Industry – Academy Collaboration

in

Cyber Physical Systems (CPS) Research

White Paper

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This White Paper is based on the results of the CCC Workshop on
New Forms of Industry – Academy Partnership in CPS Research
Held At
George Mason University, VA
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FORWARD

This White Paper summarizes the discussions and conclusions of the CCC supported Workshop on New Forms of Industry – Academy Partnership in CPS Research, which was held at George Mason University on May 19, 2009.

CPS has extraordinary significance for the future of the U.S. industry. There is much more at stake than just extending our leadership in networking and information technology to an exploding new market segment. 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 including automotive, aerospace, defense, energy, health/medical equipment, and critical infrastructure. Advancements in CPS science and technology are a national priority[1] with a wide range of stakeholders in academia, industry and federal agencies. Effectiveness of Federal investment and urgency of achieving impact require coordinated investment across agencies and a new collaboration framework for academic and industry research that facilitates interaction and dramatically improves transition of new research results into applications.

The primary goal for the workshop was to explore the dichotomy between the strong motivation of both industry and academia to conduct joint research in CPS and the challenge of making the collaborative efforts effective. The workshop provided a forum for scientists and engineers from industry and academy to discuss desired characteristics of industry-academy partnerships that make the required close integration of research activities feasible.

Workshop Organization

The members of the Organizing Committee are:

Janos Sztipanovits, Vanderbilt University	*Don C. Winter, Boeing*
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John Baras, University of Maryland	David E. Corman, Boeing
Janos Gertler, George Mason University	Marija Iljic, Carnegie Mellon University
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The workshop was hosted by the Electrical and Computer Engineering (ECE) Department of the Volgenau School of Information Technology and Engineering, George Mason University. The Workshop Report including the list of participants and agenda is accessible through the workshop web site[2]. See also http://varma.ece.cmu.edu/cps/ for general information about CPS.

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[1] Leadership Under Challenge: Information Technology R&D in a Competitive World – An Assessment of the Federal Networking and Information Technology R&D Program, PCAST.

[2] http://cps.isis.vanderbilt.edu/

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Executive Summary

Cyber Physical Systems (CPS) are *engineered systems* comprising interacting physical and computational components. The technology is pervasive, transcends industrial sectors and serves as the engine of innovation for new generation of products. CPS is disruptive technology that transforms established industries, creates new ones and rearranges the status quo in entire industrial sectors. Current industrial experience tells us that we have reached the limits of our knowledge of how to integrate computers and physical systems. The shortcomings range from technical limitations in the foundations of cyber-physical systems to the way we educate engineers and scientists that support cyber-physical system design. Over the past three years industry and university communities have collaborated extensively and developed a broad, comprehensive agenda of pre-competitive research as a foundation for a National CPS Initiative.

This White Paper presents recommendations for the creation and structure of a National CPS Initiative in science and technology integration, governance and operation. These recommendations are the results of an extended exchange of ideas between industry and academic communities over the last three years. Key ideas were summarized at the CCC supported Workshop on New Forms of Industry – Academy Partnership in CPS Research on May 19, 2009.

Recommendation 1: Establish a National CPS Initiative as a private-public partnership. A unique aspect of CPS is that results are so immediately relevant to near-term industry products that industry wants to participate in pre-competitive research. Therefore, industry is instrumental in both executing and guiding the program directed to establish new scientific foundations. Current and past industry investments in CPS technology research have been significant but focused on shorter term, quicker payoff proprietary technologies with smaller amounts dedicated to longer term, pre-competitive domains. While these investments have considerable future potential, they are fragmented across sectors and critical mass is lacking at a corporate level. The proposed recommendation offers the opportunity to aggregate these pre-competitive funds and gain substantial leverage through Government investment. This is an important and powerful incentive for achieving best of industry participation and goes a long way to ensuring that real breakthrough success can be achieved and transitioned.

Recommendation 2: Structure the Initiative around industry defined Integrative Technology programs. Integrative technologies, such as high-confidence CPS design, are novel combination of innovations from several scientific disciplines. Integrative Technology programs will be the incubators for a new CPS discipline. The programs are executed in (virtual) centers where industry and university researchers work side-by-side on joint projects. The projects are challenge-driven, and supported by open experiment platforms and industrial-strength testbeds. The CPS centers are becoming focal points of precompetitive CPS research and education, where challenge problems are mapped into scientific foundations and solutions emerge from the synthesis of multiple disciplines. The individual government-industry funded research centers are designed for sustained collaboration spanning 5-10 years.

Recommendation 3: Establish an annual CPS Research Forum. The CPS research centers are self-managed, larger collaborative activities led by industry or universities. The loose network of collaborative research programs support an open annual CPS Research Forum that informs stakeholders about emerging industry needs for specific integrative technologies, established testbeds, achieved technology breakthroughs, progress in foundations, and national

and international trends. The Forum is coordinated and organized by an Industry – Academy Steering Group under the aegis of relevant professional societies and industry associations.

