Chapter 1
Evolution of Cyber-Physical Systems: A Brief Review

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The term “cyber-physical system” (CPS) sounds like a brand-new buzzword as it occurs increasingly as a theme of many conferences, in journal articles and books – like this one. Etymologically the prefix cyber derives from the ancient Greek word *κυβἐρνησις* (kybernesis) and originally means control skills. It evolved into the Latin word *guvernare* and finally the English word to *govern*. For our context this means that we speak about systems in which physical objects and computational resources are tightly integrated and exhibit a degree of continuous coordination between each other.

Sztipanovits characterizes cyber-physical systems research “as a new discipline at the intersection of physical, biological, engineering and information sciences” [1]. In this broad sense, Konrad Zuse was a pioneer in cyber-physical systems. Why? Soon after the invention of the Z3 in 1941, the first fully functional program controlled computation machine, he developed a special device for the survey of aircraft wings. Zuse later called this ensemble the first real-time computer. This automatic computer read values from some forty sensors, working as analogue-to-digital converters, and processed these values as variables within a program. We conclude from this that real-time capabilities, reactivity, control engineering, software, and physical resources are inherent aspects of cyber-physical systems.

Somewhat later, in 1948, Norbert Wiener coined a new term in his book *Cybernetics: or Control and Communication in the Animal and the Machine* in which he elaborated on feedback concepts between men and machines, including feedback mechanisms in technical, biological and social systems. A second addition of this book, which appeared in 1961, showed how long-sighted Wiener was because he added two new chapters *On Learning and Self-Reproducing Machines* and *Brain Waves and Self-Organizing Systems*. These are still popular topics in research, for instance: self-reproduction in the context of outer space exploration or Nano technology; self-organization in bio-inspired multi-agent

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models or distributed flight areas as Raffaello d'Andrea demonstrated them in his keynote during the SDPS 2012 conference in Berlin. Long before the Society for Design and Process Science (SDPS) with its mission in transdisciplinary research and education was founded, cybernetics conferences in the fifties insisted on a finely balanced ratio of representatives from different disciplines, including mathematics, sociology, physiology and more (cf., e.g., [2]).

Claus Pias nicely characterizes the current revival of cyber-* when he says [3]: "Today the cyber-hype of these days appears like a fashion garment of yesterday, and the threshold of shame to wear it, is low anytime". Shame is not appropriate anyway because the prerequisites we find today are far more advanced than 50 years ago. We have built up a rich body of real-time and embedded systems engineering know-how; we have the world-wide web that evolved from a web of information over a web of software services to a web of people and organizations; we find advanced sensor and actuator technology and we have created a tremendous amount of algorithmic and software engineering knowledge. The chances to experience the benefits of modern cyber-physical systems research steeply increased: We see the realization of remote and robot-enabled surgery on the horizon. The Internet of things is subject to substantial research efforts and funding. Car manufacturers start embedding vehicle collision prevention systems into premium cars; the realization of low-energy buildings or renewable energy sources seamlessly integrated into smart power grids has top priority on the political agenda, even more so in public awareness. The European Union is investing substantial funds in the research and development of smart factories. For instance, the EU-project IMAGINE, which organized a workshop on End-to-end management of dynamic manufacturing networks during SDPS 2012, presented the project's approach towards the effective (re-)configuration and management of complex dynamic manufacturing networks.

This brings us to a sharper definition of cyber-physical systems by adding further characteristics: Many of the application areas mentioned are inherently *distributed* and equipped with *wire-bound or wireless communication* facilities. Their components are largely autonomous and need to be coordinated and controlled. A CPS used in such critical domains as dynamic and prospective traffic safety, factory and process control, or healthcare needs to be *highly dependable* requiring the availability of reliability performance, availability, safety and security.

Of course, the European Commission is not the only institution placing its hopes in the promotion of the next generation of cyber-physical systems. The US National Science Foundation (NSF) supported this type of research already since 2006. It funded, for example, projects on sensor-based autonomous systems, distributed robotics, autonomous vehicles (both land and air), and ambient assisted living. Encouraged by a recommendation in the December 2010 report of the President's Council of Advisors on Science and Technology on Designing a Digital Future, NSF will soon open a new window for proposals on new cyber-physical systems projects. Between mid 2010 and January 2012 the German Federal Ministry of Education and Research and German industry set up a cooperative study project to develop an “Integrated Research Agenda Cyber-Physical Systems”. The consortium involved major German industries and research institutes and investigated technological, economical, political, and social challenges and impacts of technology trends towards cyber-physical systems [4].

Besides further research in different application domains, a fresh look at CPS also requires a new transdisciplinary engineering approach. As we speak about hybrid systems including electronics, mechanics, software and other technical components, new approaches towards integrated systems modeling approach, a coherent design theory and related design, analysis and simulation tools become indispensable. However, cyber-physical systems are not just a self-contained and isolated ensemble of technical components but are often embedded in a social context to form a socio-technical system. In such systems people are embedded in complex organizational structures and interact with complex infrastructures to perform their work processes. A holistic approach towards human factors, including usability of interfaces and functionality, intuitive machine operating, and seamless coordination of human and machine behavior are of outmost importance to avoid erroneous system behavior.

Correspondingly, new curricula addressing relevant fields of knowledge need to be established at different levels of education. The Society for Design and Process Science has pioneered transdisciplinary engineering education, but CPS requires further efforts, in particular, with respect to innovative design disciplines for man–machine interfaces and interaction and the seamless embedding of CPS in the actual application domain. We also need to understand and teach how to incorporate adaptivity and context awareness in CPS.

The authors of this book touch many of the issues mentioned above in great detail and with high scientific and practical competencies. They step onto new grounds and shed a light on many aspects of our ignorance in this challenging field. I’m overly grateful to the editors of this book that they undertook the courageous endeavor of characterizing this technological field, dividing it into meaningful subthemes, and finding outstanding authors for each chapter.

References

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