International Collaboration in Computer Science and Engineering

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Executive Summary

This report documents our conclusion that international collaboration in science and technology is a fundamental paradigm for advancing knowledge and solving global problems. It urges the United States to take a leadership role in advancing international collaboration, and presents new models to achieve this mission.

In the United States, the Administration and Congress clearly support international collaboration in science and technology. International collaboration is viewed as a good way to leverage U.S. investment in science and technology, to position U.S. industry to capitalize on research breakthroughs, and to train U.S. researchers to collaborate with foreign colleagues to solve global problems. Further, the free exchange of ideas is viewed as a positive force for democratic change.

A clear and visionary plan of action regarding international collaboration in science and technology can be an essential component of national policy to address physical issues (e.g., global warming) and socio-political issues (e.g., drug trafficking, increase of democratic governments). International collaboration in computer science and engineering must be an essential component of this plan.

Advances in computer science and engineering, more than any other discipline, are responsible for the internationalization of science. Advances in these areas have created a global information network that supports distributed computing and collaboration. Future advances will reduce or eliminate remaining barriers to collaboration due to time, space and language, and support a global scientific enterprise. Quite simply, the disciplines of computer science and engineering are central to international collaboration. They are creating and advancing the essential infrastructure that is used to conduct the business of science.

The benefits of international collaboration justify extraordinary efforts to increase and sustain international research projects. The main benefits of these projects are: (a) the creation of new knowledge and technologies; and, (b) their application to global problems that threaten health, peace and prosperity. The main barriers to international collaboration are the lack of coherent and consistent policies and plans to promote and support such activities.

The report concludes that the U.S. must take a leadership position in creating mechanisms for international collaboration in science and technology. This would be a significant step toward achieving many national goals. Specifically it would contribute to: a) developing a more secure, healthier, prosperous and better-educated citizenry; b) advancing scientific knowledge; and c) finding solutions to global problems.

The United States has one key agency that is well positioned to lead this effort. It is the National Science Foundation. We conclude that the computer science and engineering community should be challenged to work with the NSF, to form bridges from it to other agencies, and to create programs leading to increased international cooperation on science and technology projects.

Among other recommendations, the report proposes several models to stimulate and sustain international cooperation in science and technology, namely:

International Science Foundation
The research community and NSF should work to establish an International Science Foundation with participation by all nations. The new institution should have as its main goal advancing knowledge and developing technologies to solve global problems. A single organization with this mission can help remove many of the current barriers to international collaboration inherent in bilateral relationships, and develop standard procedures to initiate and sustain multinational projects.

New NSF CISE Programs

The National Science Foundation should establish new programs within the Directorate for Computer and Information Science and Engineering (CISE) to support international collaboration. New initiatives with substantial resources are needed to underscore a national commitment to a world-orientation in building computer and intellectual infrastructure. Programs should ensure a focus on significant international goals where achievements are possible due to advances in computer networking. CISE is the appropriate directorate for new programs because computer science plays an essential role in developing the infrastructure and tools that support the global scientific enterprise.

International Super Centers
International Super Centers should be formed to solve specific global problems. These would be virtual collaboratives linking physical centers of excellence. Associates would use high bandwidth networks to communicate. New technology will be in place here to enable the world’s best scientists and engineers to work together to solve global problems. Super Centers will provide computer scientists and engineers an invaluable testbed for design and test of distributed networks; distributed computing; and, collaboration technologies.

Develop Next Generation Infrastructure and Tools
Fund explorations to advance the tools and infrastructure for international collaboration. With regard to this, it is noted that international projects provide the best possible environment for computer scientists to propose and evaluate advances in distributed computing, communication and collaboration.

Expand Existing Programs in Latin America and Elsewhere
Increase the amounts for, and durations of, collaborative research projects. In developing and economically depressed countries, the U.S. should subsidize joint research projects. Move current NSF funding for joint research projects from modest levels, designed to stimulate initiation of collaborative research projects in new areas, to more substantial efforts. To attract the best researchers in the U.S. and other nations these programs must include follow-on funding with a joint review scheme to sift out the most successful projects.

Introduction

The past decade’s radical changes in information and communication are having profound effects on the way ordinary people learn about and interact with the world. Moreover the conduct of business and scientific/engineering enterprises has also changed. We are moving rapidly towards a single global economy and a single global scientific enterprise.

Although professional and national competition is vital, cooperation and shared goals are needed in many domains. Evidence shows that international scientific collaboration leverages national investment and can produce great benefits. International efforts to protect ecosystems and the natural environment recognize and underscore the importance of setting objectives higher than individual gain in order to provide for societal gains. The range of international cooperation activities includes common markets, trade agreements, stronger international recognition of intellectual property rights, and world interest in educational reform.

The Administration has emphasized the importance of international collaboration in recent policy statements. In his address to the United Nations on October 12, 1998, Vice President Gore proposed five new challenges in a "Declaration of Interdependence". He challenged the world community to:

- improve access to technology so everyone on the planet is within walking distance of basic telecommunication services by the year 2005;
- bridge language barriers by developing technologies with real-time digital translation so anyone on the planet can talk to anyone else;
- create a global knowledge network of people working to improve the delivery of education, health care, agricultural resources, and sustainable development, and to ensure public safety;
- ensure that communications technology protects the free-flow of ideas and supports democracy and free speech; and
- create networks that allow every micro-entrepreneur in the world to advertise, market, and sell products directly to the world market.

Today we can only glimpse the changes that advances in information and communication technologies will bring. As scientists involved in developing these technologies, we chose to look ahead to create frameworks to successfully guide and manage these changes. We sought to harness their potential to advance science to meet global objectives.