Recommendation 4: Develop a National CPS Research Infrastructure. The CPS Research Infrastructure facilitates the transition of results among academy and industry research group. Core components if the infrastructure includes open, quality controlled repositories for challenge problems, tools and software, open experimental platforms, collaboration platforms and education materials that are accessible through a web portal. The Infrastructure facilitates experimental validation of results in different application contexts, broad dissemination of generated research artifacts and collection of experience with new approaches.

Introduction

Since the end of World War II, US universities have had a unique responsibility and societal obligation to create and operate a crucial part of the national R&D enterprise. Vannevar Bush, science advisor to President Roosevelt, published a landmark report[3] in July, 1945, that became the foundation of a "social contract" between the federal government and academia. The essence of this arrangement is that the federal government assumes responsibility for funding pre-competitive research in science and engineering in the interest of society, and academia will use these funds for generating and developing ideas while preparing future generations of scientists and engineers in graduate programs.

This arrangement has been tremendously successful and has made U.S. universities and the model itself the envy of the world. Without exception, the greatest universities in the US are research universities that fulfill a major part of their societal role through participation in the national research enterprise. These universities have become centers of research and innovation, have spun out industries, and have transformed the economy of whole regions while contributed to forming US science and technology policy. Since open, national competition for research funding is an essential part of the US model, the extent to which a university participates in and contributes to the national research enterprise has become widely accepted measure of academic excellence among the peer institutions and in the society in general.

The result has also made huge impact on the U.S. industry as well. Research in the late nineties has clearly identified the close correlation between increase in university-based research and follow-on increase in industry R&D. At the end of the last decade, President Clinton's Council of Economic Advisers found that about 50% of the growth in the economy is due to R&D investment- both in industry and academia. Additionally, the policy stimulated linkages between universities and industry, and established a unique attitude that universities should be responsive and deeply involved in solving societal problems ranging from health care to national security to industrial competitiveness.

However, the success and effectiveness of the model where basic research is performed in federally funded universities and applied research and development is the responsibility of the private sector is contingent upon the validity of the following assumptions:

- the science and technology area allows the meaningful separation of basic research from applied research and development both in objectives and in time,
- federal investment and regulatory policies keep pace with the growth and changing priorities of national R&D, and
- well-defined and adaptive collaboration forms exist and are able to couple the various players in the R&D enterprise (industry, government, and academia).

A recent report[4] prepared by the President's Council of Advisors on Science and Technology (PCAST) made a comprehensive analysis of the U.S. R&D enterprise. It identified the main challenges and barriers for university-private sector partnership and made recommendations to rectify the problems. This White Paper is built on the general findings and recommendations of

[3] Vannevar Bush: "Science: The Endless Frontier" http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm

[4] University-Private Sector Research Partnership in the Innovation Ecosystem, Report of the President's Council of Advisors on Science and Technology (PCAST), November 2008

the PCAST report supplemented with recommendations specific to the challenges in the area of Cyber Physical Systems.

Drivers of Industry-Academy Partnership in CPS Research

Cyber Physical Systems are *engineered systems* constructed as networked interaction of physical and computational components. In CPS, computations and communication are deeply embedded in and interacting with physical processes add new capabilities to physical systems. Competitive pressure and societal needs drive industry to design and deploy airplanes and cars that are more energy efficient and safe, medical devices and systems that are more dependable, defense systems that are more autonomous and secure. Whole industrial sectors are transformed by new product lines that are CPS-based[5].

Modern CPSs are not simply the connection of two different kinds of components engineered by means of distinct design technology, but rather, a new system category that is both physical and computational. Current industrial experience tells us that, in fact, we have reached the limits of our knowledge of how to combine computers and physical systems. The shortcomings range from technical limitations in the foundations of cyber-physical systems to the way we organize our industries and educate engineers and scientists that support cyber-physical system design. If we continue to build systems using our very limited methods and tools but lack the science and technology foundations, we will create significant risks, produce failures and lead to loss of market.

Based on these observations, what is unique about industry-academy partnership in this field?

- Artifacts to be investigated by CPS science are engineered heterogeneous systems - typically produced by industry. The challenges, such as lack of compositionality, lack of predictability of essential properties, lack of acceptable design automation tools, are experienced by industry while developing and operating real-life CPS. Access to credible challenge problems, experimental platforms, roadmaps to future challenges, and industry domain experts is mandatory for defining research agendas that actually answer real problems.
- The missing scientific foundation for CPS cuts across virtually all frontiers of engineered systems, therefore investment into core CPS research is highly leveraged. This gives industry strong incentives to contribute to the development of a solid, precompetitive science and technology base.
- Government funded CPS research at universities has exceptional chance for high impact and large return on investment. The rapid gain in industrial competitiveness and productivity makes measuring and assessing the results of innovation feasible. Among other factors, this can help improve accountability and shift the current publication based evaluation metrics of university researchers to more meaningful impact-based evaluations.
- CPS foundations will cut across established scientific disciplines. There is a need for strong application pull, exciting new challenges and chance for real impact to overcome the natural inertia of discipline oriented research.
- Industry-academy collaboration is also precondition for fully leveraging the significant investment in basic sciences because industrial testbeds have a primary role in converting research results into competitive advantage.

