

Rethinking Interoperable CPS

as Interactive Behavior Designs

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Evolving CPS as Interactive System-of-Systems

- Introduction
- CPS as interactive systems
- System-of-Systems & Complex Adaptive Systems
- Pathways CPS Architecting & Design
- Conclusions



Introduction



- Workforce's ability to exploit business-relevant technologies, e.g., IoT, is decisive for competitive advantage
 - https://www.gartner.com/smarterwithgartner/top-10-technologies-driving-the-digital-workplace
- Individual activities will be bound to digital actions "Internet of Behaviors" (<u>https://www.gartner.com/smarterwithgartner/gartner-top-strategic-predictions-for-2020-and-beyond/</u>).
- '40% of professional workers will orchestrate their business application experiences and capabilities like they do their music streaming services' (https://www.gartner.com/smarterwithgartner/gartner-top-strategic-predictions-for-2020-and-beyond/

- Cyber-Physical Systems (CPS) will be affected by continuous change
- ➔ For dynamic adjustment of CPS interoperability needs to be ensured

Cyber-Physical Systems



- CPS-architectures are
 - traditionally run decentralized
 - Inked to communication and modular, e.g., agent-based structures
- CPS components
 - need to co-operate through exchanging information and adapting to environmental changes
 - deliver or process data on demand
- CPS
 - allow large-scale interconnected processes as reconfigurable networks of locally autonomous actors, including IoT-enabled sensory system
 - link "cyber" (virtual, computational) and "physical" components stemming from interconnecting physical, social, and virtual worlds

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Cyber-Physical Systems





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Pathways





Pathway 1: Architecture Perspective: Towards an aligned socio-technical application architecture

Pathway 2: Modeling Perspective: Towards exectuable behavior representations



Pathways – Level 1 - CAS





Taking a System-of-Systems Perspective

- System-wide patterns shape the behavior of each actor (humans, robots, applications, etc.,) resulting in a Complex Adaptive System
- System-of-System perspective
 - helps coping with complexity, taking into account emergent behavior and transformations
 - A group of interacting components or sub systems are linked in a way their internal structure can handle their interaction in way that a unified whole can be formed
- Complex systems have various networked actors or components interacting with each other albeit their often physical and functional heterogeneity
- As System-of-Systems they are organized hierarchically, with each subsystems contributing to an overall system function
- Allowing for autonomous behavior of systems or components requires a federated CPS architecture
 - → CPS systems evolve from autonomous systems towards a network

Interoperability engineering: protocol of interacting with network actors is decisive for dynamic alignment





Sample System-of-Systems



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Level 3 – SoS Modeling/Architecting



Approach	Mod.	Exec.	Mon.	UI	Context	
IAPMM [25,26]	\checkmark	×	×	×	×	
BPMN4CPS [27]	\checkmark	×	×	×	×	
BPMN for IoT [28–30]	\checkmark	×	×	×	×	
IoT/WS-BPEL [31]	\sim (BPEL)	\checkmark	\sim (BPEL)	×	\sim (BPEL)	
IoT/WS-BPEL [32,34,35]	\sim (BPEL)	\checkmark	\sim (BPEL)	×	\sim (BPEL)	
ADiWa[36]	\sim (conc.)	\sim (conc.)	×	×	×	
Extended GSM [2,12,13]	\checkmark	×	√ (via GSM)	×	\checkmark	
This work	\checkmark	\checkmark	$\sim (BPMS)$	\checkmark	\checkmark	

Integration of IoT and BPM (Schöning et al., 2020)





System-of-Systems Modeling



Subject-oriented Modeling – Representational Meta Model (Weichhart et al., 2020)







Sample: Home Healthcare CPS Modeling





Sample: Home Healthcare CPS Modeling



Integrated Modeling & Execution Support

Validation

https://www.metasonic.de/produkte/metasonicprocess-touch/ueberblick/



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Exploration

Fleischmann, A., Oppl, S., Schmidt, W., & Stary, C. (2020). *Contextual Process. Digitalization: Changing Perspective - Design Thinking - Value-led Interaction:* Springer, Cham.





Evolving CPS as System-of-Systems



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Pathways are Likely to be Intertwined



Pathway 1: Architecture Perspective: Towards an aligned socio-technical application architecture

Pathway 2: Modeling Perspective: Towards exectuable behavior representations



C

Conclusion

- System-of-Systems development should lead to architectures allowing dynamic changes
- Situation-sensitive behavior is key in CPS engineering
 - A situation is analyzed in terms of how the different complex adaptive system parts influence and relate to each other rather than decomposing it into parts that are studied in isolation.
- Resulting CPS behavior focuses on actors of different kinds with
 - Designers tackling interoperability issues on the model
 - Model finally needs to be propagated to operation
- CPS designers need to set links and interconnections influencing behavior
- Subject-oriented design
 - can help due to its simple interaction structure and behavior centeredness
 - allows encapsulation of behavior and addressing actor behavior through data-driven message exchange
 - Stakeholders can engage more effectively into system alignment as they are relieved from transformation tasks



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