A Vision for Application-Focused International Collaboration Networks in Cyber-Physical Systems

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***Abstract*—Cyber-physical systems (CPS) is a rapidly-evolving field with a large and diverse community that is geographically distributed throughout the world. With far-reaching applications in smart mobility, smart manufacturing, smart health, smart energy, and smart society, CPS have the potential of making a transformational impact on our society at a global scale. This extended abstract outlines a vision for application-focused researcher collaboration networks to increase the impact of CPS research.**

I. Introduction

As CPS-focused research scientists at a multi-national company, we have been actively engaging with other CPS researchers, practitioners, and educators worldwide along multiple dimensions. Collaborative efforts such as the successful Smart Emergency Response System (SERS) project [1] facilitate testbeds for technology proofing to employ smart technologies in disaster response. At our MathWorks Research Summits in Boston and Tokyo, bringing together contacts from industry and academia around the world to openly share ideas, challenges, potential solutions, and even unsuccessful attempts lets us capitalize on the unique vantage point as a high-tech solution provider to industries such as Automotive, Aerospace, and Industrial Automation.

Peer-reviewed papers, organization of and participation in discussion panels, and organizing special sessions and tracks are traditional avenues for sharing insights and newly developed technology at academic research events. At the organizational level, the exchange involves discussing and supporting infrastructural advances that may include technology solutions to contribute to research reproducibility attempts, cyber-infrastructure platforms as research gateways, scholarly value of artifacts beyond peer-reviewed papers, direction and guidance for research funding, and others.

Based on our experience in a multi-faceted engagement with the international CPS research community over the years, we outline our vision for collaboration networks for maximizing the impact of CPS research.

II. CPS Collaborations: A cyclic triad

A triad between research, development (industry), and education, depicted in Fig. 1, maps the cyclic progress of advancing the state of the CPS field. Starting from the core concepts and principles at the center, the inside out direction depicts the maturation of ideas into products along various *verticals* by progressively developing new methods and technologies, new tools and intellectual property, and ultimately new products.

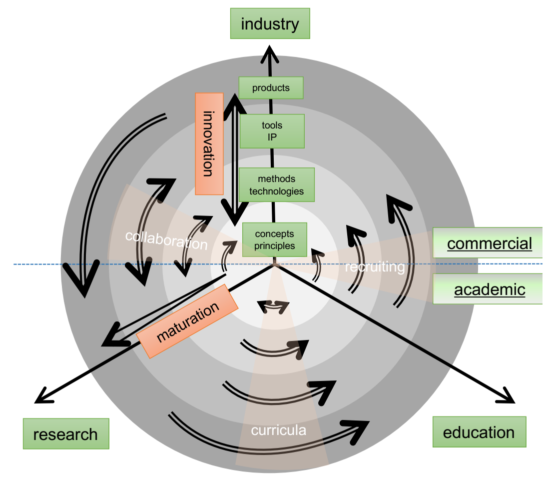

Fig. 1. A triad between research, development, and education enabling cyclic progress for advancing the state of CPS.

The concentric circles represent a cyclic exchange between the three axes of the triad. The exchange from research to education is enabled by the development of *curricula*, such as traditional and online courses and books. In turn, via *recruiting* the personnel educated on these topics for internships and permanent positions, industry can advance the state of expertise and technology. These two kinds of interactions both inherently have an associated time delay of several months to years.

In contrast, the third kind of interaction of *collaboration* is bidirectional and does not inherently have to have a time delay. The development and production engineers in industry provide researchers in academe, industry, and government with challenge problems. In return, progress made in research is implemented in industry via technology transfer and productization. In order to sustain and grow this collaboration and thereby accelerate the cyclic progress, a vision for setting up application-focused *networks of excellence* is outlined next.

III. Application-focused networks

Today's topically-organized research and educational gatherings such as conferences and summer schools can be complemented with application-focused collaboration networks that have a balanced composition and a structure conducive to technology readiness development.

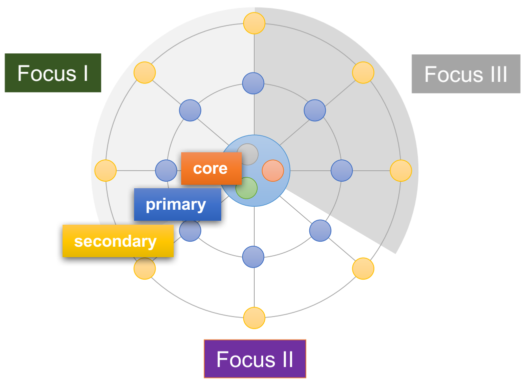

Fig. 2. Layered structure to support robust technology research and maturation to readiness for industry adoption.

A. Team composition.

Track record of collaboration. Successful collaboration rests on three pillars: (i) collaborative inclination instead of isolationist research operation, (ii) a collaborative spirit that builds on matching characters and dispositions, and (iii) organizational structures conducive to idea exchange, mutual review and challenges, direction setting and task planning.

Diverse organizational make-up. A network of excellence should include members from *universities* working with *small and medium size enterprises* to advance the methodological side and increase technology readiness levels and *larger enterprises* to reach production quality. Moreover, it should cover the wide range of combined expertise such as physical modeling, controls, communications, computer architectures, and systems engineering.

International collaborations. The global reach of CPS applications brings about a diverse set of technological, societal, cultural, and policy concerns. Synergies and differences between US and Europe [2], reduced safety margins South Asian driving conditions [3], strict budgets in developing markets [4], local customs [5], unique privacy laws, utility standards, and climate conditions become relevant based on where a CPS is deployed. Moreover, expertise in particular research areas is not uniformly distributed across the globe (e.g., architecture modeling in Europe vs. simulation-based engineering in US). Networks that span international collaborations are therefore important to leverage complementarity and tackle locale-specific concerns early on.

B. Organizational structure

A robust organization of collaboration networks requires a combination of focus and a driving force with breadth to provide critical mass and a broad enough foundation to develop viable technology, especially in light of the multidisciplinary needs to design and implement modern systems.

Figure 2 sketches the fabric of a collaboration network that addresses these requirements. The core is created by an industry partner that has a close working relationship with two academic partners, one of whom would be a senior scholar to provide mentorship but also bring in relations and connections in the technology research landscape at large to support the second academic partner who would be in the early career stage to drive the collaboration forward.

Critical mass is provided by a network of primary collaborators who have close working relationship with the core and who provide the breadth in background and expertise to build a strong research direction spanning theoretical (Focus I) and methodological (Focus II) advances combined with key application based research and development (Focus III).

Finally, a number of more loosely connected collaborators provide a platform to improve robustness of developments and support the reach into various different communities and create the surface area necessary to be informed as well as included in on-going activities.

C. Unifying themes drawn from application domains.

A focus on a common application domain provides a *shared sense of purpose* among teams working on heterogeneous domains by providing a common goal, for instance, in case of autonomous driving, that of eliminating traffic fatalities. Application-specific benchmark problems are invaluable for making concrete measurable progress towards solving multiple facets of a *common challenge problem*.

A *common technology platform*, such as a common tool chain and interface standard is needed to seamlessly leverage work done by individual teams and promote reproducibility of research results. For physically implementing the CPS, having access to *shared testbeds and environments* such as Robotarium [6] and MCity [7] is instrumental.

IV. Outlook

We proposed a vision for application-focused networks of excellence. Coupled with existing knowledge dissemination mechanisms such networks can accelerate progress along the CPS cyclic triad by strong self-sustaining international collaboration. To support geographically dispersed networks, social collaboration platforms such as Slack and GitHub can facilitate day-to-day aspects of remote collaboration.

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