Editorial: Embedded, Cyber-Physical, Hybrid . . .

This editorial is the last one in Volume 13 of this journal. Thanks to the ACM publications staff especially Laura Lander, our journal assistant, Ms. Jeyel Tecson, and, most importantly, our production manager, Joanne Pello. We have been able to fit all the pending special issues and many articles waiting in the queue for a very long time inside the various extra issues of Volume 13, some of which are online-only issues to save pages and time. The next issue will begin Volume 14 of this journal, and I note that with great admiration for everyone who helped us clear the immense backlog – in particular the special issue articles.

Before I briefly summarize the content of this last issue of Volume 13, let me bring up a topic germane to this journal and to the entire field of embedded systems research and education. It is about terminology, taxonomy of research areas or sub-disciplines that often confuse us, and often launch us into great debate at conference venues and other meeting places.

This journal is titled *Transactions on Embedded Computing Systems*. What exactly does the discipline “embedded computing systems” entail? These days, the most throw-around term is *cyber-physical systems* (CPS). In the mid-nineties there were a lot of discussions on *hybrid systems* (HS). What are their ontological relationships? It is actually interesting to note that, while all of these are related and often used in place of each other, certainly, chronologically, CPS is the newest buzzword that has been making the rounds for about the last 10 years, starting with the US federal funding agencies and gradually reaching world-wide acceptance. Hybrid systems initially meant systems where at least two models of computation interact – in particular, a continuous time one, representing the dynamics of a physical system, and a discrete time one, representing digital computer-based implementation of control algorithms that oversee such physical dynamics. In the early nineties, much of the research in hybrid systems saw a convergence of control systems research and digital implementation of control algorithms. In particular, the main focus was on formal models as well as the representation and analysis of such models for verification and synthesis purposes. Hybrid automata, rectangular automata, hybrid I/O automata, timed automata, and many other formal model and analysis techniques were proposed and implemented. Certainly, these models and analysis techniques that originated from the need to verify that control algorithms implemented on digital computers indeed can control the trajectories of the intended dynamics to keep them safe and stable even in the presence of uncertainty, were not meant for mainstream computational artifacts or their representation or verification. So hybrid systems were surely in the domain of embedded computing as opposed to generic computing.

However, embedded computing is more generic than just those in the orbit of hybrid systems. For example, design of low-power processors used in cell phones, real-time operating systems, or even embedded operating systems, such as android, or software for embedded applications – even when it does not deal with a physical system’s control – are bona fide members of the embedded systems research portfolio. On the other hand, avionics, automotive, the control automation of a manufacturing plant, or the entire distributed power grid are examples of embedded systems.

Cyber-physical systems, on the other hand are more of a coined word that encompasses the hybrid systems of yester-year, with some interesting subtleties, having more

to do with research funding calculus than real ontological necessity for a new nomenclature. First, CPS usually have a closed loop control necessitating a co-design of control and computational implementation of the control. A hybrid system does not necessarily make this distinction, but most interesting hybrid systems were not open-loop because, for open-loop systems, the computational implementation of the control and guaranteeing properties are easier. Second, we seem to focus more on the systems that are associated with national critical infrastructure, or at least safety-critical, when we discuss CPS. This certainly gets attention from a funding perspective, but it also makes it mandatory to have scalable models, analysis techniques, or algorithms. Third, we seem to care a lot about the cyber-security aspect of CPS because of their safety-criticality or infrastructural criticality. More recently, we have also been discussing resiliency and robustness with respect to cyber attacks and other kinds of faults induced by natural or other disturbances. These issues have brought to mind the need for an interdisciplinary approach where computer science, control engineering, cyber security, signal processing, sensing, networking, and many other disciplines including topics as esoteric as game theory, machine learning, and even economics are studied as an integrated unit.

This is thus a wonderful opportunity for us to engage many minds in solving very important problems of resilient, robust, sustainable infrastructures, and safety-critical system design.

Looking at the lineup of articles in this particular issue, I am not seeing this multi-disciplinary approach I allude to, and I am hoping that in the coming volume, we will see more inter-disciplinarity in the contributions. That does not mean that the articles in this issue or the past ones are not important: they indeed are solving challenging problems in specific domains, such as energy-efficient system design, real-time software and systems, risk-aware and trustworthy system design, virtual prototyping for early architectural exploration etc.

In this issue, there is a lineup of regular articles and articles selected by guest editors of three special issues. The first special issue is on “Risk and Trust in Embedded Critical Systems” with two articles. The second special issue is on “Real-Time, Embedded and Cyber Physical Systems” with eight articles, and a third special issue is on “Virtual Prototyping of Parallel and Embedded Systems” with five articles. We also have six regular articles in this issue. We thank the guest editors of the special issues for their tireless work in arranging the reviews, and rereviews on revisions, and making the final selections. We also thank the authors who have submitted regular articles as well as special issue articles and all of the reviewers who have volunteered their time to shepherd these high-quality papers.

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