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[5] 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

In summary, because CPS represents a new generation of engineered systems, it requires the establishment of a new type of relationship between industry and academic research. Basic research in CPS needs to be performed in the context of real engineered systems – typically conceived, built and deployed by industry. The nature of CPS research requires reinterpreting the usually accepted differences between basic and applied research. The primary separation is in the generality of the results and not in the time of impact. The usual model of scientific discovery followed by eventual practical application is less prevalent because discoveries will occur while solving challenges of high and immediate practical value. This fact does not change the need for long term commitment in developing and exploiting full benefits of the research because general tools cannot be validated and applied without deep domain knowledge. A further unique challenge is that CPS does not belong to any discipline or application domain: it drives the appearance of new domains and requires establishment of new discipline. In fact, CPS as interdisciplinary research is only the initial step. Ultimately, synthesis of technologies is what expected to lead to impact.

Barriers

While the motivation, pressures and potential rewards to conduct CPS research in industry-academy partnership framework are compelling, there are substantial barriers that have their roots in the different tradition and roles industry and universities play in the national research enterprise. Since partnership models need to overcome or avoid these barriers, we list here those that were discussed with the strongest emphasis at the Workshop and have impact on the creating a viable collaboration framework.

Industry Barriers

CPS is a disruptive technology that transforms established industries, creates new ones and rearranges the status quo in entire industrial sectors. It is not surprising that the list below is long and characteristic to most established industrial domains that are under intense competitive pressure while going through a technology change.

- CPS transforms established industries (both cyber and physical) with a still dominant "legacy thinking". Most people have no idea about the fundamental problems and see only their symptoms in terms of lost competitiveness.
- Economic necessities and even Government acquisition policies force industry to be second adapters of innovation. The development of CPS foundations, the adoption of new tools and processes involves cost and risk. Industry frequently chooses to take a conservative position and wait for proof of impact from someone else.
- Technology needs to be well matured before it is introduced in product lines. While this attitude is prudent, it does not work well in CPS. Many examples show that when building new generation of CPS products with mature technology infrastructure frequently fails because the established tools and methods just do not work in solving the new challenges.
- Lack of internal R&D funding. The result of legacy thinking is that CPS is not considered to be "core business" either in current physical systems industries or in IT industries. Consequently, the current approaches are fragmented, inconsistent and insufficient. The general hope is that perhaps someone else will provide solutions to fundamental problems.

- Mismatched expectations are rampant. This is usually the consequence of the lack of understanding of the depth and breadth of the problems industry faces.
- Rush to buy down risk by early standardization. The unintended consequence is stifled progress and tremendous waste in resources and time.

Academic Barriers

Similarly, CPS challenges the academic status quo as well. The dominant academic research attitude emphasizes the preeminence of curiosity driven basic research that is indifferent to applications and considers industry generated challenges with suspicion as being far too applied and short term.

- No home for CPS in academia. Established disciplinary boundaries do not mix well with the crosscutting nature of CPS. This introduces challenges in many aspects of the academic research enterprise: tenure and promotion committees, education programs, peer reviews of proposals and papers, structure of conferences and academic forums, and many others.
- Education infrastructure does not support CPS. Progress in CPS education requires understanding of the field by university leadership, willing academics to develop and offer courses, and availability of laboratory infrastructure and tools.
- No suitable set of abstractions that can bootstrap academic research. As a developing science and engineering field, CPS needs to develop established abstractions that can structure and guide academic research.
- In many industries with established best practices academics are marginalized. This creates unique problems in areas where progress has been relatively slow for long periods and where CPS is in the way of drastically changing the field (e.g., the energy industry).
- Little or no incentive to mature or transition products that are usable. The opportunity and need for rapid impact and the close, ongoing interaction between university and industry researchers require the acceptance of a new standard for the quality of outcome of university research products (methods, tools, prototypes).
- No incentive to study and understand industry generated problems. Understanding industry generated problems requires time and resource investment for understanding the domain and abstracting and generalizing CPS challenges that matter. It is typically easier to invent challenges that fit to a category of solutions than finding solutions to existing challenges.

Barriers in Effective Industry-Academy Interaction

There are several barriers that are not specific to industry or academy, but are linked to their relationships and inherent differences.

- Disconnect between funding mechanisms for theory and applications. Federal funding for basic research and applied research is executed by different agencies under strongly different appropriation and acquisition policies. Technically effective integration of basic research with applied research programs requires innovative solutions in multi-agency oversight and program management.
- Research funding does not adequately encourage (or reward) truly meaningful industrial and academic collaboration.

