SoSECIE Webinar

Welcome to the
2019 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

We will start at 11AM Eastern Time

Skype Meeting +1 (703) 983-2020, 46013573#

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August
  - SoS Track at NDIA 22nd Annual Systems Engineering Conference, Grand Hilton Tampa Downtown, Tampa, FL, October 21-24, 2019
    - Conference Info: http://www.ndia.org/events/2019/10/21/22nd-annual-systems-and-mission-engineering-conference

NDIA SE Division SoS Committee Industry Chairs:
Mr. Rick Poel, Boeing
Ms. Jennie Horne, Raytheon
OSD Liaison:
Dr. Judith Dahmann, MITRE

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- I have muted all participant lines for this introduction and the briefing.
- If you need to contact me during the briefing, send me an e-mail at sosecie@mitre.org.
- Download the presentation so you can follow along on your own
- We will hold all questions until the end:
  - I will start with questions submitted online via the CHAT window in Skype.
  - I will then take questions via telephone; State your name, organization, and question clearly.
- If a question requires more discussion, the speaker(s) contact info is in the brief.

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2019 System of Systems Engineering Collaborators Information Exchange Webinars

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November 19, 2019
Multi-Dimensional Classification of System-of-Systems
Dr. Bedir Tekinerdogen

December 3, 2019
Digital Twin Strategies for System of Systems
Mr. Michael Borth

January 14
Framework for Improving Complex System Performance
Mr. Chuck Keating

Multi-Dimensional Classification of System-of-Systems

Webinar -
System of Systems Engineering
Collaborators Information Exchange (SoSECIE)
November 19, 2019

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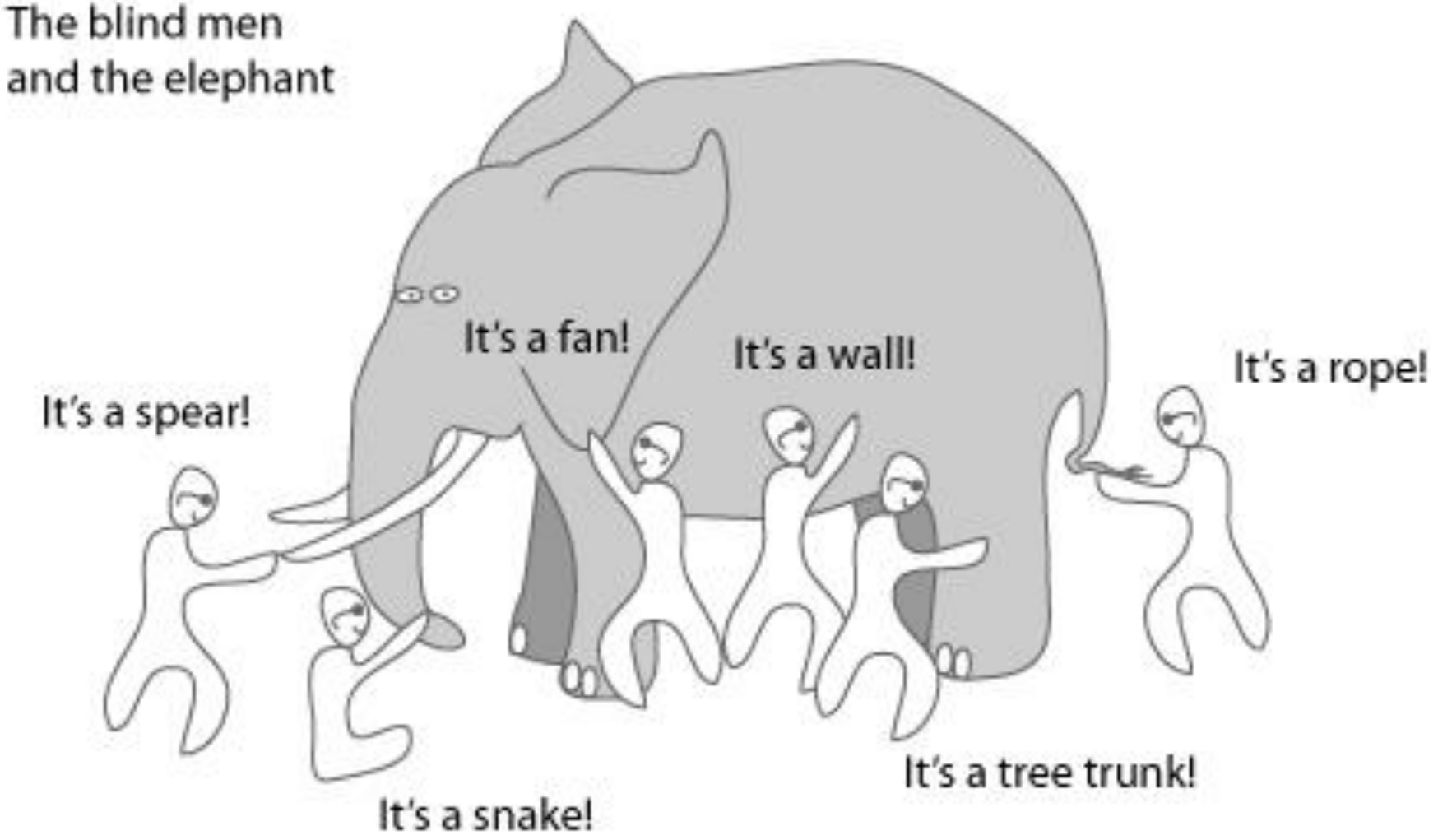
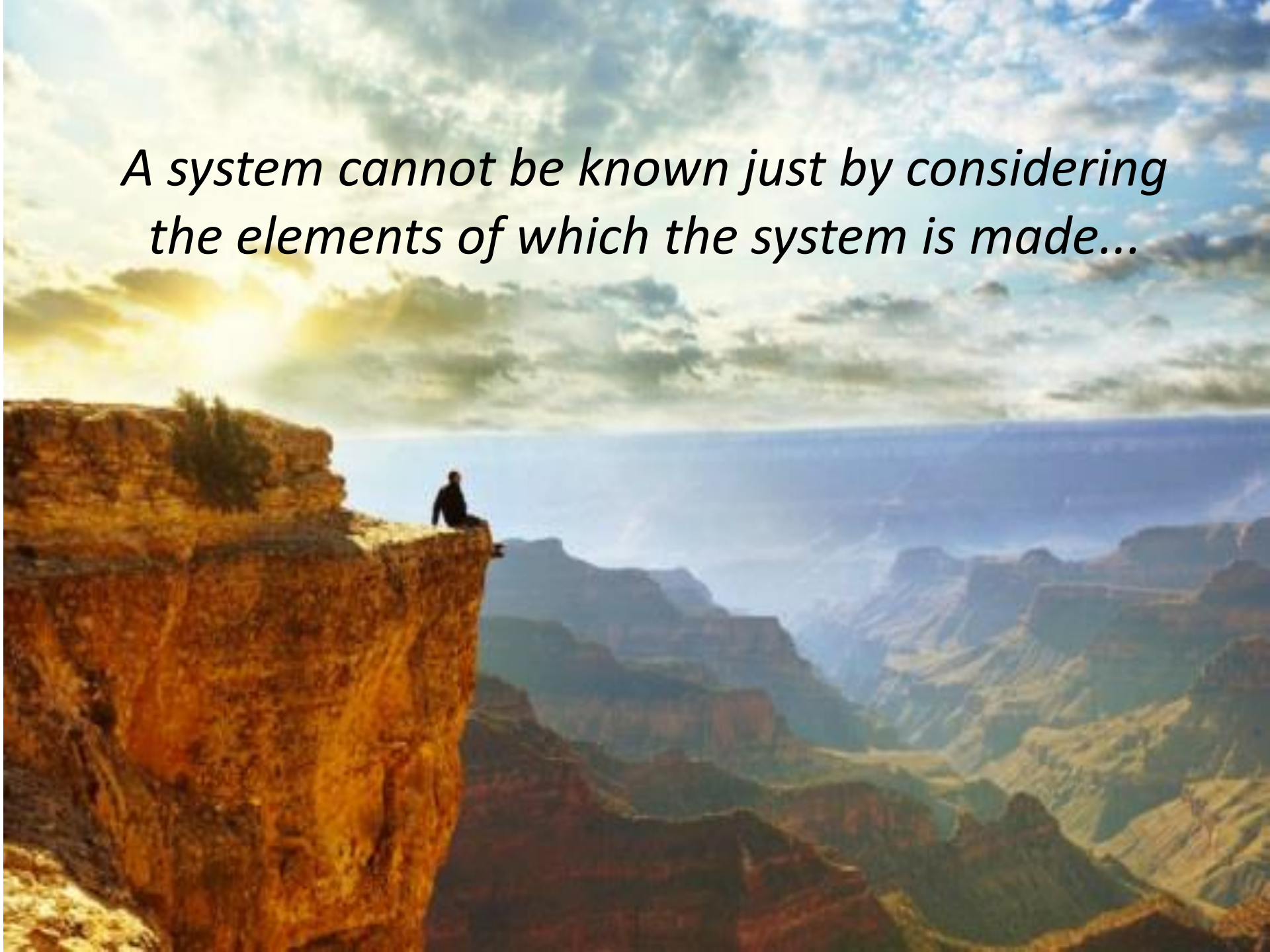
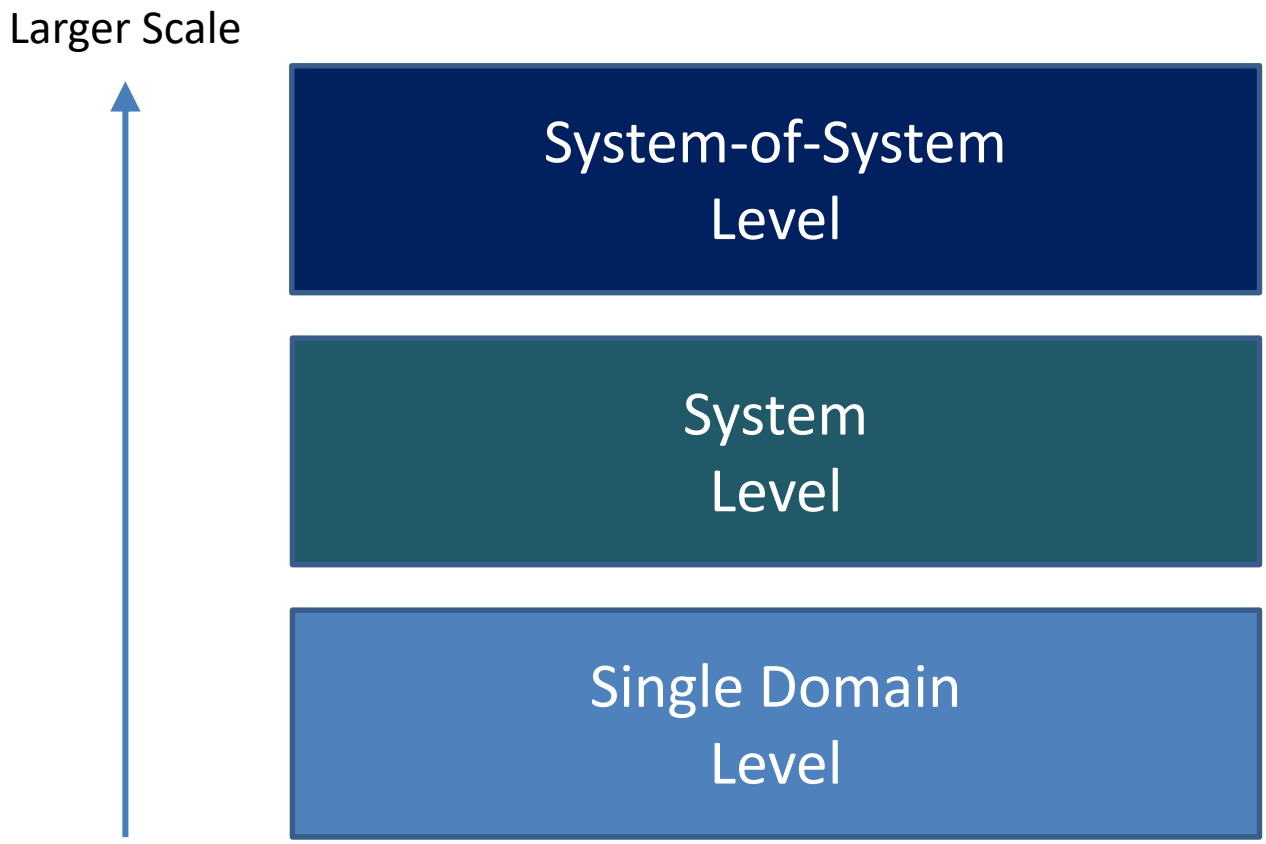

