Editor: **Daniel Zeng,** University of Arizona, zeng@email.arizona.edu

The Emergence of Intelligent Enterprises: From CPS to CPSS

Fei-Yue Wang, *Chinese Academy of Sciences*

Welcome to the inaugural issue of the Cyber-Physical-Social Systems (CPSS) department!

In recent years, Internet use and cyberspace activities have created an overwhelming demand for the rapid development and application of CPSS, raising compelling technological, economic, and social implications. In this issue, I would like to begin by addressing the philosophical and scientific foundation of CPSS. I believe any study of CPSS must be conducted with a multidisciplinary approach involving the physical, social, and cognitive sciences and that AI-based intelligent systems will be key to any successful construction and deployment. In particular, I am interested in the significance of and role that CPSS plays in regard to societal security and production efficiency in today's connected world as well as its implications for our future society.

From CPS to CPSS

The phrase *cyberphysical systems* (CPS) was coined to describe the tight conjoining of and coordination between computational (or cyber) and physical resources (see Figure 1)—that is, systems that feature a tight integration between computation, communication, and control in their operation and interactions with the task environment in which they are deployed.[1] The US National Science Foundation has identified CPS as a key area of research, and CPS is expected to impose major technical, economic, and societal impacts on the way we live our lives in the near future. Over the last few years, the NSF and other major funding agencies around the world have sponsored numerous workshops and research projects on CPS, and last year, China identified CPS as one of its major interests in their next stage of economic growth.

When *IEEE Intelligent Systems* solicited ideas for a new department at its 2008 Spring Editorial Board meeting, the suggestion of CPS received overwhelming support. The board approved the proposal for a new CPS department in 2009 and appointed Daniel Zeng as its founding editor.

Although I had promised to write the first article for the new department, as the new editor in chief, I was hesitant to execute the plan. This was because the current CPS R&D effort has concentrated heavily on networked or next-generation embedded systems, an extremely useful and important direction, but outside our magazine's primary focus. After extensive discussion among our board members, we eventually decided to change the department's name to Cyber-Physical-Social Systems—that is, CPS tightly conjoined, coordinated, and integrated with human and social characteristics.

CPSS in the Complex Space

It is my strong belief that we must add and address the human and social dimension present in CPS. This is largely due to the unprecedented sphere and speed of influence experienced in the cyberspace field and its profound impact on the way we behave and interact with each other. We have reached the point where social and human dynamics must be considered an integral part of any effective CPS design and operation, thus inserting the term *social* into CPS is fully and rightfully justified. This change in name also aligns the new department with *IEEE Intelligent Systems*' focus and key interests.

This change also has a philosophical implication that brings CPSS in line with Karl Popper's theory of reality. The theory states that our universe consists of three interacting worlds: the physical (World One), mental (World Two), and artificial

1541-1672/10/$26.00 © 2010 IEEE
Published by the IEEE Computer Society

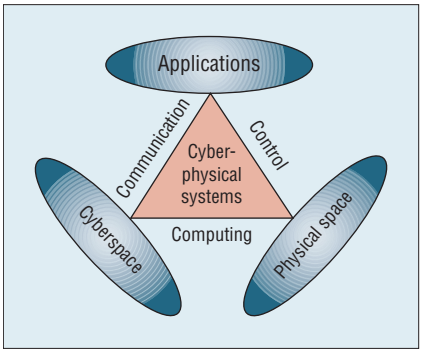

Figure 1. Cyberphysical systems. Such systems exhibit a tight integration between computation, communication, and control in their operation and interactions with the task environment.

(World Three). Before the Internet existed, our living space was limited to the physical, featuring mainly the physical and mental worlds. Today, with the presence of cyberspace, our living space features the artificial world as well, expanding it into the complex space and doubling its size. This is similar to the impact of imaginary numbers on the concept of numbers some 400 years ago—a revolutionary jump from real numbers to complex numbers. In this sense, cyberspace is the counterpart of imaginary numbers in our living space, and it must do what imaginary numbers has done in mathematics.