- Basic research is time – driven (the only thing guaranteed is that the research will be conducted for a given period, but not the breakthroughs), while industry challenges are linked to events and deadlines. Synchronizing these two different models is not easy.
- Crossover between industry and academic careers is limited. There are no common mechanisms at universities that would provide extended (1-2 year) leaves for professors to work in industry, (similar to IAP positions taken at NSF or DARPA) and similarly, there are no common mechanisms for industry to take temporary full-time positions in academia.
- Strongly different and convoluted IP strategies. IP positions and related incentives at universities are varying across disciplines and institutions. It is essential that collaboration frameworks offer simple and manageable solutions for harmonizing interests.
- There are only a few industrial chairs at universities endowed by major corporations, where industrial experience rather than publications record is the main selection criterion.

While the barriers listed above are real and represent formidable challenges to overcome, there are several examples driven by specific needs to close the gap between industry and academic research that have produced solutions that worked. The PCAST report[6] includes a detailed overview of a variety of existing collaboration frameworks. In the followings we will refer to some of these constructs, especially to those that were discussed at the Workshop.

Recommendations for a National CPS Research Initiative

The unique aspect of CPS is that industry needs to play and is willing to play a major role both in funding and executing the program. Accordingly, a national strategy is required in which long-term CPS technology needs are achieved by combined Government and Corporate investment. The aggregate funding level (Government and Industrial) ensures that the each organization receives substantial leverage. This is an important and powerful incentive for achieving the best of industry participation.

The size of the proposed investment (see Appendix B) is $375 million per year, representing approximately 10% of the current Federal NITRD budget. This will be complemented with corporate investment that will bring the total significantly above $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, and
- improve safety and lower long-term operational costs of our civilian infrastructure, and provide faster transitioning to clean energy infrastructure.

Discussions at the Workshop led to a number of specific points that we see as important considerations while developing the details of a framework for Industry-Academy collaboration in the CPS Initiative. We group our recommendations in three key aspects of the framework: Science and Technology Integration, Governance and Operation.

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[6] University-Private Sector Research Partnership in the Innovation Ecosystem, Report of the President's Council of Advisors on Science and Technology (PCAST), November 2008.

Science and Technology Integration

In CPS, challenge problems are defined across several engineering domains and new scientific foundations are expected to be developed as the synthesis of several disciplines. This makes the S&T integration aspect an essential component of the collaboration framework.