The blind men
and the elephant
It's a fan!
It's a wall!
It's a rope!
It's a spear!
It's a tree trunk!
It's a snake!

-Rumi

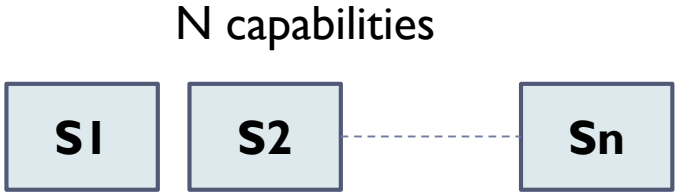

A system cannot be known just by considering the elements of which the system is made...

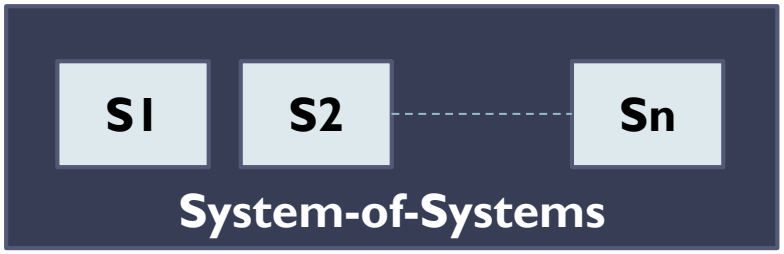
System Scale



System-of-Systems

- A system-of-systems is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities

