# 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 todays 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.



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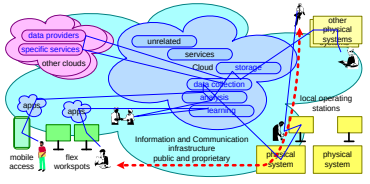
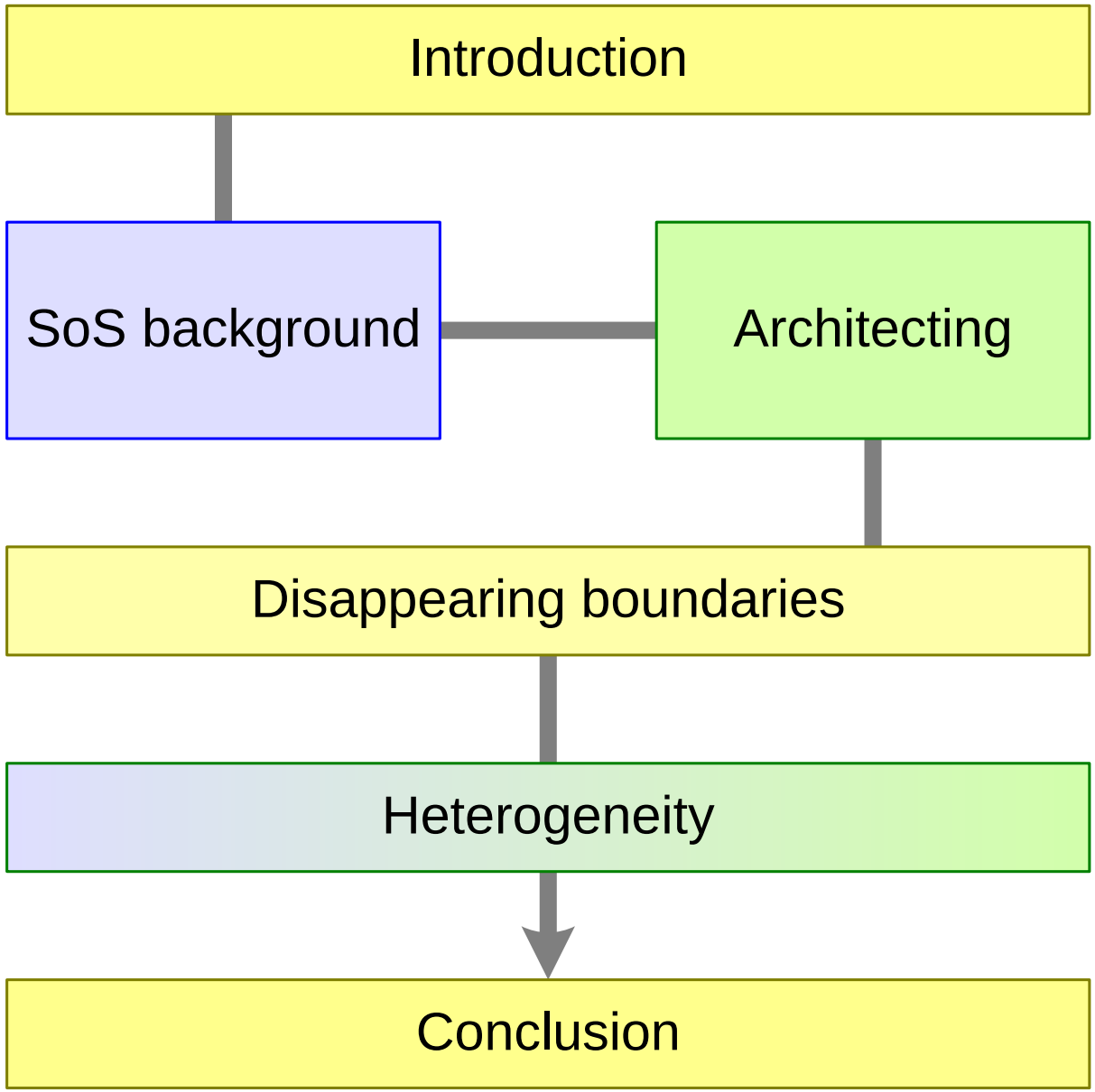


