

The challenge of increasing heterogeneity in Systems of Systems for architecting

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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 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.

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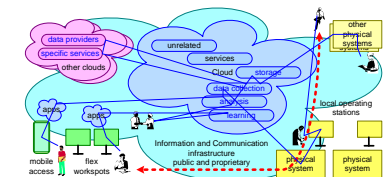
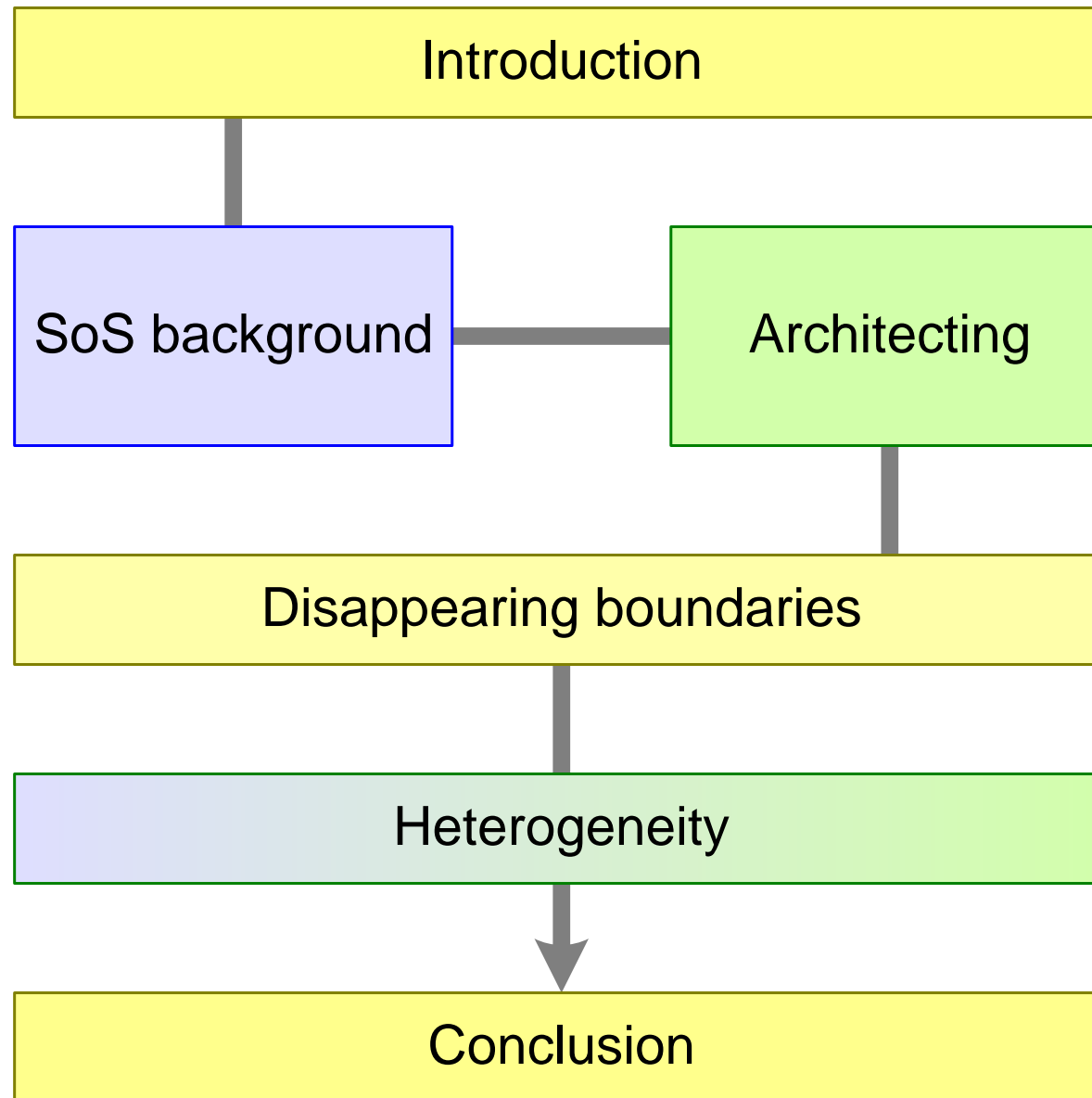