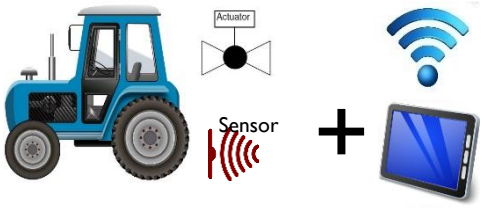




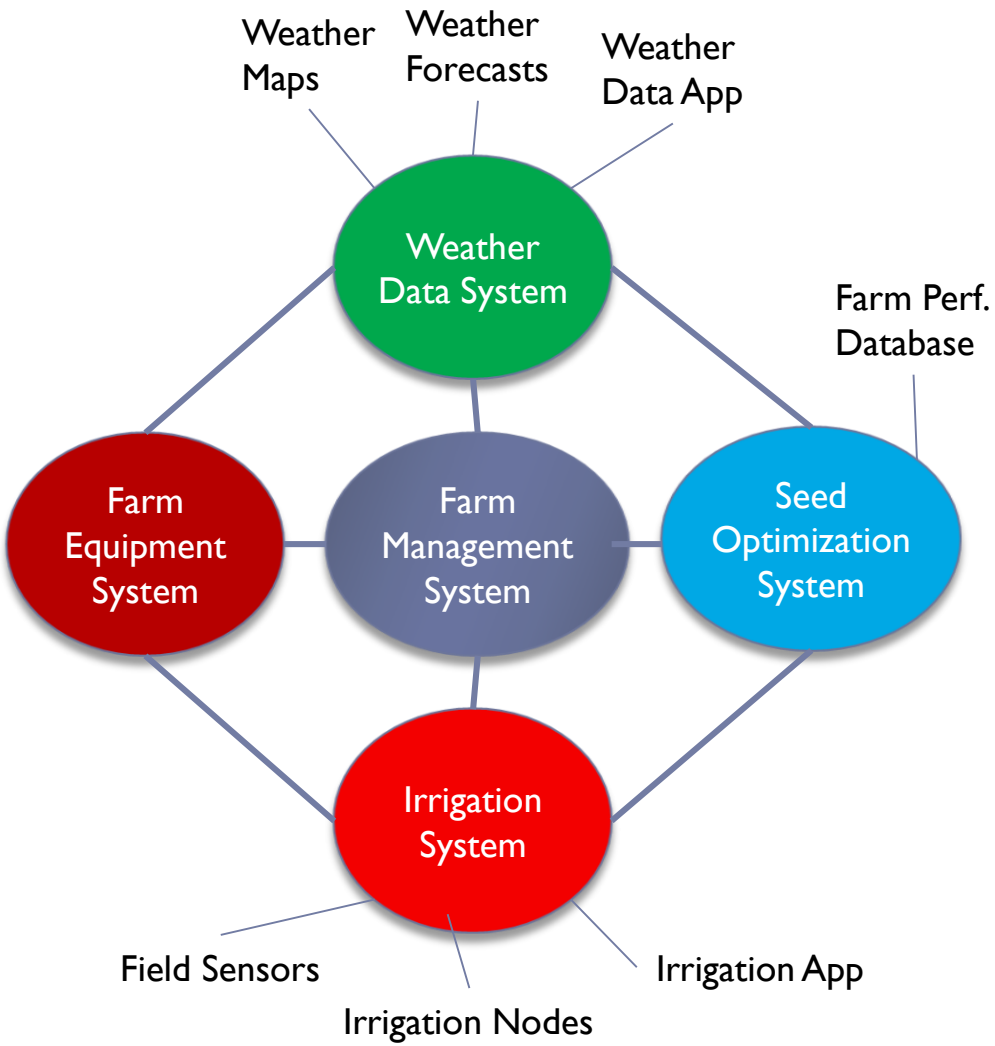
> N capabilities

more than the sum of its parts

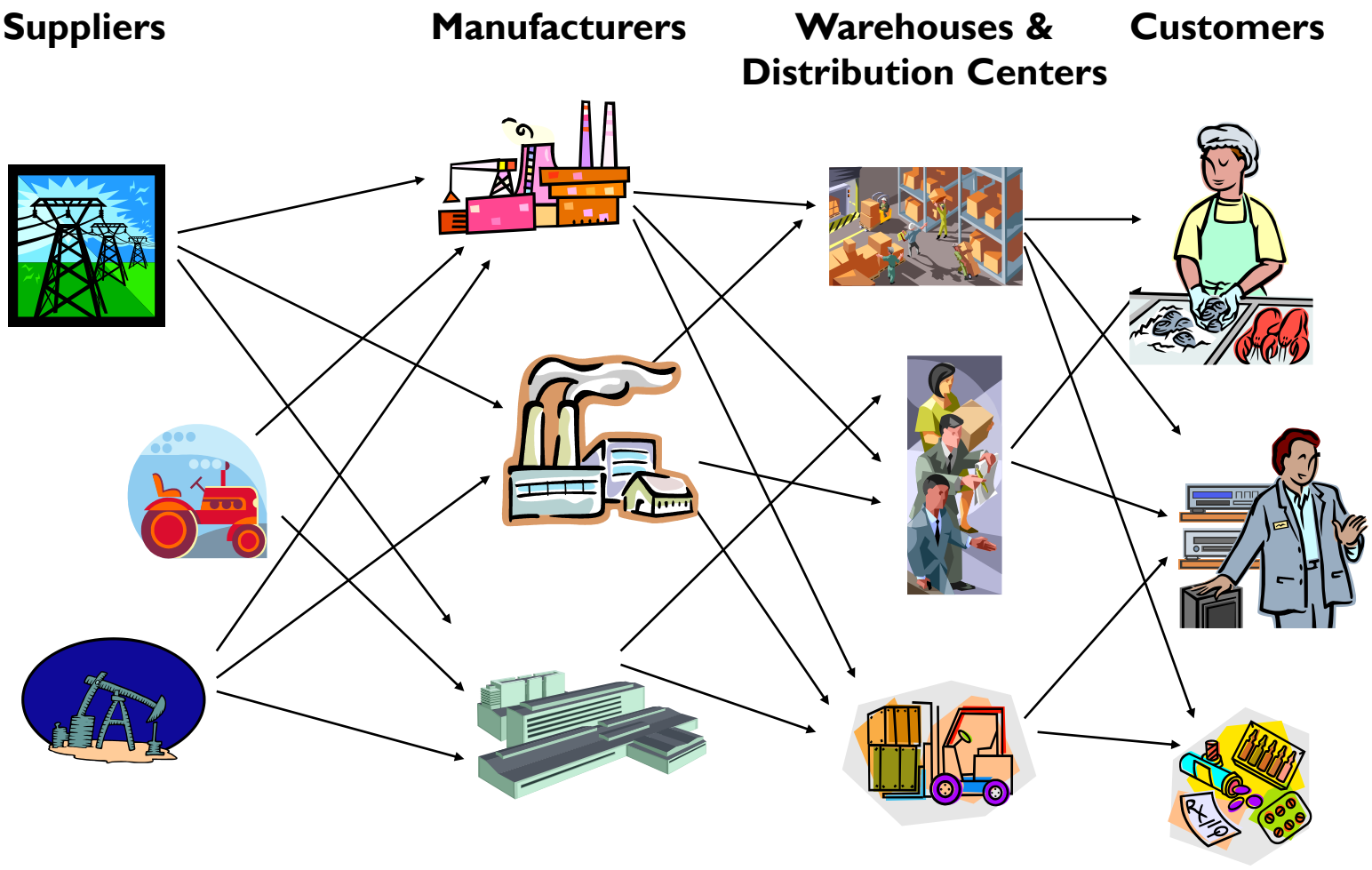
Farming System-of-Systems

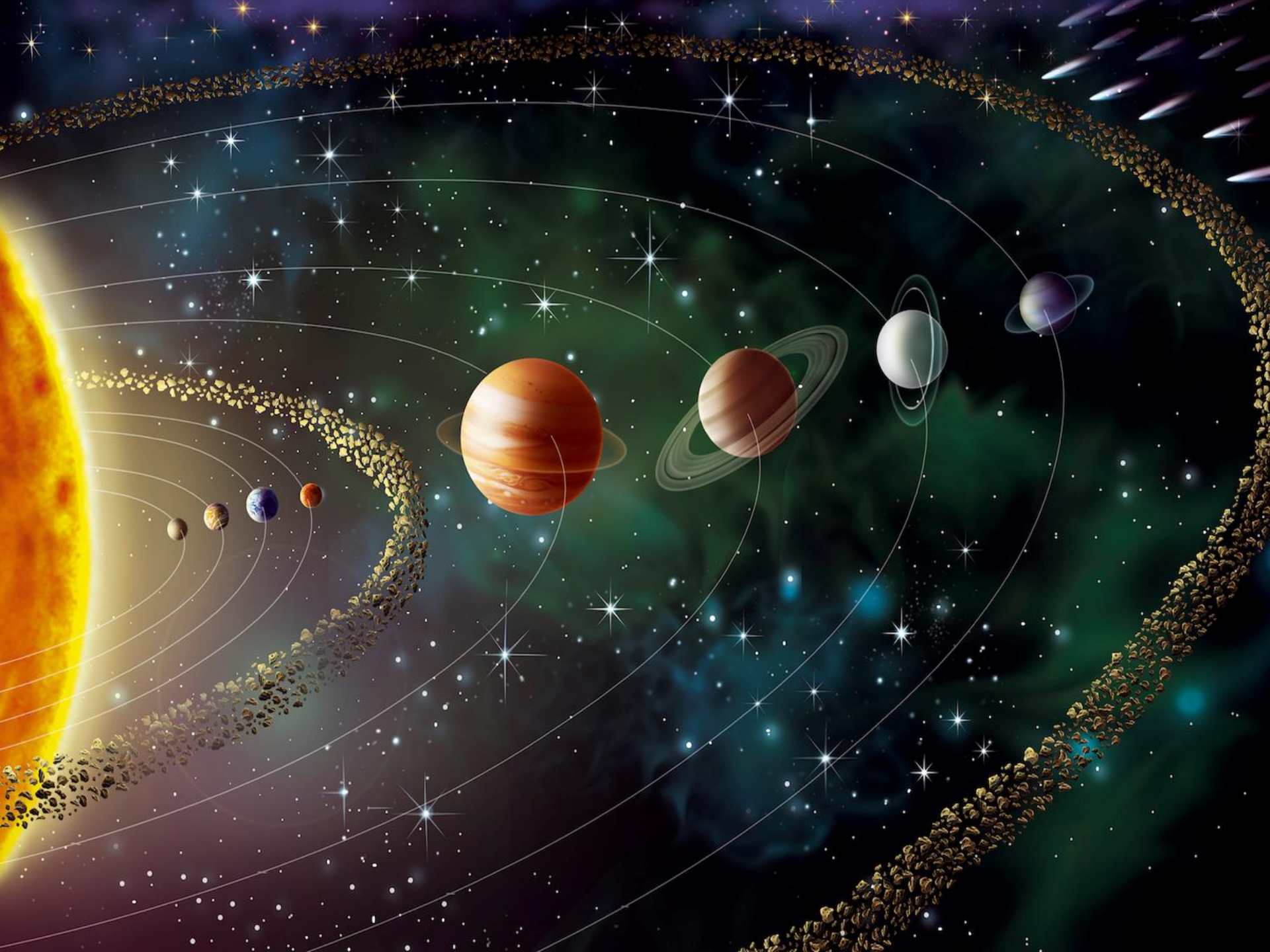


Smart Connected Product



Logistics Management/Supply Chains





Social System

Image: iStock/Easyturn

Research Questions

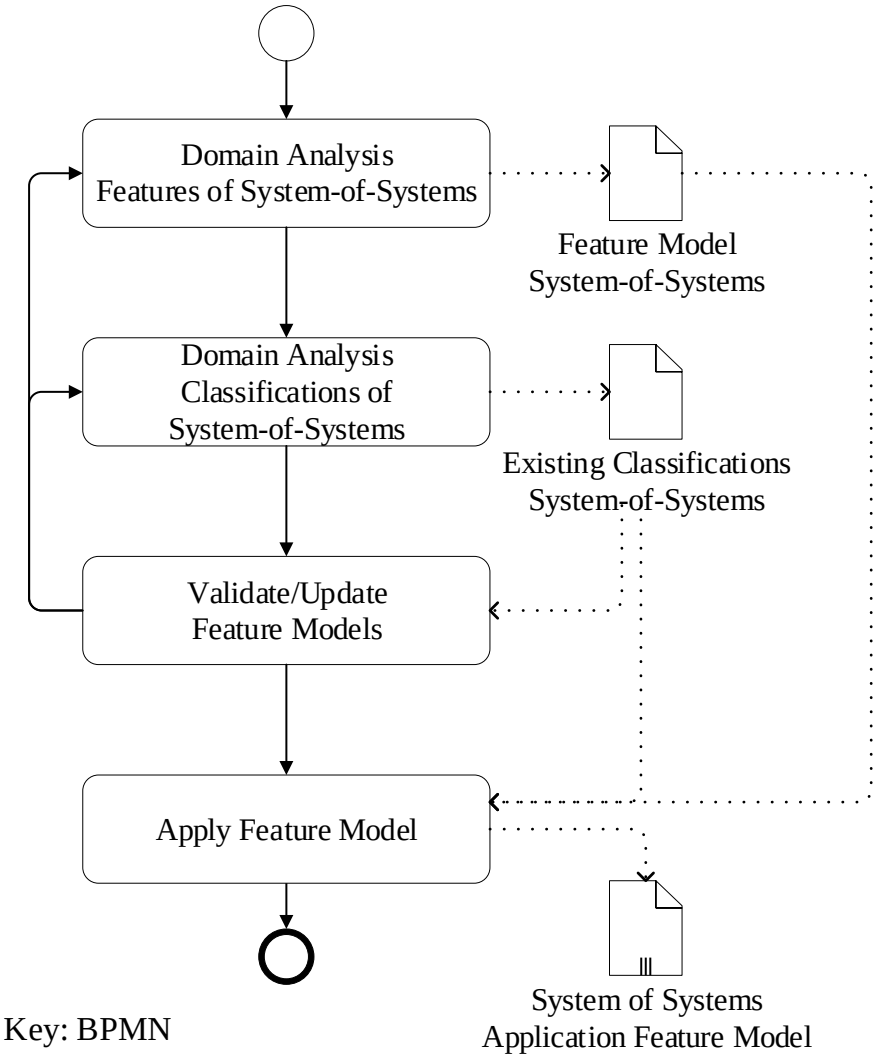
RQ1. What are the common and variant features of SoSs?

RQ2. What are the classification dimensions of SoSs?

Research Method

RQ1. What are the common and variant features of SoSs?

RQ2. What are the classification dimensions of SoSs?

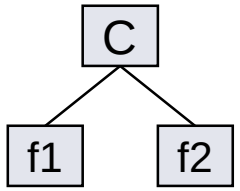


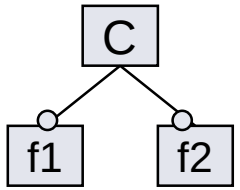
Domain Analysis

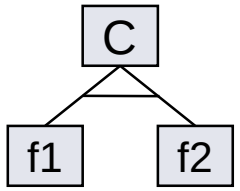
- the systematic activity of
- collecting,
- organizing and
- storing domain knowledge

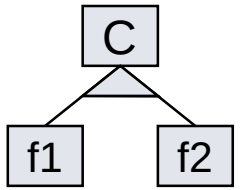
Feature-Oriented Domain Modeling

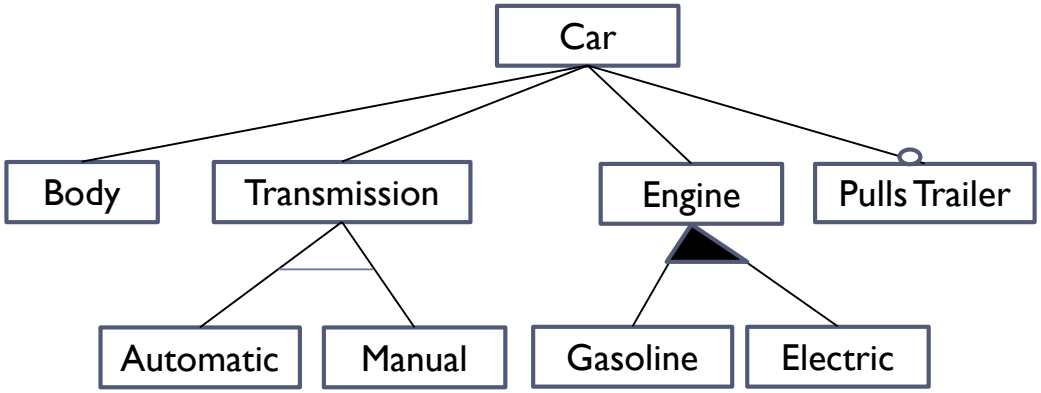
- A **feature model** represents the common and the variable features of products and the dependencies between the variable features.
- **Feature**:
  - a distinctive property of a concept (domain model)
  - user visible characteristic of a system (requirements).
- **A feature diagram** consists of a set of nodes, a set of directed edges, and a set of edge decorations.





