

Cyber-Physical Systems: A National Priority for Federal Investment in Infrastructure and Competitiveness

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Version 8: December 22, 2008¹

The roaring economy of the 1990s was enabled in large part by information and communication technologies. A catalyst of similar magnitude with a correspondingly significant return on investment is needed to unleash the next wave of innovation and entrepreneurship. Advances in Cyber-Physical Systems (CPS) promise to do just that.

Cyber-physical systems will transform how we interact with the physical world just as the Internet transformed how we interact with one another. They promise us autonomous cars; robots at work, at play and at home; intelligent, energy-efficient, earthquake-proof homes and civil infrastructure; embedded medical devices; unobtrusive assistive technologies; and more. At the heart of these applications are computational cores that interact with the physical world, with intelligence provided by software. By deeply embedding computational intelligence, communication, control, and new mechanisms for sensing and actuation, CPS transform our world with systems that respond more quickly (e.g., autonomous collision avoidance), are more precise (e.g., robotic surgery and nano-tolerance manufacturing), work in dangerous or inaccessible environments (e.g., autonomous systems for search and rescue, firefighting, and exploration), provide large-scale, distributed coordination (e.g., automated traffic control), are highly efficient (e.g., zero net energy buildings), augment human capabilities (e.g., assistive technologies), and enhance societal well-being (e.g., ubiquitous healthcare monitoring and delivery).

These new capabilities require significantly more than inserting information and communication technologies into traditional industries. The inevitable ubiquity of CPS demands that we provide individuals and society with CPS that they can *bet their lives on*. Progress requires nothing less than the reintegration of the physical and information sciences – the construction of a new systems science and technology foundation for CPS, which is simultaneously physical and computational.

What are the Opportunities?

Cyber-Physical Systems are rapidly penetrating every aspect of our lives, with potential impact on sectors critical to U.S. security and competitiveness, including aerospace, automotive, chemical production, civil infrastructure, energy, finance, healthcare, manufacturing, materials, and transportation².

¹ For the most current version of this essay, as well as related essays, visit <http://www.cra.org/ccc/initiatives>

² Jeannette M. Wing, Associate Director for CISE, National Science Foundation. "Cyber-Physical Systems." *Computing Research News* 21,1 (January 2009). <http://lazowska.cs.washington.edu/initiatives/WingCRN.pdf>

- **Transportation:** By 2015, as much as 40% of an automobile's value will be in cyber-physical components (electronics, sensors and actuators, and embedded software). The aerospace sector, too, is heavily dependent on cyber-physical components and comprises a significant portion of US exports.
- **Energy:** Buildings are responsible for almost 50% of the energy consumed in the United States for purposes such as heating, cooling and lighting. Even a modest 20% improvement in efficiency through the use of smart environment-aware technologies that minimize energy consumption while maintaining human comfort will yield enormous benefits.
- **Medicine and healthcare:** CPS innovations will revolutionize medicine and healthcare, which currently comprise 17% of the US economy (expected to grow to 20% by 2020). Robotic surgery, for example, promises surgery more precise than that provided by a human and is not prone to fatigue.
- **Smart civilian infrastructure:** Newly planned civilian infrastructures can and should be made smarter with CPS technology. These smart infrastructures can continually monitor their status without human intervention and notify maintenance personnel of potential problems before they can lead to failures damaging lives and/or property.
- **Defense:** Superiority of US military systems is predicated on superiority in CPS technologies. Network centricity, unmanned platforms, predictive human-centric C2, and distributed, time critical missions drive progress toward increasingly complex, open system-of-system architectures.

CPS has extraordinary significance for the future of the U.S. industry. Falling behind in the foundations of CPS may render our scientific and technological infrastructure obsolete, leading to rapid loss in our competitiveness in major industrial segments. A 2007 report of the President's Council of Advisors on Science and Technology³ highlights CPS as the #1 priority for federal investments in networking and information technology. The European Union has launched the ARTEMIS (Advanced Research & Technology for EMbedded Intelligence & Systems) program, investing over \$7 billion in 2007 dollars in the embedded systems aspect of CPS research. *America must have a national strategy in which CPS technology needs are addressed by combined government and corporate investment*⁴.

Why Do We Need a Multi-Agency Initiative?

Advancing CPS science and technology must be a national priority with a wide range of stakeholders in academia, industry and federal agencies. The effectiveness of the federal investment requires coordination across multiple agencies and a new collaboration framework for academic and industry research that facilitates interaction and improves transitioning of new

³ <http://www.nitrd.gov/pcast/reports/PCAST-NIT-FINAL.pdf>.

⁴ Don C. Winter, Vice President, Engineering & Information Technology, Boeing Phantom Works. Statement before a Hearing on the NITRD Program, Committee on Science and Technology, U.S. House of Representatives, July 2008. <http://lazowska.cs.washington.edu/initiatives/Winter.pdf>

research results into applications. Federal agencies must initiate research programs in CPS of various horizons in areas that are aligned with agency responsibilities:

- **NSF:** Development of new systems science and engineering foundations for CPS. Creating a university-industry-government consortium to accelerate the transition of research outcomes into products and services that in turn stimulate economic growth. *\$75 million per year.*
- **DOD/DARPA:** Design and integration of technologies, tools, testbeds and experimental platforms for heterogeneous, networked CPS that are resilient against kinetic and cyber attacks. *\$100 million per year.*
- **DOE:** CPS technologies for energy conservation, clean energy production and distribution. *\$50 million per year.*
- **NASA:** Design of technologies and platforms for high-confidence, certifiable CPS. *\$20 million per year.*
- **HSARPA:** High assurance CPS technologies for smart infrastructure. *\$30 million per year.*
- **NIST:** Standards for CPS product platforms. *\$20 million per year.*
- **NSA:** Integrated information and physical system assurance. *\$30 million per year.*
- **NIH:** High-confidence and secure medical devices, evidence-based care with automated, patient-specific alerts. *\$50 million per year.*

The proposed investment of \$375 million per year, representing approximately 10% of the current Federal NITRD budget, will be complemented with corporate investment that will bring the total to significantly more than \$500 million per year. This investment will allow the United States to:

- create new industries unimagined today,
- create hundreds of thousands of high-end jobs,
- establish and extend global technology leadership in vital economic sectors,
- provide technological solutions to reduce the impending stress on the medical system due to aging baby boomers,
- improve safety and lower long-term operational costs of our civilian infrastructure, and
- provide faster transitioning to clean energy infrastructure.

What Can We Do in the Short Term?

As part of the stimulus package the following investments would create major impact in both the short and long terms:

- **Sensor rich transportation infrastructure.** As part of the infrastructure modernization program, roads and bridges should be instrumented with wireless networked CPS sensors for structural health monitoring and traffic monitoring, thereby providing a foundation for *smart infrastructure* development. This would be significantly less expensive than retrofitting, and the technology is known and available. *Cost: 0.1% of the infrastructure investment.*
- **USCAR demonstration program.** USCAR is a collaborative research platform for the U.S. automotive companies to create, support and direct U.S. cooperative research and development to advance automotive technologies. Investment in USCAR for establishing a Plug-in Hybrid Vehicle and Fuel Cell Vehicle demonstration program including a richly instrumented vehicle fleet and charging stations is a high-payoff investment in the very short term but also for the longer term recovery of the automotive industry. *Cost: \$50 million.*