs

- *KCD-1. Provide up-to-date and accurate information to researchers, educators, practitioners, and the public.* For NEES to be seen as a focus for the community, it must provide up-to-date and accurate information to researchers, educators, practitioners, and the public. Basics aspects of this have been discussed as part of the collaborative data system in terms of the ability to query, browse, and retrieve data from NEES experiments.
- *KCD-2. Operation of a general website describing NEES and its capabilities and providing training material related to use of NEES facilities and software as well as earthquake engineering educational material.* Complimenting these capabilities would be well defined programmatic interfaces to directly query NEES data and metadata and documents from within other systems. These interfaces would be self-describing in the sense of being linked to publicly available schema or ontologies thus reducing the barrier to their effective use.
- *KCD-3. An electronic journal providing descriptions of simulations and their conclusions in the style of the general scientific literature, linked to the more detailed data and metadata.*

Long-Term Functionality and User Needs

A more complete picture of knowledge management would recognize that there are a broad range of materials related to research work that go beyond the raw data and descriptive information including, for example, the proposal leading to the work, task lists and work plans, discussions detailing decisions made to scope experiments, software to enable new experimental procedures and to enable new analysis or new visualizations of results, documentation on software, sensors, and procedures used in experiments, and derived reference data. Integration of all of this information into a common conceptual framework can greatly reduce the effort required to manage projects and facilities. Although it is difficult to quantify the value of adding one new type of information, it is clear that there is a 'network-effect' as the information becomes more complete. An environment that enables incremental additions to the information being managed and federated with NEES data and supports browsing across all of the information would enable groups to explore the utility of particular extensions to the information model and for the amount of linked information to grow over time. Furthermore, as more information about the connections between information becomes documented, functionality such as recommender systems (such as Amazon's capability to recommend books you might like) or direct public tagging (e.g., MySpace (2006) and related tools become possible. Knowledge management capabilities can also play a role in automating data integration and annotation capabilities – less custom code is required to create input forms or to integrate data in multiple formats if the logical models of data are available as schema or ontologies. Two long-term goals are thus encompassed in the following:

- *KCD-4. Collaboration tools for information federation and exchange via knowledge-based systems:* As functionality within NEES for community data sharing strategies is expanded, more general types of information may be archived and exchanged to facilitate capturing and disseminating knowledge.
- *KCD-5. Incorporation of building information models and geographic information systems into communication and management of information across NEES projects:* Building information models and geographic information systems are two contemporary examples of applications under development that can transform the collaborative exchange of information within the NEES community. These applications combine asset management with analysis and visualization to create comprehensive interfaces for sophisticated collaboration within project teams.

Key Processes

All of the patterns discussed apply to knowledge management (and in a very real sense they are a knowledge-based approach to developing cyberinfrastructure).

Key Technologies

Data management systems, visualization tools, and portal frameworks will all be crucial to create applications for knowledge capture and dissemination. The development of knowledge management capabilities in NEES will argue for specific choices in related tool areas as well. For example, portal document repositories based on JCR interfaces and tools that support XML schema or ontology-based or wrapped data and metadata formats will be simpler to federate than ones that have proprietary file or data formats.

Leveraging Opportunities

As in other areas, knowledge management needs within NEES are well aligned with those in other communities and there are a wide range of technologies and projects to draw from. A wide range of science-oriented uses of semantic web and semantic grid (De Roure and Hendler, 2004) capabilities are being developed and piloted, particularly within biology and connected with the terms e-Science and cyberenvironments.

Required Research and Development

As with collaborative data systems, many of the short-term requirements can be met through the integration of existing technologies. However, achieving the longer-term vision will require ongoing participation in semantics/knowledge management-related communities and will necessarily influence the architectural directions taken. Intermediate functionality in areas such as E-journals or personal e-notebooks as well as middleware providing capabilities for browsing, and querying heterogeneous data, generating recommendations, and automating data integration are likely to exist, though it is likely that significant customization or extension of these capabilities will be required to field highly usable capabilities.

TLE: Integrated Teaching and Learning Environment

An integrated teaching and learning environment can provide a single point to create new learning contexts using the powerful IT tools developed by NEES, create new learning materials, and disseminate knowledge generated through these activities. For example, with a single sign-on, users could use simulation, collaboration, and visualization tools to investigate real-world problems and apply earthquake engineering principles. This environment will also provide the NEES user and IT developer with a streamlined and user-friendly means to keep current with the latest tools developed.