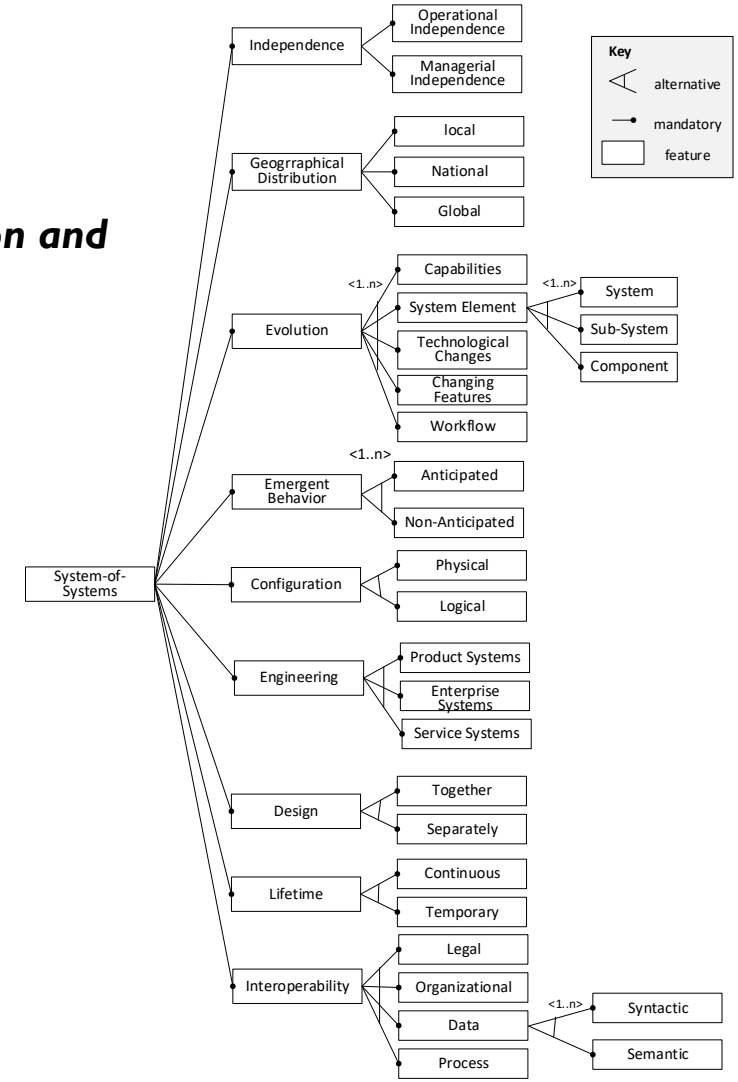






Feature Diagram – System-of-Systems

RQ1. What are the common and variant features of SoSs?



Classification Criteria

- Application Domain
- Management
- Governance
- Logical Configuration
- Technological Adaptation
- Type of System Elements
- Complexity

Classification based on Application Domain

- ***Technological Systems***: include man-made engineered artifacts or constructs; including physical hardware, software and information.
- ***Social Systems***: include elements, either abstract human types or social constructs, or concrete individuals or social groups.
- ***Natural Systems***: include elements, objects or concepts which exist outside of any practical human control.

L. Von Bertalanffy, "General System Theory," Georg. Braziller New York, vol. 1, p. 289, 1968.

System of Systems - Examples

System	System-of-Systems
Technological	
Airplane	Air Traffic Control System
Car, Road	Integrated Traffic System
Train	Rail Network
Smart Metering, Wind Turbine	Smart Grid
Computer	Distributed System
Farm	Integrated Precision Farming System
Building	Town, Shopping Mall
Social	
Town Council	Government, United Nations, European Union
Family, Social Group	Town, Nation
Student, Teacher, School	Education System
Company	Enterprise, Stock Market
Natural	
Animal	Herd
Plant	Forest
Weather, RI	Eco-system
Star	Solar System

