34th Annual INCOSE international symposium

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An Agent-Based Ontology to Support Modeling of Socio-Technical Systems-of-Systems

Jakob Axelsson, Mälardalen University & RISE Research Institutes of Sweden

Introduction

- System-of-systems (SoS) = collaborating independent systems
- SoS are socio-technical: constituent systems (CS) include technology, people, organizations
- Agents: entities that can take independent actions
- Why are SoS of higher complexity than integrated systems?
- Claim: SoS will always involve multiple models that refer to each other!

System-of-systems engineering pain points

SoS Pain Points	Questions
SoS Authorities	Effective collaboration patterns?
Leadership	Roles and characteristics of effective SoS leaders?
Constituent Systems	Effective approaches to integrate CS?
Capabilities & Requirements	Suitable abstractions for SoS & CS capabilities?
Autonomy, Interdependencies & Emergence	Address complexities of SoS interdependencies and emergent behaviors?
Testing, Validation & Learning	Approach to SoS validation, testing, and continous learning?
SoS Principles	Key SoS thinking principles?

Dahmann, J. (2014). System of Systems Pain Points. Proc. INCOSE International Symposium, 108–121.

Systems worldviews

- Survey by Dori et al. (2020) identified 7 different worldviews on ”system” among practitioners
- Worldview = Cognitive orientation of an individual toward a concept
- Constructivist view: Systems are conceptual, and not in the real world
  - Common view in soft and socio-technical system communities
  - SoS are socio-technical, hence this is a relevant view for SoS
  - Systems exist in models!

What is a model?

A model...

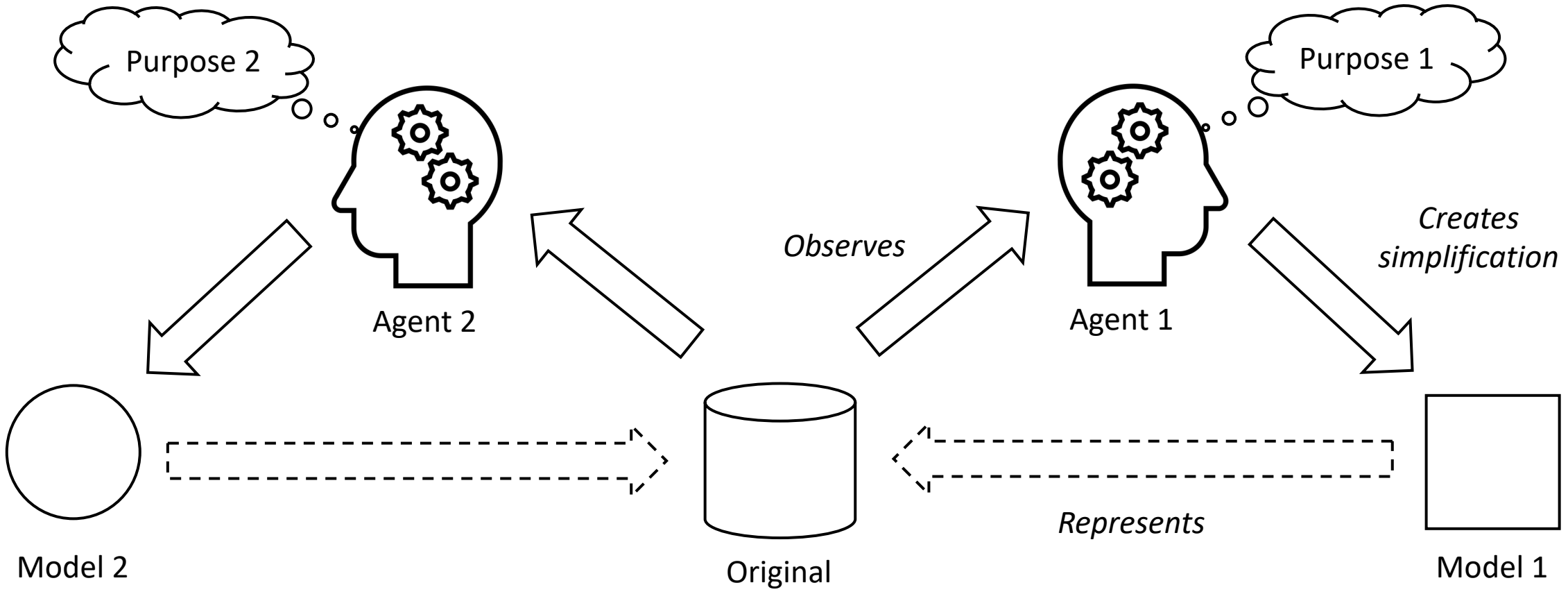
- Represents some original
- Is a simplification
- Has a purpose for its user

