NITRD Testimony
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Personal Introduction

Thank you Chairman Gordon and Ranking Member Hall for inviting me to testify before your committee on this important legislation. I am a Professor of Computer Science and Electrical Engineering at UCLA, and the founding Director of an NSF funded Science and Technology Center for Embedded Networked Sensing (CENS), established in 2002. I was educated at MIT and experienced my early career at USC supported by the Defense Advanced Research Projects Agency (DARPA) and the National Science Foundation (NSF). During the past decade I became involved in multidisciplinary work in an area that falls under the umbrella of Cyber Physical Systems. I also served on DARPA's Information Science and Technology Study Group (ISAT) and NSF's Computer and Information Science and Engineering (CISE) Advisory committees and currently sit on the National Research Council's Computer Science and Telecommunications Board (CSTB) and have participated in numerous studies over the years.

In the invitation to testify at today's hearing, Mr. Chairman, you asked whether I believe the legislation you have proposed will help ensure the Networking and Information Technology Research and Development program (NITRD) is positioned to help maintain U.S. leadership in networking and information technology. Having reviewed the legislation, I believe the bill addresses the key recommendations of the PCAST assessment, and in the process, addresses important needs of networking and Information technology research communities. I also believe that the focus on cyber-physical systems in the legislation will have an impact that extends into the country's commercial leadership, into the sciences, and into public policy.

In this testimony I will emphasize a few issues I think are key in responding to the questions you posed: cyber physical systems; the importance of experimental, purpose-driven research and opportunities for cross-agency projects; and the importance of multidisciplinary centers in realizing a research agenda and creating effective opportunities to attract and engage a more diverse student body in IT research.

The importance of NITRD and Cyber Physical Systems

The Computing Research Association's Computing Community Consortium hosted a symposium last week here on Capitol Hill, where an all-star cast of computer scientists reviewed the importance of information technology and how the advances that are now essential to science, government and citizens, are a direct result of federal support for research, particularly from NSF and DARPA. I was pleased to be invited to participate.

In my session on "Computing Everywhere," we focused in particular on how computing extends beyond the processing and sharing of knowledge encoded in text and numbers, to direct measurement, management, and manipulation of physical phenomena.

We often hear how miniaturization and Moore's law[1] has enabled the growth, proliferation and scaling of computational capabilities. Our computing power has become exponentially more powerful over time as our devices become smaller and more powerful. So the computer that once occupied the back room, then moved to the desktop, now fits in our pocket, or can be embedded in sensor rich devices.

These developments enable us to combine sensing, computation and wireless communication in integrated devices, that can be placed in situ, up close to physical phenomena. Whether embedded in:

- Engineered systems such as power grids and factory floor systems monitoring power consumption and indications of malfunctioning components
- Natural systems such as depleted forest and water resources, measuring physical (e.g., climate) and chemical (e.g., pollutants) parameters.
- Human systems such as devices worn on the human body monitoring activity and physiological indicators.

Across this wide array of applications, the ability to observe physical processes with such high spatial and temporal fidelity will allow us to create models, make predictions, and thereby manage our increasingly stressed physical world.

Cyber Physical Systems are created through a synthesis of technologies, including: embedded sensing systems, sensor-actuator control, mobile sensing, and human computer interfaces. All will be advanced by the proposed NITRD focus on Cyber Physical Systems research and **together** will bring us closer to the promise of revolutionary advances in our management of the physical world.

- **Embedded sensing** brings much needed understanding of processes and informs critical decisions. For example, the National Ecological Observatory Network (NEON) and Ocean Observing Initiative (OOI) MREFC projects are primarily embedded sensing systems in that they are comprised of in situ sensing systems which capture and transmit measurements into web-based data-management and geospatial-modeling systems, in real time. These powerful and programmable observing systems will employ a broad spectrum of sensor types (from the simplest temperature sensor, to highest resolution digital imagers), and will greatly promote understanding of ecosystem and ocean dynamics, and thus inform critical issues in resource management and land use policy. Similarly, in the context of observing systems for the built environment, transportation related embedded sensing systems, for example, are being installed along major roadways to capture real time traffic information and inform real-time driving patterns and longer term planning.
- When sensing is combined with **automated actuation** in tight control loops, we enter a new regime in which physical processes can be managed and manipulated

[1] Moore's Law is the projection that the number of transistors that can be placed on an integrated circuit will increase exponentially, doubling approximately every two years, that was first noted by Intel co-Founder Gordon Moore in 1965 and has held true to the present day.

at the timescale of the physical phenomena, not just at the timescale on which human beings are able and available to react. For example, biomedical systems can measure physiological parameters and based on the readings automatically adjust drug dosage (e.g. insulin pump) or system function (e.g. prosthetics). Similarly, systems that implement precise and localized management of water and power also can measure real-time inputs and demands on the system, and make adjustments to resource treatment or distribution in real time.