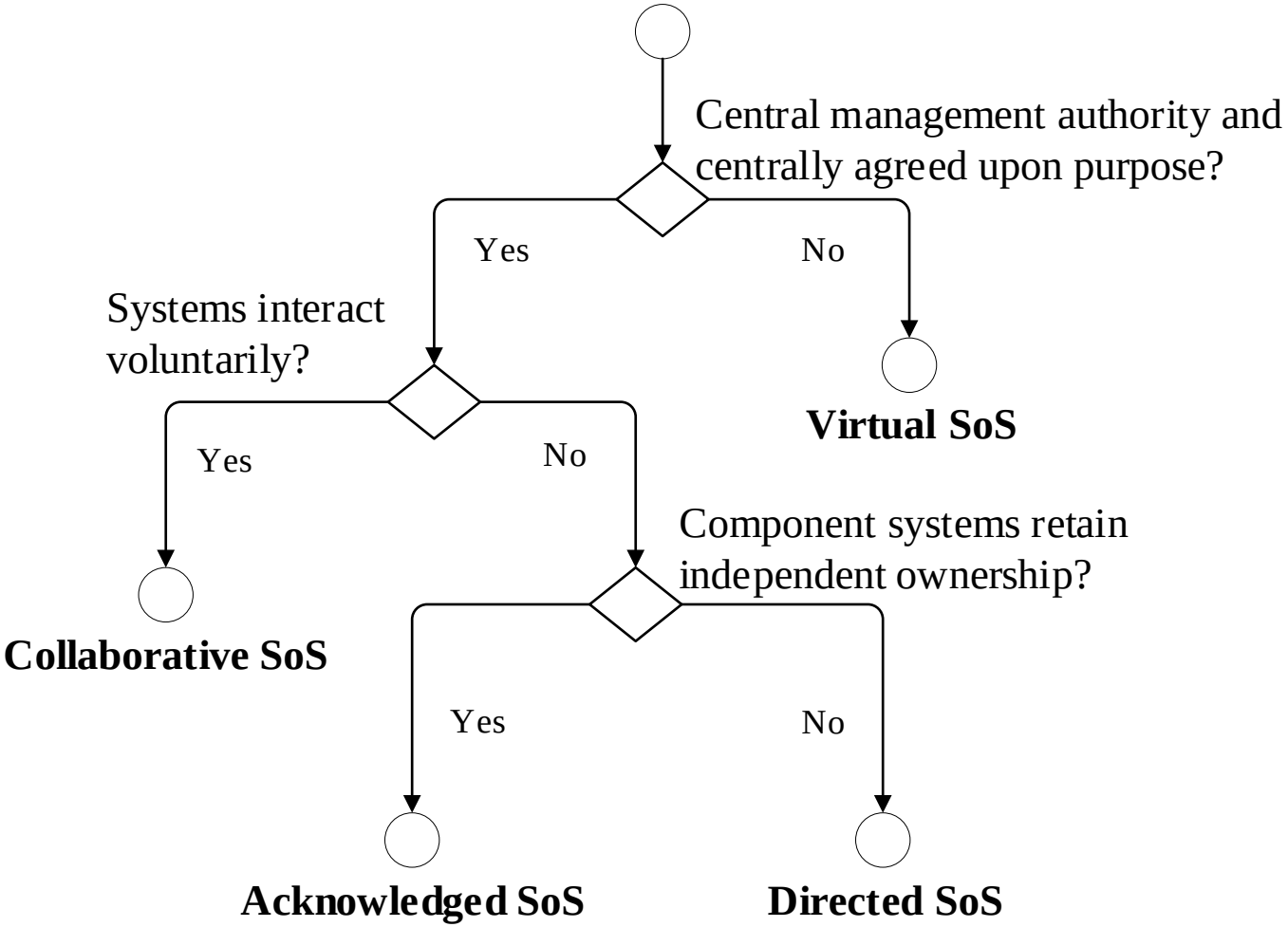
Classification based on Management Criteria

- ***Directed SoS*** are built and managed to fulfill specific purposes. The SoS is centrally managed to fulfill the agreed purpose. The component systems can operate independently, but their normal operational mode is subordinated to the central managed purpose.
- ***Collaborative SoSs*** have a commonly agreed purpose but do not have a central management. The component systems interact voluntarily to fulfill agreed-upon central purposes.
- ***Virtual SoSs*** lack a central management authority and a centrally agreed-upon purpose. Further, the component systems have their independent ownership.
- ***Acknowledged SoS*** have also a recognized objective and central management. In contrast to Directed SoS the constituent systems retain their independent ownership. Changes in the systems are based on collaboration between the SoS and the system.

M. W. Maier, "Architecting Principles for Systems-of-Systems," Syst. Eng., vol. 1, no. 4, pp. 267–284, 1998.

J. S. Dahmann and K. J. Baldwin, "Understanding the current state of US defense systems of systems and the implications for systems engineering," in SysCon 2008, 2008.

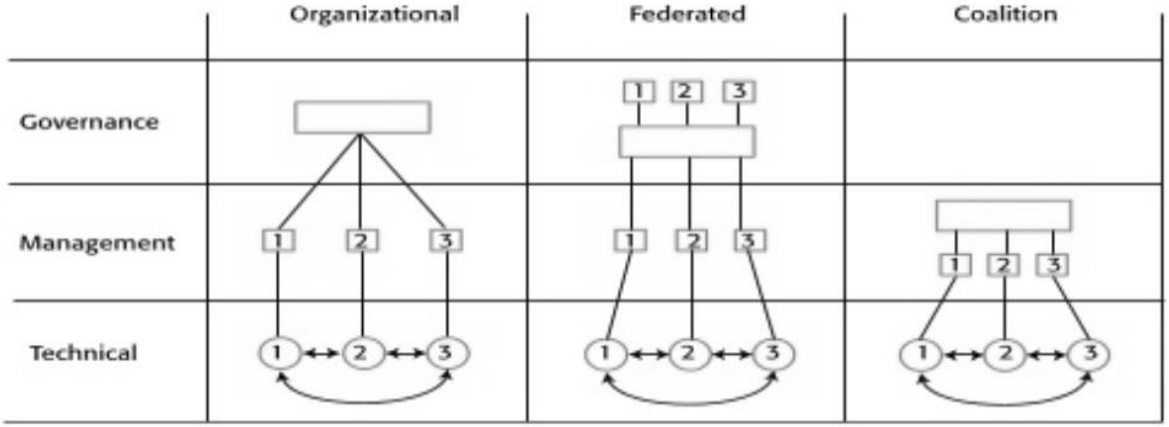
Classification based on Management Criteria



B. Tekinerdogan. Engineering Connected Intelligence: A Socio-Technical Perspective. Wageningen University, 2017

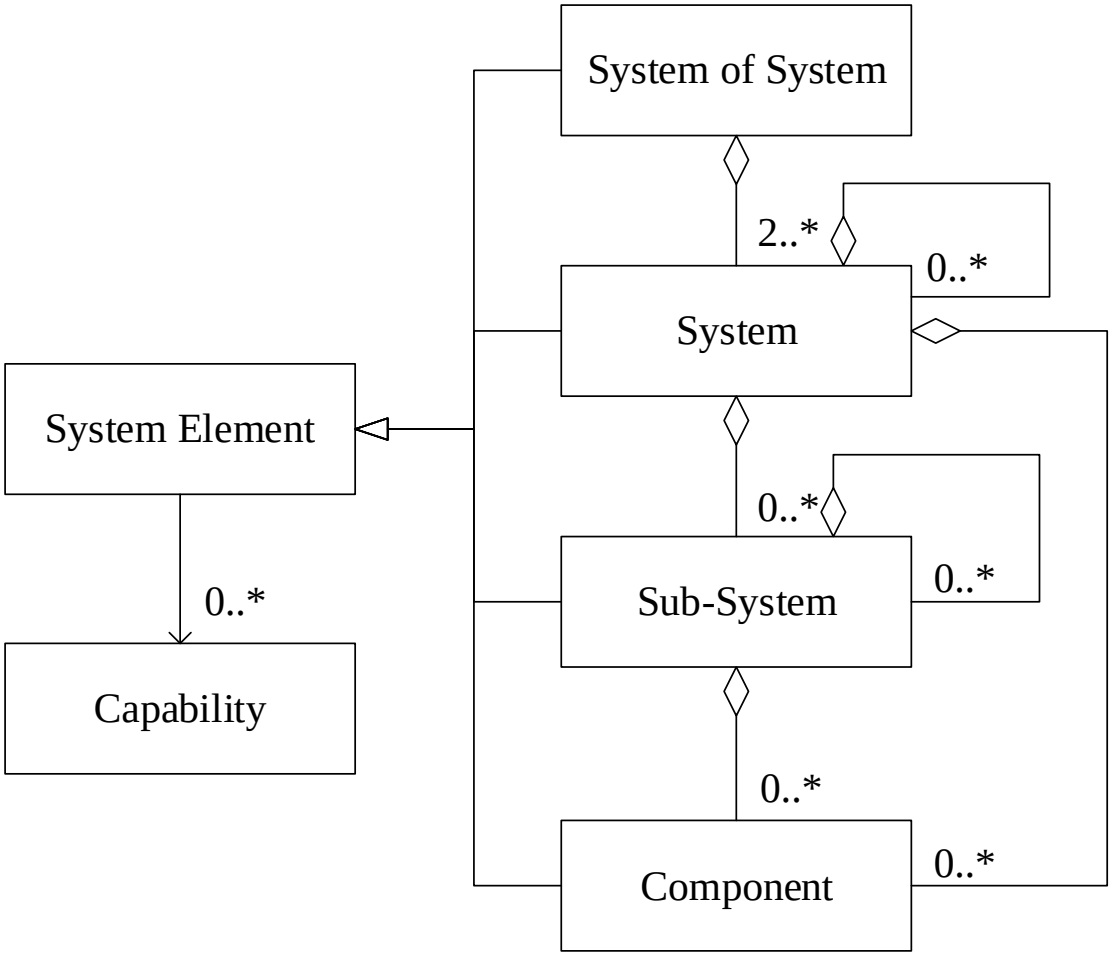
Classification based on Governance Criteria

- ***Organizational SoSs*** are SoSs where the governance and management of the system resides within the same organization or company. Collaboration between system owners is managed by the organization. A governance authority within the organization sets the policies, which are implemented in different ways by system managers.
- ***Federated SoSs*** are SoSs where the governance of the SoS depends on a voluntary participative body in which all of the system owners are represented. The system owners agree to collaborate and that decisions made by the governance body are binding.
- ***Coalition SoSs*** are SoSs where there is no governance authority but where the organizations involved informally collaborate and manage their own systems to maintain the system as a whole.