Figure Of Contents™



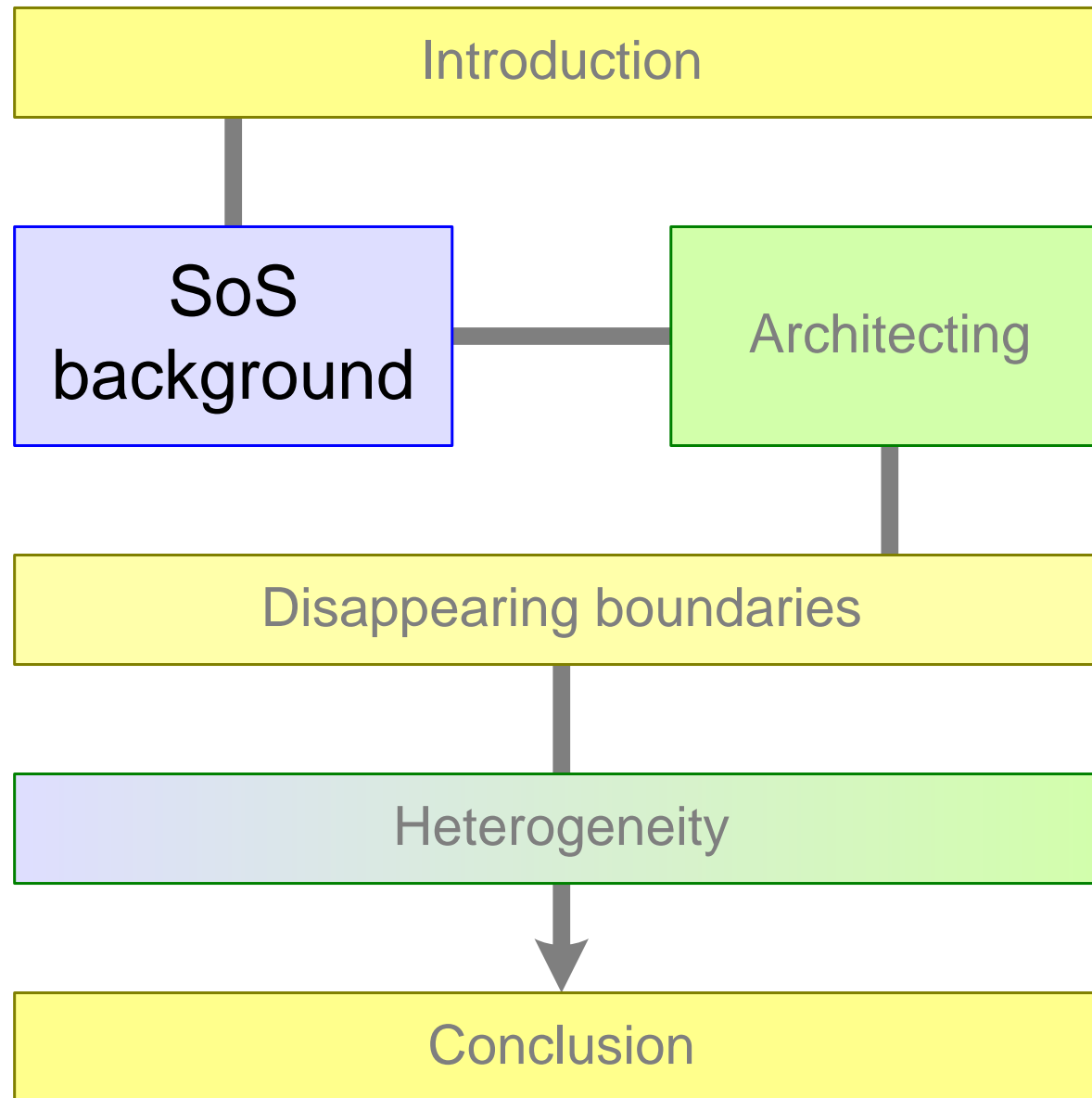
Observations from teaching in various domains

- 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

SoS Background



Keywords from various SoS models in literature

| Boardman and Sauser | Maier | DeLaurentis | Dahmann and Baldwin |
|---------------------|--------------------------|-----------------------|---------------------|
| Autonomy | Operational independence | Type | Directed |
| Belonging | Managerial independence | Control (or autonomy) | Acknowledged |
| Connectivity | Geographic separation | Connectivity | Collaborative |
| Diversity | Emergent behavior | | Virtual |
| Emergence | Evolutionary development | | |