While the United States maintains a leadership position in many areas of information and communication technologies, federal agencies supporting computer science and engineering research have been slow to consider and implement new policies to support international collaboration. Given the global changes in communication, commerce and collaboration driven by the growth of the Internet, we considered whether new policies are necessary. Likewise, we examined the issues that an integrated comprehensive policy must address.

As a start toward understanding the internationalization of science and technology, and specifically of research on computer, communication and information science and engineering, the NSF funded a Workshop on International Collaboration in Computer Science (WICCS-97). The goal of the workshop organizers and participants was to arrive at a deeper understanding of the benefits of international collaboration, the costs and risks associated with these activities, and to recommend ways to increase opportunities and optimize future benefits.

The workshop was held October 9-11 1997 in Stevenson, Washington near Portland, Oregon. It brought together recognized leaders and visionary young investigators. All participants were strongly interested in contributing to international scientific cooperation. The workshop agenda and the list of participants can be viewed at http:/www.cse.ogi.edu/CSLU/wiccs97/wiccs97.html . The wide-ranging discussions at the workshop mainly focussed on these issues:

- What are the main benefits, barriers and risks associated with international

scientific collaboration with respect to individual investigators, to the interests of the U.S., and to the global community?
- What does the global landscape of international collaboration look like today, and what might we anticipate in the future?
- What are the existing opportunities for U.S. scientists? What is the special role of computer science and engineering in international collaboration?
- What steps should the community in general, and the NSF in particular, take to guide rather than be swept up (or aside) by the forces of globalization?

This report summarizes the main insights and recommendations of the workshop. It also responds to recent developments subsequent to the workshop including new international initiatives, and recent activities of the U.S. Congress and White House. The report also includes many beneficial contributions by members of the research community who did not attend the workshop.

The main conclusion of this report is that international collaboration in computer science is vital to our national interest. This is so because international participation is required for solutions to global problems that threaten our welfare and security. Indeed some global problems could even impact the long-term survival of humanity.

Moreover, computer and information science and engineering provide infrastructure necessary to conduct the business of science. Computing and communications are essential means to enable cooperation among diverse international workers. The report recommends that the CISE community be challenged and given means to take leadership in promoting international collaboration in computer science and engineering. International CISE collaboration must include sufficient investigators to positively address those global problems whose solutions depend on advanced CISE technologies.

Progress toward these goals can be materially advanced by NSF activity. That could be a simple programmatic assertion that international CISE collaboration is of highest priority. Similarly, the process of supporting international interaction would benefit greatly from definite standards, new research funding initiatives, and significant programs at the level of major NSF divisions. These should be focused on CISE topics, and oriented to stimulating and supporting international collaborative CISE research.

The remainder of this report is organized as follows. Next, we briefly review the changing landscape of U.S policy regarding international collaboration in science and technology, and the nature of the NSF’s participation in support of international collaboration in CISE. In the following section, we explore the many benefits of international collaboration in CISE, as well as the barriers. In the final section, we submit a set of recommendations for increasing and optimizing international collaboration.

The Changing Landscape

The Cold War Agenda

Until quite recently, science and technology policy in the United States was driven by national security needs. The critical role of science and technology in winning World War II underscored the importance of national investment in science and technology. In a 1993 report, the House Committee on Science provides this summary:

> *World War II dramatically altered the relationship between science, engineering, and the government. The atomic bomb, radar, nylon, penicillin, electronic computers, and a host of other products demonstrated the power of fundamental research when combined with engineering skills. Americans emerged from the war with a wholly new appreciation of the research enterprise and of the products it could generate.*

This new appreciation was focused and elaborated in Vannevar Bush's 1945 report Science, the Endless Frontier *. Bush, who was head of the federal Office of Scientific Research and Development during the war, argued that new knowledge generated by basic scientific research was essential to the national defense, the war against diseases, and the creation of new products, new industries, and new jobs. Traditional patronage of basic science—primarily from philanthropies and other private sources—was no longer sufficient; only the federal government had the resources and the broad public mandate to take full advantage of the promise offered by science* [1].

During the cold war years, the U.S. research agenda in most areas of CISE was heavily influenced by DARPA, and reflected the needs of the defense establishment. Until quite recently, DARPA was the only federal agency with sufficient resources to support large multi-site programs in computer science with ambitious, long-term goals. These programs have provided both a stimulus and a model for programs in other countries. For example, DARPA sponsored programs in speech and natural language research with results evaluated in international competitions run by NIST. These competitions engaged international research communities in common research and system development efforts. This was a form of international collaboration; it amplified a national effort to achieve some world-relevant U.S. scientific goals.

Transition

The end of the Cold War had dramatic effects on our nation's international science and technology policy. In a 1995 report submitted by the President to Congress [2], a new agenda was proposed for international collaboration in science and technology. The new agenda was based on five tenets: (a) promoting the spread of democracy worldwide; (b) promoting and maintaining peace; (c) promoting economic growth and sustainable development; (d) solving global problems; and (e) providing humanitarian assistance.

In 1997, the Speaker of the House of Representatives charged the House Committee on Science to develop a new science and technology policy for the U.S. The letter included the following motivation for this task:

With the collapse of the Soviet Union, and the de facto end of the Cold War, the Vannevar Bush approach is no longer valid. Appealing to national pride in the sense that "Our science is better than your science" is no longer meaningful to the American public. The needs of our military mission today are far different, and the competitions we are engaged in now are less military and largely economic. Science today is an international enterprise, and we must assume a leadership role in guiding international science policy. [3]

In the Congressional Hearings that followed in March of 1998, Congressman Vernon Ehlers noted the importance of international collaboration in his opening statement [4]:

"While the United States still leads the world in the largest number of research disciplines, the growth of modern communications technologies, coupled with the existence of cutting-edge scientific research programs in foreign countries, has made it both possible and scientifically useful for the United States to leverage our own investments in research with those taking place in foreign nations. Not only does this allow U.S. researchers access to unique research, it allows them to reap the full benefits of that research at a fraction of the cost of performing the research ourselves. International collaborations also help build positive, sustainable relations with other nations based upon mutual self-interest. Even more importantly to the United States, we are perfectly positioned to take advantage of the new knowledge we gain through international collaborations with foreign researchers because we have the most fertile

innovation environment in the world."