Allgemeine modelltheorie (Stachowiak,1973)

Cost-effectiveness trade-offs:

- Occam's razor: Principle of parsimony
- Box: "All models are wrong, but some are useful"
- Einstein: "A theory should be as simple as possible, but not simpler than that"

Observers and models



Definition of system

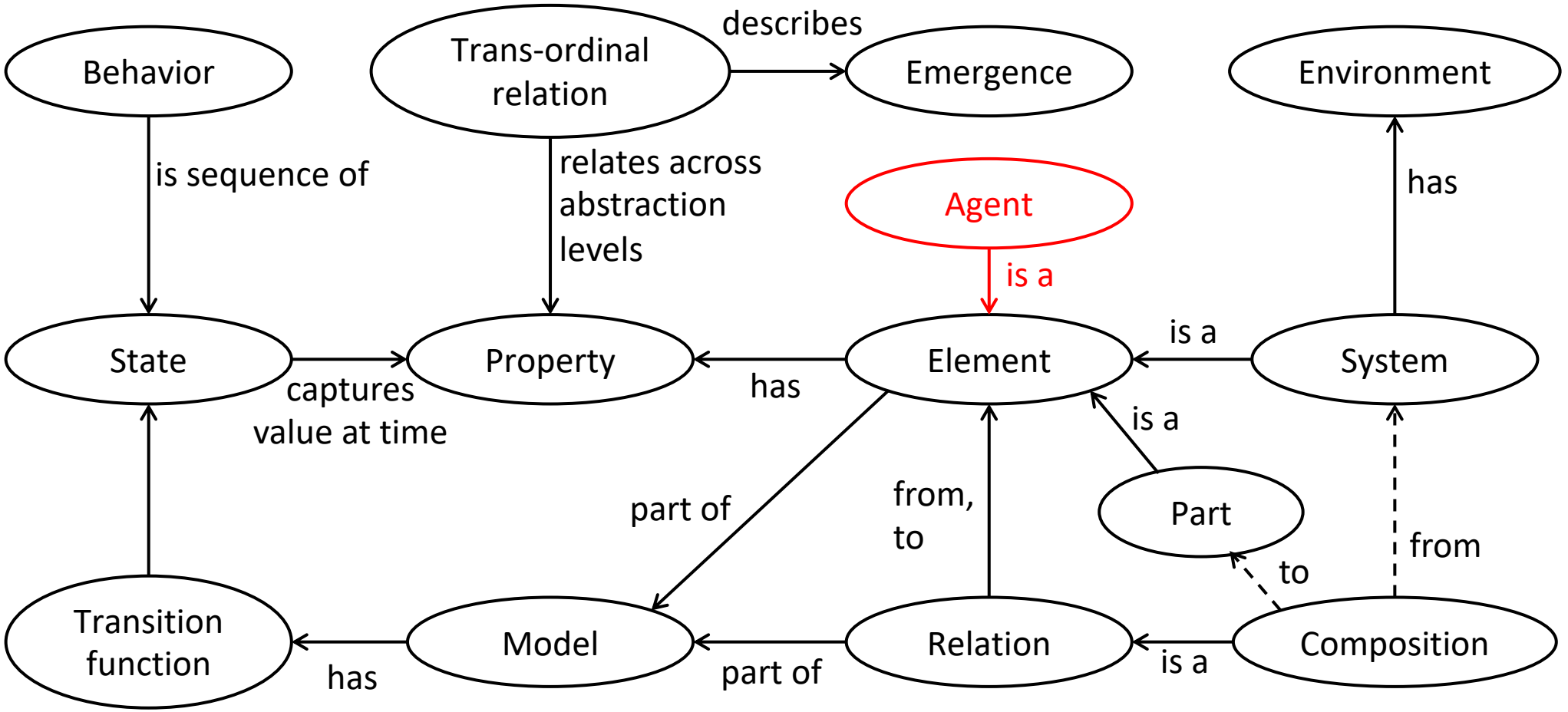
INCOSE definition of system:

- An arrangement of parts or elements that together exhibit behavior or meaning that the individual constituents do not.
- The system's properties (as a whole) result, or emerge from:
  - the parts or elements and their individual properties
  - the relationships and interactions between and among the parts, the system, and its environment

Sillitto, H., et al. (2019). Systems Engineering and System Definition. INCOSE.