Types of Systems of Systems

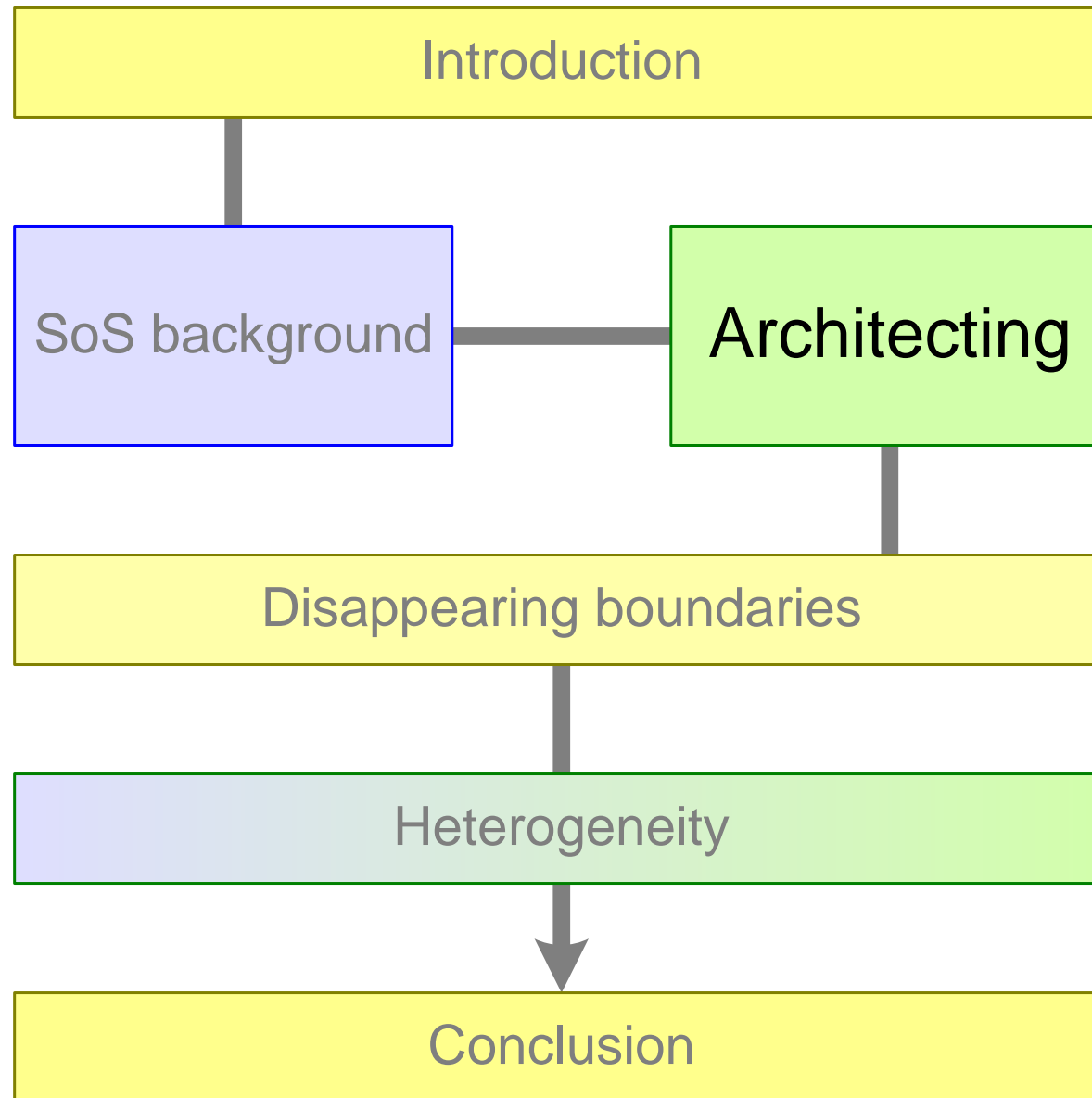
Directed - The SoS is centrally managed

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

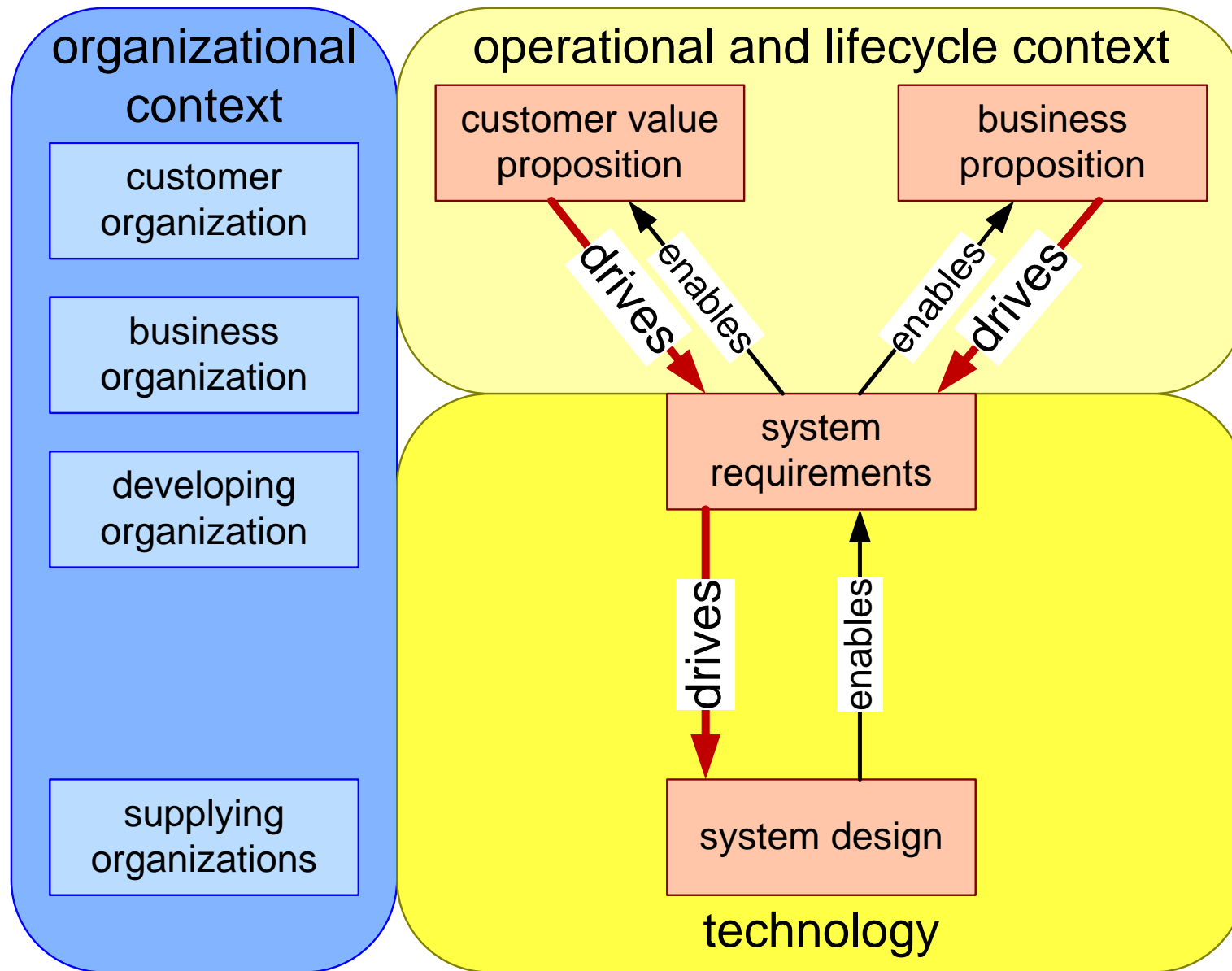
Collaborative - The constituent systems and stakeholders cooperate