These activities will further the goals set forth in the NEES EOT Strategic Plan (Anagnos et al., 2005) and will engage key constituency groups and strategic partners in the use of the online site/portal. For example, in accordance with the NEES EOT Strategic Plan (Anagnos et al., 2005), activities will be undertaken on an ongoing basis to support the development of an active NEES educational community. One way this may be accomplished is to promote ongoing collaboration and engagement of key constituency groups through the use of the e-conferencing and other collaboration tools that will be a prominent part of the site. The Strategic Plan also envisions that NEES will improve the teaching and learning of earthquake engineering in undergraduate, graduate and K-12 education by providing professional development in the use of NEES materials and facilities for educational and outreach activities. The online site may contain resources to inform faculty and K-12 educators about ways that the IT tools and resources can be used to integrate NEES research and research practices into the teaching and learning environment. Interested faculty and educators could collaborate with EOT professionals and others synchronously and asynchronously around such work through the use of IT tools available on the site.

Examples of EOT Applications

Telepresence Applications

A key feature of the NEES IT infrastructure is the ability to provide telepresence for anyone with Internet access worldwide. Following directly from the NEES EOT Strategic Plan (Anagnos et al., 2005), the capability of telepresence for K-12 or undergraduates could be utilized in the following ways: (1) telepresence could be combined with visualization tools to provide students the opportunity to participate in a test, or possibly plan a payload experiment; and (2) telepresence could also be used to allow undergraduates at two (or more) locations the ability to participate in benchtop-sized distributed tests including enabling them with the ability to change a test or model parameter. This active learning experience would be underscored through integration of visualization tools such as those developed by an undergraduate with a background in computer science as part of the NEES Research Experience for Undergraduates (REU) program in the summer of 2006.

Wiki Programming of TLE Tools

It is envisioned that an REU with a computer science background, or NEESit personnel, can develop a core Wiki web site in which the users are able edit content including documentation related to worldwide distributed programming efforts. One application of the Wiki is the development of TLE tools and payload experiments for NEESR projects. In this approach, the ability to get widespread feedback is fully integrated because the users are the developers. Engaging developers and users with various backgrounds in this way would be particularly helpful in making these tools effective for teaching and learning activities at all levels.

In addition to applications, learning objects can be created and served through this environment. Research findings, experimental data, videos and photos taken during research may be classified through the metadata model, indexed, and made available to users depending upon interest criteria set. The environment can also be used to create new online and conventional learning objects.

Aspects of this environment are included within several other IT applications and services in this strategic plan, including Community Data Sharing, Collaboration, and Knowledge Capture and Dissemination. Including this unified environment as a separate element underscores the importance of considering teaching and learning as integrated into research, while recognizing distinct requirements to facilitate successful learning using information technology.

Short-Term Functionality and User Needs

In the short term, the priority is to develop applications that provide a single point of access to NEES tools and learning resources, including:

- *TLE-1. Single sign-on web portal application for teaching and learning:* A web portal application for teaching and learning is needed to provide immediate access to simulation, visualization, and collaboration tools created by the NEES community.
- *TLE-2. Educational versions of visualization, simulation, other research tools with scaffolding and detailed documentation for effective teaching and learning activities:* Customized versions of powerful research tools can be created that can be used for learning activities by students.
- *TLE-3. Digital Library with access to educational objects created throughout the NEES network and federated with other digital libraries (e.g. via the National Science Digital Library (NSDL)):* Learning objects can be stored in a digital repository, and will be accessible based on keywords, educational level, and other criteria established through meta-tagging. These resources could be harvested from the NEES experimental site and NEES research communities.

Many elements of this functionality are included in portal applications that are currently reaching maturity; these efforts should be reviewed and built upon.

Long-Term Functionality and User Needs

- *TLE-4. Support multimedia learning object authoring and inclusion:* An increasing number of user-friendly applications to create online and conventional learning objects exist. This application would allow for the creation of new objects that integrate NEES research content.
- *TLE-5. Create advanced interactive learning environment with self-directed student activities:* An interactive learning environment will allow teachers or students to create custom learning environments for own classes by integrating educational versions of research tools, learning content created through the NEES community, and collaboration applications.

Key Processes

Distributed content management, virtual organization-based management, resource virtualization, and composable interfaces are all at the core of functional teaching and learning environment development. Education materials pulled from disparate sites will build crucial flexibility into the teaching and learning environment. Provenance associated with the content of these education, outreach, and training portals can also provide a rich array of information that is currently rarely available with education materials.

Key Technologies

Data management systems, visualization tools, middleware, and portal frameworks may all be harnessed to create advanced teaching and learning environments.