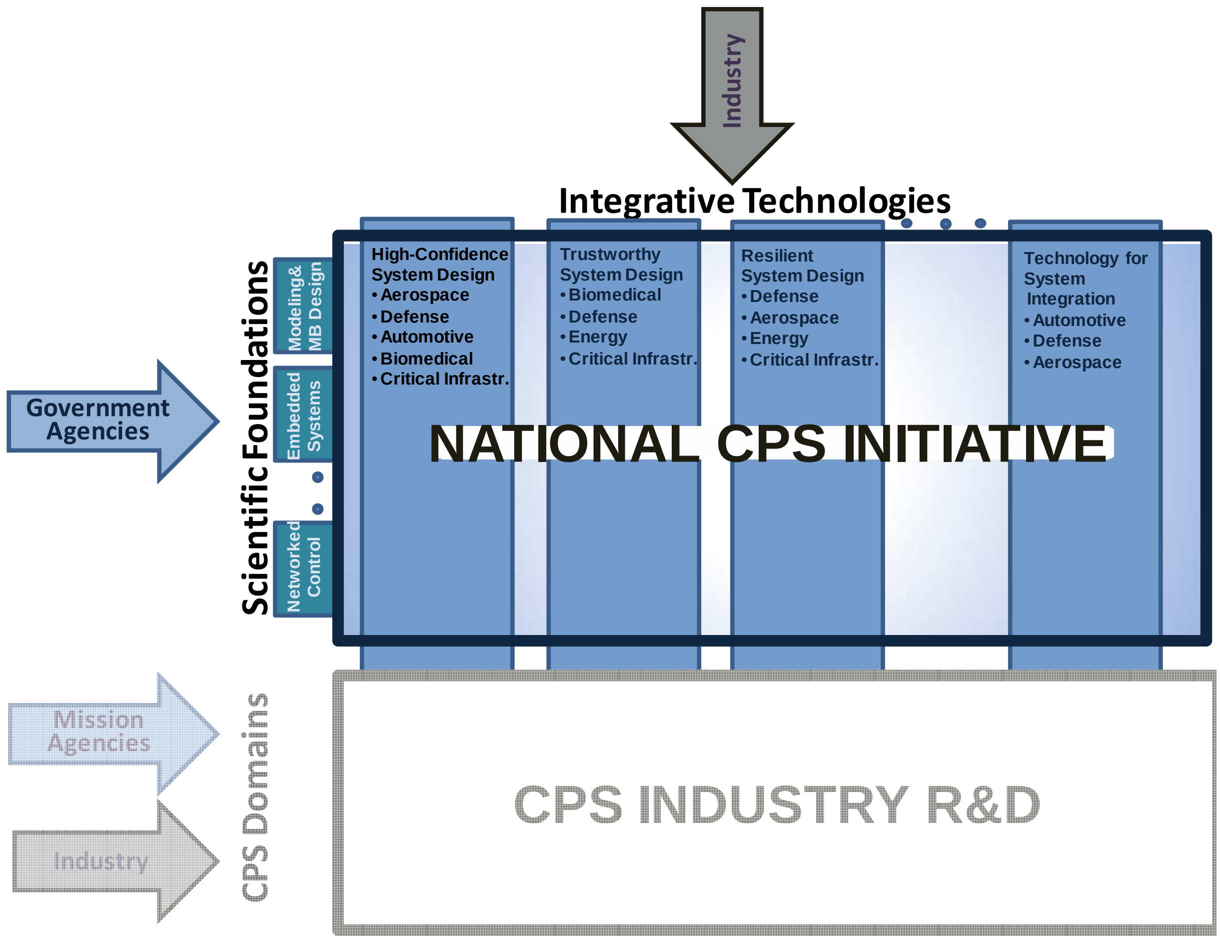

Figure 1: CPS Initiative is structured around industry defined Integrative Technology programs

There are highly successful examples for research program organizations that answer this challenge at least partially. Effective integration of different fundamental science disciplines is one of the primary goals of the NSF Integrative Activities (OIA) programs (e.g., NSF Science and Technology Centers), and the Engineering Research Centers (ERC). The Army Research Lab (ARL) Collaborative Technology Alliance (CTA) targets the development of fundamental scientific and technological underpinnings for military defense by combining specific scientific disciplines and defining integrative research themes. Some of DARPA's research programs are driven by challenge problems and results evaluated on industry provided open experiment platforms (OEP). These examples suggest that effective integration frameworks have the following common elements: (a) they not only enable, but necessitate integration by selecting challenges that require multidisciplinary solutions, (b) results are assessed in terms of metrics of the integrative themes, (c) industrial strength integrative testbeds combined with active industry, academic, and Government partnership, and (d) funding level that is adequate to complete the job.

These principles suggest a matrix structured CPS collaboration framework captured in Fig. 1. The National CPS Initiative focuses on open, pre-competitive research; therefore its scope does not include proprietary R&D pursued by the CPS Industry. The verticals in the research activities are Integrative Technologies defined by industry and government stakeholders. For example, High-Confidence System Design is a common concern for companies building safety critical systems where providing safety guarantees (e.g., for certification) may be extremely expensive. Integrative Technologies have industry defined challenge problems and assessment metrics. The horizontal layers represent disciplines that are expected to contribute to the emergence of CPS scientific foundations. The list of Integrative Technologies is not closed, they are formed and prioritized according to emerging societal challenges and threats to industrial competitiveness.

We recommend the adoption of an open innovation model that facilitates and encourages the integration across disciplines and industrial domains. The model should have the following main characteristics:

- Research programs are structured around Integrative Technologies with well defined challenge problems, supported by open experiment platforms and testbeds. The challenge problems are mapped into scientific foundations and solutions emerge along the synthesis of multiple disciplines. This requires long-term commitment and larger-scale efforts that provide sufficient time and resources to abstract generic problems from application domains and to develop deep domain knowledge for the application of the generic tools.
- The programs are executed in (virtual) centers whose size is commensurate with the challenges – typically in the range of \$5M-\$20M/year with funding sustained for 5-10 years.
- In these centers industry and university researchers work side-by-side on joint projects that are evaluated on industrial-strength testbeds in solving challenge problems and using established domain-specific metrics for measuring outcomes.
- The initiative is supported by infrastructure facilities including testbeds, repositories, and simulation platforms.
- Interaction among industry and university researchers are supported and stimulated by exchange of people. Universities provide extended leaves for professors to work in industry and industry people - with or even without Ph.D. - take temporary full time position at academia.
- Education is a fundamental responsibility of all centers and the programs extending to K-12, undergraduate, graduate, postdoctoral and continuing education. Essential metrics for the program are the number of graduated students, industry internship program for students and the number of participating professionals in continuing education.
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Table 1: National CPS Initiative as a Private-Public Partnership

Existing forms of research centers, such as UARCs and CTAs created by the DoD, ERCs and S&T Centers funded by NSF, MARCOs funded through SRC and DARPA programs such as SEC and MoBIES have some elements of the CPS-specific requirements. A notable aspect of the CTA program is that ARL requires the establishment of program headquarters where researchers from industry, university and government labs work together for a considerable time. The Aerospace Vehicle Systems Institute (AVSI) similarly was created to address issues that impact the aerospace community through international cooperative research and collaboration conducted by industry, government and academia.

Governance

The National CPS Initiative has three groups of stakeholders: Government, Industry and Academia. The governance structure needs to provide a framework, in which the stakeholders can contribute to shaping the vision and to conducting the strategic and tactical management of the research program according to their specific role. There are working examples for governance solutions that are relevant to CPS.

