Abstract

The transition from capabilities provided by traditional physical systems to today's capabilities provided by heterogeneous systems of systems complicates architecting. In this paper, we look at trends in this ongoing transition, especially into the degree of heterogeneity of technologies and the context. We observe in an increase in virtual intangible technologies from the cyber domain, and an increase in human and organization aspects. Main question is how the heterogeneity of concerns, needs, considerations, and technologies impacts architecting and the role of architects.
The challenge of increasing heterogeneity in SoS for architecting

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Observations from teaching in various domains

- Health care
- Defense
- Maritime
- Oil and gas
- Manufacturing
- OEM equipment for imaging, printing, machining
- Automotive
Trends across domains

- Growth of data/information collection
- High expectations from harvesting useful data across systems to improve performance and functionality
- Infrastructure platforms using cloud technology, factoring out common digital functionality
- Ubiquitous use of commodity devices as smart phones, tablets, and laptops
- Focus on trustworthiness and affordability
- More automation and considering autonomy
- Societal pressure for privacy and responsible behavior
The challenge of increasing heterogeneity in SoS for architecting

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## Keywords from various SoS models in literature

<table>
<thead>
<tr>
<th>Boardman and Sauser</th>
<th>Maier</th>
<th>DeLaurentis</th>
<th>Dahmann and Baldwin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy</td>
<td>Operational independence</td>
<td>Type</td>
<td>Directed</td>
</tr>
<tr>
<td>Belonging</td>
<td>Managerial independence</td>
<td>Control (or autonomy)</td>
<td>Acknowledged</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Geographic separation</td>
<td>Connectivity</td>
<td>Collaborative</td>
</tr>
<tr>
<td>Diversity</td>
<td>Emergent behavior</td>
<td></td>
<td>Virtual</td>
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<tr>
<td>Emergence</td>
<td>Evolutionary development</td>
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</tbody>
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MSISS theory
Types of Systems of Systems

**Directed** - The SoS is centrally managed

**Acknowledged** - The SoS has recognized objectives, and active cooperation between SoS and constituent systems

**Collaborative** - The constituent systems and stakeholders cooperate

**Virtual** - The SoS nature more or less emerge from the constituent systems

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CHSOSlogoArchitecting
The architecting playing field

organizational context
- customer organization
- business organization
- developing organization
- supplying organizations

operational and lifecycle context
- customer value proposition
  - drives
- business proposition
  - enables

system requirements
  - drives
  - enables

system design
  - technology

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ARCVtopViewExpanded
Thinking skills in Blooms revised taxonomy

Higher Order Thinking Skills
- more difficult to teach
- more valuable
- takes time to develop
  - must be mastered before, however when missing can be acquired fast

Lower Order Thinking Skills
- people can acquire them fast
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Where are the System Boundaries?

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MSISSboundaries
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End-to-End Function

- Data providers
- Specific services
- Other clouds

- Mobile access
- Flex workspots

- Information and Communication infrastructure
  - Public and proprietary

- Physical system
  - Local operating stations

- Other physical systems

Cloud

- Data collection
- Storage
- Analysis
- Learning
- Unrelated services
- Specific services

Apps

Other physical systems
Heterogeneity

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CHSOSlogoHeterogeneity
New Virtual Technologies

**traditional (physical) technologies**
- chemical engineering
- mechanical engineering
- electrical engineering
- optical engineering
- civil engineering
- operations research
- physics

**upcoming technologies**
- Internet of Things
- miniaturized and commoditized sensors
- ubiquitous networking, storage and processing resources
- Artificial Intelligence, ((deep) learning, data mining, data analytics)
- block chain
- microservices
- clouds
Non-technical heterogeneity

### non-technical considerations

- economical
- ecological
- legal
- social
- political
- psychological
- criminal

human behavior:
- emotions
- social pressure
- political gains
may trigger unexpected behavior.
The challenge of increasing heterogeneity in SoS for architecting
tension between control and emergence

safety, security, etc. requiring analysis and control

versus

emerging and changing behavior, e.g. due to Artificial Intelligence

clear ownership

versus

dynamic allocation and distribution of services
Conclusion

Introduction

SoS background

Disappearing boundaries

Heterogeneity

Architecting

Conclusion
Systems of Systems Integration continues in the field during operation.

Ownership and responsibility for end-to-end performance is ill-defined.

Your system may be blamed for problems with a root cause elsewhere.

End-to-end performance depends on a mix of:
- traditional technical systems
- modern technologies like learning
- humans in their organizational and societal context (psychological, social, political, economical, legal, etc.)
- the physical context (location, climate, etc.) and laws of physics
The challenge of increasing heterogeneity in Systems of Systems for architecting

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