Leveraging Opportunities

Portal frameworks that provide users with targeted content based upon specifications such as Sakai (http://www.sakai.org), which is open-source, and the COTS Blackboard (http://www.blackboard.org) are maturing rapidly and are being deployed throughout higher education and industry. Online course content creation tools have also been developed through, for example, the NSF National STEM Digital Library program (http://nsdl/org/).

Required Research and Development

There are a number of research and development opportunities in the area of education, outreach, and training. Examples include:

- Integration/customization of metadata models targeted specifically for creation of teaching and learning objects.
- Developing an education portal that provides multimedia learning materials coupled with interactive tools for development and incorporation of new learning modules into the portal.

APPENDIX B

INFORMATION TECHNOLOGY PROCESSES IN NEES

As noted, the challenge in building a state-of-the-art IT infrastructure within NEES is to support various applications and ongoing NEES activities in the context of current and future community practices, interests, and cyberinfrastructure technologies, and to do so in an incremental manner driven by the needs of earthquake engineering. To do this, the NEES cyberinfrastructure components in particular must be designed on the assumption of continuing technological progress within cyberinfrastructure and earthquake engineering and thus must focus on scalability and evolvability rather than aiming for an all-encompassing scale and scope. The NEES community must thus design and develop cyberinfrastructure to assemble the resources required to address the issues driving the science and engineering plan, yet recognize that NEES will not be the sole driver of advancements. Researchers will need a well managed set of core capabilities yet will also desire the ability to include new data sources and tools (from local projects or other national/international projects) to explore beyond the original science plan and contribute to community capabilities. New and developing cyberinfrastructure technologies enable harnessing this powerful mix of current and future functionality. The following elements of the recommended strategic plan, as presented in this appendix, encompass these core objectives and applications.

To develop the strategy for NEES IT, there is a need for several critical core cyberinfrastructure capabilities:

- Community-scale sharing of experimental (physical and computational) results,
- Real-time access to data and control mechanisms supporting remote and distributed experiments, and
- A ubiquitous collaboration infrastructure.

However, characterizing cyberinfrastructure development solely in terms of the applications and services to provide this capability is not sufficient to guide the cyberinfrastructure effort and assure that NEES can play an ongoing catalytic role in enabling earthquake engineering research.

To realize the proposed vision in directions such as enabling tighter coupling of physical experimentation and computational modeling and increasing ties between earthquake engineering researchers and practitioners, it is clear that continuing progress will be needed in increasing the fidelity in the description of experimental data and protocols, in reducing the manual effort required to produce and consume community information, and in lowering the barriers between NEES cyberinfrastructure and those of other communities will be needed. Thus it is useful to characterize the cyberinfrastructure effort not only in terms of delivered capabilities but also in terms of a requirement to enhance the capacity to create and evolve new cyberinfrastructure capabilities more quickly and more cost-effectively. As noted, agile processes and modular designs are critical pre-requisites for developing such a capacity. A wide range of cyberinfrastructure research, development, and deployment efforts are innovating in this aspect of cyberinfrastructure development through the identification of, and implementation around, flexible design patterns (strategies, processes) that decrease software coupling and parameterize the infrastructure such that third parties can more easily evolve, for example, the models for data and metadata, the set of administrative and scientific processes applied to the data, the implementations of system services, and the security and other policies applied to subsets of system resources. For example, if data resources can migrate between storage sites, the system should incorporate global identifiers that are location independent and provide a resolution mechanism to provide a current location and access method(s) for a resource given its identifier, i.e., the basic idea of names coupled with address books and phone directories.

Table B.1 summarizes some of the major design strategies that may be relevant to NEES IT. In defining a set of core technologies and overall architecture within the strategic plan, these patterns (and the adoption of interfaces and tools that support them) can play a useful role in enhancing the capacity of IT within NEES to rapidly respond to new requests from the community. The following subsections provide additional detail on specific patterns that should be considered. They also map the use of those patterns to examples of the increase in capacity they provide.

Table B.1. NEES Cyberinfrastructure Processes

Process Strategy	NEES-Specific Opportunities for Harnessing Cyberinfrastructure Design Patterns for Earthquake Engineering
P-CM: Distributed Content Management	Ability to support storage of new file types and the recording of additional types of metadata without programming. Ability to incrementally add new file translators to the system. Ability to define review processes for new material. Ability to seamlessly migrate/replicate data.