# Figure Of Contents™



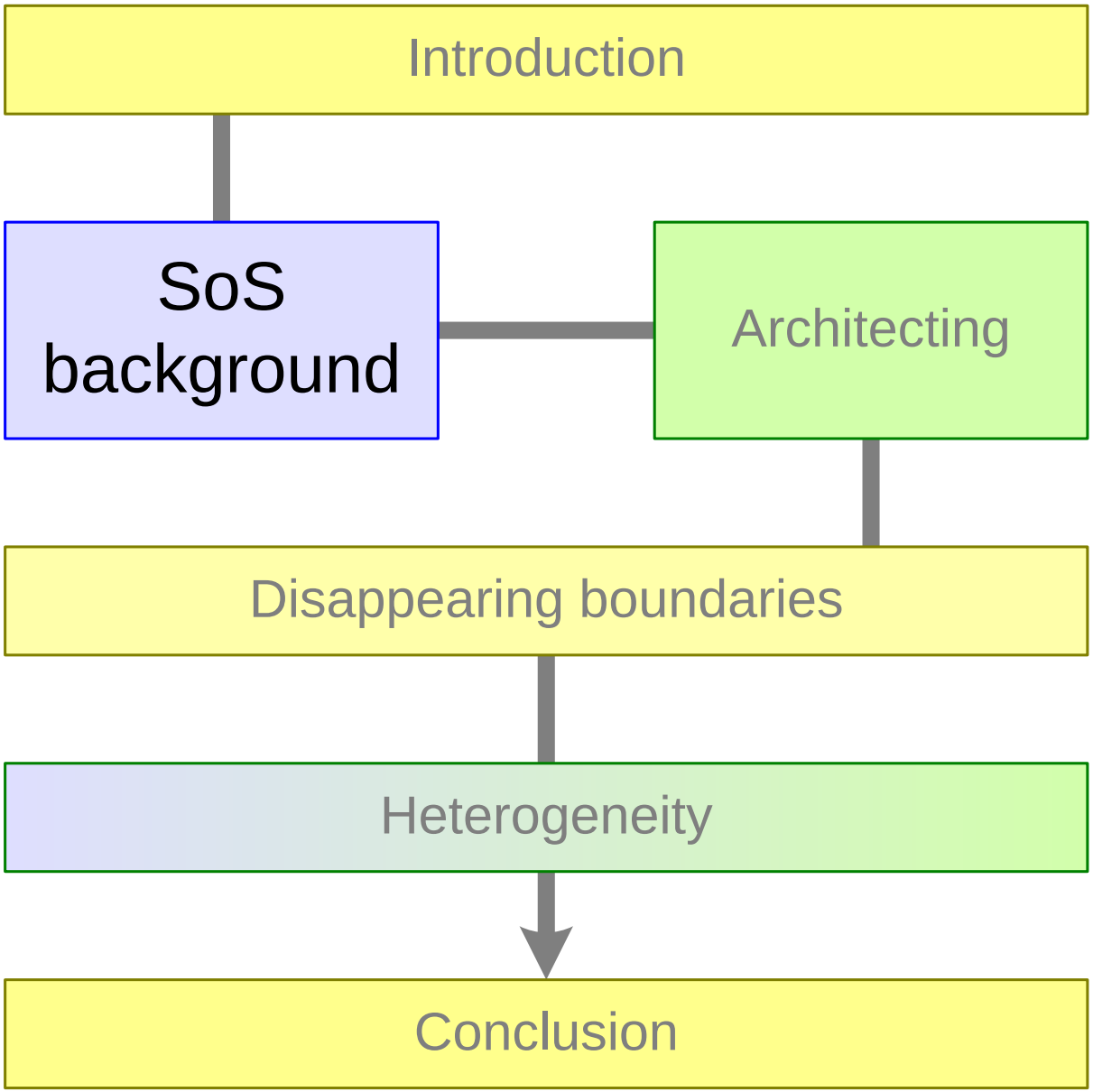
# Observations from teaching in various domains

- 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 | | Collaborative |
| Diversity | Emergent behavior | Connectivity | Virtual |
| Emergence | Evolutionary development | | |

# Types of Systems of Systems

**Directed** - The SoS is centrally managed

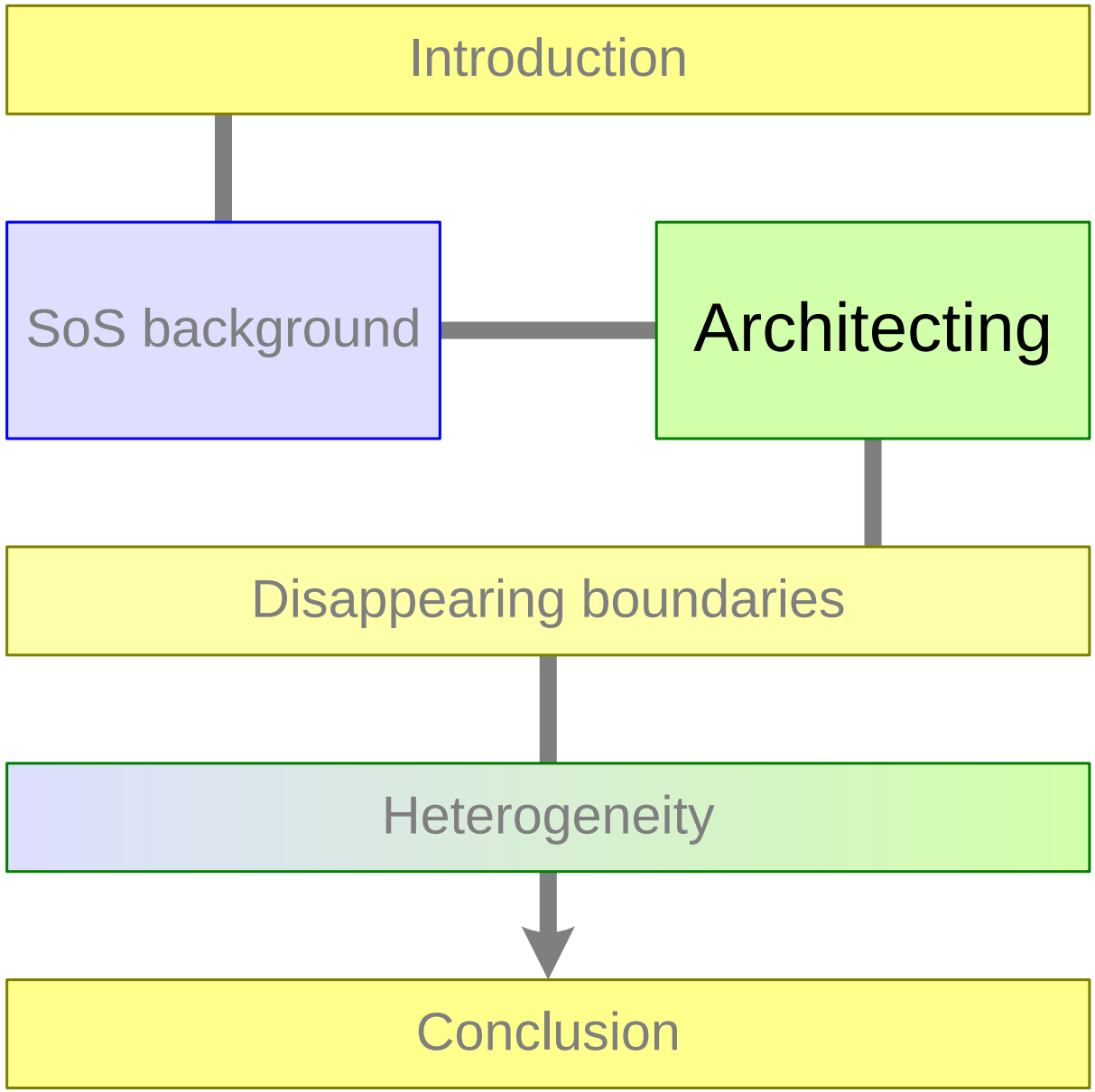
**Acknowledged** - The SoS has recognized objectives, and active cooperation between SoS and constituent systems