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

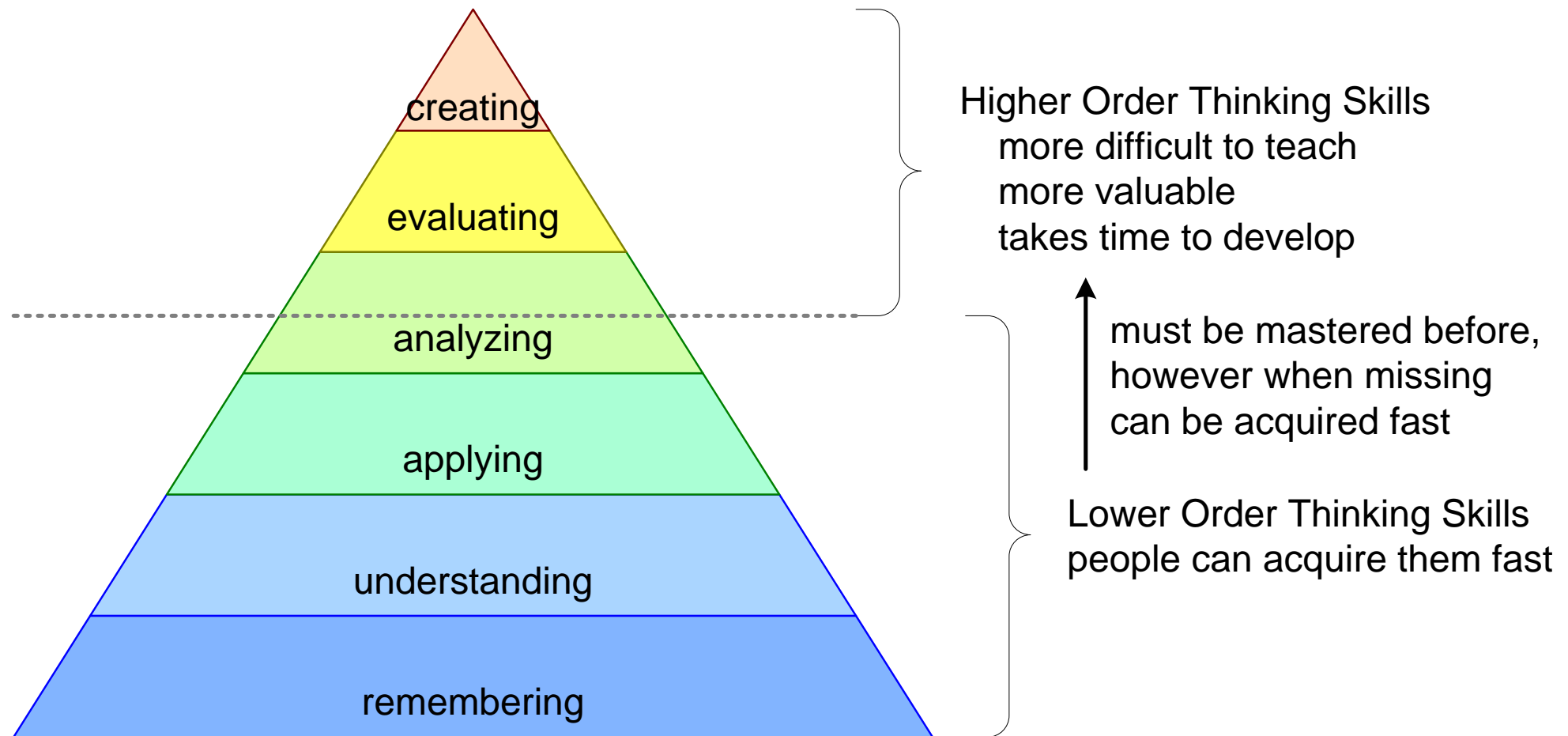
J. Dahmann and K. Baldwin. 2008. "Understanding the Current State of US Defense Systems of Systems and the Implications for Systems Engineering." IEEE Systems Conference 2008 in Montreal, 2008



