Resource Constrained Self-Aware Cyber-Physical Systems (Tutorial)

N. TaheriNejad*, P. Lewis†, A. Jantsch*, A. Rahmani*‡, and L. Esterle†
* TU Wien, Vienna, Austria
E-mail: {axel.jantsch, nima.taherinejad}@tuwien.ac.at
† Aston University, Birmingham, England
E-mail: {p.lewis, l.esterle}@aston.ac.uk
‡ University of California, Irvine, USA
E-mail: a.rahmani@uci.edu

***Abstract*—The overlap of the two established fields of cyber-physical systems and self-aware computing systems constitutes a challenging class of systems that require autonomy and must satisfy multiple, possibly conflicting constraints (e.g., performance, timeliness, energy, reliability). Self-aware cyber-physical systems are situated in dynamic physical environments and constrained in their resources, they understand their own state and that of their environment. Based on that understanding, they are able to make appropriate decisions autonomously at runtime with high efficiency. In this tutorial, we will review the state of the art of this exciting domain.**

I. Introduction

Many Cyber-physical systems (CPS) are expected to operate autonomously and reliably under changing environmental conditions. Although, the research community has recognized the value of self-awareness for CPSs [1, 2, 3], we still have incomplete understanding of the relevant concepts and their realization. In this tutorial we review key aspects of self-aware CPS, namely the need for reliable, comprehensive observation, the fact that every CPS has a unique position in the world, self-awareness as a method for understanding a situation by the system itself, and the self-* properties that can be build on this basis of self-awareness.

II. Comprehensive Observation

The processing of sensory data in a self-aware system would ideally be accompanied with the collection of meta data that allows for assessing the quality of the observations and their relevance to the goals of the system. In [4], these meta data were categorized into Abstraction, Disambiguation, Desirability, Relevance, Data Reliability, Confidence, Attention, and History. In this tutorial, using some examples [5, 6, 7, 8, 9], we show how applying simple strategies regarding this fundamental aspects can lead to significant improvements in performance of the system, in particular regarding its reliability and resource efficiency. A key feature is the limited resources these techniques require.

III. Situatedness

The system is always in a physical situation relating its body to environmental bodies [10]. It lives through and keeps track of a sequence of situations for which subjective models are built. Hence, the system is keenly aware of spatial and time relations between its body and its environment. Spatial relations are based on absolute (a coordinate system) and/or relative (right, left, above, below, ...) relations. In a similar fashion, time relations are also based on absolute (some world time) and/or relative (earlier, later, ...) relations and imply real-time properties. Within this tutorial, we will also shed light on various other forms of relations in which a system can be situated [11]. Systems operating on these subjective experiences and the challenges of interactions based on such knowledge will be discussed. Furthermore, we explore potential issues of extracting meaningful information from such models for other systems to enable and improve collaborative behaviour.

IV. Computational Self-awareness

Computational self-awareness has a dual role in self-* systems. On the one hand it provides a foundation for these self-* properties, as it is concerned with getting the right self-knowledge to inform other self-* behaviours. On the other hand, it also provides a meta-reasoning layer above them, in order to guide effective self-* behaviour. We will review role and benefits of computational self-awareness in resource constrained Cyber-Physical Systems (CPSs).

V. Self-* in in Mobile Resource Management

Battery powered-devices are the most ubiquitous computers in the world. In order to meet performance demands by users utilizing complex workloads, increasingly powerful hardware platforms are being deployed in battery-powered devices [12]. These platforms include several configurable knobs that allow for a tradeoff between power and performance. With such a large number of possible configurations, Mobile platforms require intelligent runtime management in order to achieve system goals for complex workloads [13, 14]. In this part of the tutorial, we will present lines of research [15, 16, 17, 18] addressing key challenges for achieving computational self-awareness that can make the design, maintenance and operation of complex, heterogeneous systems adaptive, autonomous, and highly efficient.

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VI. Conclusion

In this tutorial, we approached resource constrained self-aware CPSs and their design from different angles. First, using examples (in particular from healthcare domain), we discussed how employing simple strategies inspired by elements of observation can improve the performance of a self-aware system without requiring a large overhead. Next, we discussed how the environment affects self-aware CPSs and how considering this situatedness can lead to better operations of a self-aware CPS. Next, we delved deeper into computational models of self-awareness and what their role is enabling self-aware CPSs to meet their goals. Lastly, we concluded the tutorial presenting a concrete and exciting example of embodied CPS, namely neuro-robotic. We hope that the tools, ideas, and concepts presented in this tutorial will inspire attendees in design and development of their own resource constrained self-aware CPS.

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