Changing national priorities have impacted the National Science Foundation and the U.S computer science community. In the past two years, the NSF's funding of computer science related research has increased dramatically, with major initiatives such as the $68 million Knowledge and Distributed Information initiative. For the first time, the NSF funding of basic research in computer science and engineering exceeded funding by DARPA. Moreover, the NSF has sponsored an increasing number of programs encouraging interdisciplinary efforts, multiple institutions, and technology transfer from laboratories to classrooms. These programs reflect changing national priorities and the growing realization that advances in computer science and engineering are vital to our national interest. New initiatives and programs have not included an international component.

Current Events and Recent Trends

In Computer Science and Engineering, the vast majority of international collaboration occurs at the level of individual investigators, or through collaborative relationships between research laboratories or academic institutions. International collaboration is also stimulated by the large population of foreign graduate students trained in U.S. universities.

The NSF's INT division provides a vital role in stimulating and supporting international collaboration in computer science. The focus is on exploring collaborative opportunities through workshops and visits, and stimulating collaborative research projects through seed grants. Joint research projects are typically supported for two to three years at the level of individual investigator awards. Activities supported by INT require direct cooperation between U.S. scientists and foreign scientists through their respective institutions, and cost sharing by each side. The exact requirements of joint research projects depend upon bilateral agreements between the U.S and its partner countries.

The United States and European Union (EU) are currently working together through joint efforts to support international collaboration in digital libraries and multilingual information management. Both the U.S. and EU support substantial research efforts in these areas, and are seeking to accelerate progress by leveraging on existing work and the many benefits of international collaboration.

In the area of multilingual information management, significant efforts are underway to promote collaboration between the U.S. and EU. A new study, funded by the NSF and the EU, focuses on technologies required for multilingual information management including: machine translation, information retrieval, language resources, information extraction, text summarization, evaluation, multimedia work, speech processing, and language and speaker identification. A report of the working group is available at http://www.cs.cmu.edu/~ref/mlim. This report and other recent activities culminated in a formal agreement between the United States and the European Union to support collaboration in multilingual language technologies.

In the area of Digital libraries (DL), both the U.S. and EU support significant research programs. Although the digital libraries they are creating are inherently international, by and large, scientists involved in the U.S. and EU DL projects have not had the opportunity to work together. To meet this challenge for an international DL research agenda, the NSF and the EU Special Programs Division have established five working groups in key technical infrastructure areas of digital libraries. A summary of this program can be found at http://www.si.umich.edu/UMDL/EU_Grant/home.htm.

New initiatives are also underway between the U.S. and Latin America. International workshops in Brazil and Mexico, sponsored in part by the NSF, have led to joint research programs with these countries to support international collaboration in computer science. The joint research program between the NSF and Mexico's CONACyT has resulted in a dramatic increase in funding of computer science research in Mexico. International collaboration between the U.S and Brazil is now supported through a joint initiative of the NSF and Brazil's CNPq, providing up to $200k for U.S. researchers to collaborate on joint research projects with their Brazilian colleagues.

The NSF has joined other nations in funding the interconnection of their computer networks, as exemplified by TransPAC and Startap. TransPAC provides high performance international Internet service connecting the Asia Pacific Advanced Network to the vBNS and other global networks for international collaborations in research and education. It is funded by the National Science Foundation and the Japan Science and Technology Agency. The NSF CISE Networking and Communications Research and Infrastructure (NCRI) division funded STAR TAP, the Chicago Science, Technology And Research Transit Access Point, a persistent infrastructure to facilitate the long-term interconnection and interoperability of advanced international networking in support of applications, performance measuring, and technology evaluations. STARTAP is already linked to fast research networks in Canada, Northern Europe, TransPAC (i.e. Japan, Singapore, Taiwan) and Russia. The number of interconnected countries is expected to continue to increase at a fast rate.

Recent developments in international cooperation are associated with projects that are pushing both the state of the art in fast networking and applications enabled by the Internet of the future. These are broadly referred to as the Next Generation Internet and the Internet 2. They have wide support from the government, industry and academia. Progress in these projects already enables more than 100 universities to be connected by very fast networks that are to be used for both research and education purposes. While the US has been leading in the push for fast network infrastructure, several other countries have similar initiatives. Collaborative arrangements between the organizations leading these efforts are being established. At the time of this writing the Internet 2 has Memoranda of Understanding with countries in Europe, North America and the Asia/Pacific Rim. In addition to the physical interconnection of their networks the participating countries have also agreed to promote the development of applications and to collaborate in the definition of standards that might be needed to make such applications possible.

The Opportunity

The White House and Congress have identified international collaboration in science and technology as a national priority. The research community should be involved to help identify new opportunities and models for international collaboration. This report is a first step in that direction.

Benefits and Barriers

International Collaboration Benefits

Solving Global Problems

As the dominant species on this planet, it is our responsibility to support biological well being (ourselves and other creatures), protect future generations and foster global health and prosperity. Threats to our health, prosperity and future include: terrorism; drug-trafficking and abuse; compromises of computing infrastructure integrity and security; international monetary instability; spread of AIDS and other diseases; poverty and starvation; natural resource depletion; environmental pollution; bio-diversity losses; global warming; and natural disasters. Each of the above ultimately impact everyone, and are therefore global problems.

