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Chairman Burns, members of the subcommittee, thank you for allowing me the opportunity to testify on the National Science Foundation's role in fostering the development of the next generation of information science and technology.

NSF has supported some of the most successful and innovative communications concepts and technologies at their earliest, most experimental stages. This support dates back to NSF's support of high-end supercomputing centers in the mid-1980's and their link via the NSFNET backbone -- beginning what we now know as the Internet. NSF leadership in the area of high-performance computing, communications, and networking has also led to significant accomplishments and breakthroughs that have not only pushed the frontiers of science and engineering, but have created real economic and societal benefits for the Nation and the American people.

Significant NSF-supported breakthroughs include:

- **Creation of the popular Mosaic web browser software**- This development spawned industry leader Netscape Communications and eventually led to the blossoming of a multi-billion dollar industry.

- **Network video-conferencing** - CUSeeMe software developed through NSF support was one of the first software programs for video conferencing. It is the precursor of most Internet video conferencing software commercially available today. CUSeeMe is now available free on the Internet and is widely used in many elementary and secondary schools.

- **CAVE 3-D Virtual Reality** - This 3-D environment gives scientists and engineers a powerful tool to visualize their data. A researcher can walk through the enzyme she is studying or fly through a developing galaxy, as seen in the IMAX film Cosmic Voyage.

- **Global School House** - Originally supported by NSF - The Global SchoolHouse has gone on to receive tremendous private sector support, including Cisco Systems, Microsoft, and MCI. This "school of the future" uses the most powerful Internet

tools to link classrooms to their communities and to other children around the world.

- **Digital Libraries** - NSF manages this multiagency initiative that seeks to dramatically advance the collection, storage, and organization of digital information to make it readily available in user-friendly ways.

At NSF we are proud of our record of accomplishment in computer networking and communications and we hope to build on this record in the future. We've already seen advanced information technologies transform how research is conducted. We've glimpsed how they can dramatically improve teaching and learning in schools and classrooms at all levels of education. We've seen the Internet grow into a veritable global village. We've even seen a supercomputer crowned king of the world of chess.

But as impressive as those advances are, I truly believe that we have not even scratched the surface. That is why at NSF we are already concentrating on what's next for information science and communications -- and what's next is not simply the creation of a new network or an increase in computer speed, but the dawning of a new era of "knowledge and distributed intelligence".

What's Next: Knowledge and Distributed Intelligence

We have known that access to knowledge and information confers very real and powerful benefits -- economic, social, and political -- to those who have it. The concept of "Knowledge and Distributed Intelligence" -- or KDI -- is our way at NSF of envisioning how emerging technologies hold promise to make knowledge rapidly available to anyone, anywhere, anytime, and that power, information, and responsibility are moving away from centralized control to the individual.

The challenge today is to develop new ways to manage and make productive use of the flood of information released by these emerging technologies. To address this challenge, NSF is proposing to make a significant investment in this emerging area. For FY 1998, Knowledge and Distributed Intelligence is an investment priority for the Foundation, with over 60 percent of NSF's requested increase slated to go for KDI activities. NSF plans a focused, multidisciplinary program of activities totaling almost $58 million in support of KDI research, infrastructure development, and education, which builds on a base of existing KDI-related projects of more than $355 million.

Investments in KDI fall into two categories: Multidisciplinary Approaches to Knowledge and Distributed Intelligence and the Next Generation Internet Initiative.

KDI and the Most Difficult Problems in Science

Many of today's most pressing problems in science and engineering are more complicated then anything done before. In order to address these problems, we need first to support research to create new ways of collecting, transforming, representing, sharing, and using information. Research is also needed to develop methods of understanding complex behaviors across time or space, managing cast amounts of data, and merging data and models. NSF's initiative in Knowledge and Distributive

Intelligence will address these types of complex, interdisciplinary problems. These problems range widely; a few examples are:

- New technologies such as satellite and airborne sensors, and automated or remotely-operated sampling stations are generating an explosion of geospacial information. Integration of these data is necessary to proceed with multidisciplinary research on problems in a number of areas, including environmental phenomena such as the Ozone Hole, and using real-time data to understand and predict storms.

- Taxonomists are building a Web-linked network to share databases, and to analyze and identify biological specimens. A major challenge they face is managing and coordinating the amount and complexity of information. However, the availability of quick and accurate taxonomic identification would be valuable for uses ranging from agricultural extension agents encountering a new weed, to customs officials interdicting imports of new biological materials, to geologists searching marine cores for fossils indicative of petroleum deposits.

- Systems as dissimilar as an economic market, the brain, and large computer networks have one important trait in common: information is widely distributed throughout the system, and no identifiable entity coordinates the information or makes decisions. Yet, this information is somehow coordinated and focused into sensible outcomes. Researchers in disciplines ranging from economics to neuroscience to mathematics and computer science currently study these types of systems separately. Collaboration may reveal similarities in how these systems function, and point to ways to improve system performance.

- Most simulations of complex phenomena generate vast volumes of numeric data. Whether these simulations address natural processes -- the collapse of a star, global weather patterns, groundwater flow, or the function of the nervous system -- or engineering or social processes -- the management of electrical power networks, fluid flow around an airplane, or behavior of financial markets -- the phenomena are too complicated to be understood either by simple observation or by reduction to isolated components. The only hope of extracting useful information from those volumes of data depends on visualization techniques that are beyond current capabilities.