P-PM: Distributed Process Management	Enhanced ability for researchers to understand/share/reuse/modify analysis procedures. Ability to capture and view data history (provenance) information in a uniform manner. Clear interface for adding community developed tools to the NEES suite of capabilities. Ability to migrate analyses from desktop to larger shared resources.
P-VO: Virtual Organization-Based Management	Ability for groups of researchers to customize NEES functionality for their purposes by, for example, specifying preferences on which data, viewers, and tools are defaults for the group, having shared task lists and calendars, and defining group norms related to preferred data types and metadata
P-RV: Resource Virtualization	Ability to hide non-science-relevant aspects of the infrastructure, i.e., whether data is stored in a particular format or dynamically translated, and which language algorithms are coded in and where they run (e.g., using web services). Ability for NEES IT to optimize and evolve the mix of underlying technologies without disruption to applications.
P-CI: Composable Interfaces	Ability for groups and individuals to customize and extend the common interfaces of NEES-relevant tools (e.g., via web portlets, workflow modules, and application, plug-in capabilities)
P-QC: Quality Control	Implementation of procedures and processes for delivery of robust, valid software.

P-CM: DISTRIBUTED CONTENT MANAGEMENT

Content Management (CM) recognizes that, independent of the type of data (content), the NEES community has common needs to store, locate, version, describe, relate, control access to, annotate, and convert the data. The content being managed could be numerous types of data, documents, software, workflows, services, or representations of sensors, compute resources, storage resources, etc. *With a CM abstraction, the types of content being managed, how that content is described, and even what processes are applied to that content can be changed without modifying the underlying software;* such decisions are managed by the end-user (or by administrators on their behalf) rather than by the software developers. Content management would allow NEES researchers to dynamically extend the information stored within NEES to support new types of experiments or pilot additions to or modifications of the data model. Using distributed content management, applications could be built that access data from multiple sources (site and central repositories and/or repositories of international partners) and that would not break if data were later migrated.

To enable CM across a distributed system then requires the use of globally unique identifiers for content, content types and descriptors and resolution/look-up mechanisms as introduced above. Support for database/CM federation in terms of format translation, schema mapping, and semantic integration are also necessary with numerous options available related to the integration model chosen (e.g. loose integration through information retrieval/harvesting mechanisms, use of a data warehouse model, or direct database/CM federation). Various aspects of CM can be seen in web content management systems, laboratory information management systems (LIMS), grid metadata and replica catalogs, document and data sharing portals, semantic grid/e-Science systems, etc. In the context of NEES requirements, CM as a design principle is an effective means to support the continuing evolution and extension of the types of information managed by the system and to decouple this from the specific initial and upgrade choices made for underlying storage technologies.

P-PM: DISTRIBUTED PROCESS MANAGEMENT

Analogously, designing in terms of *Process Management (PM)* recognizes that, independent of the details of individual processes, NEES researchers have a need to create and share process descriptions and manage the repeated execution of experimental and computational workflow. A PM abstraction minimally involves the concepts of explicit workflow execution and provenance (data history) mechanisms but can also involve capabilities for creating explicit descriptions of processes at multiple layers of abstraction (e.g., scientific, mathematical, service-level template, execution instance), the ability to semi-automatically move between layers, and the ability to migrate execution to appropriate resources. *Workflow systems,* which have traditionally focused only on the last step, provide a key starting point in some communities, but a wider infrastructure to manage experiment protocols and process descriptions (e.g., as content that can be shared and versioned), and automatically track provenance is necessary within NEES because of the heterogeneity of the processes involved both within and outside the NEES facilities and the interest in sharing procedures and producing validated reference information for the community. For example, software modules for site applications that record provenance and related tools for viewing/querying provenance information could be a more cost effective solution than refactoring all applications to work within a workflow engine. By defining processes in terms of clearly defined steps and by separating the specification of processes from the development of software to execute them, workflow systems enable sharing and evolution of experiment protocols and their migration between desktop tools and community or third-party resources and services. Provenance capabilities provide similar clarity in understanding historical information and the processes that have led to specific derived data.

Provenance can be considered a type of metadata, complementing the NEES Data Model and its description of data and the experimental framework in which they were generated with process information linking raw data with derived results and to publications. Given that NEES may not be the repository of choice for all of the derived data and for publications created by users of NEES, it will be important for NEES to maintain compatibility with provenance capabilities being developed in the broader community and to assume in the design that NEES will need to manage provenance information related to data and document resources it does not control.