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

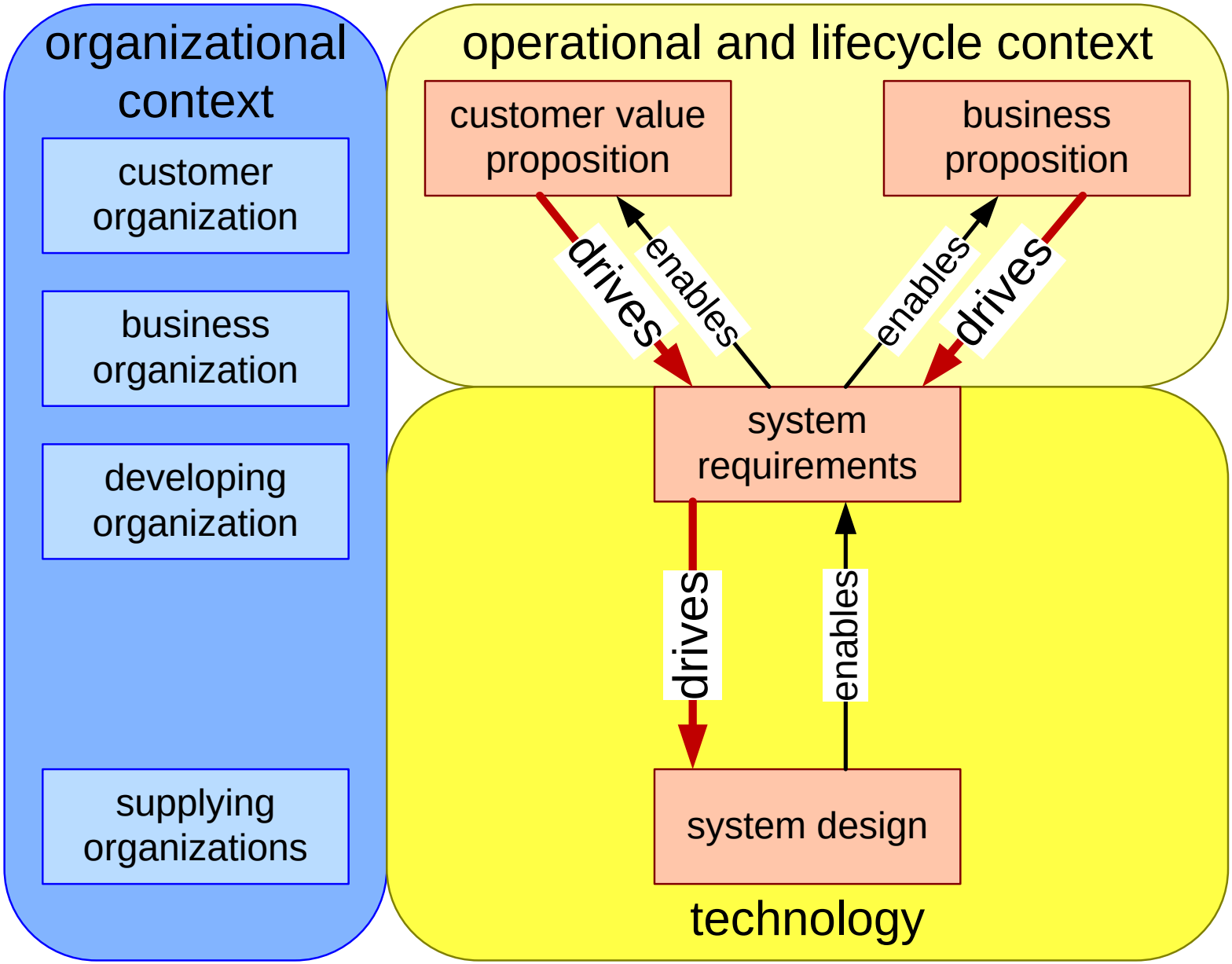
**Virtual** - The SoS nature more or less emerge from the constituent systems

