Challenges for Application Platforms for integrated Cyber Physical Systems

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Emerging Trends: Cyber-physical systems (CPS) such as Electric Grids, Water Supplies, and Transportation Systems form the backbone of modern civil infrastructure. We are increasingly moving towards CPS wherein sensor and actuator capabilities can be distributed to remote devices, which are part of a logical cluster. Creating, managing and operating distributed software on these systems present many challenges that are not obvious in traditional distributed systems.

While traditional CPS design issues caused by the tight integration between the physical and cyber elements both within and across the components and subsystems remain, the newer issues due to distribution of applications in both space (physical nodes) and time (deployed and configured over time) persist.

Use Case: In this paper the example of a future urban transportation system will serve as motivation for integrated Cyber Physical System. Such a system may consist of the following main components:

- Interconnected cars able to perform limited autonomous driving, e.g. that are able to park autonomously in a parking facility.
- Parking facilities equipped with sensors (see figure 1) to determine usage of parking space and/or advanced sensors that may aide cars in parking. Further, the parking facilities may be equipped with indoor navigation systems to help cars finding their way inside the parking garage.
- Traffic management systems operated by city authorities will use historic usage patterns of parking facilities and historic traffic and destinations patterns to guide motorists to appropriate facilities.
- Sensors embedded in light poles, traffic lights or other objects that gather information about available on-street parking spaces and traffic density.
- Motorists that express their individual traffic preferences and make ultimate decisions regarding their transportation needs.
- Parking Management Systems that may decide based on current or predicted demand patterns how to use their resources and how to price them.

The platform must support providing guidance for both networked cars and classic cars under complete control of a motorist. Also with regards to the cars itself, different capabilities must be supported. For example, some cars may be equipped with advanced, laser or radar based sensors while other may only use a camera system for navigation. In the parking facility scenario, it would be beneficial to let a car use the sensors of a already parked car to aid with navigation or high-precision maneuvers.

Fig. 1. Parking guidance system and occupancy sensors (Source: Siemens)

Challenges: A platform for such a cyber physical system must cope with the following challenges:

• **Heterogeneity**. Applications will typically span multiple nodes, for reasons related to the availability of resources. For example, some nodes may have sensors, some may have actuators, some may have the computing or storage resources, some applications need more than the processing power available on one node. Applications that use these resources must therefore be architected to rely on loosely connected, interacting components, running on different processors. Moreover, each of these system components may have been developed by varying vendors using different protocols and technologies for inter-component communication.

• **Discovery:** For entities to communicate with each other, how do they even find each other? For example, if a device wants to express interest in receiving some type of event, how does it express this interest in a way publishers can understand? How is matching done? Thus, the key question is how can we

realize a discovery process that overcomes the heterogeneity and can evolve to include future generation of devices?

• **Lifecycle:** Most CPS are intended for continuous operation. The entities that compose a CPS must support the continuous operation of a CPS during its different lifecycle phases. This starts with the engineering of a CPS, its initial installation and configuration, its commissioning, handover and operation and decommissioning. Most important, during the operation the CPS will continuously evolve through maintenance, extension and reconfiguration. All entities must support these scenarios which can not be planned in advance.

• **Variants:** Currently, CPS are often engineered as one-off solutions. They are usually not architected in a way that would ease a new variant with different types of sensors or actors or in smaller or larger installations of the system.

• **Information Dissemination:** Information must somehow reach the recipients despite no common protocol and data model (as of now). Moreover, for services that may be critical, e.g., services that track hazardous pollutants in the air or water, must be able to deliver the sensory data in a timely and secure manner.

• **Big Data:** Since the generated information in the realm of very large and continuously streamed, there is a need to deploy in-stream information processing blocks at strategic locations that can dynamically be migrated. These processors must be able to handle data from heterogeneous sources.

• **Timeliness, Reliability and Security:** Orthogonal to the above concerns are the non functional properties of timeliness, reliability and security that help to realize resilient systems. This is an important dimension to be considered while addressing other concerns and not as an afterthought. For example, information flows in general and access to shared resources in particular should be controlled under some overarching security policy. High quality, sensitive customer data (*e.g.*, from the power grid) cannot be made available to untrusted applications that are supplied by parties needing access to derived data containing daily averages only—and those applications should not have any means to access that high-grade, sensitive data.

This broad set of requirements presents a vexing challenge given the tools, techniques, and technology available today. Other domains have solved some of these challenges, either in isolation or as part of a subset of the above, to a greater or lesser extent. Unfortunately, most of these solutions are successful by limiting choice, either in implementation (e.g. requiring use of a particular distribution middleware or application platform), or by limiting variability and adaptability at run time (e.g., static application architectures). The fact remains that there is no single silver bullet that will solve these challenges simultaneously and satisfactorily. Participants in next generation CPS will be far too varied to take advantage of a single approach; solutions appropriate for highly resource constrained portions of the system will likely be a combination of others.