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

CPSoS Roadmap

European Roadmap on
Research and Innovation in

Engineering and Management of Cyber-physical Systems of Systems

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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)

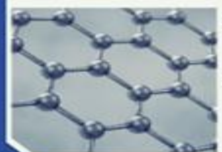
Tight interaction

of many distributed, real-time computing systems and physical systems

Examples

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

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

Systems of Systems (SoS)

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

CPSoS Partners

- TU Dortmund (Coordinator)
  - Sebastian Engell
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inno

Analysis of the State of the Art

Kick off of 3
Working Groups
(2… members)

Analysis of relevant programmes

38 intervie…
…ons

C…

…the art –
reports

3 public meetings with 100+ participants

CPSoS State of th…
art document and
initial roadmap

MAJOR INDUSTRIES AND 17 SMEs INVOLVED

Jan 2014 **June 2014** **Dec 2014**

Research and Innovation Challenges

- **Distributed management of cyber-physical systems of systems**
- **Methods and tools for the engineering of CPSoS**
- **Cognitive CPSoS**

- See the roadmap document at **http://www.cpsos.eu/roadmap/**

Medium-term Research and Innovation Domains in Cyber-physical Systems of Systems

www.cpsos.eu

Overcoming the modelling bottleneck

- Faster model development and better model reuse, automated modelling
- Model maintenance and adaptation
- Collaborative environments for model exchange between competing companies, trust in models from others
- Integration of legacy system models
- Combination of models of different depth and different formalisms in system-wide models of CPSoS, co-simulation, hierarchical modeling, appropriate levels of abstraction
- Meta-modelling and model management to ensure model consistency
- Modelling over the full life cycle of the system
- Combination of model- and data-based optimization
- Economic / socio-technical modelling

System integration and dynamic reconfiguration

- Dynamic requirements engineering
- Plug-and-play integration and live removal of components
- Configuration control
- Incremental live validation of modifications to the system
- Integrated engineering over the full life-cycle
- Reference architectures, open platforms and easy-to-test interfaces for integration, semantic integration to simplify the interactions of existing systems as well as the deployment of new systems
- Standardization

Robust distributed system-wide control and optimization

- Coordination mechanisms for systems with autonomously managed units
- Understanding how the management and control structure (centralized, hierarchical, distributed, clustered) influences system performance and robustness
- Dealing with uncertainty, neglected couplings, stochastic effects, user interactions
- Combining model-based and data-based optimization
- Involvement of humans

Resilience in systems of systems

- Strategies for system-wide fault detection and mitigation
- Integrated cross-layer handling or disturbances and break-downs
- Advanced integrated monitoring of the state of the system and triggering of preventive maintenance to improve long-term performance

Human in the loop

- Filtering and appropriate presentation of information to human users and operators for the acceptance of advanced computer-based solutions
- Investigation of the human capacity of attention and of measures to provide motivation for sufficient attention and consistent decision making
- Analysis of the cognitive models of system operators
- Monitoring of the actions of the users and anticipating their behaviours and their situation awareness
- Social phenomena (dynamics of user groups)
- Combination of the capabilities of humans and algorithms in real-time monitoring and decision making (collaborative decision making and control, e.g. autonomous cars)

Towards cognitive systems: data-based system operation

- On-line data stream analysis to monitor the system performance, to detect faults and degradation, and to identify characteristic situations
- Combination of (semi-)rigorous and data-based models
- Data-based prediction and its use for control and optimization
- Visualization of the results of online data analysis
- Automatic reconfiguration and adaptation, learning good operation patterns from past examples
- Trust in data

Manufacturing Systems

- New ICT infrastructures for adaptable, resilient, and reconfigurable manufacturing processes
  - Seamless and low-effort reconfiguration of manufacturing systems for fast adaptation to changing customer demands
  - Self-adaptation of production machines and robots
  - Semantic system integration of decentralized manufacturing systems across the complete value chain
- Data and information visualization for decision support in manufacturing
  - Automatic extraction of crucial indicators from large amounts of data
  - New HMI paradigms for responsive data visualization to maximize the real-time situational awareness of human operators

Transportation and Logistics

- Development and exploitation of ICT to support multi-disciplinary, multi-objective optimization of operations in complex, dynamic, 24/7 systems
  - Improve capacity, efficiency and reduce cost
  - Maintain continuous operation and provide resilience to disruption and failures
  - Reduce emissions
- Safe, secure and trusted autonomous operations for systems with humans in the loop
  - What systems should be made autonomous and what should be left to the human operator?
  - Homogeneous HMIs
  - Societal acceptance, trust, privacy
  - Liability

Thank you very much for your attention!

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