The scientific community plays an essential role in solving global problems because its work leads to understanding their causes, and the ability to evaluate potential solutions. Such work consists of defining the problem space, collecting and analyzing data, and proposing and testing solutions. The best progress in this work requires scientists from many nations: global problems require global solutions, and global solutions require global participation.

Climate change is an example of a global problem requiring widespread participation. The consequences of even small increases in global warming -- fewer than five degrees Centigrade -- are losses of life and property.

It is well recognized that global initiatives are necessary to deal with all facets of this problem. There are a significant number of international collaboration efforts already under way in the area of Remote Sensing and Earth Observation [5]. According to Wagner's report [5], there are a total of 490 international agreements involving 76 countries and six multinational organizations. However, none the 15 subjects addressed by these collaborations are in CISE disciplines, despite the fact that most of these projects use or could benefit from using CISE technologies.

The applicability of CISE research to monitoring and managing global weather follows from the need to collect, process, understand, predict and evaluate (enormous amounts of) information at large numbers of world sites where unique resources (people, laboratories, sensors, computers, actuators, etc.) are located. The following lists ten sample areas of CISE research essential to world weather and other global tasks:

1. **World-level networking**. Size, heterogeneity, software demands and hardware requirements of large global networks present unique CISE research problems. (This is needed to enable seamless access to weather information across the world from both sensors and databases.)
2. **Archiving and processing massive amounts of data**. Coping with real-time data collection rates. (Processing accumulations of weather data is needed to address global warming, climate trends.)
3. **Intelligent data retrieval.** Means to support timely selection and distribution of data. (Obtaining weather information and directing it to the people and locations where it is needed.)
4. **Distributed processing of information.** Means to enable local processing and global sharing and analysis of data. (Weather information and its analyses possess value apart from its geographic source.)
5. **High-performance computing.** Means to provide the necessary computational power for detailed simulation beyond the ability of any existing supercomputer. (Needed for weather simulations across the world.)
6. **Knowledge understanding and data mining.** Methods to search, detect and explain phenomena from aggregated data sources. (Weather-relevant issues are present in the massive resources present in existing databases.)
7. **Computer interfaces and language translation.** Technology to allow people of varied cultures and languages to work and collaborate effectively. (This is essential to create world weather management infrastructure, and to support more effective air traffic control.)
8. **Software engineering.** Standards to enable worldwide software development. (Practices to support interfacing software modules developed in different countries, particularly for issues that bridge political borders, e.g. weather, natural resources, and biology.)
9. **Network-based machine operation.** Means to support remote operation of sensors, actuators and instrumentation from anywhere in the world. (Seismological and weather measurements require new network modalities.)
10. **Intelligent sensor and instrumentation technology.** Means to allow data to be collected anywhere and anytime. The range of such technology goes from the extremely small (nanomachines) to the uniquely large (e.g. arrays of large antennas and satellites) and encompasses a multitude of CISE topics. (As in 9., weather and other issues require new modalities.)

The above contains central CISE topics. Research activities on these themes are underway in universities, industries and national research laboratories around the world. However, global warming presents problems of unprecedented scale. The complexity of coordinating, managing, maintaining and programming many millions of information sources networked across the world dwarfs that of any system in existence today. To collect, store, process and manage these data requires infrastructure involving large constituencies and capable of surviving geopolitical phenomena. Global problems can be solved only through novel structures ensuring world participation of specialists in computer and information science.

Leveraging International Investment

Major scientific countries, the United States, the European Union, Japan, Korea, the nations of the former Soviet Union, have invested billions of dollars in information and communication technologies through their governmental and industrial organizations. Researchers educated in computer science and engineering there and elsewhere are an existing resource. International collaboration can leverage this investment, building upon it to cause new technologies to serve groups of nations and the world community.

Cost Sharing

The 1998 House Report identifies cost sharing as an important benefit of international collaboration in science and technology. "One rationale for entering into international science collaborations is that the costs of large scale science projects, such as colliders for high-energy physics, can be shared among participating countries." Dr. Bruce Alberts, president of the National Academy of Sciences, noted that "Some research facilities are so expensive that international collaboration is necessary in order to make them affordable. In order for the U.S. to be able to capitalize on discoveries made elsewhere and facilities located elsewhere, we must have world-class researchers who maintain constant communication and work frequently in collaboration with the best scientists in other countries."[3]

Harnessing Talent

The basis of the economic growth in many world areas has been highly educated population. Israel, Japan, Korea, Taiwan and other nations have moved forward through focused investment to develop and use an existing pool of knowledgeable workers. Whether through institutional means (Binational Science Foundation, International Information Science Foundation) or due to immigration or other population movement, and informal connections to the United States, trained personnel have been the basis of new industries, many centered on computer and information technology.

International collaboration builds upon the education, training and experience of tens of thousands of engineers and computer scientists, the lessons they have learned, and the discoveries they have made. The diversity of the talent pool produces synergistic results: Scientists from different countries approach problems with diverse skills, attitudes and perspectives that stimulate novel approaches and creative breakthroughs. Providing scientists from different countries the opportunity to work together not only increases the talent pool, but also changes and enhances it. The potential synergy of the hybrid talent pool could greatly accelerate the advancement of knowledge, the creation of new technologies, and the solutions to global problems.

