Guest Editorial: Special Issue on Cyber-Physical Systems and Services

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A cyber-physical system (CPS) integrates a vast variety of static and mobile resources, including sensor and actuator networks, swarms of robots, remote-controlled vehicles, critical infrastructures, control and decision software, static data and just-in-time information from sensors, knowledge, data analytics and fusion software, event-driven supply chains, and humans, and offers great potential for achieving tasks that are far beyond the capabilities of existing systems [1]. Individual users, organizations, and various communities can transform the vast space of cyber-physical entities into capabilities that no single entity can achieve alone. However, these capabilities do not come easily. Intelligence is needed for just-in-time composition of resources into services. Associated challenges include how to manage the vast number and diverse varieties of static and mobile physical entities, how to describe the capabilities of the cyber-physical entities, how to decompose high-level goals into low-level control commands for the individual entities, how to achieve intelligent coordination and manage information flow among the entities.

Existing technologies may be leveraged to provide partial solutions to challenges in cyber-physical systems and services (CPSS). Rapidly developing service-based technologies, such as service discovery, service composition, service adaptation, dynamic service reconfiguration, and service interaction models can be applied to integrate cyber-physical entities into desired system capabilities and to mediate the interactions among physical entities, software, information, humans, and applications. Semantic technologies can offer higher-level abstractions for specification of the capabilities of CPSs. Intelligent agents and coordination technologies can facilitate smart collaborations. Data services and information-sharing technologies can be leveraged to help manage information flow in the CPSS.

Responsiveness, dependability, and security have also been major issues in cyber-physical systems [2]. Due to the vast number of entities in the CPSS, failures become inevitable. Support of robust and adaptive system integration and execution is an important topic. In the physical world, many systems are event-based and have to react in real time to newly arising situations. It can be challenging to achieve responsiveness in a large-scale and complex CPS whose components are potenially from different providers. The real-time requirement becomes even more challenging when a reactive action requires dynamic integration of cyber and physical entities into a cyber-physical service. Physical system security has long been an area demanding research. The ubiquity of physical entities makes them vulnerable to physical attacks. Such entities may become the breaching point for a CPS into which they are integrated. Further exacerbating security and especially access control concerns is the significant complexity typical of CPSs.

Determining or predicting correct behavior of a system has always been a challenging issue. Due to the complexity and dynamicity of the CPSS, it is difficult to analyze and predict emerging behaviors of the composed system. Techniques for formal, experimental, or simulation-based analysis of CPSS are highly essential. Humans constitute a class of physical entities in the cyber-physical world and influence the operation of cyber entities. When a CPS has human in the loop, system behavior analysis and validation become extremely challenging.

Financial issues, such as accounting, pricing decisions, and payment mechanisms, have not been widely explored for CPSS. A system may consist of cyber and physical entities from multiple owners. The potentially complex relations among the entities complicate cost estimation, pricing, and accounting.

As can be seen, numerous issues in CPSS remain open for further research. This special issue presents research results related to these open challenges. Three papers were selected through a rigorous review process. The paper "Uncertainty analysis of middleware services for streaming smart grid applications" by Akkaya, Liu, and Lee investigates timing issues in the data exchange middleware that channels information flow in CPS. In almost all cyber-physical systems, a large number of sensors are utilized to monitor system conditions and facilitate decisision support for control. Thus, the timing of data exchange service is highly critical. Uncertain behaviors occur when the volume of sensor data varies significantly or the middleware topology changes due to resource constraints or failures. The authors of this paper propose a method where system entities in the data exchange middleware are modeled in a fashion that captures the system uncertainty parameters. They use a Monte Carlo simulation-based approach to determine the

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Digital Object Identifier no. 10.1109/TSC.2016.2547518

parameters that characterize timing properites of various system entities and estimate the end-to-end performance of the system. The modeling and analysis approach is applied to two case study middlewares and the results provide valuable insights toward the design of data exchange middleware services.

The paper "Service pricing decision in cyber-physical systems: Insights from game theory" by Liu, et al., considers service pricing issues from the perspective of CPS service organizers (SOs). A CPS SO collects primitive services (simple services) from one or more providers and composes them into a user-oriented higher-level service. Example service organizers include VTrack, which provides omnipresent traffic information based on traffic data collected from multiple service providers, and NoiseTube, which creates noise maps from noise data collected from other providers. Due to the complex dependencies among services, the pricing issue can be complicated. This paper formulates a price competition model, namely, the game based services price decision (GSPD) model, in which the SOs periodically update their service prices based on the game theory. The Pareto-optimal equilibrium points are computed for price decisions. The experimental studies conducted by the authors demonstrate that their GSPD model can explain the price dynamics in the real world, and can help SOs make prudent pricing decisions.

The paper "SEED: A scalable approach for cyber-physical system simulation" by Garraghan, et al., proposes a simulation system design for CPSS to facilitate the study of real operational behaviors of complex CPSS, forecast future system behaviors, and explore hypothetical scenarios. The focus of the paper is on real-time simulation of systems, even those that involve interactions between millions of cyber-physical entities. The authors have developed a Simulation EnvironmEnt Distributor (SEED), which supports automated simulation partitioning and simulation task distribution. The SEED system is validated through large-scale experiments and the results demonstrate that it is capable of simulating very large-scale CPSs with minimal slow down.

We hope this special issue provides insights for research in CPSS. Many colleagues have contributed towards its success. First, we would like to thank the authors who submitted their high-caliber work to this special issue. We especially appreciate the reviewers who spent time and effort to provide their valuable comments for improving the quality of the submitted papers. We would also like to thank the Editor in Chief, Dr. Ling Liu, and the Administrator, Ms. Christine Kurzawa, of *IEEE Transactions on Service Computing* for their help and support throughout the preparation of this special issue.

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