**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

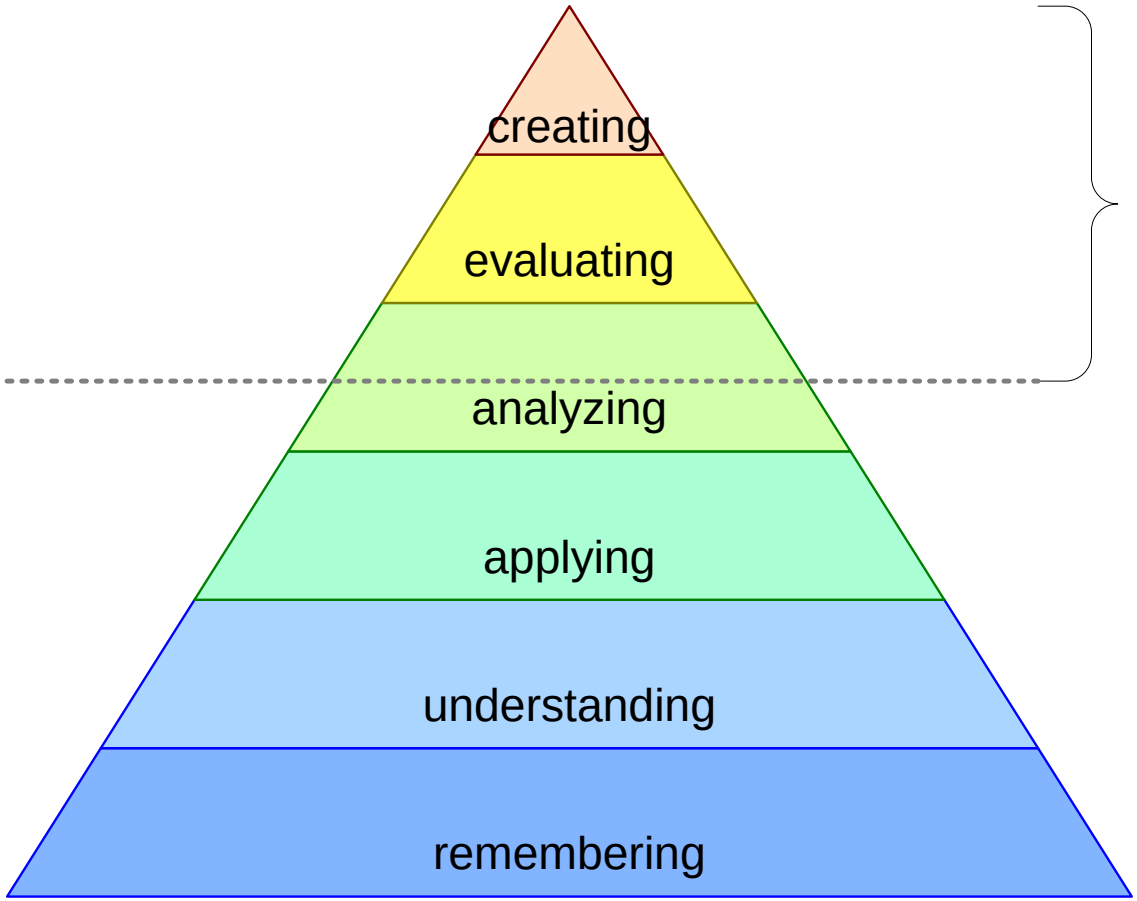
# Architecting



# The architecting playing field



# Thinking skills in Blooms revised taxonomy

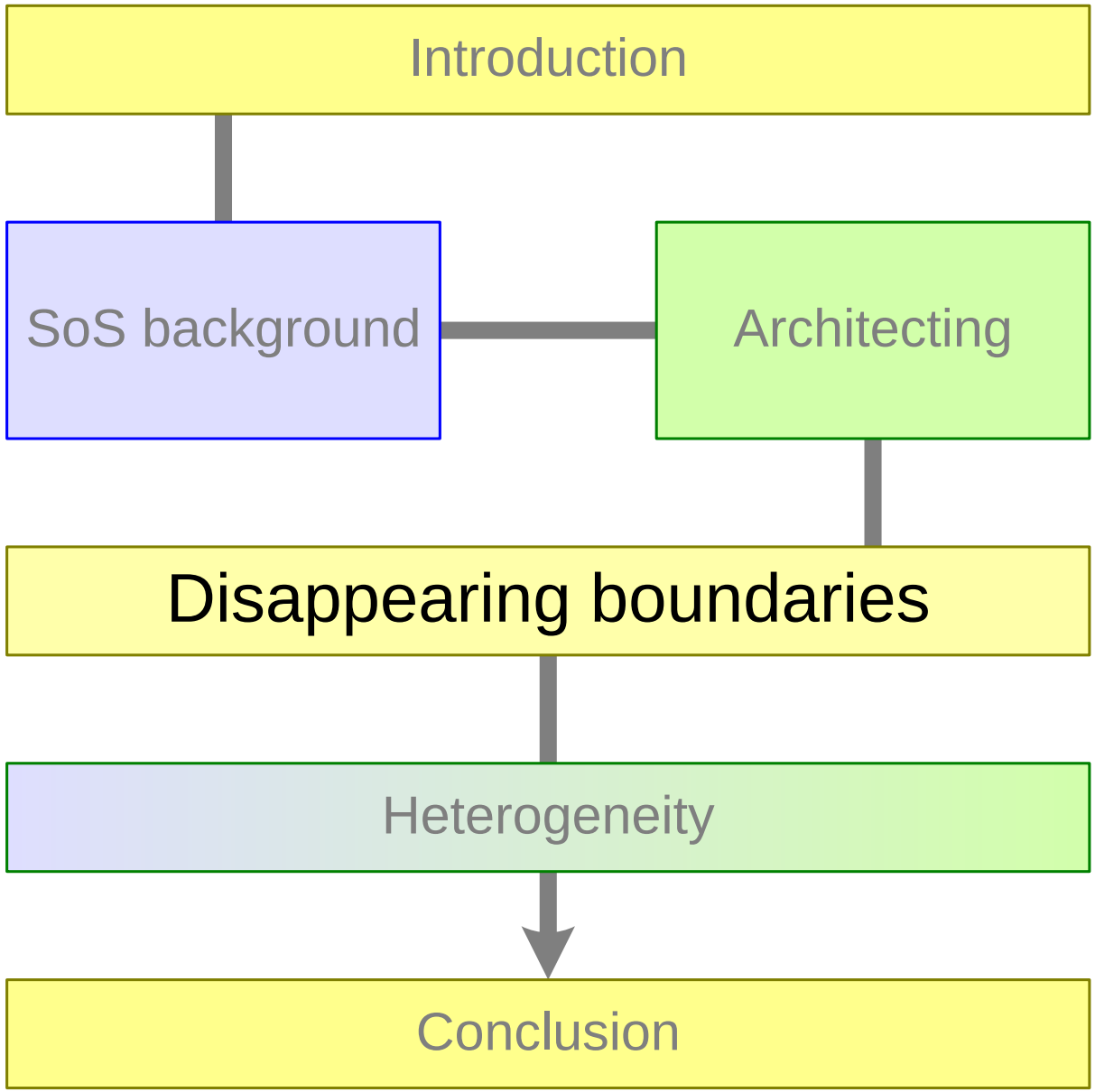