- Ontology can be seen as a set of concepts that are defined in terms of each other
  - More stringent than just text
  - A basis for models (similar to a metamodel)
- Reminder: In the adopted constructivist worldview, systems are concepts in a model!

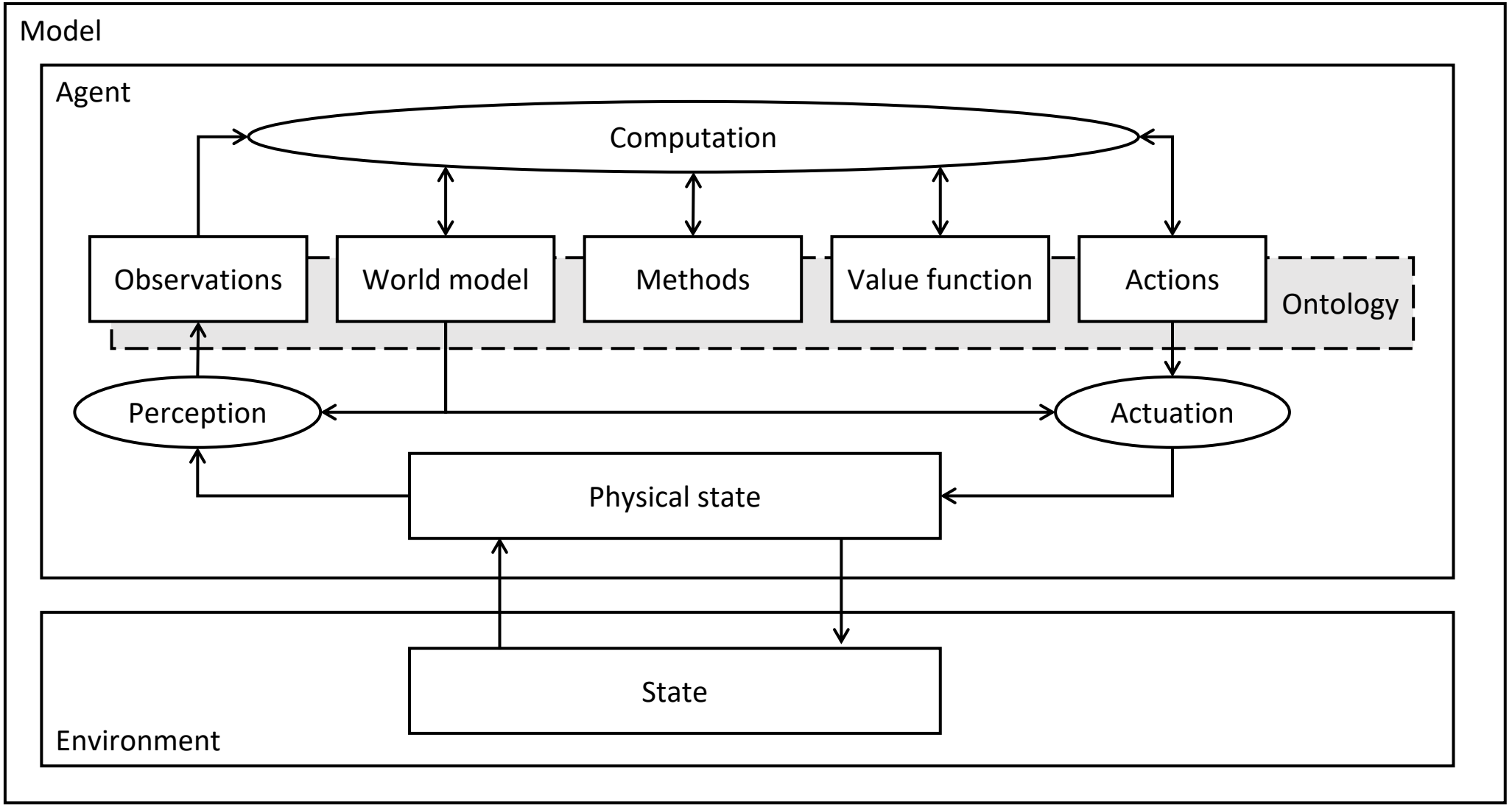
Basic system ontology



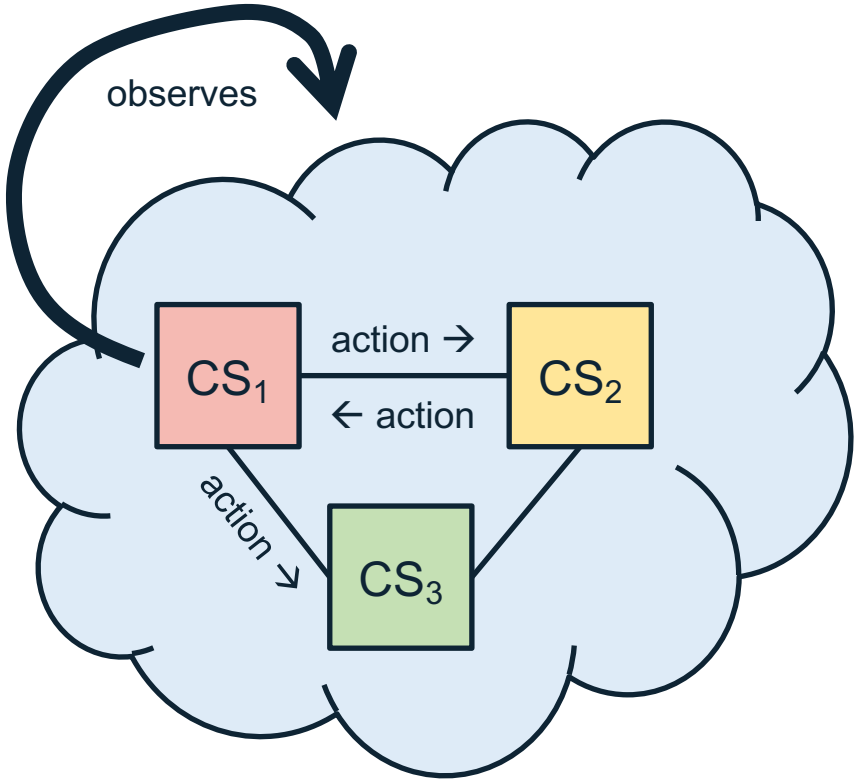
Agents

- Agents are used to model elements with agency (that can choose their actions)
- The original they represent can be, e.g., autonomous technical systems, humans, or organizations
- The independent CS of an SoS can also be seen as agents
- Key question: What characteristics must an agent have in order to choose its actions?
- An agent ontology captures these characteristics