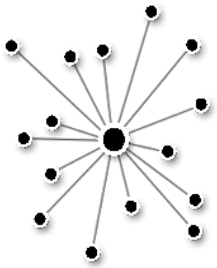
I. Sommerville, Software Engineering, Pearson, 2018.

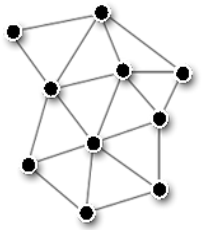
Classification based on Logical Configuration



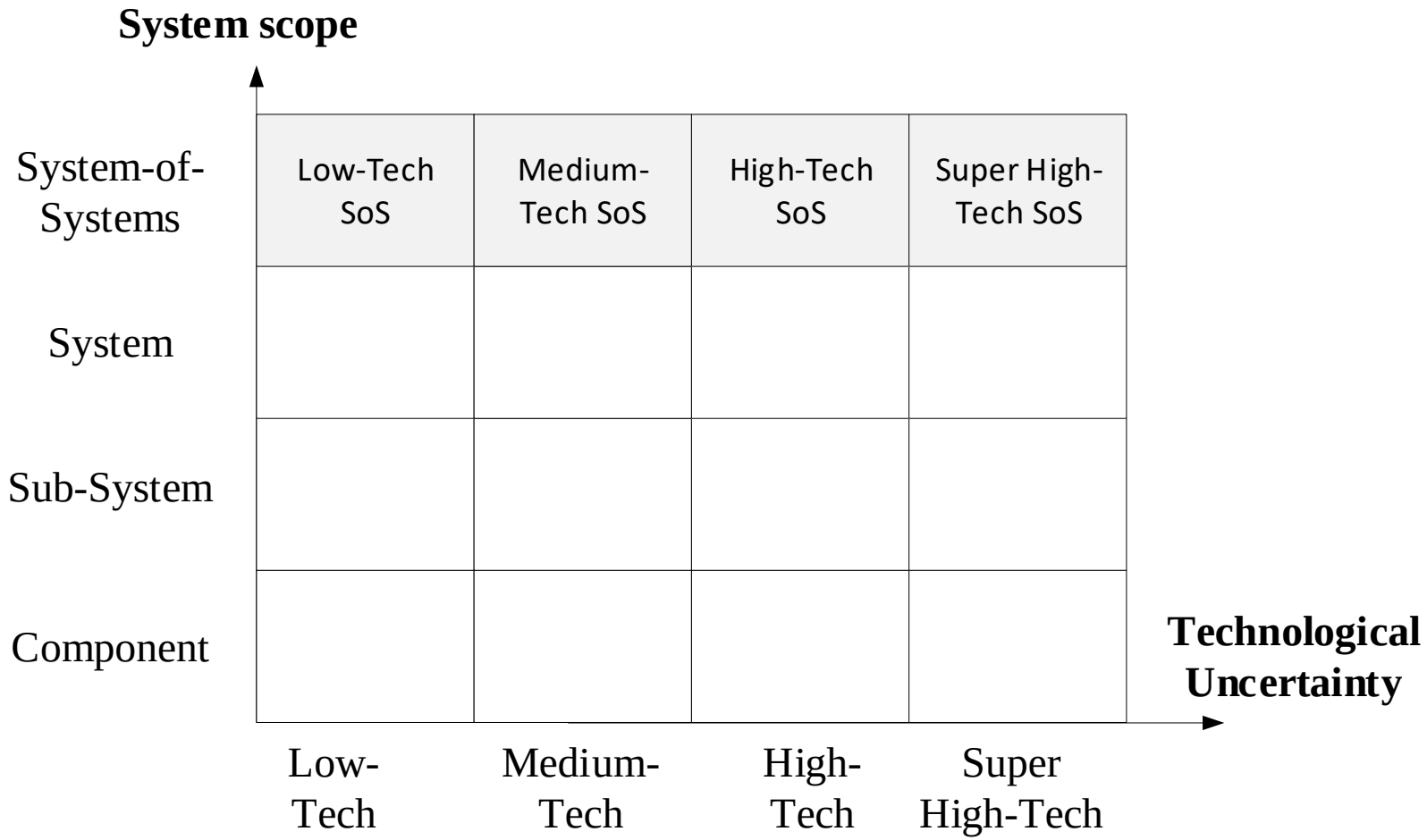
Classification based on Logical Configuration

- ***Centralized SoS*** is configured in such a way that it has a single central system element has the authority, and all constituent systems obey the commands of the central system element.
- ***Distributed SoS*** does not have a single authority but each constituent system is directly connected to every other constituent system.
- ***Decentralized SoS*** have also no single authority but include selected constituent systems that collectively define the authority.





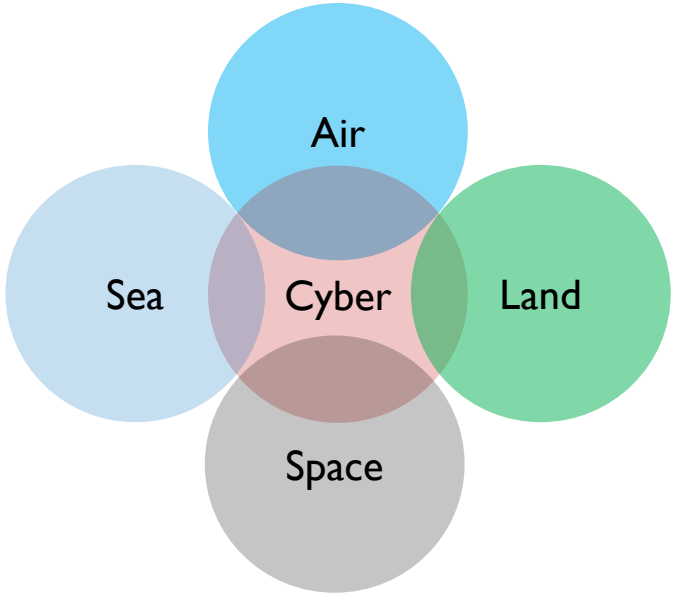
Classification based on Technological Adaptation



A. J. Shenhar and Z. Bonen, "The new taxonomy of systems: Toward an adaptive systems engineering framework," IEEE Trans. Syst. Man, Cybern. Part ASystems Humans., 1997.

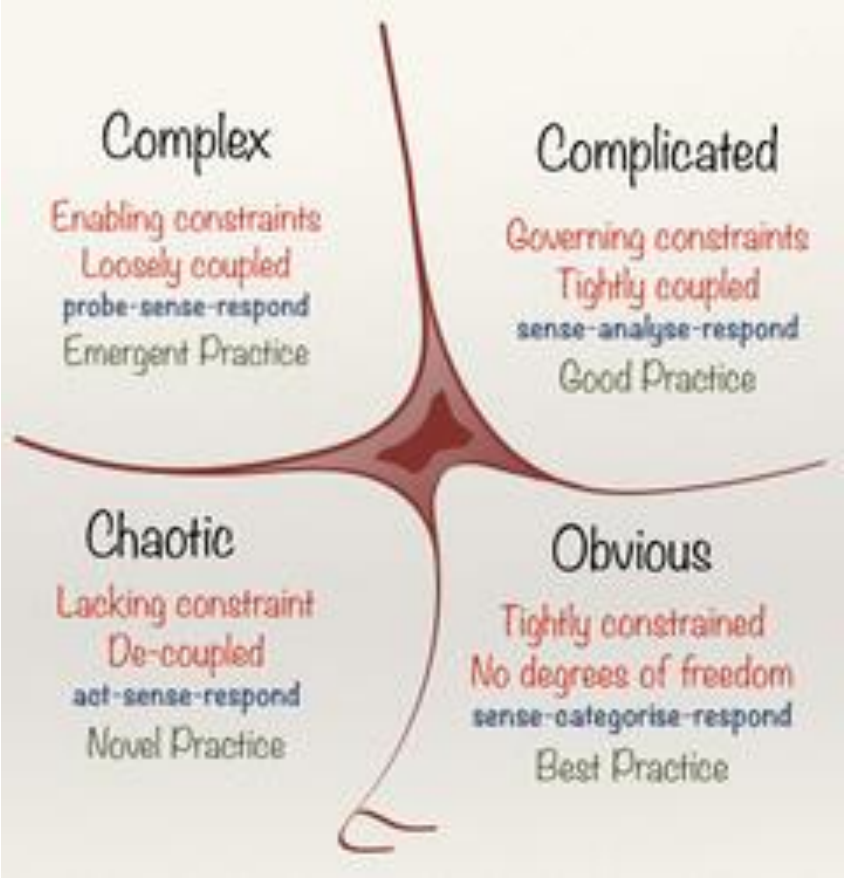
Classification based on Type of System Elements