New Paradigms

Current NSF CISE initiatives, such as Digital Libraries, Educational Innovation and Knowledge and Distributed Information (KDI), will create new technologies, tools and paradigms for scientific collaboration and discovery. International collaboration extends the scope of these activities to overcome challenges of physical distance, time zones, languages, cultures, computing environments, etc. Scientists in different countries who collaborate to solve global problems test the effectiveness of new tools and technologies. International collaboration is a valuable laboratory for research, development and evaluation. It will lead to new paradigms for scientific discovery and collaboration.

Tools and Infrastructure

Computer scientists and engineers play a special role in science and technology: they provide the infrastructure used by the scientific community to conduct research and advance knowledge. This includes the tools used by the international community to collaborate and solve global problems. Better tools, infrastructure and focus can greatly improve our chances of understanding and solving global problems.

New paradigms for collaboration will require new infrastructure. Understanding these infrastructure needs and defining the best implementation strategy is itself a major research challenge in part due to the rapid change in computer and information technology. It is both inefficient and risky to address related problems locally and hope that these solutions generalize to support international collaboration. Similarly, in disciplines other than computer science, it is equally inefficient to develop international cooperation mechanisms and policies without any involvement by the CISE community and hope that they are the most efficient in leveraging information processing and communication techniques.

Training Leadership

If the U.S. is to maintain world leadership in information and communication industry it must train students to work and compete in a global arena. Projects requiring international collaboration provide valuable experience for scientists, engineers and managers to function in an increasingly global marketplace. Graduate students participating in global projects will gain competitive advantage, for themselves and the companies that will employ them: in distributed virtual environments; working with people in other cultures; and via discovery of new technology commercialization opportunities.

Promoting Democracy

International collaboration promotes democracy. In his congressional testimony, Dr. Bruce Alberts noted that "In a world full of conflicting cultural values and competing needs, scientists everywhere share a powerful common culture that respects honesty, generosity and ideas independent of their source, while rewarding merit. Knowledge is power, and diffusing it more widely across the globe also provides a strong force that favors democracy." [3]

Economic Issues

A main tenet of U.S. international science and technology policy is to promote our economic well being. "While we must remain ever vigilant and militarily strong, the need to maintain economic strength has taken on primary importance today." (1998 House Report, page 4)

In the past five years the high technology sector has contributed the largest share to our national growth, about double the national average. Growth in high technology is perhaps the most prominent factor contributing to recent U.S. economic prosperity.

The Asian financial crisis underscores the extent to which the economies of individual nations are interrelated. International collaboration in computers (science, information, and engineering) would support global financial stability. It would enable developing nations to participate in this fast-changing field. As a result their citizens would become both consumers and producers of high technology.

Foreign Policy

Support to foreign research can serve U.S. policy abroad. Supporting research and education in developing countries is an efficient means of foreign aid. Such support reaches respected and influential people in targeted nations, provides them means to collaborate with U.S. researchers; it contributes to U.S.-friendly leaders. Direct research support could help less developed countries build centers of excellence, computing infrastructure and industries. It would help bring developing countries into the information age. This aid can take the form of computing equipment and software produced by U.S. companies. It would thereby establish markets for the U.S., and provide motivation for industrial participation in foreign research initiatives.

Investment in foreign research increases the hybrid talent pool, builds lasting professional relationships and earns good will for the U.S. while producing advances in science and technology. U.S. support of research in other countries (under international collaboration activity) would benefit highly capable and motivated scientists and students there who otherwise lack the resources to achieve their potential. Scientists in these countries could participate in large international projects only if needed infrastructure, tools and training become available. The ever-decreasing costs of computers, and the ability to collaborate over long distances using computer networks, mean that relatively small investments in foreign research can produce enormous returns. In cooperation with U.S. colleagues, scientists in these countries could be helpful participants in multinational projects.

Information Technology Leadership

The trend toward a global information society brings with it an urgent need for engineering leadership in the definition of standards, international protocols and mechanisms for trade, commerce, intellectual and cultural exchanges. The U.S. should provide this leadership. It involves a unique historical opportunity and multiple benefits to the participants.

Information technologies have led to new modes of interaction via publicly accessible infrastructures. This is the key paradigm of CISE technology. To lead the technology deployment it is essential to be involved in early development stages. This produces a strong argument for involvement of U.S. scientists in international CISE research efforts.

Personal Realities

The Workshop on International Collaboration in Computer Science began with a session entitled "The Good, The Bad and The Ugly." Participants shared feelings and stories about international collaboration. A clear consensus emerged from our work that the benefits of international collaboration outweigh the difficulties and hardships often encountered. U.S. researchers' motivations range from the desire to collaborate with the best people in the world, to the desire to help talented colleagues in less prosperous countries who cannot realize their creative potential because of insufficient resources.

Summary

The benefits described in this section indicate an urgent and vital need to accelerate international collaboration in computer science, computer information, and computer engineering. Providing the means and motivation for scientists to collaborate effectively across national and political boundaries would create infrastructure and synergies needed to advance knowledge, create new and improved technologies and provide solutions to coordinated global problems that cannot be solved locally. In addition, international collaboration will train U.S. researchers to participate in global projects, and position U.S. industry to both provide and participate in the development of new technologies to support international efforts.

International Collaboration Barriers

A surprising number of factors work against international collaboration in computer science and engineering. This section reviews some of the most important.

U.S. Policy

The main barrier to international collaboration in computer science and engineering is lack of U.S. policy to promote and support it. Although international collaboration is now identified as a national priority, policies and programs have not yet been put in place to translate this priority into a plan of action. For example, within the National Science Foundation's Computer and Information Science and Engineering (NSF CISE) directorate, procedures for funding international collaboration differ from country to country, when such opportunities exist at all.