However, instead of offering new solutions to equations that were previously unsolvable, cyberspace should enable new methods and systems to solve complex and challenging problems in the real world that have found no effective solutions so far. In my view, under such thinking, CPSS will be one such enabling technology in which Popper's three interacting worlds can be quickly and effectively coordinated and integrated, as Figure 2 illustrates. In the process, this will elevate artificial intelligence to complex intelligence, as I discussed in one of my previous letters.[2]

Toward Pervasive Intelligent Spaces

With CPSS, the age of the pervasive intelligent space (PIS) able to interact smartly with people and objects anywhere, anytime will be a logical consequence. Of course, this would be built upon the foundation of pervasive computing, communication, and control.

Spaces become smart or intelligent when they are able to observe what is happening within them, construct a model of themselves, communicate with their inhabitants, and act based on their own decisions.[3] Clearly, this requires both inhabitants and a large number of sensors, actuators, appliances, and other devices with embedded processors capable of communicating with each other as well as the formation of an integrated global information network. Although CPS offers the backbone for building such intelligent spaces, the realization of PIS demands CPSS support.

CPSS-based PIS promises a scenario involving parallel universes where a real system and its artificial counterparts are always running in parallel and interactively through cyberspace. For example, critical bridges, dams, and buildings can be linked to their artificial duals via wireless sensing networks and wide area networks for testing, evaluating, monitoring, and managing the health of infrastructures and improving the safety and effectiveness of their operation and usage (see Figure 3). This kind of cyberspace-enabled parallelism could open a range of new application scenarios, such as future driving in intelligent transportation spaces for more integrated and better traffic management, vehicular safety, energy efficiency, reduced pollution, and maintenance services. In this world, vehicles, highways, roads, intersections and operation centers will be embedded with various types of intelligent spaces, fixed, mobile, mixed, hybrid, and so forth.

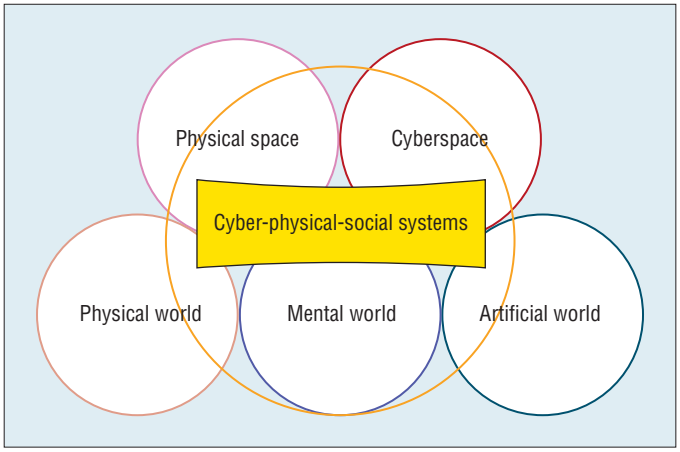

Figure 2. From Popper's three worlds to cyber-physical-social systems. CPSS technology will enable us to coordinate and integrate the real and artificial worlds.

The Coming of Intelligent Enterprises and Industries

Some people have a much larger vision for CPS and CPSS; they believe that, even with CPS alone, its applications have the potential to dwarf the 20th century IT revolution.[4] I agree that a new revolution is already in progress, or at least will come soon. This time it could be an intelligence or knowledge revolution, in which CPSS is the enabling platform technology that will lead us to an era of intelligent enterprises and industries. In my opinion, the searching and social media industries are the precursors of this new era.

The Industrial Revolution reduced the agricultural population from more than 90 percent