P-VO: VIRTUAL ORGANIZATION-BASED MANAGEMENT

The concept of Virtual Organizations (VO) recognizes that distributed groups have requirements analogous to those of traditional organizations to manage membership, policies, resources, procedures, organizational knowledge, etc. VO-based management also recognizes that sub-groups within the larger community will have different interests, different timescales, different work practices, etc. and therefore need a mechanism to customize the core capabilities of a community infrastructure for their use, to control the schedule for adopting new capabilities, and to have a means to extend the system independently of the larger collaborative. Some of the clearest examples of VO-based management in current cyberinfrastructure are the management of authentication, authorization, and allocation policies in grid systems and the management of group context (e.g., group-specific calendars, task lists, document repositories, and custom science portlets) in collaborative portals. These concepts can be extended to IT within NEES to manage site and group-level agreements about, for example, access policy, preferred/supported content types and tools, required metadata, data pipeline configuration, and curation procedures.

P-RV: RESOURCE VIRTUALIZATION

Another design principle, a corollary of the previous ones designated as Resource Virtualization (RV), is the use of open, standard programming interfaces and protocols as a means to assure end-to-end functionality without constraining implementation – virtualizing resources to hide non-functional aspects of their implementations. For example, web services are virtualized resources in the sense that details about the programming language used to create them and the operating system they run on, which are not directly relevant to the scientific service they provide, are hidden and can be changed without affecting their use. Virtualization of services in this manner provides a number of advantages and leads to the overall concept of Service Oriented Architectures (SOA). (The use of grid and virtual machine technologies are also relevant examples of virtualization, focused on lower level resource distribution and scaling.) The resource virtualization principle favors the use of limited but broadly adopted standards in preference to more comprehensive ones that limit the choice of implementation. This helps avoid a lock-in to a particular commercial or research implementation path. Functionality beyond the standard interfaces can be exposed through discovery mechanisms and additional management interfaces, enabling use of advanced capabilities in the system but clearly delineating where they are used. For example, the Java Content Repository (JCR) standard covers a wide range of capabilities for creating and managing resources and their properties but does not specify the means of managing content types. This has led to commercial and open-source implementations and, while it has not eliminated all dependencies on the particular implantation chosen, it has significantly improved the interoperability of JCR-based applications and the ability for developers and end-users to migrate to faster, more robust implementations as they arise. Using this approach across the NEES cyberinfrastructure would provide internal flexibility as well as maximize the potential for direct interoperability with other cyberinfrastructures. It is particularly applicable to the collaborative software components of NEES that are linked to hardware that is evolving quickly.

P-CI: COMPOSABLE INTERFACES AND NEES-AWARE APPLICATION ENGINES

At the user interface level, resource virtualization argues for the use of a standard interface sharing and plug-in mechanisms such as portlet and rich-client standards to create a Composite Interface assembled from independently created tools. Considering larger application engines as well as lighter-weight analysis and visualization tools, resource virtualization implies the design of applications and application components that are aware of standard NEES interfaces and protocols. Effective virtualization would not make such applications dependent on the existence of NEES infrastructure, i.e., they would write using a content management applications program interface that could be connected to a local file system or to a central NEES-managed data system. Visualization tools written as portlets or plug-ins could be wrapped as stand-alone tools or incorporated (without modification) into larger suites.

P-QC: QUALITY CONTROL

Although quality control and software validation are not architectural concerns in the same sense as the preceding topics above, they are influenced by architectural decisions and there are associated patterns and best practices for producing robust, valid software. These include traditional techniques such as coding standards, documentation, use of versioned source code repositories and bug tracking systems, and system testing. Unit testing, automated test and build mechanisms, automated system operations monitoring, automated and manual code reviews, and related techniques are also relevant in a project as large as NEES.

These practices are largely focused on robustness rather than scientific validity, though practices such as unit testing can be used to assure that components produce scientifically valid results over a given range of inputs. Given the size and complexity of NEES, and the open nature of the community, more public techniques for validation, i.e., storing validation procedures and test results in a public repository, opening the validation processes up for the community to manage, or both, should also be considered. These mechanisms could be well integrated with the data infrastructure of NEES and could form a valuable link between the repository and community software.

APPENDIX C

INFORMATION TECHNOLOGIES IN NEES

Making choices about information technologies involves balancing several factors. Some selection metrics, such as how well software meets stated requirements, are fairly concrete, while others, such as estimating the technical and market momentum behind specific standards and technologies can be highly subjective. As with other large scientific IT efforts, NEES faces challenges in deciding between technologies driven by the far larger business community and potentially better suited but less mature, and/or less well supported, software built within the scientific community or internally. The risks involved in choosing the 'wrong' technologies can be substantial in terms of reduced functionality, added costs, and development delays. A combination of wise technology selections, coupled with strategies such as those outlined above to reduce the coupling of software components and hence lowering the barriers to replacing technologies that do not meet expectations, are both critical in NEES.