- **Mobile sensing** presents tremendous economies to cyber physical systems because by moving a sensor through an environment you can achieve high spatial resolution measurements that are not achievable with fixed sensors. Mobility takes multiple forms. Pan-tilt-zoom cameras are useful in both ecological and built-environment settings. Unmanned Arial Vehicles are emerging for practical use in surveying natural and urban settings. Vehicle-mounted sensors on public transportation vehicles, can capture data specific to traffic, but more generally can take advantage of the natural coverage that these vehicles provide to measure other parameters such as air quality. And finally, human-carried devices offer tremendous opportunity for individual and aggregate measurements related to human exposure and interaction. Mobility presents tremendous coverage benefits but does call for more sophisticated internal operation of the system.
- Most cyber physical systems are part of larger systems with **"humans in the loop,"** operating on human timescales. For example, all of the cyber physical applications described above require visualization of the observed data and physical system. They are designed to be used by human users as real time interactive systems to inform both short and long term decisions and actions. Moreover, in some cases, human assistance and augmentation is desired to contribute additional data feeds to the system that can not be fully automated (e.g., laboratory based analyses of manually-collected samples). Finally, the proximity of these systems to people raises the need to attend to privacy in their design, deployment and usage, which is another area in which research can contribute significantly.

In summary, Cyber physical systems cover a broad and important range of networking and information technologies and are essential to meeting the key challenges facing the nation, and the planet as a whole, including: the need for cleaner and more efficient manufacturing, transportation, and energy production and distribution; water treatment and conservation; personalized health management, treatment, and care; and preservation and recovery of key ecosystems and services. The proposed support for CPS in the NITRD legislation will greatly enhance our ability to address the design challenges of physically-coupled systems by supporting research in robust and reusable, scalable and validated components, algorithms, and integrated sub-systems to enable broad scale, powerful and programmable environmental observing systems.

Importance of Federally funded research to US leadership

Federally funded research is directly responsible for today's technologies and the technologies we'll deploy tomorrow. Indeed, the development of every major sub-sector of the IT industry bears the stamp of federally-supported research, usually research supported at U.S. universities In fact, perhaps the most important aspect of federally supported university-led research is that it generates both the ideas of tomorrow and the people necessary for turning those ideas into reality. These are the students and researchers who generate the ideas that will power the innovations of tomorrow.

One of the great success stories of federally funded research in information technology in my own research area has been the growth of entirely new sectors and phenomenally successful commercial companies in support of the use of computing everywhere. These are companies like Apple that has revolutionized the design of personal technologies, and Nokia that has proliferated sophisticated mobile technology around the world at such a rate that now there are over 3 Billion cell phones and Nokia sold devices at the rate of 16 million per quarter in 2008. At the same time, the existence of this strong commercial sector has not lessened the need for federally funded research dollars. While these companies are spending, in some cases, considerable dollars investing in research and development, that investment is almost always focused on reasonably short-range development efforts – generally the next product cycle or two. Federal support, particularly at U.S. universities, is essential for the long-range research necessary to advance the field and enabling the game-changing technologies of the next 10 – 20 years.

Even if, and that's a big if, commercial investment in R&D was high enough to maintain a healthy flow of new, long and mid term technology innovation, the role of federal dollars would still be essential. One of the reasons it is so essential to maintain a healthy investment in publicly funded technology research is so that issues of public good, which can not always be the primary drivers in a commercial enterprise, can shape our technology; not to prevent commercialization and private investment, but rather to promote it in a form that addresses externalities such as open interfaces and privacy preserving architectures. Moreover, innovation can be focused in areas that don't yet have established revenue streams or business models, such as aspects of ecosystems science, for example.

This research ecosystem I've described -- the interplay between federal support for university research and commercial research and development efforts -- has been, as the National Research Council declared back in 1995, "extraordinarily productive." But in order to keep it as productive as possible, it's important to keep it as finely tuned as possible. . Balanced ecosystems are essential in nature, in our diets, in our financial portfolios, and in our research. Currently our research ecosystem is lacking balance on both ends of the research time horizon. On the one hand there is a need for more basic research that explores foundational algorithmic capabilities. On the other hand, there is also a need for bold, experimental, purpose-driven research with discovery that comes from synthesis, problem solving and use. Space missions and the Internet are both excellent examples of the latter approach. And much of the work funded under NSF's highly successful Information Technology Research (ITR) program, which ran from 2000 to 2004, had this latter quality.