These types of science and engineering problems are computationally intensive, data intensive, and representationally difficult. It is this merging of computation, data, and representation for highly complex problems that makes KDI a significant new challenge for NSF.

NSF will support scientists and engineers, selected through the merit review process, to begin working in focuses, multidisciplinary areas, on problems including the management of large amounts of data, data security, sharing of databases, visualization of multidimensional and multivariable data, recognition of patterns, and graphic representation of data. Through this effort, we will gain a better sense of the range and type of problems that researchers consider most pressing, as well as enabling researchers to begin working toward solutions to these problems.

Next Generation Internet: An Integral Part of KDI

Unless researchers have the networking tools that will allow sharing and collaboration in real time, the vision of Knowledge and Distributed Intelligence will never be realized. For this reason, NSF is also a key participant in the President's 5-year program to move toward the Next Generation Internet. The Foundation's role builds on its current programs of networking, infrastructure development, and research. NSF's contribution will be devoted to enhancing Internet capabilities for research and education at colleges and universities as part of this multi-agency program.

This initiative is a prime example of where NSF seeks to build on its past success with the original Internet. NSF has unique expertise in helping universities to develop connections to foster innovative research across the fields of science and engineering. But while the Internet has passed from the domain of the researcher to the private marketplace, the need for greater connectivity and communication between researchers is greater than ever. That is why there is need once again to improve the network infrastructure for research, not just in capacity, but in basic functionality.

We at NSF have already begun to address this next generation question by investing in the development and implementation of a national-scale high performance network known as the Very High Speed Backbone Network -- or vBNS -- to address the needs of the university research community.

NGI funds will greatly accelerate these ongoing efforts. NSF's high-performance vBNS connections will play a central role in achieving a major goal of the Clinton Administration's Next Generation Internet initiative by linking roughly 100 leading universities and their research partners. The network will facilitate the joint development of software applications and communications technologies for the Internet of the future. Through this program, NSF will help to develop the next generation network fabric and connect researchers and students at universities and Federal research institutions. At rates that are 100 - 1000 times faster than today's Internet.

NSF will achieve this goal by substantially accelerating our program to interconnect additional research universities and centers through the vBNS. This funding -- totaling $7 million -- will complement some $33 million in base funds allocated to this effort, accelerating the new connections by years to meet NGI goals.

Other important areas of NSF's NGI investment will go to support technologies to support advanced network services. This will support the development of new software systems to enable the seamless convergence of computing and communications. Funding will also go for the study of basic technologies of future networking.

The other important activity is in the area of applications, where NGI is very closely linked with NSF's own effort in Knowledge and Distributed Intelligence. NSF investment in KDI seeks to harness the information revolution to address complex problems across the spectrum of science and engineering. In the specific area of computer science and engineering, NSF will increase funding for the development of core applications such as voice and video over the Net. This will leverage on-going NSF efforts to fund research

in grand challenges, digital libraries, and new core applications, as well as the much larger collective efforts of faculty and staff at the connected universities.

Because many academic researchers have contracts and grants with mission agencies, it is highly desirable that the NGI interconnect both federal and academic sites. This is why NGI is an effort that includes a number of federal research agencies. Through NGI, federal research institutions like the national laboratories will also be connected through primary support from DoD and DoE -- it is anticipated that up to 100 Federal research institutions will be connected at speeds 100 times faster than today's Internet. A smaller number of Federal research institutions at speeds that are 1,000 times faster than today's Internet.

To ensure that the NGI will be a seamless network for research and collaboration, NSF works closely with other agencies to interconnect research networks across the entire research community to achieve maximum benefit and leverage. The primary avenue for coordination is the Large Scale Network working group, co-chaired by Dr. George Strawn of NSF and Dr. Dave Nelson of DoE. The working group is part of the Committee on Computing, Information, and Communications which reports to the White House via the National Science and Technology Council.

NSF's investment in NGI will leverage private sector and university funds to upgrade campus and related networks, especially the university-driven Internet 2 project. Internet 2 is a separate project that is related to NGI but is organized and funded by the academic research community to upgrade their on-campus network capacity with the goal of spurring the interconnection of the academic research community for better research and education applications. The Internet 2 project has designated the NSF vBNS as its primary network for high-speed connections.

Conclusion: Limitless Potential

In conclusion, let me say that It is clear that what we are seeing today in information science and technology is only the beginning for forging connections to learning and creativity.

If history is any guide, it won't take long for the capabilities being developed today to reach the typical user. When combined with technologies such as palmtops, handhelds, intelligent agents, and omnipresent sensors, the potential before us takes on an entirely new dimension.

Information and knowledge will be available in forms that make it easier for everyone to use effectively - voice, video, text, holograms, to name but a few of a universe of possibilities. Will we develop new ways to express and unleash our creative talents - talents that are now limited by our ability to interface via a keyboard and mouse? What tools will enable us to control and master this ultra-rapid flow of information? Will having the proverbial Library of Congress in your pocket be a blessing or a burden?

The answers to these questions begin with the work by the Nation's finest researchers and educators. That is what we seek to enable at the National Science Foundation through our investment in Knowledge and Distributed Intelligence. These efforts and

the leadership of all institutions, the private sector, academia, and government can transform this immense, unprecedented, and somewhat intimidating potential into true progress, economic opportunity, social gain, and rising living standards for our society.

Thank you for letting me discuss the views of the National Science Foundation on this important issue. I look forward to answering any questions.

Thank You.