While a full analysis is beyond the scope of this document, it is possible to frame some of the choices that will be faced in developing major IT components within NEES and to highlight some of the risks and trade-offs that will be incurred in transforming the NEES vision into reality. This appendix highlights these critical information technologies for NEES.

T-DB: DATA MANAGEMENT SYSTEMS

Relational databases form the core of most modern data management systems and a wide range of high-performance, scalable, well supported choices are available in the open-source (e.g., MySQL, Postgress) and commercial domains (e.g., from Microsoft and Oracle). A common query language (SQL) and middleware (i.e., JDBC drivers) provide a fairly high degree of interoperability (developers do not need to be trained on specific products, data can be migrated between products, etc.) and a wide range of products exist for mirroring and federating databases and creating data warehouses. However, this level of interface exposes details of how information is structured within the database(s), which then creates an undesirable degree of coupling between user tools and the storage system. Middleware to wrap databases as services and/or abstractions such the JCR interface, XML schema used in web services, or Resource Description Framework (RDF, 2006) encoding for semantic integration all move towards a model in which client applications are only concerned with the logical structure of information. While a fully distributed secure semantic data system that meets all of the requirements within NEES does not yet exist, content management systems are mature enough that they could provide a useful starting point for further work. For example, a number of companies and open-source projects support JCR (e.g., Oracle, Apache Jackrabbit). To go beyond this level of sophistication, NEES should participate in the larger semantic web/grid efforts and should be able to leverage a wide range of technologies for data integration (e.g., from the use of semantic web technologies to enable federated access to information from multiple independent biological databases), provenance management (e.g., capabilities and standards being coordinated through challenges sponsored through the International Provenance and Annotation Workshop (IPAW Challenge, 2006), and metadata management and curation (leveraging expertise and software from digital library efforts).

T-HC: HIGH PERFORMANCE COMPUTING

As discussed in Sections 1 and 2, high-performance computing has transformed many fields of science and engineering because of the ability to perform high-fidelity simulations. In earthquake engineering, modeling and simulation capability has grown with the exponentially increasing computational power of high-performance computing (HPC). For earthquake engineering, HPC technology provides the opportunity for unprecedented increases in the accuracy and of simulations.

A vast majority of high-performance computers are now based on large and scalable clusters of interconnected processors with local memory (Top500, 2006). It must be recognized that algorithms and software must be designed and tuned to maximize concurrency and take advantage of the peak performance of the highly interconnected processors working in parallel. In the scientific arena, the national TeraGrid is an open infrastructure that integrates high-performance computers, data storage, and other services (TeraGrid , 2006). TeraGrid provides substantial resources through 9 Resource Provider sites including the San Diego Supercomputer Center and the National Center for Supercomputing Applications for adapting applications to the high-performance computing resources. NSF has recently announced plans for supporting peta-scale computing to move high-performance computing to the next level.

In earthquake engineering, smaller scale computing clusters are becoming realistic in research labs and professional engineering offices. The cost of computer hardware has dropped so substantially, the PC clusters, rack clusters, and blade computing, offer substantial computing resources not imagined even five years ago. For NEES, it will be important to develop and support software that is functional over a wide range of computing scales from a single PC or lab-notebook, to a cluster, and all the way up to a high-performance supercomputer.

T-VZ: VISUALIZATION

Visualization technology provides the supporting hardware and software for the NEES visualization applications discussed in the strategic plan and detailed in Appendix A. Increasingly visualization technology is moving towards photorealistic, real-time imagining, much of it driven by computer games and the entertainment industry. Visualization technology includes several categories, such as displays, rendering methods, and graphics toolkits. Visualization displays range from single monitors with a graphics board, to large PowerWall displays, to immersive visualization systems (such as caves). High-end visualization requires parallel processing and high-bandwidth communication because of the large data volume and real-time applications. Software systems such as Building Information Models and Geographical Information Systems (GIS), image synthesis, and terrain mapping software all provide powerful functionality that may be harnessed within NEES. Programming toolkits, such as the Scalable Adaptive Graphics Engine (SAGE, 2006), are also very important for developing visualization applications because they provide a high level functional abstraction and are generally independent of the display, which is particularly important for earthquake engineering because of the variety of displays users may have available.

T-HN: HIGH PERFORMANCE NETWORKS

High-performance network communication is essential to the distributed nature of the NEES system, the integration of experiments and computation, providing telepresence capability, and new educational delivery methods. When the NEES program began in the early 2000's, advanced research networks could provide 1 to 10 gibabit/second bandwidth. Since then, 1 gigabit/second network communication is standard on many personal computers, network switches, and communication networks. The future technology is looking towards terabit/sec bandwidth to support television and movie applications in the entertainment world and very large datasets, immersive visualizations, grid computing, and real-time data services in the scientific realm.