Higher Order Thinking Skills
more difficult to teach
more valuable
takes time to develop

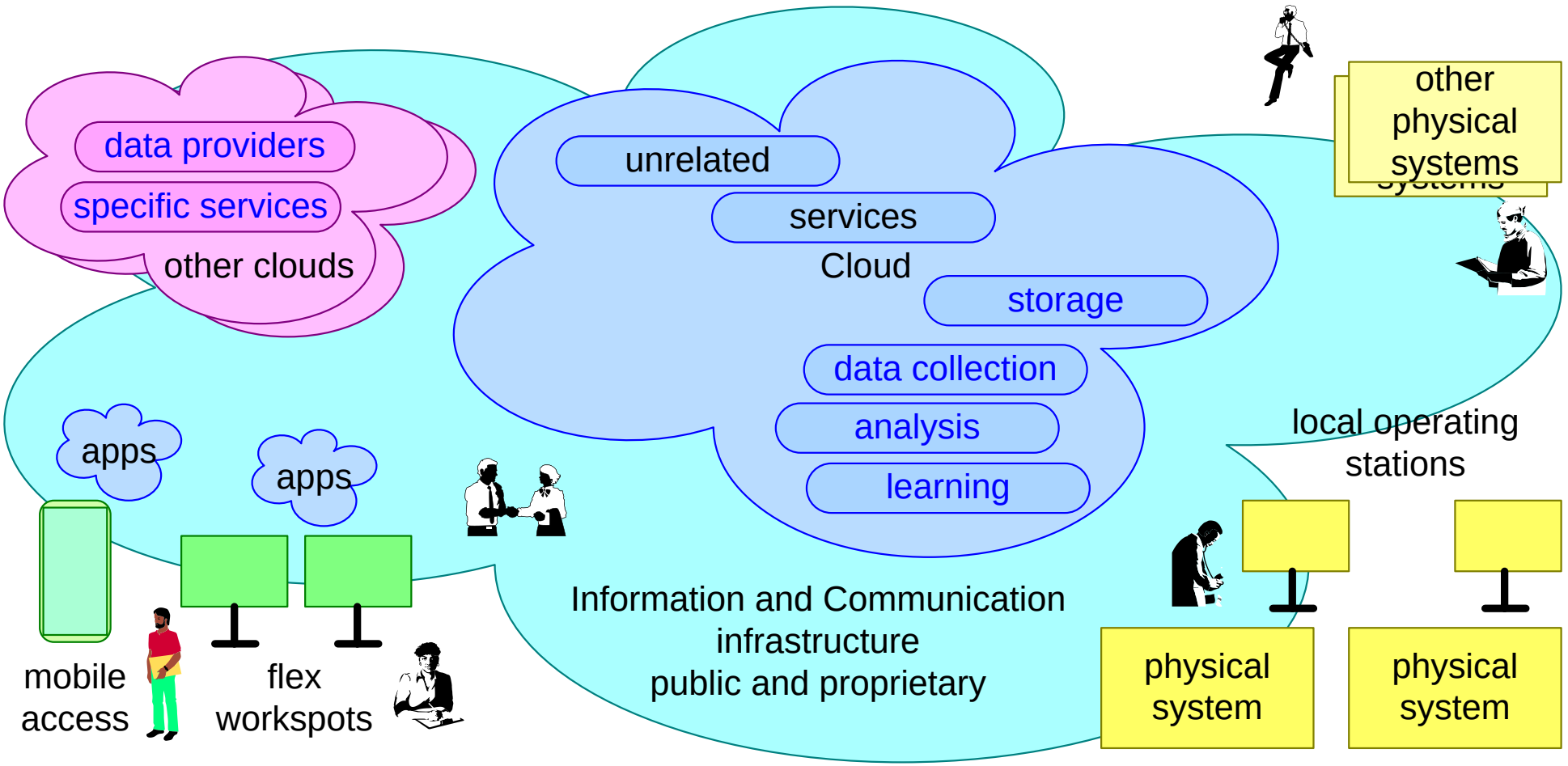
must be mastered before,
however when missing
can be acquired fast