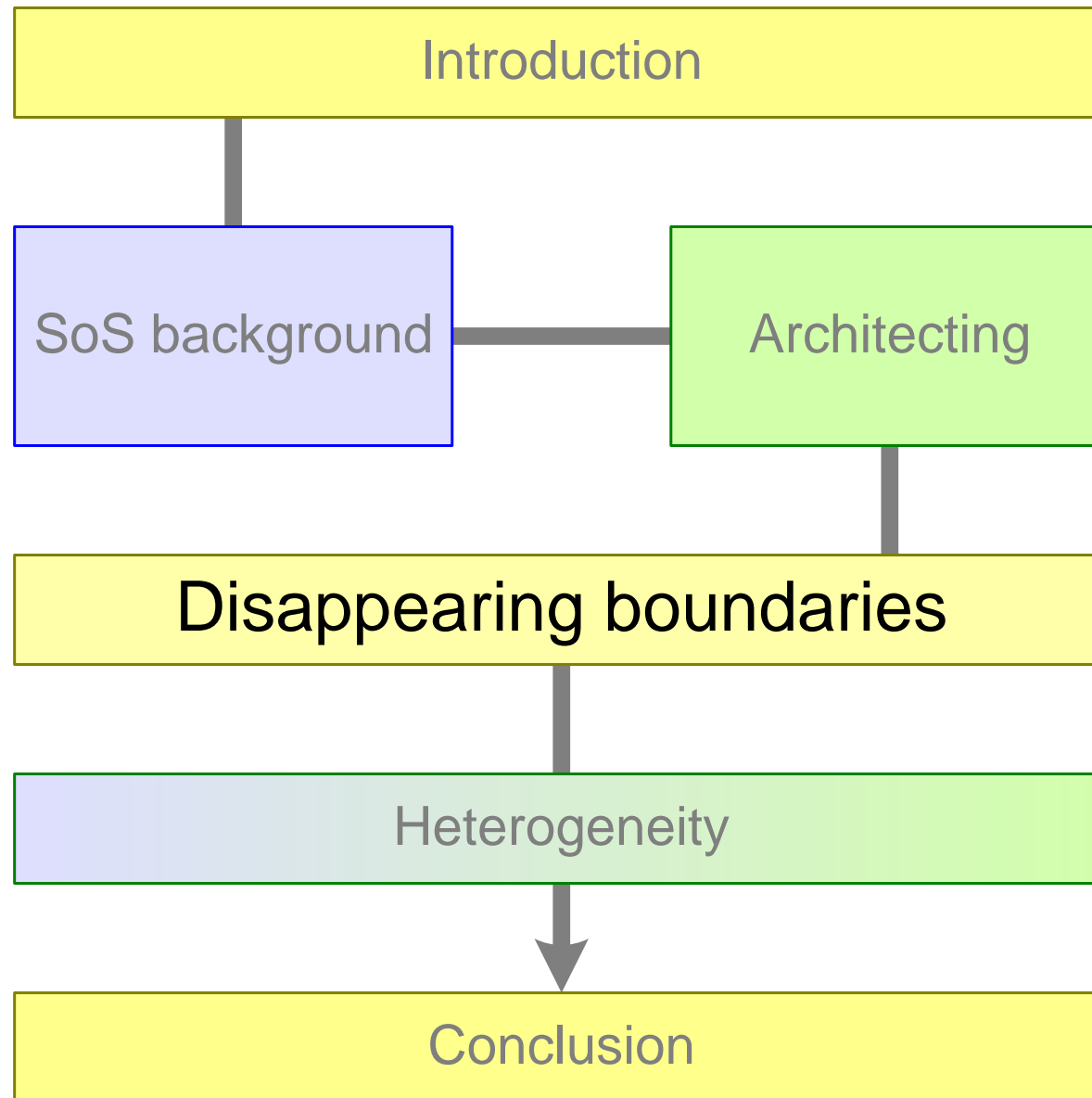
The architecting playing field



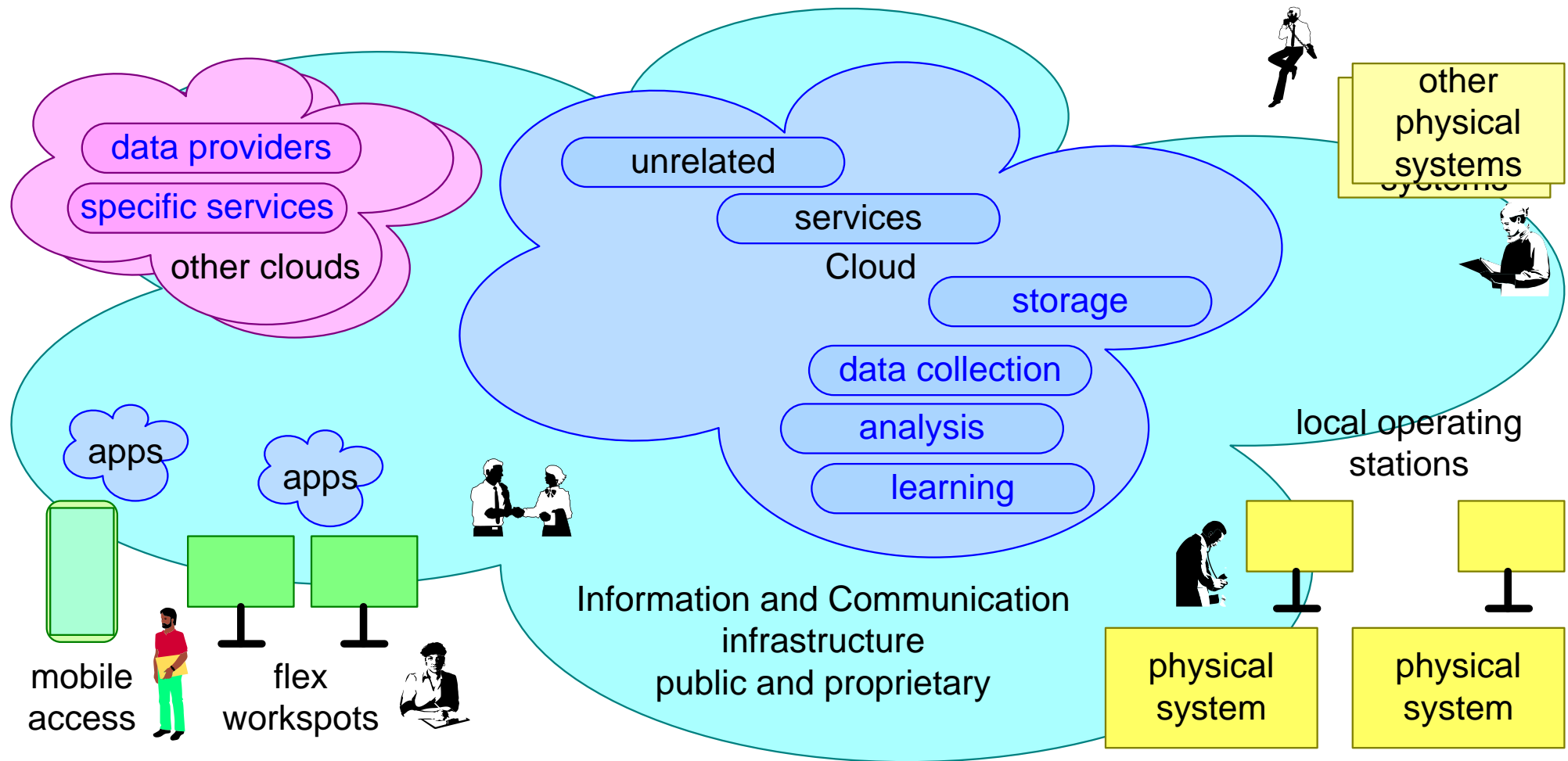
Thinking skills in Blooms revised taxonomy