International collaboration in science and technology is the province of the Department of State. Congressional testimony by several experts noted that State is poorly provisioned to promote international collaboration or take advantage of opportunities that arise. According to Congressional testimony, the Department of State has failed to provide the necessary vision, leadership and support for international collaboration in computer science. The 1998 House Report cites testimony that "scientific expertise and commitment is severely lacking within the Department of State." Admiral Watkins noted that "leadership there always seems to be lacking in both timely enthusiasm and technical qualifications."

NSF Realities

International Collaboration in CISE has a relatively weak constituency within the NSF. Activities within CISE are driven by a constituency of managers and researchers who support and lobby for the importance of their programs. Each program has a clear focus for advancing knowledge and creating new technologies in areas of national importance. Given this organizational structure, it is difficult to motivate support for international collaboration since funding is perceived as a "zero sum game." Support for international collaboration necessarily eliminates support for other programs. (Supporting international collaboration would rob Peter to pay Paul, but Peter is better armed.)

Support for international collaboration is also relatively weak in the U.S. computer science academic community. Researchers understand where the "action" is within the NSF, and invest their time in activities that promise to deliver the greatest amount of funding. The NSF divisions in CISE science have relatively large budgets to support research. Likewise they have relatively small budgets to support international collaboration. The NSF's approach to international collaboration provides seed money to stimulate cooperative activities. Because the NSF does not provide resources to fund major efforts involving international collaboration, these efforts are not taken seriously by the research community. Whether intentional or not, the NSF sends a message to researchers in computer science and engineering: International collaboration is encouraged but is not a priority.

This message is reinforced by the resources allocated to marketing and funding international programs in computer science within the NSF. According to Caroline Wagner [6] the funds allocated to CISE international collaborative research by the US in FY95 are less than 0.1% of the total amount, placing CISE in 13th place among 18 disciplines. Within the NSF, the CISE allocation for international collaboration ranked last among the 12 disciplines considered in Wagner's report, corresponding to approximately 1% of the total CISE budget and to 1% of the total NSF funds used for international collaborative research.

National Priority

Funding research in computer science and engineering in the United States is guided by such national priorities as maintaining technological superiority in computing and communication. National priorities often conflict with international collaboration—shared knowledge and technology (research advances and new technologies would no longer be "owned" by the U.S.). This conflict is compounded by industry participation in federally funded projects (stimulated by agencies' requirements of matching funds), since industry participation is often motivated in part by the opportunity for competitive advantage in the marketplace. These same barriers to international participation are present—to greater or lesser extent—in all countries.

Attitudes shaped by the Cold War continue to influence Congressional funding. The 1998 House Report reminds us that "The political consensus necessary to build today's science and engineering enterprise was forged largely by the Nation's needs and priorities in the period following the second World War, when the threat of total destruction by nuclear weapons was frighteningly real. Under these circumstances, the exigencies of the Cold War made science politically unassailable." [3] While the 1998 House Report acknowledges that international collaboration is a "strong force that favors democracy," it is difficult to change the attitudes of the past. International collaboration in science and technology is not yet in favor.

Bureaucracy

For international collaboration to be truly effective, collaboration must occur between national governments and their agencies. Even when all parties share the same vision, existing rules and regulations (immigration, taxation, etc.) complicate the process. Government bureaucracy often is frustrating to researchers and program managers within the U.S. Difficulties when government bureaucracies attempt to work together on international programs are significant.

Summary

There are significant barriers to international collaboration in computer science. Because there is a clear, important and urgent need to increase international collaboration, the computer science research community seeks to facilitate it and to lower existing barriers to such activities. This requires proposing, examining and testing new models for international collaboration. We present a set of recommendations for consideration. These share a common theme. All recommendations for new programs and models for international collaboration are based on rewards that would accrue from a dramatic increase in cooperative transnational opportunities.

Recommendations

International Science Foundation

Bilateral agreements are inefficient and perhaps ineffective. Consequently the workshop proposed forming an International Science Foundation with participation by all nations. The organization would work like NSF, accepting unsolicited proposals from scientists, or proposals in response to programs and initiatives it develops. All proposals, however, would require collaboration by scientists from two or more countries. This model is already followed within the European Union where a variety of research programs have been established with the explicit requirement of international collaboration. These programs have been driven by the creation of the European Union. However, they also illustrate the efficiency and effectiveness of an infrastructure that can stimulate, evaluate and fund international collaborative research while satisfying the political and scientific goals of the participating countries.

There is a strong reason for the above suggestion. Experience shows that establishing joint initiatives between countries requires a great deal of time and effort. Champions must be identified within the funding agencies and research communities in two countries, workshops must be proposed, organized and funded, and the many details of a joint program worked out. Given the time and effort involved, it is probably not practical for the U.S. to establish joint funding initiatives with all countries. Even if this could be a done, joint programs exclude collaboration by scientists from more than the two participating countries. Establishing programs between three or more countries may be possible, but the difficulties probably increase exponentially, and political sensitivities may arise if other countries feel that they are being excluded.

We believe that the notion of an International Science Foundation has great merit, could overcome major barriers to cooperation, is inevitable, and that the U.S. should take leadership in its definition. Creation of the ICCSE division is a step towards the establishment of an International Science Foundation. The foundations of operational procedures, mechanisms for pooling of international funds and awarding grants could be established by the ICCSE and International Program divisions of NSF and then transferred to the proposed International Foundation. It is beyond the scope of this report to conceptualize this in detail. If the idea of an International Science Foundation is well received by the research community, we recommend that a separate workshop be organized to consider its principles and organization, perhaps with international advisors.