- Physical SoS
- Cyber SoS
- Cyber-Physical SoS



Classification based on Complexity

- ***Simple SoSs*** are self-evident systems in which cause and effect relations are clear, predictable, repeatable, and often linear. The advice in such a situation is to "*sense–categorize–respond*"
- ***Complicated SoSs*** are systems in which there is a logical relationship between cause and effect, but this is not self-evident. There are a range of right solutions and analysis and expertise is needed to find the proper solution. The advice in such a situation is to "*sense–analyze–respond*"
- ***Complex SoSs*** are systems in which the cause and effect relationships can only be observed in retrospect, usually with unpredictable outcomes. The decision strategy here is to "*probe–sense–respond*"
- ***Chaotic SoSs*** do not show a relation between cause and effect. The objective here is to restore order. The advice for such a situation is "*act–sense–respond*".
- ***Disorder SoSs*** are systems in which the actual context is not known, and it is not clear to which context the situation should be appointed. The advice here is to break down the situation into constituent parts and assign each to one of the other four realms.



https://en.wikipedia.org/wiki/Cynefin_framework

Classification Criteria

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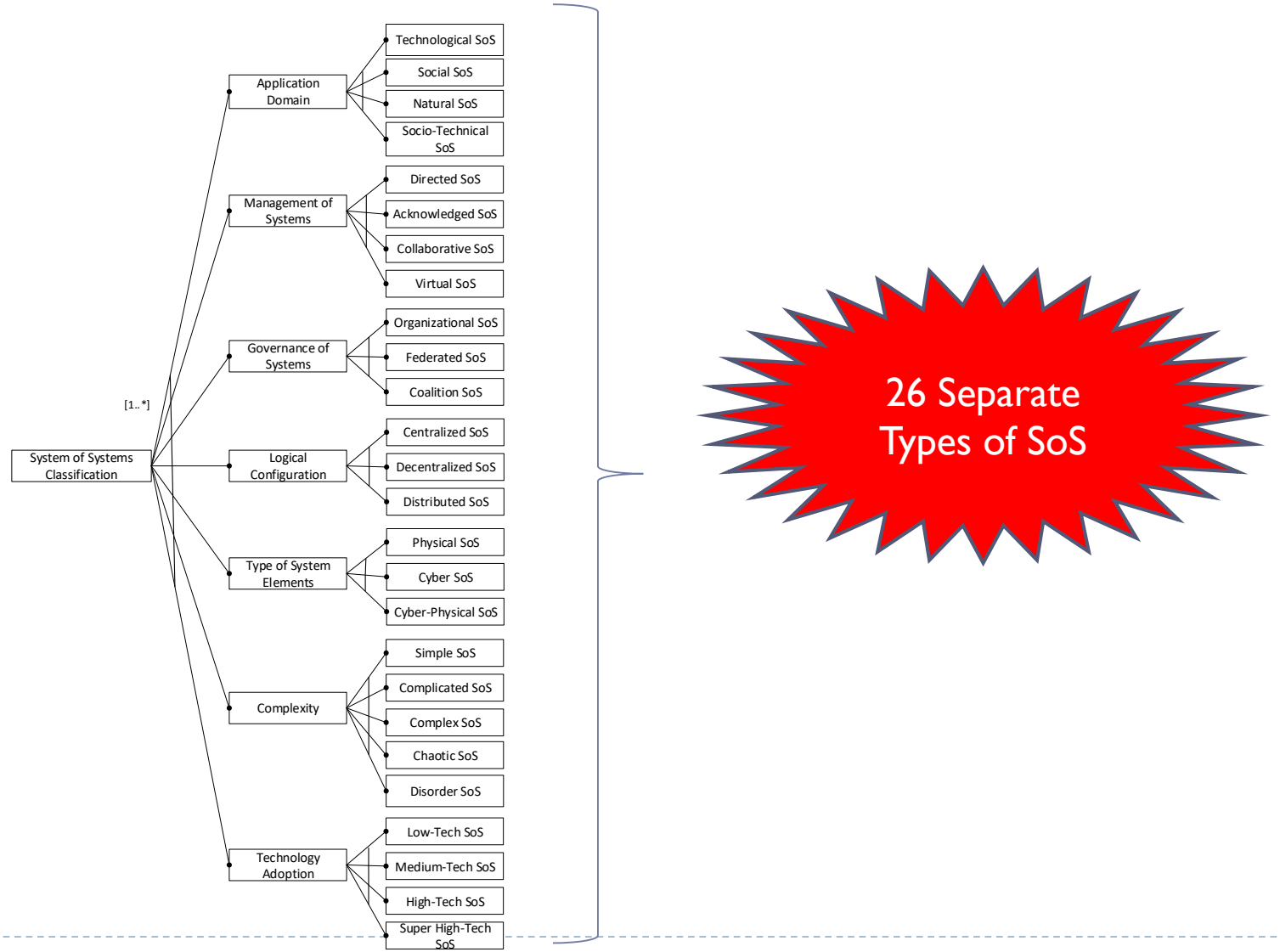
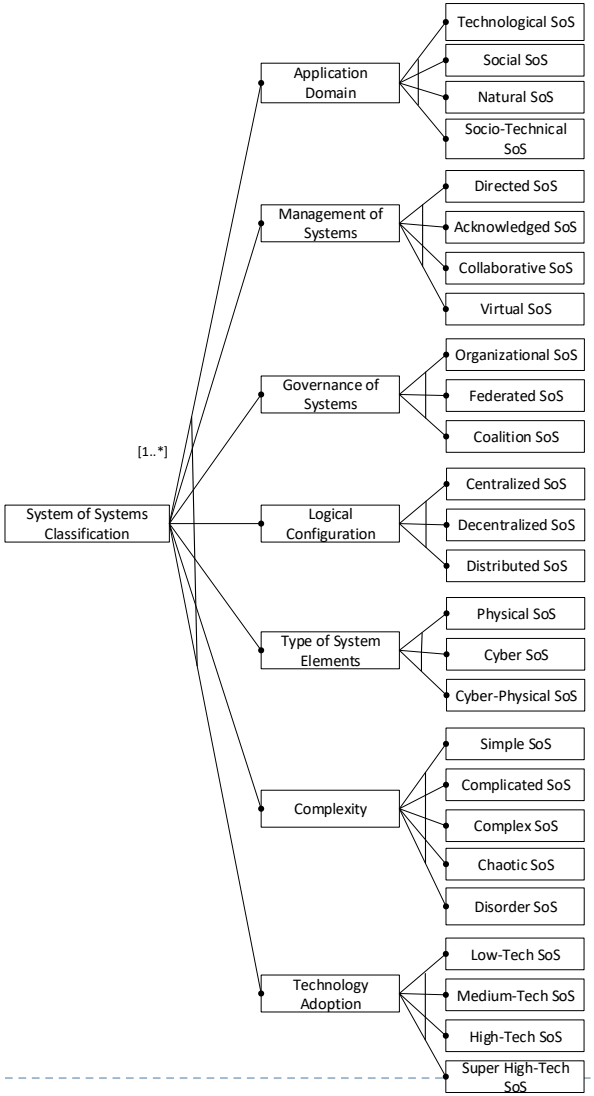
- …

Multi-Dimensional Classification



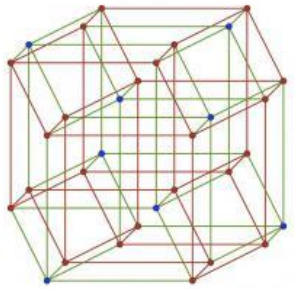
Multi-Dimensional Classification



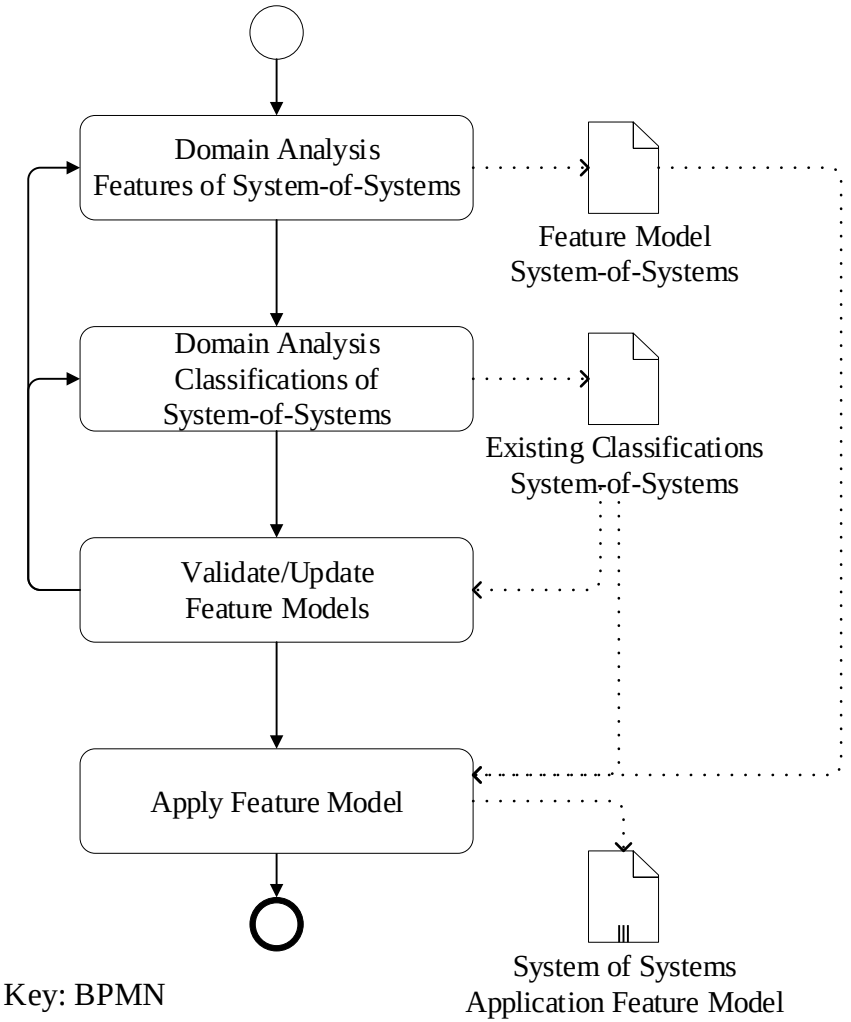
Example SoS Type Configurations:

- SOS1: {technological, acknowledged, organizational, decentralized, Cyber-Physical, Complex, Medium-Tech}.
- SOS2: {socio-technical, collaborative, federated, decentralized, Cyber-Physical, Complex, Low-Tech}.
- SOS3: {social, virtual, coalition, distributed, physical, complex, Medium-Tech}.

The total theoretically possible number of combinations given the alternative types per dimension, are 4x4x3x3x3x5x4=8640.

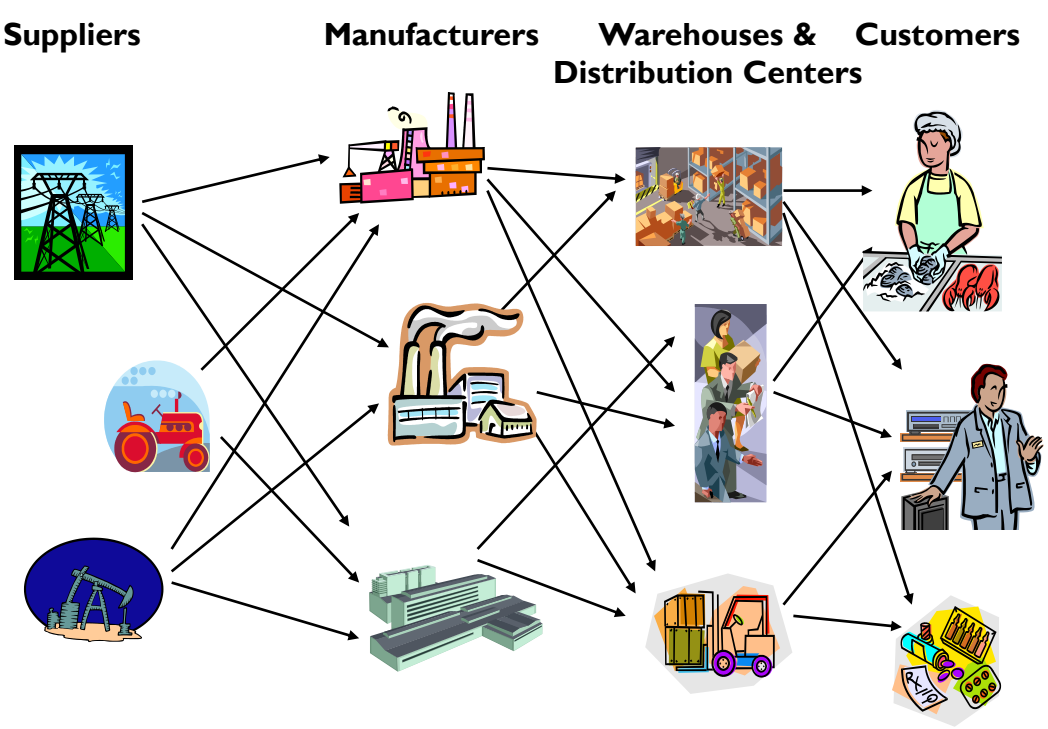


Application of Classification

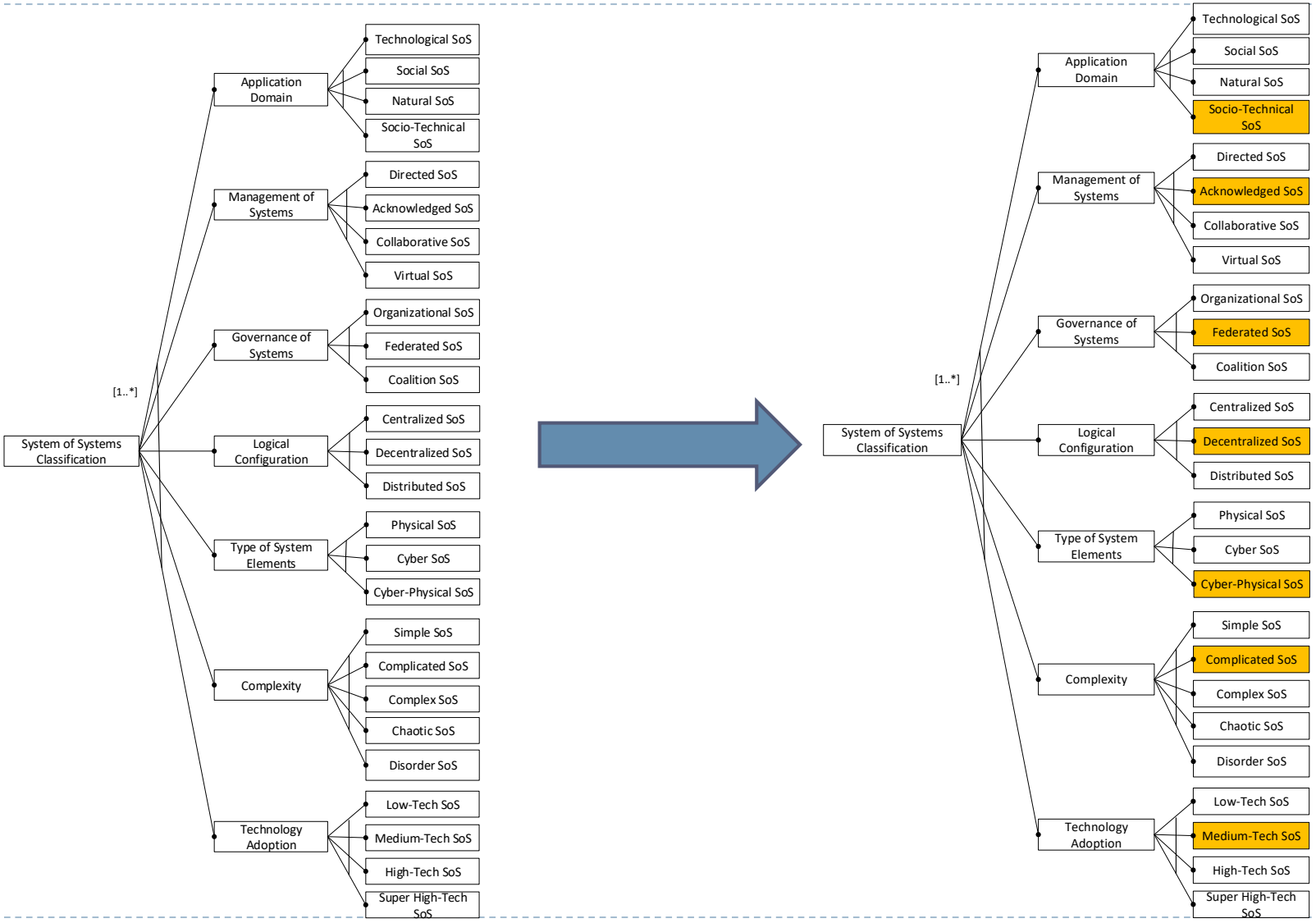


Case Study – Supply Chain Management

- Supply chains consist of autonomous organizations that independently make decisions
- Each organization can be considered as a complex system
- The operational performance of a supply chain relies on the proper integration of the activities of the organizations
- Hence, a supply chain system can be viewed as a system of systems



Case Study – Supply Chain Management



Conclusion

- There is no clear consensus yet on the classification of SoS
- SoSs are classified from a particular standpoint only.
- This reductionistic and fragmented perspective on SoS can impede the proper understanding, development, and analysis of SoSs.
- We have provided a classification of SoSs that provides a more holistic perspective on SoSs considering seven different dimensions.
- Each dimension has a direct impact on the design and understanding of the SoS.
- The provided multi-dimensional classification enhances the awareness of these dimensions and can pave the way for a further understanding of SoSs, and trigger research activities.
- In our future work, we aim to apply the classification to the field of SoS engineering and focus on both the development and analysis of SoSs.