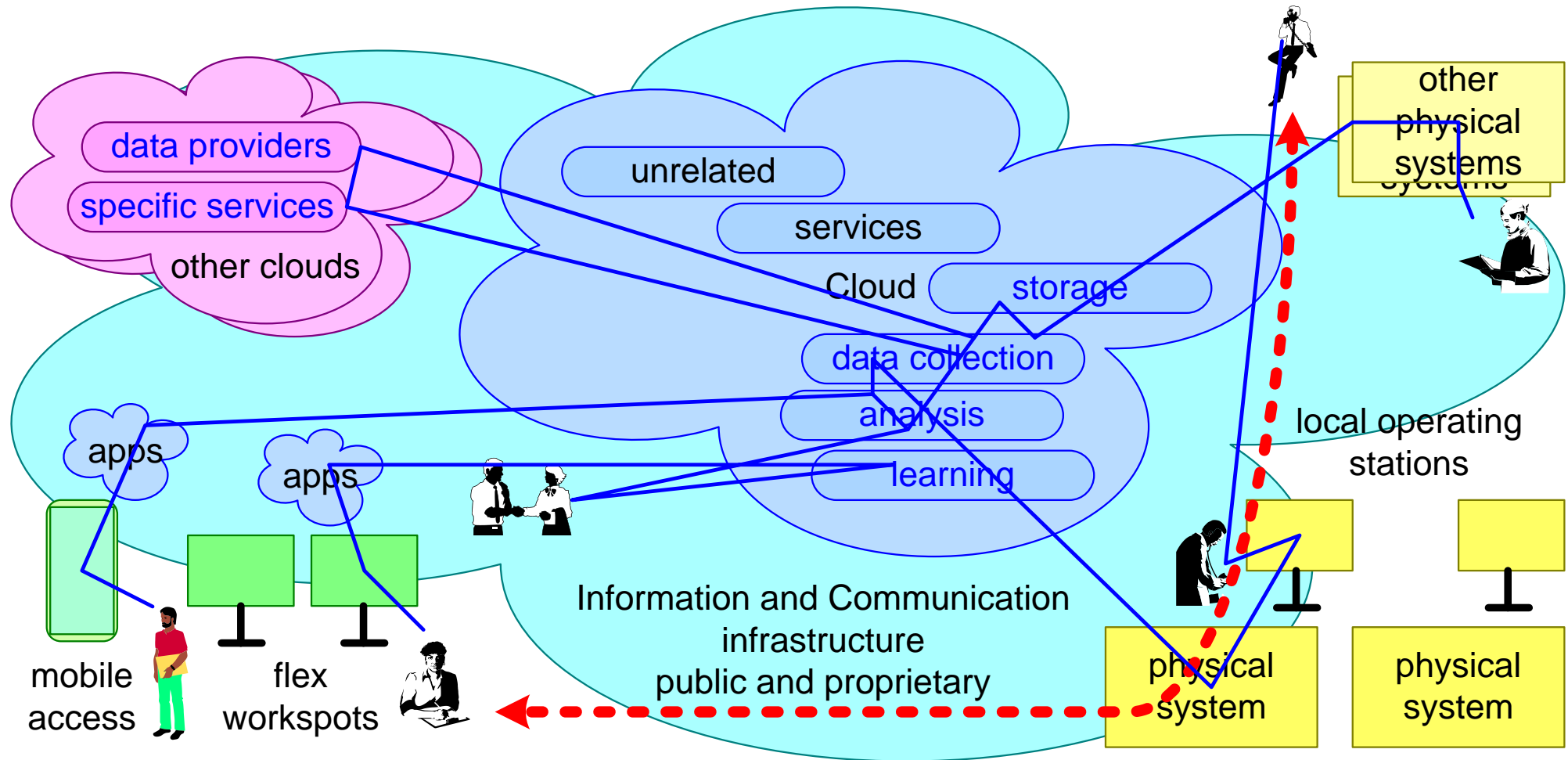
Disappearing Boundaries

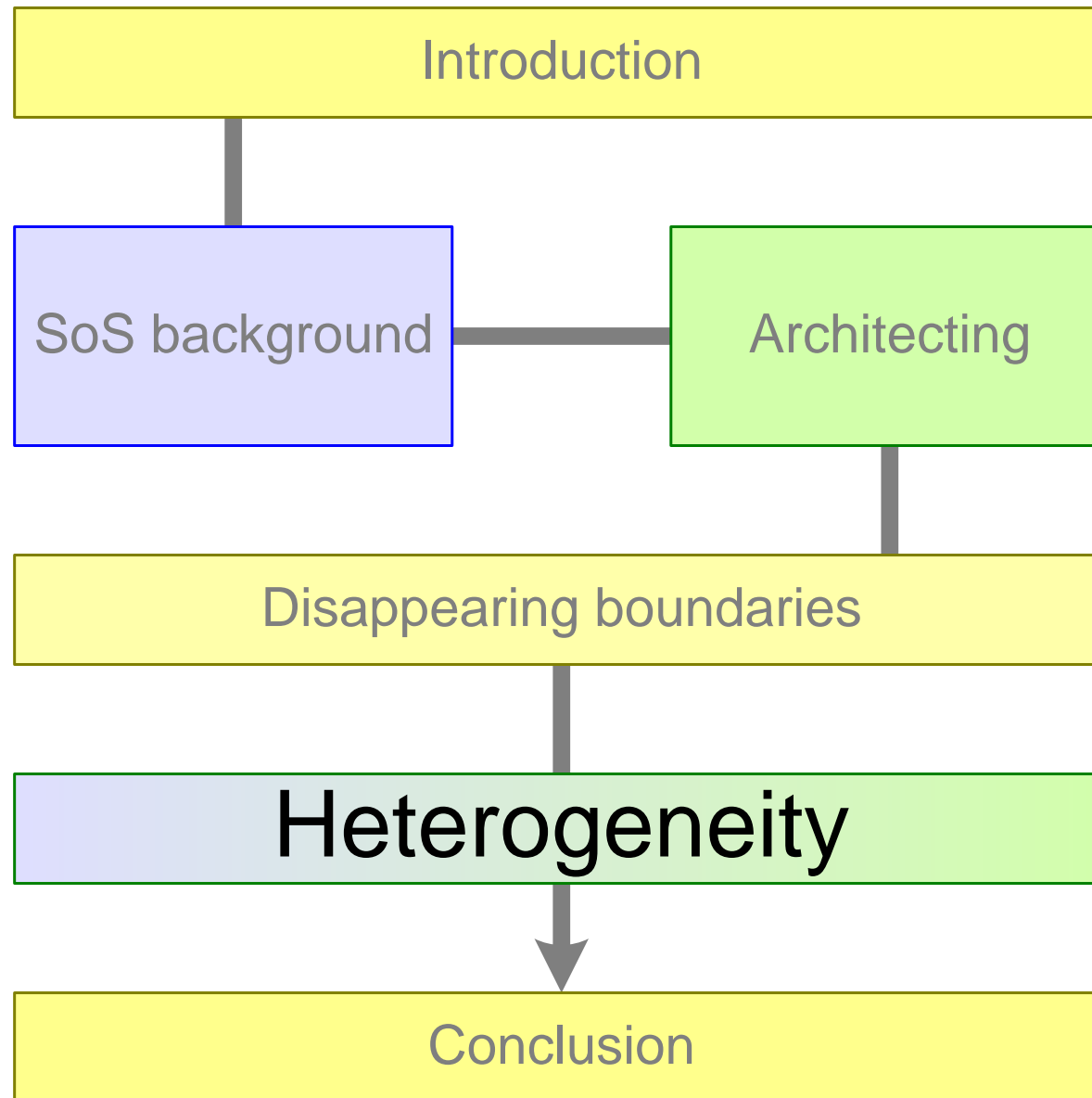


Where are the System Boundaries?



End-to-End Function





New Virtual Technologies

traditional (physical) technologies

- chemical engineering
- mechanical engineering
- electrical engineering
- optical engineering
- civil engineering
