Road2CPS Roadmapping Workshop

CPSoS
Towards a European Roadmap on Research and Innovation in Engineering and Management of Cyber-physical Systems of Systems

Roadmap Presentation

Presenter: Christian Sonntag
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CPSoS Overview (1)

- 30 month Support Action
- Provides an exchange platform for Systems of Systems related projects and communities
- Focus on Systems of Systems where large complex physical systems interact with computing and communication systems – Cyber-physical SoS

Goal:

Define a European research and innovation agenda on Cyber-physical Systems of Systems
CPSoS Overview (2)

- Not campaigning for a single community, but
- **Bridging between communities**
  - Systems and control
  - Computer science
  - Software and systems engineering
  - Physics
  - Tool developers (simulation, verification, software engineering)
- **Bottom-up and top-down approach**
  - Analyse the needs in application domains
  - Analyse the state of the art in methods and tools
  - Integrate the two views to define the most important gaps and actions needed
Cyber-physical Systems of Systems

What are Cyber-physical Systems of Systems?

Large, complex, often spatially distributed Cyber-physical Systems that exhibit the features of Systems of Systems

Cyber-physical Systems (CPS)

- **Tight interaction**
  - of many distributed, real-time computing systems and physical systems

Examples
- Airplanes
- Cars
- Ships
- Buildings with advanced HVAC controls
- Manufacturing plants
- Power plants
- ...

Systems of Systems (SoS)

- **Many interacting components**
  - Examples
    - Large industrial sites with many production units
    - Large networks of systems (electric grid, traffic systems, water distribution)

- **Dynamic reconfiguration**
  - Components may...
    - be switched on and off (as in living cells)
    - enter or leave (e.g. in air traffic control)

- **Physical connections**
  - Material/energy streams
  - Shared resources (e.g. roads, airspace, rails, steam)
  - Communication networks

- **Continuous evolution**
  - Continuous addition, removal, and modification of hardware and software over the complete life cycle (often many years)

Examples of Cyber-physical Systems of Systems

- **Integrated large production complexes**
  - Major source of employment and income in Europe
  - Major consumer of energy and raw materials
  - Many interconnected production plants that are operated mostly autonomously with distributed management structures

- **Transportation networks (road, rail, air, maritime, …)**
  - Vital to the mobility of EU citizens and the movements of goods
  - Large integrated infrastructures with complex interactions, also across national borders
  - Involve multiple organizational and political structures

Many more examples, e.g. smart (energy, water, gas, …) networks, supply chains, or manufacturing

Partial autonomy

Local actors with local authority and priorities

- Autonomic systems ...
  - … cannot be fully controlled on the SoS level
  - … need incentives towards global SoS goals

- Examples
  - Local energy generation companies
  - Process units of a large chemical site

Emerging behavior

The overall SoS shows behaviors that do not result from simple interactions of subsystems

- Usually not desired in technical systems, may lead to reduced performance or shut-downs

- Examples
  - Power oscillations in the European power grid
  - Oscillations in supply chains
Enabling Technologies

- Communication technologies, standardized protocols, Internet of Things, Big Data
- Computing technologies
  - High-performance and distributed computing, multicore and mixed-criticality computing, low power processing / energy harvesting for ubiquitous installation
- Sensors, including energy harvesting
- Human-machine interfaces, e.g. head up displays, display glasses, polymer electronics and organic LEDs
- Security of distributed/ cloud computing and of communication
- Systems and control theory and technology

...
Recommendations for Research Priorities

1. Distributed Management of Cyber-physical Systems of Systems

- Decision structures and system architectures
- Self-organization, structure formation, and emergent behaviour in technical systems of systems
- Real-time monitoring, exception handling, fault detection and mitigation of faults and degradation
- Adaptation and integration of new components
- Humans in the loop and collaborative decision making
- Trust in large distributed systems
Recommendations for Research Priorities

(2) Engineering Support for the Design-operation Continuum of Cyber-physical Systems of Systems

- Support of the design-operation continuum of cyber-physical systems of systems
- Integrated engineering of CPSoS over their full life-cycle
  - New frameworks for integrated cross-layer design, collaborative engineering, (semantic) systems integration, ...
- Establishing system-wide and key properties of CPSoS
  - Automatic analysis and verification, ...
- Modeling, simulation, and optimization of CPSoS
  - Model management, global high-level models, efficient simulation algorithms, legacy systems integration, ...
Recommendations for Research Priorities
(3) Cognitive Cyber-physical Systems of Systems

- Situational awareness in large distributed systems with decentralized management and control
- Handling large amounts of data in real time to monitor the system performance and to detect faults and degradation
- Learning good operation patterns from past examples, auto-reconfiguration and adaptation
- Analysis of user behaviour and detection of needs and anomalies
Unique Findings

- Similar CPS(oS) challenges arise in many different areas, e.g.
  - Transportation (marine, rail, aerospace, automotive)
  - Logistics
  - Electric power grids
  - Process industries
  - Smart buildings

- Common challenges in these areas
  - Full-life-cycle engineering
  - Coordination and optimization
  - Modeling, simulation, and model management
  - System-wide validation and verification
  - Systems integration
  - Humans in the loop
Main Barriers Identified

- CPSoS usually already exist -> legacy systems integration essential
- Lack of interdisciplinary heterogeneous, multi-scale CPSoS modeling at different levels of resolution
- Certification of safety-critical CPSoS (parts) is difficult due to CPSoS unpredictability and constant evolution
- Integration, processing, and management of high-quality data across a complete CPSoS is essential
  - Data sources are often not yet accessible to a degree that is needed for CPSoS services and applications
  - CPSoS require continuous monitoring based on high-quality data sets to detect malfunctions and abnormal operation (which are the norm in CPSoS)
- Cyber security is a major concern
Contact

Haydn Thompson (Haydn Consulting Ltd.)
Christian Sonntag (TU Dortmund / euTeXoo GmbH)

haydn.thompson@thhink.com
christian@eutexoo.de

http://www.cpsos.eu