Lower Order Thinking Skills
people can acquire them fast

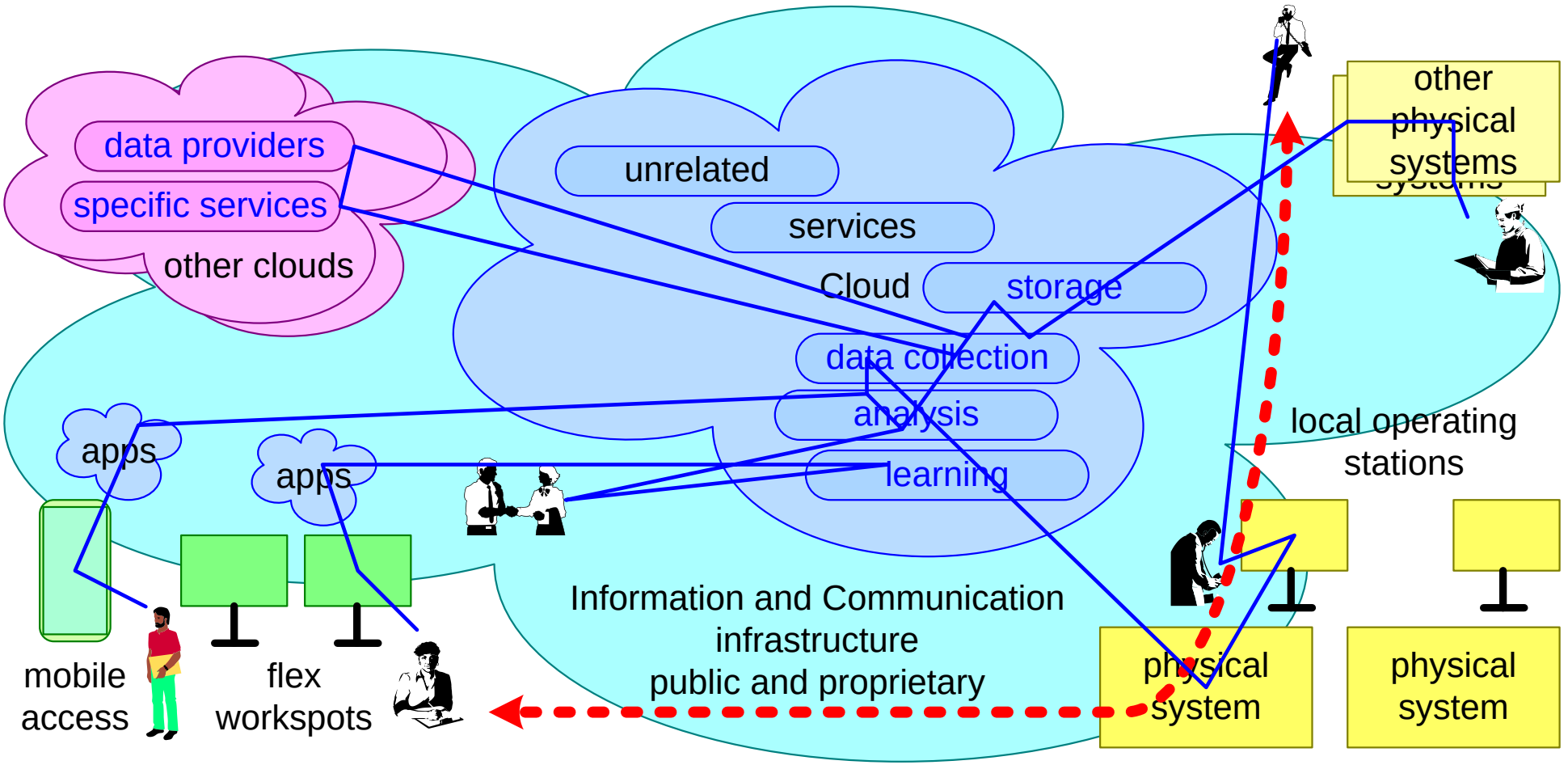
# Disappearing Boundaries



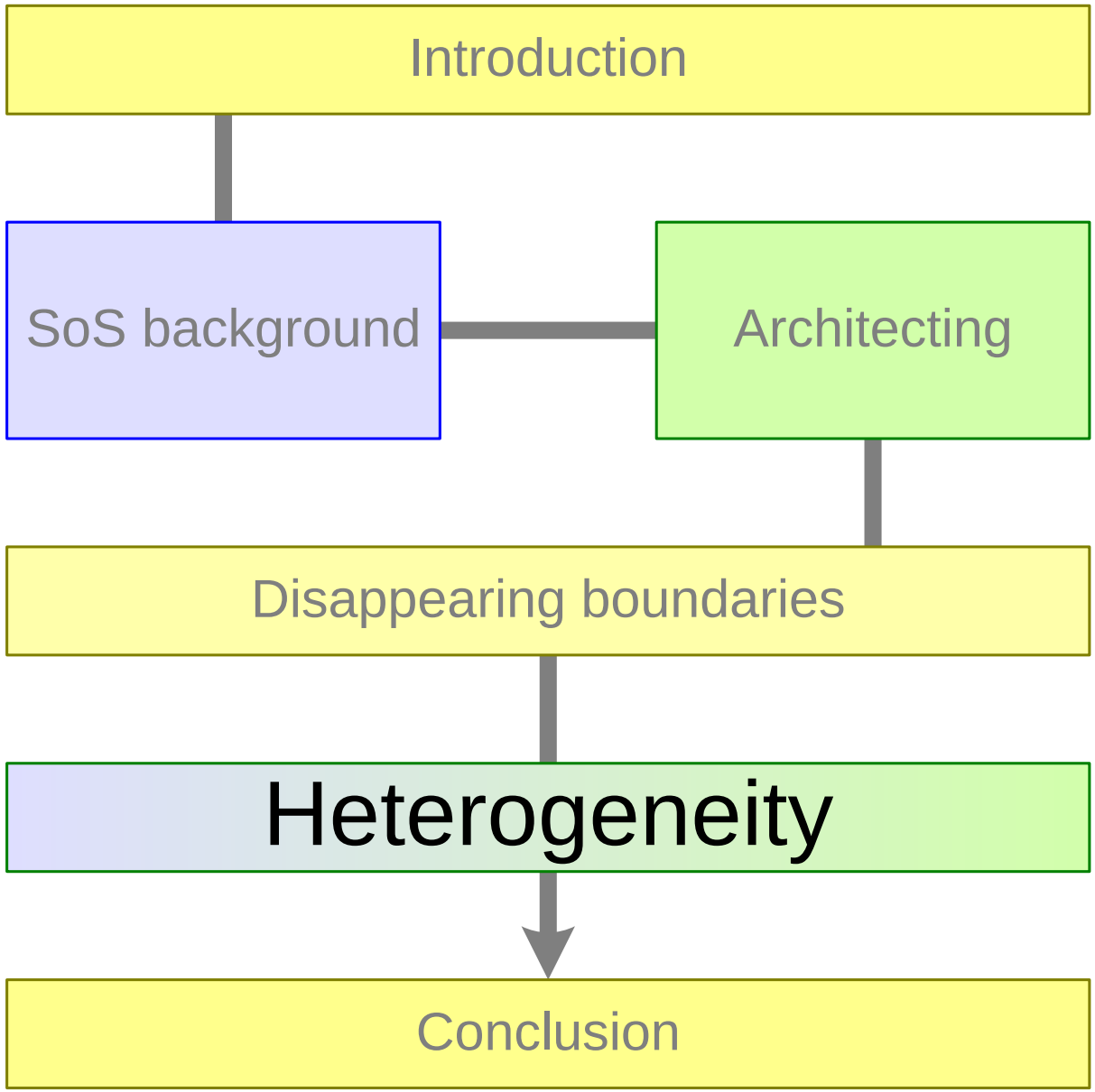
# Where are the System Boundaries?