- operations research
- physics

upcoming technologies

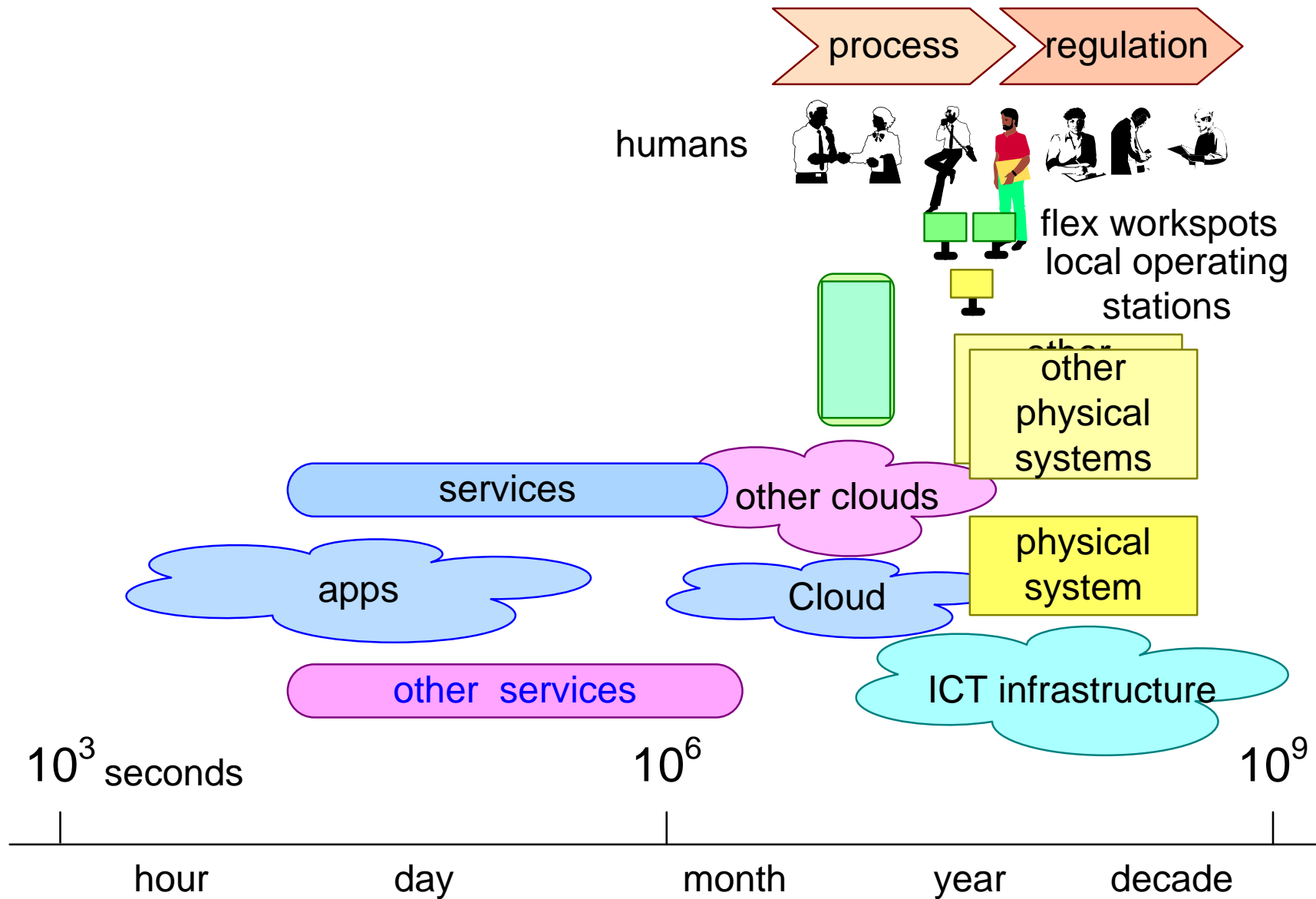
- Internet of Things
- miniaturized and commoditized sensors
- ubiquitous networking, storage and processing resources
- Artificial Intelligence, ((deep) learning, data mining, data analytics)
- block chain
- microservices
- clouds