New NSF CISE Programs

The workshop recommends that international collaboration become a high priority within CISE. Making international cooperation a high priority within CISE through substantial and highly visible programs would remove the most serious barriers to international collaboration. We recommend new highly visible and ambitious programs with resources totaling as much as 5% or 10% of the CISE budget. NSF and CISE managers would employ their contacts with the research community to highlight international collaboration, ensuring that the new efforts become marketed effectively to potential investigators within the U.S. New programs are necessary to achieve the benefits of international cooperation on projects to address global problems.

The workshop believed NSF to be uniquely qualified to assume leadership in international collaboration in computer science and engineering. The NSF CISE directorate is one of the leading agencies worldwide supporting research in computer science and engineering. CISE has demonstrated an increasing interest in international collaboration, with recent international initiatives underway with European partners (Digital Libraries, Multilingual Language Resources) and joint initiatives in Mexico (with CONACyT) and Brazil (with CNPq). We concur with J. Thomas Ratchford, Director of the Center for Science, Trade, and Technology Policy of George Mason University, that [7]:

> "… there is a special role for the NSF in effecting these solutions. The NSF is highly respected at home and abroad". The "NSF organic act provides the authority". The existing "NSF international office provides a solid base"

Establishing international initiatives within the NSF would demonstrate assigning high priority, commitment and focus to international collaboration. In short, it says that the U.S. supports and will initiate means for international collaboration in computer science. It establishes the NSF as a U.S. point of contact. Thus it enables ideas to filter into an organization with a track record for initiating new programs.

International programs within CISE will serve the national interest by advancing scientific knowledge in computer science and engineering. The goals of such programs might be to support: training of U.S. researchers through participation in international projects; establishing global computing and communications infrastructure; and development of new technologies for solving global problems through international collaboration. A program to establish international "Super Centers" to solve global problems is proposed below.

Successful programs in international collaboration require new infrastructure and focus within NSF. For example, NSF must work with the international science community to seek out opportunities for international collaboration in computer science. NSF personnel could work in different regions of the world either by regional offices or through embassy scientific representatives.

International Super Centers

Distributed international centers of excellence provide a new model for international collaboration. International super centers could be established to advance science and technology in areas of computer science, such as digital libraries, multilingual information management or virtual environments for collaboration, or to solve global health, environmental or national resource problems.

The vision of international super centers is consistent with a recommendation offered by the President's Information Technology Advisory Committee (PITAC). The committee's August 1998 Interim Report recommends establishing Enabling Technology Centers. These are envisioned as centers of excellence that focus on applying information and communications technology to a particular application domain, such as health care, crisis management, environmental monitoring, life-long learning, or law enforcement and public safety. These Centers "will conduct R&D in CS&E to support the chosen application domain, develop new curricula for students and mid-career professionals, participate in testbeds, and identify barriers to more widespread adoption of IT in a particular applications domain." [8]

The NSF is well positioned to assume a leadership role within the U.S. and internationally to promote the establishment of international centers of excellence in computer science and engineering. In recent years, the NSF has developed a number of successful initiatives that require or encourage interdisciplinary and inter-institutional collaboration. For example, the NSF Challenge initiative supported projects that required collaborative research among scientists in several sub-disciplines of CSE to develop technologies or applications of immediate benefit to the nation. The NSF has also supported distributed centers through its Science and Technology Centers (STC) program. For example, the Graphics and Visualization Center (www.cs.brown.edu/stc), one of 24 NSF Centers funded through the foundations STC program, comprises five universities: Brown, Caltech, Cornell, UNC, and Utah. The NSF's International and CISE Divisions could work together, taking advantage of complementary expertise and resources, to extend the model of distributed centers to international super centers.

Joint Research

The NSF should increase the number and scope of joint research programs in developing countries. While we have argued that bilateral agreements are not the most efficient means to promote internationalization of computer science, they can be very effective in specific countries, and should be pursued at increased funding levels until more ambitious multinational initiatives can be implemented. Establishing such programs requires identifying researchers in the U.S. and partner nations who are willing to organize workshops to promote joint research programs.

It is important to find ways to subsidize foreign institutions to support joint research efforts because this is good foreign policy. In many countries, financial resources are simply not available; amounts as low as $30k to $50k can support students, postdoctoral fellows and faculty in other countries. Presently, this is very difficult to do within the NSF. This investment would enable U.S. investigators to utilize unique resources, and to leverage CISE funding. In many countries, small U.S. dollar investments can make a big difference.

The benefits of U.S. participation in joint research programs in developing countries are illustrated by the success of the NSF / CONACyT program. During the last five years, the NSF and Mexico's CONACyT have sponsored three workshops to promote collaboration in computer science between the U.S. and Mexico. Prior to these workshops, there was no division or program within CONACyT responsible for funding computer science. Mexican computer scientists were forced to submit proposals to programs supporting research in Chemistry, Biology, Physics, etc. The NSF / CONACyT workshops helped mobilize the Mexican computer science community. Computer science is now a top priority within CONACyT, which recently funded the establishment of several centers of excellence in computer science at Mexican universities.

The NSF / CONACyT program has also demonstrated that joint projects with relatively small capitalization can yield significant outcomes. In one project, the Oregon Graduate Institute and the Universidad de Las Americas, Puebla (UDLA) were funded to develop Mexican Spanish language technologies. Prior to this project, Mexico had no major research program in language technology. Today, UDLA's TLATOA speech group is an international center of excellence, with twelve faculty, research staff and students. As documented on its Web site the TLATOA group provides language resources, technologies and short courses to other academic institutions in Mexico. CONACyT has funded a new research center at UDLA, with speech as one of three focus areas. A U.S. speech technology company has established a subsidiary at UDLA, and has invested over $100,000 in support of the TLATOA group (triple CONACyT's original investment). The international research community has also benefited from this effort; Mexican Spanish speech recognition and text-to-speech synthesis systems are now available from the TLATOA Web site.