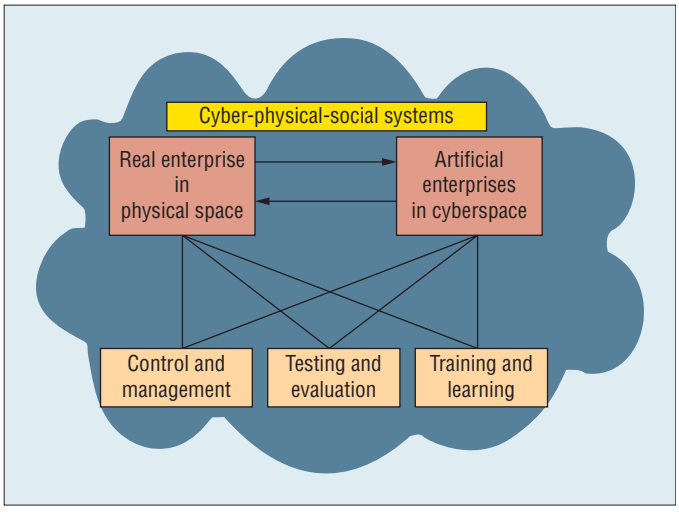

Figure 3. Intelligent spaces and parallel systems for enhanced safety and service of critical infrastructures. Cyberspace-enabled parallelism could open a range of new application scenarios.

to less than 5 percent in many developed countries, transferred those laborers into the manufacturing industries. Now the IT revolution has reduced the manufacturing population from more than 70 percent to approximately 15 percent in some developed countries, moving those laborers into the services industries. In the near future, the Intelligence Revolution will reduce the entire services population to less than 10 percent, as the Industrial Revolution did to the agricultural population. Where will people go, and what will they do then? Gaming! Not gambling in Las Vegas, but scientific gaming in cyberspace.

Intelligent enterprises will need huge labor sources to build all kinds of artificial societies, organizations, and systems; perform different types of computational experiments for analysis, evaluation, and decision support; and carry out various decisions and tasks through parallel execution of and interaction between real and artificial dual entities. All these will be built and conducted using some CPSS platforms in cyberspace. This is similar to the current Internet gaming, digital animations, and second-life scenarios, but rather than leisure, these programs will be used in real production and decision making. As I have claimed before, we will need a new profession of game engineers to construct the complex space infrastructure to translate everything we possess in the physical space into the cyberspace, so we can then play, work, and live with them.

Artificial societies, computational experiments, and parallel execution—the *ACP approach*[5,6]—will form the scientific foundation while CPSS will be the enabling infrastructure for such intelligent enterprises. In an intelligent enterprise, before any major decision or operation, we will conduct numerous scientific games to analyze, evaluate, and optimize processes as well as master skills and resources required for a successful real execution in the shortest time, with the least energy and cost. This will eventually lead to high production efficiency and satisfaction in all aspects.

The multiverse or parallel universes based on Hugh Everett's many-worlds interpretation will be a reality in the age of complex spaces with intelligent enterprises. All companies or businesses, governmental agencies, military establishments, and social organizations must maintain their dual artificial entities in cyberspace (see Figure 4). Some might have several duals with differing functions and must be linked to them constantly through CPSS. Thus, the need to hire game engineers to conduct their decision making and operational games required for their survival and general competence. Everything will have its parallel avatars in the cyberspace for enhanced capacity and efficiency. We will see complex-space-based parallel production plants, parallel agricultural firms, parallel business organizations, and many other types of parallel social commerce, all operated with CPSS-based parallel control systems (PCS) and parallel management systems (PMS). If an operation does not do so, it will and must fail.

However, we should never forget that CPSS technology is a double-edged sword. The capability of CPSS to collect tremendous energy from the masses through crowdsourcing in the cyberspace, quickly with little resources, and then release it into the physical space can bring us both favorable and unfavorable consequences. Unfavorable examples include the extensive Web uses of terrorist and extreme organizations, as well as the bad side of the explosive Human Flesh Search (HFS) Web phenomenon that originated in China and was used by some netizens as a powerful tool to identify and attack their targets. Therefore, societal and individual security will be an extremely important issue that must be addressed in the transition from our current social structure to the new, yet unknown CPSS-enabled connected lifestyle and working environments. There are no obvious solutions at this point, but we should learn from our experiences and the evolution of our own history.

Let us be hopeful, because the potential and future of CPSS are unlimited. As for this new CPSS Department, its future and success depends on your support and involvement!