While there is a need for far out, theoretical work that disconnects from constraints – indeed, the PCAST assessment concluded that the portfolio is currently imbalanced in favor of low-risk projects and that too many are small-scale and short-term efforts -- there is also a need for work that explores applying what is possible now but on a grand scale and to grand problems. Such projects lead researchers to uncover the "interconnection between the pieces" – and not just between technologies, but between technology and people, and in the case of Cyber Physical Systems between technology and nature as well! This research offers further value added relative to commercial R&D when it serves non-monetized applications such as environmental monitoring and public health, thereby creative innovative technologies for the under-served markets, while providing the technologists with the integrative experience they can only get when their technology or system is deployed and used

The role of multidisciplinary research centers

Multidisciplinary research centers offer scope, as well as scale, i.e,. extended timelines in addition to increased funding levels. Multidisciplinary research, by definition, requires that you have more people at the table, and also produces its most important results when there is enough time for the collaboration to iterate and thereby expand on its own findings. In my research center, CENS, the most important results have been iterative: where we began by applying existing technology in an innovative manner to the application scientist's observational science problem, and based on the resulting experience identified the most important areas for the next phase of innovation. Two key innovations from the center came about in this way--the use of mobile sensing to achieve high spatial resolution, and the development of smart cameras as "biological" sensors for flora and fauna. It was only by engaging in this collaborative iterative process between the application scientists and technologists that these innovative solutions emerged. This style of work has great potential for serendipitous results where you end up in places you did not expect, having learned tremendously more. Through this we have discovered other new opportunities for addressing pressing problems--for example, using the mobile phone as an instrument for personal and participatory sensing, e..g, for congestion-based pricing on highways, personalized and precise management of medication, and individualized behavior shaping to combat avoidable health care burdens such as obesity.

Education opportunities also flourish in centers. At CENS we developed a hands-on research experience for undergraduates and high school students interested in the application of information technologies to environmental and urban sensing. We have had tremendous success with the program. It has been a source of innovation within the research agenda, and has produced excellent students, many of whom decided as a result to continue their studies in graduate school, and who are demographically more diverse than the equivalent populations in their local engineering schools. However, we also learned that these programs scale up better than they scale down. With a core of coordinated programming and staffing you can support a wide range of projects and students. However if you support only a few students, we found that they do not get the same structured social setting for their research, without generally unsustainable Inputs from the supervising faculty and graduate students.

We have also found consistently that the nature of these applications attracts a relatively diverse student population--perhaps because the social utility is very self evident and is explicitly a part of the design discussions. We speculated that this social utility would end up appealing and attracting more women and we were not disappointed--our CENS averages for women students are consistently double that of the rest of the school.

Finally, multidisciplinary research centers in pursuit of cyber physical systems and applications could contribute greatly to collaborative agency programs where a technology creation agency could partner with a mission agency to help bridge the gap between funding of the basic ideas and early prototypes, and systems that can actually be used and run through trials and exploration before commercialization:

- A good example of this would be a large scale, ~million-person, mobile-sensing system that supports preventative and chronic health management and research. Today's mobile phones can easily report activity, location, and prompted user input (e.g., pain, emotional state, and other self-reports). Such a project, coordinated between the NSF and the mission oriented needs of NIH and CDC, could prototype and pilot a privacy-preserving, population-scale system that would drive innovation in privacy and security of electronic health records, data analysis and fusion, and human computer interaction, while also providing unprecedented data-sets for public health and epidemiological studies.

Another example opportunity would be for multiple user agencies with overlapping needs to launch development of an innovative sensor type that is not being brought to market because revenue streams are not large enough to justify the capital investment by commercial enterprise.

- Development of specific sensors for environmental monitoring is a good example. There is not a large enough commercial market to drive development and production of miniaturized, high precision, nitrate sensors for example which are critical to both ground water testing systems, coastal margin ecosystem health, and terrestrial ecosystem carbon cycle characterization. In this case, a coordinated effort between the NSF and the mission-oriented needs of EPA, USGS, NOAA, USDA to develop and produce such a sensor could have significant long-term ecological benefit to the country.

Conclusion

I was pleased to see the inclusion of cyber physical systems as an area of emphasis in the PCAST assessment of 2007 and I'm pleased to see its inclusion in the NITRD legislation under discussion today. As I noted above, cyber physical systems cover a broad and important range of networking and information technologies and will be essential in meeting some of the key environmental, economic, and quality of life challenges facing our nation and the world. A broadly focused cyber physical systems research program in NITRD, balanced between fundamental and applied efforts and leveraging university, agency, and corporate research and development efforts will go a long way towards ensuring that the United States continues to hold a leadership position in this critical field.

Thank you, Mr. Chairman, for the opportunity to provide my testimony on this important issue. I am pleased to answer any further questions you might have as you and your colleagues on the committee move this legislation forward.