The challenge of increasing heterogeneity in Systems of Systems for architecting

by Gerrit Muller  
University of South-Eastern Norway-NISE  
e-mail: gaudisite@gmail.com  
www.gaudisite.nl

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

2 Gerrit Muller

version: 0.2
August 21, 2020
CHSOSlogo
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

Version: 0.2
August 21, 2020

Gerrit Muller
## 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><strong>Autonomy</strong></td>
<td>Operational independence</td>
<td>Type</td>
<td>Directed</td>
</tr>
<tr>
<td><strong>Belonging</strong></td>
<td>Managerial independence</td>
<td>Control (or autonomy)</td>
<td>Acknowledged</td>
</tr>
<tr>
<td><strong>Connectivity</strong></td>
<td>Geographic separation</td>
<td>Connectivity</td>
<td>Collaborative</td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td>Emergent behavior</td>
<td></td>
<td>Virtual</td>
</tr>
<tr>
<td><strong>Emergence</strong></td>
<td>Evolutionary development</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

The challenge of increasing heterogeneity in SoS for architecting

Gerrit Muller
The architecting playing field

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

operational and lifecycle context
- customer value proposition
- business proposition

system requirements

system design

technology

drives
enables

drives
enables

The challenge of increasing heterogeneity in SoS for architecting
Thinking skills in Blooms revised taxonomy

Higher Order Thinking Skills
- more difficult to teach
- more valuable
- takes time to develop

Lower Order Thinking Skills
- people can acquire them fast
- must be mastered before
- however when missing can be acquired fast
The challenge of increasing heterogeneity in SoS for architecting

Gerrit Muller
Where are the System Boundaries?

The challenge of increasing heterogeneity in SoS for architecting

Gerrit Muller

version: 0.2
August 21, 2020
MSISSboundaries
The challenge of increasing heterogeneity in SoS for architecting

End-to-End Function

Information and Communication
infrastructure
public and proprietary

physical system
physical system

local operating stations

other physical systems

Cloud

storage

data collection

analysis

learning

unrelated

services

data providers

specific services

other clouds

mobile access

flex workspots

apps

apps

Version: 0.2
August 21, 2020
MSISSend2endFunction

Gerrit Muller
The challenge of increasing heterogeneity in SoS for architecting

version: 0.2
August 21, 2020
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.
Varying Dynamics

The challenge of increasing heterogeneity in SoS for architecting

version: 0.2
August 21, 2020
MSISSdynamics

The challenge of increasing heterogeneity in SoS for architecting
<table>
<thead>
<tr>
<th>tension between control and emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>safety, security, etc. requiring analysis and control</td>
</tr>
<tr>
<td>versus</td>
</tr>
<tr>
<td>emerging and changing behavior, e.g. due to Artificial Intelligence</td>
</tr>
<tr>
<td>clear ownership</td>
</tr>
<tr>
<td>versus</td>
</tr>
<tr>
<td>dynamic allocation and distribution of services</td>
</tr>
</tbody>
</table>
The challenge of increasing heterogeneity in SoS for architecting

Introduction

SoS background

Disappearing boundaries

Heterogeneity

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

https://gaudisite.nl/SoSE2018_Muller_heterogeneity.pdf