We recommend that joint research programs, such as those established by the NSF with federal funding agencies in Mexico and Brazil, be initiated in other countries. The amount of the awards in these programs must be increased to attract top U.S. researchers. It is also necessary provide significant follow-on support beyond initial grants. A seed grant is a good way to initiate collaboration, but there must also be mechanism to support successful collaborations, so they can realize their potential. Follow-on funding is necessary to attract top researchers to international programs. The model could be the successful SBIR program.

Collaboration Model

A model for supporting international collaboration among different countries or funding agencies that is reasonable, consistent and understandable by researchers and program managers world wide is highly desirable. Ideally, it would support training international research teams on the basis of scientific goals and complementary expertise. It would enable groups to seek funding for their work by submitting research proposals to a single agency with the ability to review and fund the proposal. The details of what agencies in different countries should be involved, their deadlines, requirements and other idiosyncrasies should be hidden from the researchers by the agency that receives the proposal.

Funding agencies have a major organizational role to play in this context and should reexamine and reform their inner workings and formal relations with foreign counterparts. Their international funding units should capitalize on the new interest and high priority placed on international collaboration and global efforts. In order to seize this opportunity, they must re-evaluate and revise policies to remove barriers and constraints that were imposed by Cold War attitudes and policies. They have a major responsibility and much of the necessary competence and experience in developing an international collaboration model that reflects the CISE needs in the 21st century.

Marketing

Many in the CISE community do not know about existing international opportunities. Funding agencies should market existing international activities and opportunities more aggressively.

Funding agencies should actively encourage researchers to take advantage of opportunities for international collaboration when they can show that such collaboration is appropriate and desirable. In such cases, concrete measures should be used to quantify the benefits of collaboration.

The NSF should develop better reporting mechanisms regarding INT proposals, research results, the investigators and their international collaborators. The information should be collected and made available readily to the CISE community.

It is also important to make the CISE community aware of international activities, such as those of the European Union, including RACE, PACE, ESPRIT, etc. Some of these multinational programs require the participation of universities, industry and government labs, and serve as interesting models for international collaboration.

A good way to promote and market opportunities for international collaboration is to support the development and maintenance of new infrastructure. This could include linked Web sites (similar to the U. of Arizona site on Japan), that identify existing collaborations, areas of expertise in computer science worldwide, opportunities for collaboration, etc. The NSF could provide support for developing this infrastructure by relatively modest funding; e.g., several grants of about $25k to $50k per year.

The importance of international collaboration must also be marketed within funding agencies. Leading officers should encourage and empower program directors to take advantage of existing mechanisms to stimulate and fund international collaborative research.

Further, we recommend that a small delegation of workshop participants make a presentation to leading officers of funding agencies to underscore the importance of international collaboration, and the recommendations herein.

Finally, a follow-on workshop should be held in about one year, to examine the outcomes of the first workshop, and to continue to find ways to support international collaboration in CISE.

Funding

Funding barriers to international collaboration could be overcome in several ways.

- Congress should be lobbied for additional support for international programs. The good news here is that 1998 House Report notes that "The importance of stable funding for large-scale, well-defined international science projects should be stressed in the budget resolution and appropriations process."
- By involving other divisions within the NSF such as INT.
- By involving other government agencies whose participation is needed to solve global problems such as the DOE or NASA.
- By enlisting the support of industry. Since U.S. software, hardware and communications industries are dominant in many areas, they are well positioned to provide the resources needed to support international collaboration, and to capitalize on technological advances.

Infrastructure

International collaboration requires developing transnational facilities. Whether infrastructure is via Internet, Unix operating system, database or PC standards, its development is essential to successful research. New tools that enable international collaboration are needed.

International networking infrastructures are essential for both CISE research and international scientific collaboration. Efforts are needed to investigate and develop new classes of applications that explore these infrastructures. Examples of such applications include tele-immersion and virtual collaboratories.

Tele-immersion is defined as collaborative virtual reality over networks, an extension of the "human/computer interaction" paradigm to "human/computer/human collaboration." In this paradigm, the computer provides real-time data in shared, collaborative environments, to enable computational science and engineering researchers to interact with each other (the "tele-conferencing" paradigm) as well as their computational models, over distance. Current tele-immersion research focuses on providing easy access to integrated heterogeneous distributed computing environments, whether supercomputers, remote instrumentation, networks, or mass storage devices using advanced real-time 3D immersive interfaces (http://www.evl.uic.edu/EVL/RESEARCH/art_science.shtml).

Virtual collaboratories allow scientists to access and use tools in different geographical locations. The tools can be software for computer-aided simulation and modeling or actual computer-controllable instruments.The computer resources can be distributed and shared across many locations and so can the users. An example of such a system is PUNCH (Purdue University Network-Computing Hubs) which provides web-based access to the use of simulation tools for several CISE and engineering disciplines. It is the enabling infrastructure for the NSF-funded distributed center for advanced electronics simulations (DESCARTES) which includes the University of

Illinois-Urbana, Arizona State University, Stanford University and Purdue University. International distributed centers can make use of similar network-computing infrastructures. Similar systems can be develo ped for other disciplines. For example, the Web site at OGI provides a free set of tools and technologies for building and researching spoken language systems in different languages.

Conclusions

The potential benefits of international collaboration justify extraordinary efforts to produce new programs and initiatives, and to explore new models for collaboration and funding. Coordination of resources contributed by other countries and international organizations will have major impact on world problems.

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