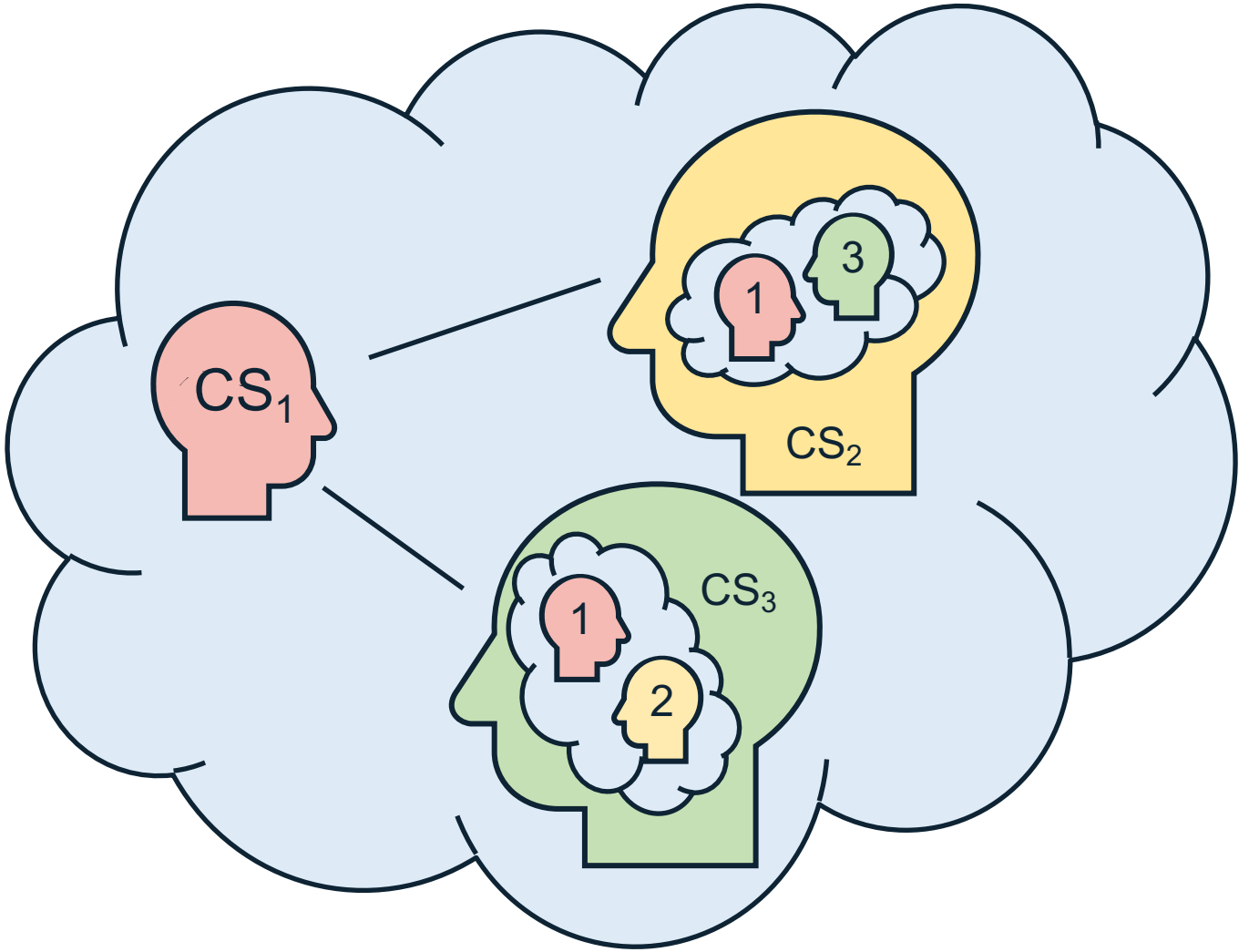
Agent ontology



Models of models of ...



SoS situation (real world)



SoS situation (CS_1's model)

Ontologies and models in SE practice

- Help describing a socio-technical SoS situation:
  - Each element in ontology leads to a question to ask
  - Example: ”Agent” → What CS exist in the SoS?
- Basis for formal MBSE metamodel
  - Analysis techniques that capture relevant SoS and CS aspects, such as game theory
  - Design space exploration as model transformations
- Clarify differences between SE and SoSE
  - In an integrated system, agents are outside the system-of-interest
  - In an SoS, agents are inside the system-of-interest

Implications on SoSE pain points

SoS Pain Points	Contributions of ontologies
SoS Authorities	Make authorities explicit as agents, with elicited WMs and incentives
Leadership	Articulate differences in agent WMs, cognitive biases as basis for situationally adapted SoS leadership
Constituent Systems	Model CS adaptation as transformations from being SoS ignorant to being active constituents
Capabilities & Requirements	Capabilities represented by agent behavior
Autonomy, Interdependencies & Emergence	Agent collaboration models capture interplay of independence and interdependence
Testing, Validation & Learning	Modeling CS as adaptive agents captures how SoS evolve, and the need for online validation
SoS Principles	A solid ontology is the basis for SoS thinking

Conclusions

- Independent CS of an SoS conceptualized as agents with individual objectives
- Agents observe the world and create models of it as a basis for deciding actions
- The agents' world models need to include models of other agents, since in an SoS the observers are inside the system, not outside of it

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