The Semiconductor Research Corporation (SRC) that funds academic research using 50-50% government and industry funding operates under an industry led governance mechanism. The MARCO program of SRC involves DARPA program managers in funding and management decisions because DARPA is the government agency that contributes nearly all of the Federal investment in the program.

AVSI is funded by contributions from members (e.g., Airbus, BAE Systems, Boeing, , GE, Honeywell, Lockheed Martin, Rockwell Collins, UTC, Texas A&M, as well as DoD). AVSI members define research projects with the potential to dramatically impact future aerospace systems. Once a project is launched, a Project Management Committee is formed to oversee the project. It includes one representative from each company that has joined the project.

ARTEMIS[7] is a major Joint Technology Initiative in Europe in embedded computing systems (an essential aspect of CPS). It is organized as a public-private partnership that is investing 2.5B euros in research between 2008-2017 (this is beyond the IST program investment in embedded computing). The Governing Board of ARTEMIS[8] is formed by the Board of Public Authorities (European Commission and Member States) and the ARTEMISIA Association[9] - a not-for profit organization including stakeholder industry, academy and small company representatives. The Governing Board decides priorities for research programs that are competed under the oversight of the Public Authorities (primarily the EU Commission).

The National Nanotechnology Initiative (NNI) was established in fiscal year 2001 to coordinate Federal nanotechnology research and development. NNI has created an active, competitive R&D environment in the U.S. that involves thirteen government agencies funding over $1.5B/year research in a large network of nanotechnology and education centers. NNI is managed by the Nanoscale Science Engineering and Technology (NSET) subcommittee of the National Science and Technology Council (NSTC). NSET includes representatives from agencies participating in NNI.

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[7] https://www.artemis-ju.eu/
[8] ftp://ftp.cordis.europa.eu/pub/ist/docs/embedded/pr-artemis-090307_en.pdf
[9] https://www.artemisia-association.org/

These examples show that establishing a governance structure that includes stakeholders from Government, Industry and Academia has been accomplished previously in related domains, and could be developed for the CPS domain.

Federal agencies have a variety of existing forms and contracting vehicles for funding and managing research programs organized as public-private partnerships. There are examples at NSF, DoD, NIST, DoE and other agencies for programs that enable federal funding of university research with substantial industry involvement and support. There are also established forums for inter-agency coordination of national initiatives.

There are also well established governance constructs for industry – university collaborative centers. For example, NSF funded large research centers (ERCs, S&T Centers) have Industrial Advisory Boards that are integrated in the overall management structure of the centers. However, the proposed industry-university collaborative centers must go beyond these forms. Industry will commit significant internal resources to participate in executing the proposed research agenda of the centers, therefore industry will be also direct participant in their management.

A significant challenge towards the effectiveness of the CPS Initiative is to find a forum that enables the required broad-based information exchange among stakeholders in spite of a highly distributed program execution. Since this information exchange needs to cut across disciplinary and sector boundaries that usually confine existing mechanisms, particular attention needs to be paid to find an effective methods for filling this need. We recommend the following structure for the information exchange mechanism among the stakeholders in the CPS Initiative:

- *Distributed program execution.* The research programs are executed by (virtual) centers that are self-managed and led by industry or universities. Industry participation is direct and typically includes in-kind and/or cash contribution. In-kind contribution means providing engineering research staff and testbeds for executing the research programs.
- *Annual National CPS Forum.* The CPS Forum informs stakeholders about emerging industry needs for specific integrative technologies, established testbeds, achieved technology breakthroughs, progress in foundations, and national and international trends.
- *National Industry-Academy Steering Group.* The CPS Forum is organized by the Industry-Academy Steering Group under the aegis of relevant professional societies and industry associations. The Steering Group includes leaders of the stakeholder industry-academy communities.

Table 2: Role of the Annual National CPS Forum

How far are we from the implementation of a governance structure for a National CPS Initiative? Not far! There is a joint, informal Industry-Academy Steering Group for CPS that has been coordinating the many activities (NSF workshops, seminars, round tables, web sites) in a self organizing manner during the past three years. On the Government side, NSF has established a CPS program and advocates the extension of research agenda across NSF and at other agencies. At this point, the HCSS Coordinating Group of the National Coordination Office (NCO) of the NITRD program was involved in supporting various CPS related activities. The academic community has numerous seedling activities that include establishment of workshops and conferences (e.g., the CPS Week), tracks in conferences, organizing seminars, starting up courses and summer schools, and actively participating in proposal writing.

However, developing the detailed plans for transforming current activities into a National CPS Initiative requires further coordinated effort from all stakeholders.