For research and scientific networking, the Internet2 (2006) consortium has grown in scope and technological capability since 2000. It includes the Abilene network now upgraded to 10 gigabit/second. The backbones for Internet2 (2006) use fiber optic communication networks extensively. Protocols for high performance networking are now well established. Scientific applications that utilize gigabit level bandwidth include the Gemini Observatory, the Aricebo Observatory, and several applications of real-time manipulation of scanning electron microscopes.

The major technology issue in addition to bandwidth is quality of service, which deals with guaranteed bounds on latency, jitter, error-control, and other factors that affect real-time communication of data and video streams. Multi-casting for streaming data and video is also an important issue, particularly for scalability as the number of users increases. Current discussions nationally on tiered service (or network neutrality) will have an effect on scientific and engineering uses of communication networks, such as in NEES. Increasingly, security and reliability considerations are factoring into high-performance communications networks. Technology and support for monitoring and optimizing end-to-end throughput will be important for effective utilization of the networks for NEES applications.

T-MW: MIDDLEWARE

Middleware is the software layers that allow transparent interoperability of applications and resources in a scalable and heterogeneous computing and communications environment (SEI, 1997). Examples of middleware for distributed computing include the Distributed Computing Environment (DCE) by the Open Systems Foundation (OSF , 2005), CORBA (2006), and most recently Grid Software (2006). In the scientific computing domains, the National Science Foundation has provided substantial support for middleware through programs such as the National Middleware Initiative (NSF NMI, 2006).

Middleware supports virtualization of a broad range of functionality. For example, the Internet-2 Middleware Initiative provides "glue" software between applications and high-performance networks (Internet2 , 2006). Globus (2006) and related Grid efforts provide standard interfaces for services such as:

- Remote job execution, such as for runs for a large simulation model or a hybrid simulation.
- File transfers, such as for transferring experimental or simulation data sets along with metadata.
- Workflow management, such as for specifying and tracking a complex earthquake engineering projects with numerous participants, computing tasks, and process steps.

Also very relevant to NEES IT are web service and portal middleware (including efforts such as the Open Grid Computing Environments (OGCE , 2006) and the Java Commodity Grid Kit (Java COG , 2006), which integrate Grid and portal technologies). Over the lifetime of NEES, there will be a continuing evolution of middleware as well as the deployment of new middleware, especially for content management, data integration, provenance, scientific instrument operation, and resource scheduling. NEES should take advantage of the substantial development of middleware in many areas (specific examples are mentioned above and in other sections) to reduce required development and to decrease coupling of system components. However, there are many non-technical factors that may determine the viability of specific middleware standards, and thus NEES must also evaluate options from this perspective. This also suggests that NEES carefully plan any transition of exploratory work involving advanced middleware to production and explore the possibility that, at the point when the key features are understood, use of a simpler, more broadly supported standard may make the most sense and ultimately reduce operations costs and thus free resources for further development.

T-CY: CYBERSECURITY

NEES faces a wide range of cybersecurity challenges include those related to controlling access to experimental and computational resources as well as to the long-term security of data. Although most NEES data is expected to be public, some experiments performed at the NEES sites are confidential and access to real-time information (i.e., through telepresence) and data must be restricted. In all cases, the ability to control equipment must be restricted to authorized users. Thus, NEES will require middleware and services to support user authentication and authorization and, for simplicity, should support single-sign-on capabilities across NEES components where feasible. Encrypted communications channels are also required to foil potential eavesdroppers on the open Internet. To protect data and serve the community, NEES must assure the authenticity of its holdings (i.e., that the values have not been altered and that they correspond to real experiments) and maintain their availability to the community in the face of security threats such as denial of service attacks as well as more mundane equipment and network failures. While aspects of these requirements go beyond cybersecurity, technologies and operational procedures to detect and thwart intrusion attempts (firewalls, antivirus and system monitoring tools) and to be able to detect changes to data (checksums or digital signatures) directly relate to security and are a necessary part of the overall strategy. Similarly, the use of checksums to enable efficient detection of changes or, more robustly, the use of digital signatures and notarization services to be able to supply cryptographic proof that changes to the data and information about who created it and when could not have been altered also have ties to security but play a role in a larger preservation and curation strategy. As in many areas, technologies and best practices for cybersecurity are changing rapidly (under evolutionary pressure from attackers) and NEES will need to stay at the state of the art. Further, NEES will require interoperability with resource (data, computation) providers such as Teragrid and international affiliates. Thus leveraging leading solutions from the Grid and from industry, and minimizing the dependency of NEES functionality on the particulars of the solutions chosen (i.e., through virtualization interfaces such as Pluggable Authentication Module (PAM) and the Java Authentication and Authorization Services (JAAS)), should be elements of the IT strategy. It should also be noted that, if NEES relies on service providers rather than managing its own infrastructure (i.e., using shared computational and data resources at a national center), the technology choices may already be set and the role of NEES would shift to reviewing the adequacy of protection measures and participating in their periodic testing.