# End-to-End Function



# Heterogeneity



# 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

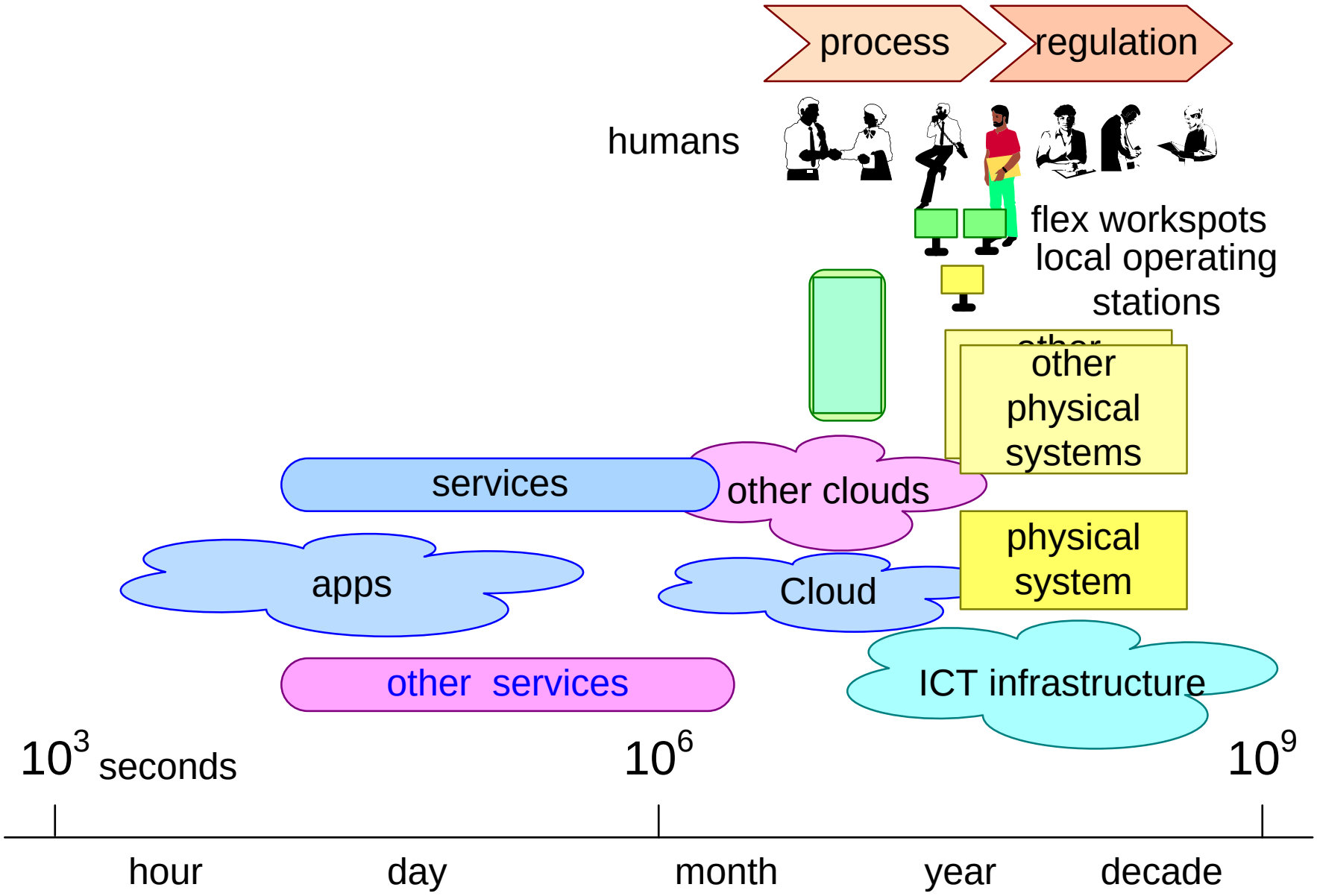
# Non-technical heterogeneity

*non-technical considerations*

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

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

# Varying Dynamics



*tension between control and emergence*

safety, security, etc. requiring anaylsis and control

