Road2CPS
Roadmapping Workshop

CPSoS

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

Roadmap Presentation

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24/06/2015

Paris

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

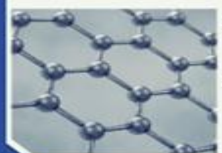
Cyber-physical Systems (CPS)

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)

Physical connections

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

Dynamic reconfiguration

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

Continuous evolution

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

Partial autonomy
Local actors with local authority and priorities

Autonomous 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 behaviours 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

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

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

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