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Introduction

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Cyber-physical systems

What is it? Definition:

- Cyber-Physical Systems (CPS) is defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities. [*A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems Jay Lee, Behrad Bagheri, Hung-An Kao*]
- The term cyber-physical systems (CPS) refers to a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities. [*The Impact of Control Technology Published by: IEEE Control Systems Society February 2011 Radhakisan Baheti and Helen Gill*]
- Cyber-physical systems (CPS) are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. [*Cyber-Physical Systems: The Next Computing Revolution, Lee , Sha, Stankovic*]

The concept of a cyber-physical system is a generalization of embedded systems. An embedded system consists of hardware and software integrated within a mechanical or and electrical system designed for a specific purpose. CPS consists of a computational unit, sensors, actuators and a physical world which it must observe and react on it. CPS are reactive systems which interacts with its environment in an ongoing manner. There is an

endless loop of data collection and input evaluation throughout the time. In a cyber-physical system, the controller consists of discrete software concurrent components operating in multiple modes of operation, interacting with the continuously evolving physical environment.

Why is it useful?

Advance in the field of Cyber-physical systems will bring us closer to usage of high-speed, low-cost, and real-time embedded computers in technologies like electric networks that employ advanced monitoring [Smart Grids: A Cyber–Physical Systems Perspective, By Xinghuo Yu and Yusheng Xue], networked autonomous vehicles [*E. A. Lee, "Cyber Physical Systems: Design Challenges," 978-0-7695-3132-8*] or prosthesis like neural controlled artificial leg [*On Design and Implementation of Neural-Machine Interface for Artificial Legs, Xiaorong Zhang, Yuhong Liu*]. CPS are a research priority for both, government agencies (National Science foundation) and industry (automotive, avionics, medical devices).

What challenges does it offer?

In comparison to the traditional software development architecture, the creation of control software for CPS differs in the emphasis on the security, reliability and performance of the system. CPS are intended in areas which have direct impact on people's lives and carry much more responsibility than general software programs.

High safety and reliability requirements can be particularly difficult if we consider that CPS are operating mainly in physical unpredictable world. Such environment puts many obstacles in development of the final product.

In the world of embedded systems people always put strong requirements for high reliability and predictability both on the hardware and software. Given CPS these requirements will only get higher. CPS are intended to be deployed in areas as automotive industry, avionics or medical devices. Apart from embedded systems, CPS will not be operating in a controlled environments and must be robust to unexpected conditions and adaptable to subsystem failures. [E. A. Lee, *Cyber Physical Systems: Design Challenges*, 2008,978-0-7695-3132-8]

Real-time computing

CPS are intended to seamlessly interact with the physical world around in an infinite feedback loop. Computations in CPS computation unit are affected by the data gathered from sensors and based on the result of the outcome, the system reacts accordingly. Real-time computing can be very challenging, because it usually consist of processing huge amount of inputs and delivering immediate reactions.[TODO: more info needed, articles to support my opinions]

Concurrence

When defining CPS, many publications emphasize the importance of concurrency. [E. A. Lee, *Cyber Physical Systems: Design Challenges*, 2008,978-0-7695-3132-8]

Communication and data exchange is indeed an important part of CPS, but not a necessity. Many CPS are based on a distributed network model [TODO: more info needed, an article] or combines together multiple devices into one, more compact system. Since there are not yet mature techniques for development of solid purely concurrent real-time software, it represents a challenge. [E. A. Lee, *Cyber Physical Systems: Design Challenges*, 2008,978-0-7695-3132-8]
TODO: more publications to be more reliable

Models of Cyber-Physical systems

Introduction

The design of a complex cyber-physical system — especially one with heterogeneous subsystems distributed across networks — is a demanding task. Commonly employed design techniques are sophisticated and include mathematical modeling of physical systems, formal models of computation, simulation of heterogeneous systems, software synthesis, verification, validation, and testing.[J. C. Jensen, D. H. Chang and E. A. Lee, *A model-based design methodology for cyber-physical systems*,978-1-4244-9538-2].

Model-Based design

Embedded system is usually constructed from the physical plant and the controller module. The controller contains specific algorithm, designed for capabilities and resources of given embedded system. In industry production area a Model-driven development paradigm has been deployed and successfully tested. Unfortunately when we move from simple programs to more complex software systems and particularly to cyber-physical systems, former design techniques and tools are no longer applicable.

A different paradigm was created, founded on a Model-based design. Jensen et al. 2011 [J. C. Jensen, D. H. Chang and E. A. Lee, *A model-based design methodology for cyber-physical systems*,978-1-4244-9538-2] propose a 10-step methodology for developing cyber-physical systems:

1. State the Problem
2. Model Physical Processes
3. Characterize the Problem
4. Derive a Control Algorithm
5. Select Models of Computation
6. Specify Hardware
7. Simulate
8. Construct
9. Synthesize Software
10. Verify, and Validate, and Test

This approach helps designers break enormous task of creation of CPS into manageable iterations, which can be repeated if needed, or to which we can return if we identify an error. Using such paradigm we can create a whole model of CPS by moving forward through a set of logically sorted steps that address first general and later more concrete aspects of the

cyber-physical system. As soon as we have the model complete this methodology helps us to specify and create a real prototype that we can further test and verify.

About V model of model-based design….

Model example