Operation

Besides research and overall management, there are operation support and dissemination activities that are required for coalescing the many threads of the National CPS Initiative into a

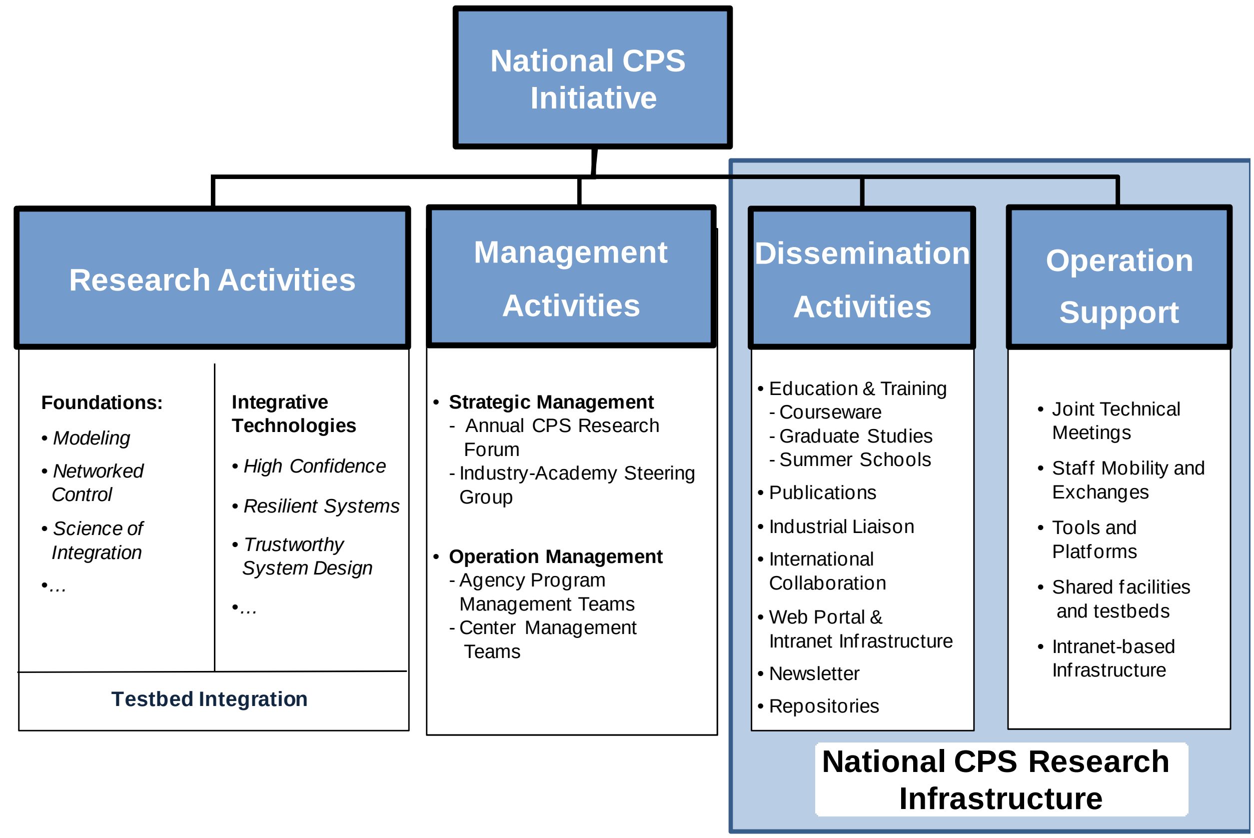

Figure 2: Core Activities

cohesive, efficient and well integrated science and technology effort. These activities can be folded into a National CPS Research Infrastructure (see Fig. 2) with the mission to serve all research and management functions. The effectiveness of shared infrastructure for national scale research programs is well established and widely practiced in programs such as NNI, HPCI and others. It is similarly important in CPS where facilitating experimental validation of results, broad dissemination of generated artifacts and providing a robust infrastructure for wide-scale collaboration are mandatory for the success of the Initiative. Therefore, we recommend the establishment of a National CPS Research Infrastructure that includes the following main components (there are three different models with several examples for providing these services):

- *Dissemination Activities.* The primary targets for the dissemination activities include industry partners, the scientific and technical community in CPS and students on all levels. There are many effective forms of dissemination activities that can serve such a broad audience. Examples include:
    - development and dissemination of education material,
    - offering Summer Schools and short courses,
    - maintaining a centralized repository for publications, challenge problems,
    - establishing quality controlled repository for tools and software that can be directly utilized by industry,
    - providing help for international collaboration,
    - maintaining web portal,
    - publishing newsletter.
- *Operation support.* While Centers and Networks of Excellence are self-managed, the integration challenge across the Initiative makes centralized Operation Support an effective choice for the functions below:
    - organization of joint technical meeting,
    - logistic support and coordination for staff mobility and exchanges,
    - quality control requirements and mechanisms for tools and platforms produced by the program and operating a shared tool and software repository,
    - tracking of shared facilities and testbeds,
    - maintaining an intranet-based infrastructure,
    - providing support for IP management.

