Guest Editors' Introduction: Special Issue on Autonomous Systems Design

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Fueled by the progress of artificial intelligence, autonomous systems become more and more integral parts of many Internet-of-Things (IoT) and cyber–physical systems (CPSs) applications, such as automated driving, robotics, avionics, and industrial automation. Autonomous systems are self-governed and self-adaptive systems that are designed to operate in an open and evolving environment that has not been completely defined at design time. However, this does not come for free. The advance from established systems technology to autonomous systems is not an issue of developing and introducing new functions in existing design processes. We firmly believe, and will elaborate, that it will have a deep impact on engineering, on the way we design, verify, test, and operate systems. We must find ways to keep high engineering standards, such as dependability and controllability, when allowing the system to change its behavior in the field. In other words, the future of autonomous systems is not only an issue of systems intelligence, but depends on our capability to design them responsibly.

To raise awareness of the new design problem space, we will begin this special issue on autonomous systems design with an overview in "Autonomous Systems Design: Charting a New Discipline." This article elaborates the challenges and initial solutions for the design of system architectures, patterns, and mechanisms providing autonomous capabilities and reason about their correctness and safety. The authors approach the topic from different perspectives, starting with: 1) assuring autonomy as dictated by safety standards beyond the design phase and during the operational phase; then 2) building hardware/software (HW/SW) architectures with autonomy supervision capabilities enabling the system to evolve safely and correctly under new environments conditions during operational time and interact and coordinate with other autonomous systems components; and 3) verification of autonomous systems where the emergence of previously unseen behavior needs to be specified and also verified. This article concludes with the role of design automation and its requirements in the process of building autonomous systems and the need for a closely coupled interface between the design phase and the operation phase in controlling autonomy.

Following that overview, the special issue provides a collection of high-profile articles that address the new field of autonomous systems design in more depth.

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In "Verification Approaches for Learning-Enabled Autonomous Cyber–Physical Systems," Hoang-Dung Tran from the University of Nebraska-Lincoln, Taylor T. Johnson from Vanderbilt University, and Weiming Xiang from Augusta University discuss verification methods for neural network control systems (NNCSs) where specifications are defined based on the state of the control plant. One major challenge in the verification process is that the behavior of the neural network controller depends on the system's physical dynamics described in terms of ordinary differential equations (ODEs). The authors discuss and also propose a classification of the existing proposed methods like polyhedron-based considering linear and discrete dynamics to verify system-level safety properties of NNCS with feed-forward neural network controllers using hybridization approaches that transform NNCS to an equivalent nonlinear hybrid system where standard verification techniques can be applied. This article closes with a summary of challenges and future directions in this domain like scalability of verification techniques, formal specifications, and compositional verification, in addition to integrating verification techniques in the training process to enhance robustness or safety of the NNCS.

In "Real-Time Requirements for ADAS Platforms Featuring Shared Memory Hierarchies," a team of researchers from the University of Modena and Reggio Emilia led by Marko Bertogna address nonfunctional properties like timing in autonomous systems platforms with a focus on the memory hierarchy. The authors discuss, in particular, the impact of interference resulting from complex memory hierarchies in embedded high-performance accelerators [e.g., general purpose computing on graphics processing units (GPGPUs)]. The authors additionally advocate for the necessity of mitigation techniques like cache partitioning and recent memory system resource partitioning and monitoring (MPAM), which allows the partitioning and monitoring of all memory components in the systems.

In "Autonomous Systems, Trust, and Guarantees," Nima TaheriNejad and Axel Jantsch from TU Wien together with Andreas Herkersdorf from TU Munich present a position article that reviews some of the challenges and possible approaches for providing trust and guarantees in autonomous systems. The authors, in particular, discuss the deterministic methods for more dependable autonomy where working within hardbounded corridors for operational parameters allows to guarantee functional and extra-functional lower and upper bounds for system operation and define safety margins around these areas can be applied to provide counter actions possibly using degraded behavior to prevent violations. The authors introduce orthogonal autonomy where functional and extra-functional properties are autonomously controlled and optimized in the design process through diverse spatial redundancy. The authors emphasize as well the need for expressive system design that allow autonomous systems to trace and explain their decisions and reaction which is often required for providing guaranteed operation and performance in safety-critical applications.

In "Creating a Foundation for Next-Generation Autonomous Systems," David Harel and Assaf Marron from the Weizmann Institute of Science together with Joseph Sifakis from the Université Grenoble Alpes advocate the need for a new autonomics foundation focusing on different aspects of system engineering for autonomous systems with a focus on decision-making logic and its processes for building trustworthy autonomous systems. This requires modeling the environment as well as the infrastructure in terms of mechanisms used to adequately orchestrate and control execution, as well as controlling and measuring the behavioral coverage. Supporting techniques like metamorphic testing in physical environment allows to check that the system behaves correctly for a given scenario and then provides assurances for many other scenarios that differ from the basic scenario by environmental changes. The authors discuss as well an important challenge combining model- and data-driven approaches where the design process intrinsically differs. ■

Selma Saidi is a Professor of Embedded Systems with TU Dortmund. Her research involves the design, implementation, and validation of innovative intelligent embedded systems. Key aspects are the development of novel hardware and software design methods for embedded and autonomous systems where performance, predictability, and self-adaptability play an important role. She has a PhD in computer sciences from the University of Grenoble, Grenoble, France, conducted together with STMicroelectronics (2013). She is an initiator of the DATE Special Initiative on Autonomous Systems Design.

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