non-technical considerations

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

human behavior:
emotions, social pressure, political gains
may trigger unexpected behavior.

Varying Dynamics



tension between control and emergence

safety, security, etc. requiring analysis and control

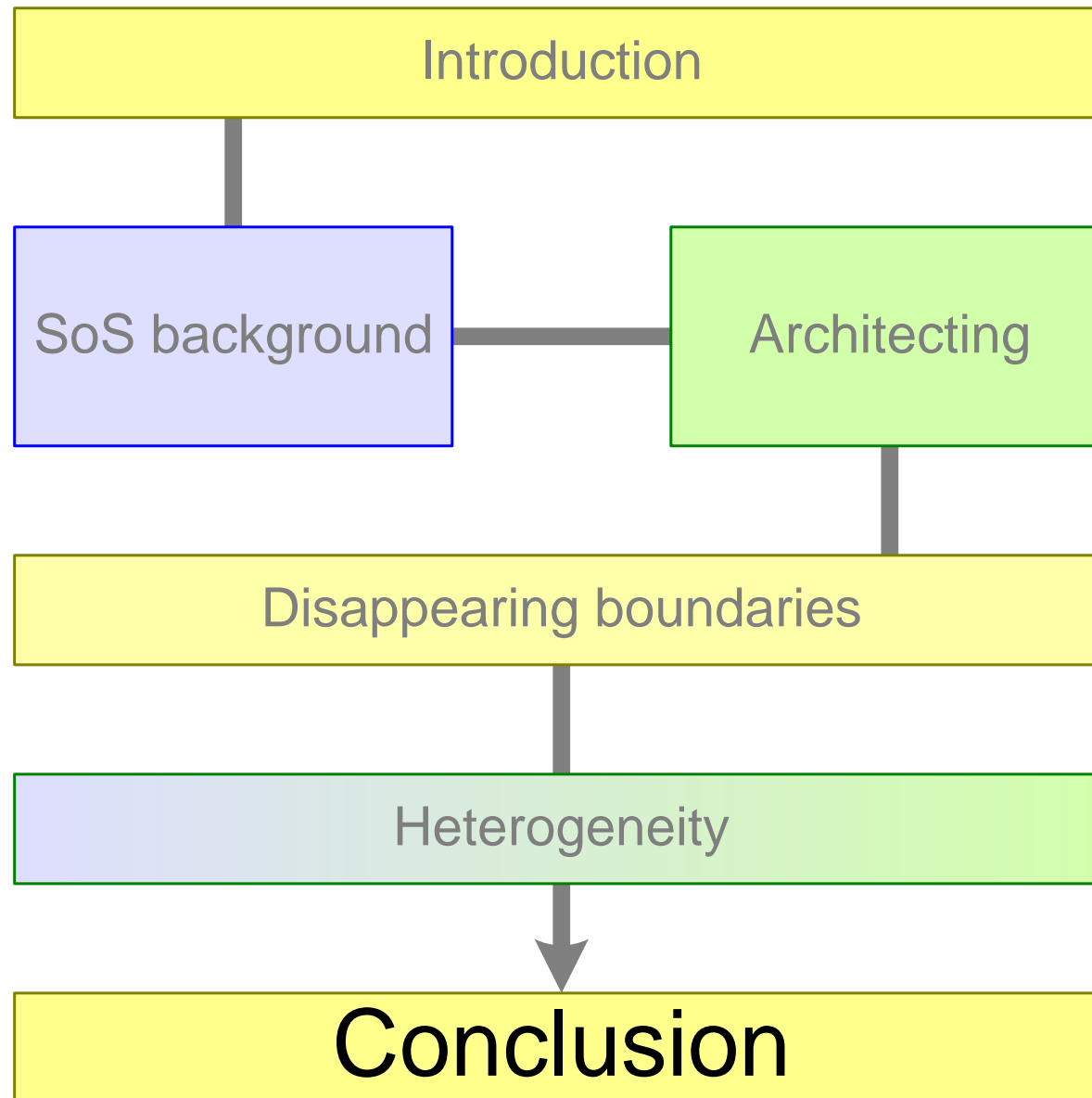
versus

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

clear ownership

versus

dynamic allocation and distribution of services



Summary

- 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
IEEE SOSE 2018 in Paris, France, copyright IEEE "<http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=7533679>"