Table 3: National CPS Research Infrastructure

There are three different models with several examples for providing these services:

- Operation support and dissemination responsibilities are assigned to the individual research programs/centers. This is the most common approach, with many examples such as NSF ERC and S&T Centers, CTA and others.
- Operation support and dissemination is provided as a centralized function by an organization, usually a university or other 401c not-for-profit corporations. The selection of this organization can be accomplished through an Initiative-wide competition, somewhat independently from the research programs. There are several examples for this approach both in the US and internationally. For example, the newly started CPS program of NSF CISE included a competition for a CPS Virtual Organization (CPS-VO) with the primary purpose of dissemination. The ESCHER Institute has been created to operate a quality controlled repository and maturation program for the “leave behind” of DARPA and NSF projects in the embedded systems research area. SPRUCE is a web portal and collaboration site and S3 is Repository for the DoD SISPI initiative managed by AFRL and ARL. A massive undertaking of the IST program in Europe are the ARTIST, ARTIST 2 and ARTISTDESIGN[10] Networks of Excellence that provide

[10] http://www.artist-embedded.org/artist/

research coordination, dissemination, and partial operation support for embedded systems programs.

- Operation support and dissemination responsibilities are assigned to a permanent or semi-permanent centralized Consortium organization. Examples for this structure are SRC[11] and AVSI[12]. An important characteristic of these organizations is efficiency and light-touch management.

The scale of activities and the need for effective communication justifies organizing a National CPS Initiative such that operation support and dissemination activities are offered in a centralized form – probably through a periodically competed program element. This particularly important in CPS where research outcome includes tools and software where maturation and quality control is essential requirement for effective transition. The rapid progress in ARTISTDESIGN suggests that adopting a similar construct needs to be seriously considered.

[11] http://www.src.org/Default.asp
[12] https://avsi-tees.tamu.edu/default.aspx

Appendix A: Workshop Summary

Workshop Participation

There were 31 participants at the workshop. The list of companies represented is as follows:

1. Boeing
2. BAE Systems,
3. Bosch
4. Ford
5. Lockheed-Martin
6. National Instruments
7. Raytheon
8. SRC
9. Toyota
10. United Technologies.

The list of Universities represented is as follows:

1. UC Berkeley
2. CMU
3. GMU
4. U.Penn,
5. UIUC
6. UT Austin,
7. University of Arizona
8. University of Maryland
9. University of Virginia
10. Virginia Tech
11. Vanderbilt University.

Workshop Agenda

The Workshop Agenda began with a keynote entitled "Cyber Physical Systems – An Aerospace Perspective" delivered by Don C. Winter, VP of Engineering & Information Technology, Boeing Research and Technology. Following the keynote, there were two panel discussions:

1. Expectations for University - Industry Collaborative Research in CPS
   Panelists: *Richard Buskins (LM), Clas Jacobson (UTRC), Sri Kumar (BAE Systems), John Baras (UMD), Marija Iljic (CMU), Edward Lee (Berkeley) and Alex Levis (GMU)*
   Moderator: *Doug Schmidt (Vanderbilt)*
2. Existing Forms of University-Industry Collaborative Research
   Panelists: *Celia Merzbacher (SRC), David Corman (Boeing), George Pappas (Upenn), Raj Rajkumar (CMU), Bill Milam (Ford), Hugo Andrade (NI)*
   Moderator: *John Stankovic (UVA)*

The two panel discussions prepared the ground for a lively open discussion in the afternoon moderated by *Bruce Krogh (CMU)* on developing recommendations for the White Paper.
The Workshop program was closed with a discussion moderated by *Janos Sztipanovits (Vanderbilt)*.

In summary, there was a general consensus among participants that CPS requires close industry-university collaboration because of the following unique characteristics of CPS:

- acute industry needs practical results in many areas but fundamentals are important as well,
- research needs to be done in the context of real systems,
- there is a need for long-term commitment because general tools cannot be applied without deep domain knowledge,
- the scientific areas do not belong to any one of the established disciplines, and
- embraces critical issues for a number of government agencies.

During discussion, a number of suggestions emerged that would address many existing roadblocks. These suggestions are summarized in the White Paper.

Post Workshop Activities

Workshop organizers Janos Sztipanovits and John Stankovic collected comments, notes and presentations from the workshop participants. These notes serve as input for constructing and discussing a White Paper on the findings and recommendations. The White Paper is drafted by a drafting committee including David Corman, Bruce Krogh, Edward Lee, Bill Milam, John Stankovic and Janos Sztipanovits. The draft was distributed to all participants for review and comments.

Appendix B: CCC Computing Research Initiatives:

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

Janos Sztipanovits
Vanderbilt University

John Stankovic
University of Virginia

Version 8: December 22, 2008[13]

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 transportation[14].

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[13] For the most current version of this essay, as well as related essays, visit http://www.cra.org/ccc/initiatives

[14] 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 healthcar**e: 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 Technology[15] 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*[16].

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

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[15] http://www.nitrd.gov/pcast/reports/PCAST-NIT-FINAL.pdf .

[16] 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*