Dear Madam/Sir:

It is a pleasure to share my thoughts on the Five-Year Strategic Plan for the Federal NITRD Program as per your Request for Input of June 30. Let me introduce some of my views by an excerpt from the abstract to a presentation of mine entitled “Engineering cyber-physical systems: a strategic outlook”.

Computation has established itself as the technology of choice to implement system functionality of otherwise unattainable capabilities. The exponential increase in computational power, however, has outpaced advances in design approaches. To bridge this productivity gap, the level of abstraction in design must be raised by exploiting automation. Where automatic code generation has made great strides for Von Neumann architectures, it has yet to scale the concurrency, and, moreover, heterogeneity of emerging electronics platforms necessary to keep pace with Moore’s Law. In other developments, heterogeneous platforms are coming about because of the increasing demand for networked low power mobile devices as well as high-power manipulation such as increasingly autonomous robots. All this is giving rise to a new breed of *cyber-physical systems*, systems that integrate physical with computation and network capabilities.

Our society is quickly and increasingly relying on cyber-physical systems for its technological needs. Six general drivers for networked information systems in general and cyber-physical systems in particular can be identified:

(i) the need to reduce *power* consumption and to provide high power density to implement functionality;

(ii) the rise of *heterogeneity* in computation, in systems, and in design methods;

(iii) the increasing exploitation of *computation* in scientific discovery, in (automated) design, and in product differentiation;

(iv) the omnipresence of *communication* connecting everybody and everything;

(v) the conversion and extension of information terminals to devices for *physical interaction* such as sensors, actuators, and manipulators;

(vi) the emerging sense of *autonomy*, especially in consumer and defense products.

Examples of future systems that rely on these drivers are no-charge mobile devices, smart infrastructure (e.g., power grid and transportation), cyber government, and automated domestic help and health care (where automated could be teleoperated as a stop-gap towards truly autonomous machines). These future systems will be self-adaptive in order to support, for example, self-reconfiguration, self-healing, and self-(re)design. Research challenges to successfully produce such systems can be identified as shown in Table 1. These areas are invariably of a multi-disciplinary nature, involving Computer Science, Electrical Engineering, and Mechanical Engineering at the core with some profound psychological, ethical, and social elements involved. As Table 1 conveys, many different areas within each of these disciplines are involved.

To address the agenda in Table 1, the NITRD Program should provide a strategic framework that outlines the key research challenges. Expertise in the respective areas can then be developed in academic institutes and amalgamated into a selection of comprehensive demonstrator programs. Early multi-disciplinary and cross-institute collaboration should be encouraged.

Table 1: Cyber-physical systems research and development agenda		
Area	**Research Goals**	**Technical Agenda**
Control	• Computation and communication in control	• Technology to represent implementation effects
	• Collaborative control methods	• Mixed-initiative control technology
	• Self-adaptive control theory	• High confidence control synthesis
Mechatronics	• 10 times increase in power density	• Integrative system technology
	• Fail-safe and reliable mobile machines	• Mixed-signal computational technologies
	• Machine form factor and dexterity on par with humans	• Methods for approximate performance
Machine intelligence	• • • Modalities for human/machine interaction Certifiable learning and programming Robust operation in open environments	• • • Symbol extraction from massive correlated data sets Situational awareness and ambient intelligence Rigorous testing and verification technology
Design automation	• • • Theory and methodology for multi-view, multi-abstraction models Novel design languages for heterogeneity Eliminate system integration pain	• • • • Performance estimation technologies Model relation and transformation technology Technologies for semantic definition Component and platform based system design
Network	• Secure and trusted connections	• Secure transmission and authentication
	• • Always available Mixed protocol systems	• • technologies Technologies for safe co-protocol design Technologies for data intensive applications

NITRD should inventory and streamline the vested interest of all stakeholder agencies. In particular, with regards to cyber-physical systems, DARPA, NSF, and NASA have direct interests. Less pronounced is the relation with NIH research, where automated health care is a prime consideration.

Furthermore, NITRD could attempt to help start, for example, a series of workshops of a specific multi-disciplinary nature to provide acclaim within the academic merit system. In addition, an infrastructure to support an ecosystem of computational models could be an effective approach to increase the utility of computation in cyber-physical system design. This could be chartered under NIST. Farther removed could be exploiting multi-view modeling for weather forecast as a NOAA responsibility. Finally, overlapping activity at the Department of Homeland Security, such as the efforts on securing our critical infrastructure, may be identified.

The commercial sector should help provide the means for the academic programs, including realistic scenarios, data sets, and problems to enforce the multi-disciplinary character that cyber-physical systems inherently impose. Furthermore, internships should be actively installed as a means to transfer technology.

Strategically selected contacts should be established with international programs, which is best done at the academic and research institute level. For example, collaboration on architecture and performance research with European institutes and robotic research with Japanese and Korean institutes could be valuable. This will allow the U.S. to play the role of integrator and to define general-purpose approaches of a comprehensive nature.

If you wish to discuss the matter presented here in more detailed, I very much look forward to your comments, questions, or suggestions. I hope to have provided some valuable feedback.