Tutorial: Self-Awareness in Cyber-Physical Systems

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Abstract

The concept of self-awareness has become a hot research topic in a variety of disciplines such as robotics, artificial intelligence, control theory, networked systems, and so on. Its applicability has been explored in various application domains such as automotive, consumer electronics, industrial control, medical equipment, and so forth. The topic owes its attractiveness to many examples in insects, animals and humans, where self-awareness is attributed to facilitate highly resilient and outstandingly efficient behaviors. Thus, self-awareness holds the promise to promote dependability in all types of smart gadgets and artificial agents in the interconnected world of future.

This tutorial will introduce the concepts surrounding self-awareness in the context of Cyber-Physical Systems (CPS). A key facet of CPS is the inherent control function where the environment is sensed, the system is analyzed, and adaptions are applied to respect constraints and achieve desired goals. In control theory the design and analysis of autonomous systems has long been subject of intensive research. In recent years self-awareness has been proposed as a handle to equip traditional control systems with a deeper understanding about itself and its environment in the context of the goals of the system. The design community of complex hardware integrated circuits, embedded and cyber-physical systems has also recognized self-awareness as a means to improve dependable behavior in the presence of uncertainties, faulty components and unexpected changes of the environment.

In the first part of this tutorial, we begin with a brief review of self-awareness in nature and motivations behind implementing self-awareness in our systems and its respective benefits. We review the concepts of environment- and self-models, self-inspection, semantic interpretation, semantic attribution, goals and expectations, history, prediction, and how they contribute to awareness and self-awareness, how they contribute to improved robustness and meaningfulness of behavior, and, finally, how they can be realized in cost-efficient hardware structures. We then provide an overview of notions of self-awareness for CPS, various levels of self-awareness and respective taxonomy, as well as some examples. We wrap up this section by outlining some of the challenges faced during the design of self-aware CPS.

In the second part of the tutorial, we delve deep into details of a specific example of self-aware systems with severe resource constrains, namely System-on-Chip. We highlight the need for a self-aware design paradigm in the context of complex many-core Systems-on-Chip that must address the often conflicting requirements of performance, resiliency, energy, heat, cost, security, and so on, in the face of highly dynamic operational behaviors coupled with process, environment, and workload variabilities. Unlike traditional Multi-Processor Systems-on-Chip (MPSoCs), self-aware SoCs must deploy an intelligent co-design of the control, communication, and computing infrastructure that interacts with the physical environment in real-time in order to modify the system's behavior so as to adaptively achieve desired objectives and Quality-of-Service (QoS). Self-aware SoCs require a combination of ubiquitous sensing and actuation, health-monitoring, and statistical model-building to enable the SoC's adaptation over time and space. Towards this end, we describe CyberPhysical-Systems-on-Chip (CPSoC), a new class of sensor-actuator rich many-core computing platforms that intrinsically couples on-chip and cross-layer sensing and actuation to enable self-awareness. The CPSoC design paradigm enables self-awareness (i.e., the ability of the system to observe its own internal and external behaviors such that it is capable of making judicious decision) and (opportunistic) adaptation using the concept of cross-layer physical and virtual sensing and actuations applied across different

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layers of the hardware/software system stack. The closed loop control used for adaptation to dynamic variation -- commonly known as observer-decide-act (ODA) loop -- is implemented using an adaptive, reflexive middleware layer. The learning abilities of CPSoC provide a unified interface API for sensor and actuator fusion along with the ability to improve autonomy in system management.

Speaker Biographies

Nikil Dutt is a Chancellor's Professor of CS, EECS and Cognitive Sciences at the University of California, Irvine. He received a B.E.(Hons) from BITS Pilani in 1980, MS from Penn State in 1983 and PhD from the University of Illinois at Urbana-Champaign in 1989. His research interests span embedded systems, electronic design automation, computer architecture, compilers, and brain-inspired architectures and computing. He has received numerous best paper awards and is coauthor of 7 books. Professor Dutt served as Editor-in-Chief of ACM Transactions on Design Automation of Electronic Systems (TODAES) (2003-2008) and as Associate Editor of ACM Transactions on Embedded Computer Systems (TECS) and of IEEE Transactions on VLSI Systems (IEEE-TVLSI). He has served on the steering, organizing, and program committees of several premier CAD and Embedded System Design conferences and workshops, and has served on the advisory boards of ACM SIGBED and ACM SIGDA. Professor Dutt is a Fellow of the ACM, Fellow of the IEEE, and recipient of the IFIP Silver Core Award.

Nima TaheriNejad is a post-doctorate University Assistant at TU Wien (Technical University of Vienna), Institute of Computer Technique (ICT) and a PhD graduate of Electrical and Computer Engineering Department at University of British Columbia (UBC), Vancouver, Canada. Currently his main areas of research focus are Systems on Chip, Self-awareness, Embedded Systems, Intelligent Systems, Learning and Robotics.
Accomplishing his degrees with A+ GPAs, Dr. TaheriNejad has been granted several awards and scholarships from attended universities and conferences. He has authored a book and published in/served as a reviewer for several journals and conferences. Dr. TaheriNejad has been invited to give talks for Canadian Manufacturers and Exporters as well as different universities. He has also taught courses on Electronics and Robotics, based on his extensive experiences in teacher assistantship.
Dr. TaheriNejad served as chair and secretary (public relations) in several robotic competitions and has served as an executive member of the AUTO21 HQP Advisory Committee since October 2012. Since May 2013 to May 2015, Dr. TaheriNejad was the chair of the AUTO21 HQP Advisory Committee and joined the AUTO21 Board of Directors.