Rethinking Interoperable CPS as Interactive Behavior Designs

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

- Individual activities will be bound to digital actions - “Internet of Behaviors”

- ‘40% of professional workers will orchestrate their business application experiences and capabilities like they do their music streaming services’

- 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
  - linked 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
Cyber-Physical Systems

CPS

Information systems

Communication
Connectedness

Control
Responsiveness

Cyber
Physical

Computation
Intelligence

CPPS

BUSINESS INFORMATICS – COMMUNICATIONS ENGINEERING
Pathways

Modeling and Architecture Language for Interoperable CPS

Pathway 1: Architecture Perspective: Towards an aligned socio-technical application architecture
Pathway 2: Modeling Perspective: Towards executable behavior representations
Pathways – Level 1 - CAS

1. Agents interact

2. System-wide patterns emerge

3. Those system-wide patterns, in turn, influence the behaviors of the agents

Complex Adaptive Systems
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 sub-systems 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

Digital Twin (S-BPM) model of CPS component
Message / Data Exchange
Dedicated Privacy Management Handler

Privacy Management Support
- Interactive Explanation Access
- Privacy Requirement Mapping
- Configuration and Monitoring

xPrime Tool

CPS (component)

CPS (component)

CPS (component)

CPS (component)

CPS (component)

xPrime Platform

Level 3 – SoS Modeling/Architecting
## System-of-Systems Modeling & Execution

<table>
<thead>
<tr>
<th>Approach</th>
<th>Mod.</th>
<th>Exec.</th>
<th>Mon.</th>
<th>UI</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAPMM [25,26]</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>BPMN4CPS [27]</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>BPMN for IoT [28–30]</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>IoT/WS-BPEL [31]</td>
<td>~ (BPEL)</td>
<td>✓</td>
<td>~ (BPEL)</td>
<td>✗</td>
<td>~ (BPEL)</td>
</tr>
<tr>
<td>IoT/WS-BPEL [32,34,35]</td>
<td>~ (BPEL)</td>
<td>✓</td>
<td>~ (BPEL)</td>
<td>✗</td>
<td>~ (BPEL)</td>
</tr>
<tr>
<td>ADiWa[36]</td>
<td>~ (conc.)</td>
<td>~ (conc.)</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Extended GSM [2,12,13]</td>
<td>✓</td>
<td>✗</td>
<td>✓ (via GSM)</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>This work</td>
<td>✓</td>
<td>✓</td>
<td>~ (BPMS)</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Integration of IoT and BPM
(Schöning et al., 2020)
System-of-Systems Modeling

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

(Venkatakumar et al., 2019)
Sample: Home Healthcare CPS Modeling

Integrated Behavior Model

Subject-Interaction Diagram

- Item request
- Shopping Collector
- Drug request
- Item availability report
- Drug availability report
- Scheduling Approval/Rejection
- Personal Scheduler
- Scheduling request
- Medication Handler
- Measurement request
- Conformance check request
- Blood Pressure Measurement
- Completion report
- Conformance report
Sample: Home Healthcare CPS Modeling

Integrated Behavior Model

Subject-Interaction Diagram

- Item request
- Item availability report
- Scheduling request
- Measurement request
- Completion report

Shopping Collector

- Drug request
- Drug availability report
- Scheduling approval/rejection
- Conformance check request
- Conformance report

Medication Handler

Subject-Behavior Diagram

- Send request for measuring
- Receive data set
- Interpret data set
- Send data set

Patient

Blood Pressure Measurement

Role-specific Actor Models
Integrated Modeling & Execution Support

Validation

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

Exploration

Evolving CPS as System-of-Systems

Behavior Encapsulation

Communication-centered Modeling & Execution

System-of-Systems Perspective

Communication
Connectedness

Cyber

Physical

Information systems

Control
Responsiveness

Intelligence

Computation

CPS

CPS

Johannes Kepler University Linz
Business Informatics – Communications Engineering
Pathways are Likely to be Intertwined

Modeling and Architecture Language for Interoperable CPS

Level 1: General System Modeling
- Complex Adaptive System Architectures
- CAS-models

Level 2: Socio-technical System Modeling
- Socio-technical System Architectures
- Socio-technical Models

Level 3: System-of-Systems Modeling
- Soc-tec. SoS-Architecture
- Socio-technical SoS Models

Level 4: Asset Behavior Modeling
- CPS-System Architecture
- Technical System Models

Level 5: Organisational Behavior Modeling
- Role-specific Business Logic Architecture
- Role-specific Actor Models

Level 6: Behavior Alignment Modeling
- Pragmatic Interoperability Architecture
- Integrated Behavior Model

Pathway 1: Architecture Perspective: Towards an aligned socio-technical application architecture
Pathway 2: Modeling Perspective: Towards executable behavior representations
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