T-PF: PORTAL FRAMEWORKS

The term portal is often used to describe a wide range of functionality from a basic web presence and secure web site (e.g., an Apache Web server and/or Tomcat application container), to the ability to aggregate independent view panes within an encompassing web page (e.g., the Apache Jetspeed or UPortal), to a gateway for launching grid computations and data transfers (e.g., Gridsphere , OGCE), to shared web-based spaces with a suite of embedded collaboration capabilities (e.g., Liferay and Sakai). There are also products that provide collaboration capabilities directly within a web site (e.g., webEx , Macromedia Breeze videoconferencing) as well as non-portal (desktop) solutions (e.g., Access Grid videoconferencing, VNC display sharing, and shared file systems) that have similar capabilities.

As suggested by the list of examples, these different capabilities are provided by a range of products, none of which span all categories. Given that NEES has needs across these areas, the first challenge in selecting portal technology for NEES is simply recognizing that there is unlikely to be a single choice available today that will satisfy all NEES needs, though many groups are working on expanding the functionality of individual products and/or creating bridges between them. Given that NEES has significant production needs, leveraging industry-leading efforts and standard interfaces is critical and should allow NEES to effectively leverage the broad talent pool supported by industry. Examples include standards such as JSR168 defining an API for basic portlets, and JSR170, defining a common repository interface to back document and data portlets, both of which are gaining broad support and both of which would give NEES a range of providers from which to choose based on price/performance. To support the longer-term vision, particularly for collaboration and knowledge management, NEES will again need to participate in the cyberinfrastructure research and development community and leverage middleware and experience from other communities in defining and piloting new capabilities. Given the ability to use web links between systems, the existence of single-sign-on mechanisms, service-level middleware linking to other NEES capabilities, and emerging standards such as Web Services for Remote Portlets (WSRP), it will be possible to connect production and pilot capabilities at the user level without tight coupling on the back end.

T-SA: SENSOR ACQUISITION AND DISTRIBUTION

Over the last decade, sensor technology has exploded with new devices enabling both a breadth and depth of measurement that greatly increases the range of information that may be acquired. New technologies that are being used increasingly in experimental and field studies include wireless sensors, photoimaging, global positioning systems, lasers used to generate data clouds to digitize objects, remote sensing and satellite technology, LIDAR, and a variety of associated hardware and software acquisition systems. These technologies offer new opportunities for linking experimental, field, and computational simulation, as well as provide new types of information for laboratory-based education related to earthquake engineering.

T-AT: OTHER ADVANCED TECHNOLOGIES

As is discussed throughout the report, NEES must straddle between current available technologies and new capabilities emerging from the rapidly evolving IT industry. While many of the anticipated advances are discussed in other sections as straight-forward extrapolations from current capabilities, NEES must also consider advances that represent new classes of capabilities. The emergence of the World Wide Web in the 1990's is an obvious and extreme example of where it would be difficult to classify a new capability as an obvious extension of earlier capabilities (i.e., FTP in this case). While the appearance of a new capability with the impact of the WWW may be unlikely, NEES should clearly anticipate the emergence of new capabilities that may shift its plans. Technologies such as electronic notebooks, where initial capabilities are available off-the-shelf but mature standards-based solutions do not yet exist, or social tagging software (i.e., MySpace), which has proven effective in the general population but not yet in science and engineering, may progress over the lifetime of NEES from pilot applications to standard tools that could potentially displace other components (i.e., submitting data directly from electronic notebooks could eliminate the need for upload forms) and define how functionality is viewed (curation becomes just one use of MySpace-style tags). Similarly, advances in high bandwidth, low-latency networking, on-demand computing capabilities, robust sensor networks, GIS-based modeling capabilities, or other areas could shift thinking about what is practical and change NEES timelines and build/buy decisions. An agile mechanism to pilot such capabilities within the community, without disrupting production capabilities will be important for keeping NEES at the forefront. The design patterns and processes discussed, which aim to modularize and decrease the coupling between NEES components, can then be seen not only as a means for evolving the production infrastructure, but also as a key mechanism for enabling this type of experimentation.

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