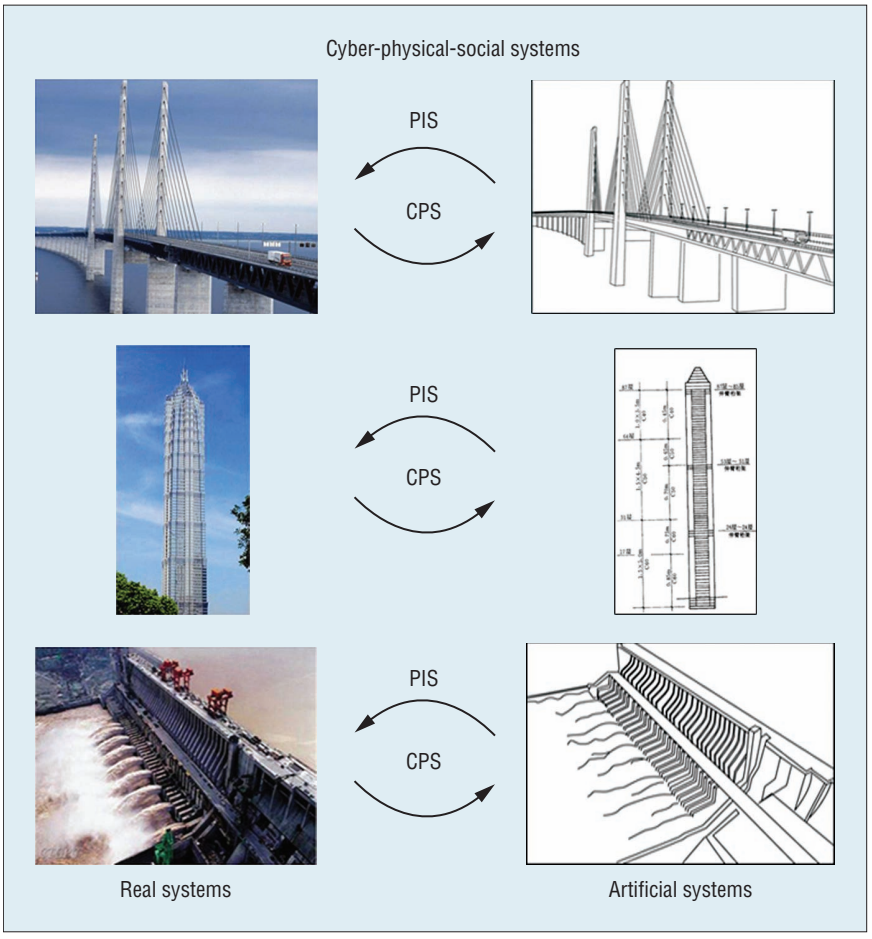

Figure 4. Intelligent enterprises and their operations in parallel universes of complex space. All enterprises will eventually operate with CPSS-based parallel control systems (PCS) and parallel management systems (PMS).

Acknowledgments

This work is supported in part by grant numbers NNSFC 70890084, 60921061, 90924302, and MOST 2006CB705506.

References

1. US National Science Foundation, "Cyber-Physical Systems (CPS)," NSF 08-611, 2008, http://www.nsf.gov/pubs/2008/nsf08611/nsf08611.htm.
2. F.-Y. Wang, "Moving Toward Complex Intelligence?" *IEEE Intelligent Systems*, vol. 24, no. 4, 2009, pp. 2–4.
3. S. Wright and A. Steventon, "Intelligent Spaces: The Vision, the Opportunities and the Barriers," *BT Technology J.*, vol. 22, no.3, 2004, pp. 15–26.
4. E.A. Lee, "Cyber Physical Systems: Design Challenges," *Proc. Int'l Symp. Object/Component/Service-Oriented Real-Time Distributed Computing*, 2008; http://chess.eecs.berkeley.edu/pubs/427/Lee_CyberPhysical_ISORC.pdf.
5. F.-Y. Wang, "Toward a Paradigm Shift in Social Computing: The ACP Approach," *IEEE Intelligent Systems*, vol. 22, no. 5, 2007, pp. 65–67.
6. F.-Y. Wang, "Toward a Revolution in Transportation Operations: AI for Complex Systems," *IEEE Intelligent Systems*, vol. 23, no. 6, 2008, pp. 8–13.

Fei-Yue Wang is the vice president for research, education, and academic exchange at the Institute of Automation, Chinese Academy of Sciences, and the editor in chief of IEEE Intelligent Systems. Contact him at feiyue@ieee.org.