versus

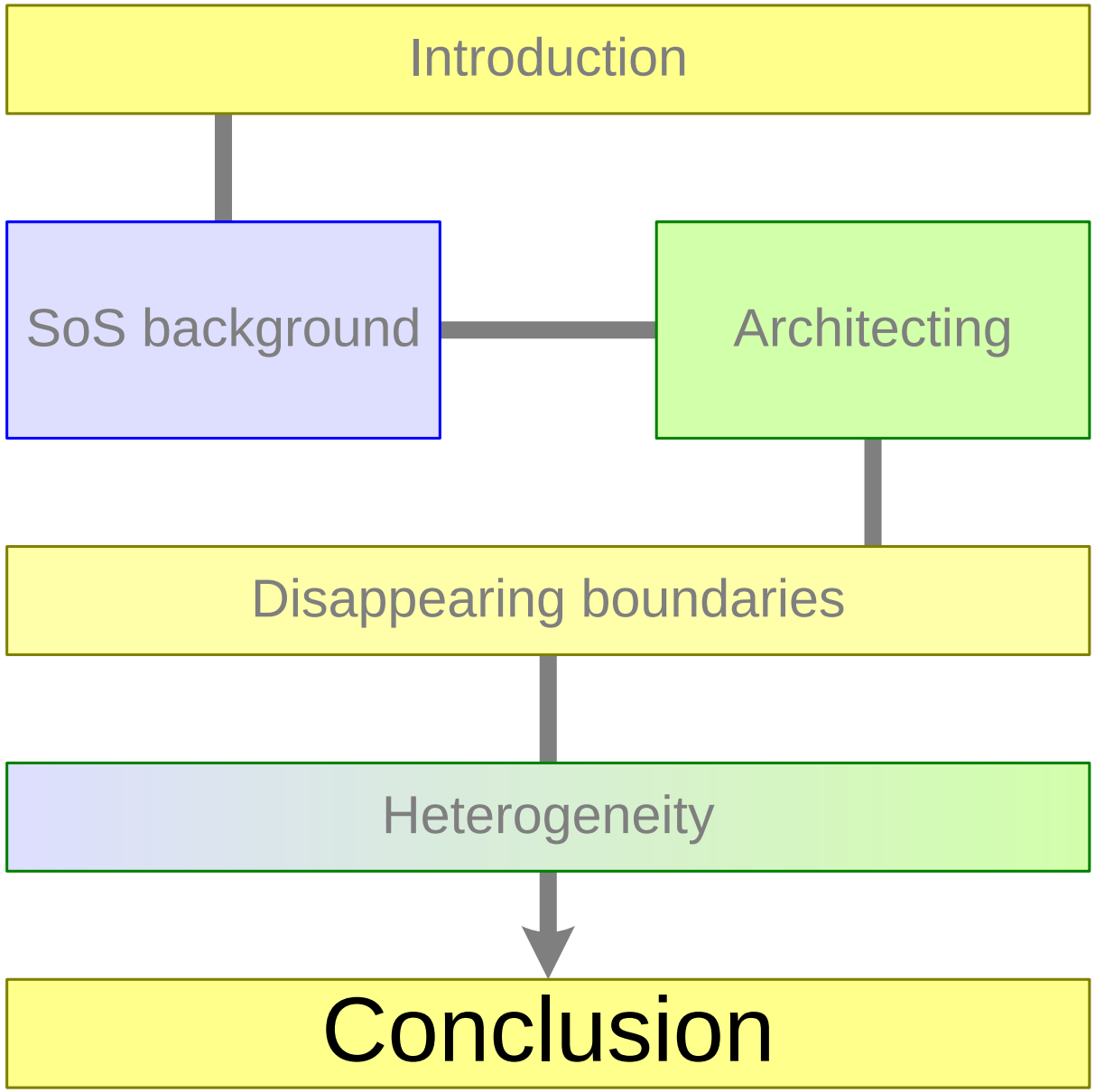
emerging and changing behavior, e.g. due to Artificial Intelligence

clear ownership

versus

dynamic allocation and distribution of services

# Conclusion


Introduction
SoS background
Architecting
Disappearing boundaries
Heterogeneity
Conclusion

# 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

# Links

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"