A Few Words First

Audio Connection –Please mute phone (*6 toggle) –or your GM left-side name

Phone connections may be muted during presentation. Put questions in chat box.

Upcoming Meetings:

- November 11, 2020: Dr. Heidi Hahn – Empowering Women Leaders in Systems Engineering
- December 9, 2020: David Hartley and Dr. Paul Clements – Patterns for Success in the Adoption and Execution of Feature-Based Product Line Engineering
- January 13, 2021: David Long – Schema and Metamodels and Ontologies – Oh My!

CSEP Courses by *Certification Training International:*

CTI currently is offering online course offerings, see https://certificationtraining-int.com/incose-sep-exam-prep-course/

Chapter SEP mentors: Ann Hodges alhodge@sandia.gov and Heidi Hahn drsquirt@outlook.com

And now - introductions

Enchantment Chapter Monthly Meeting

4:45pm – 6:00pm MT

Achieving System-of-Systems Interoperability Levels

Abstract: Interoperability is a key concern in systems-of-systems (SoS). Numerous frameworks have been proposed to deal with this, but they are generally on a high level and do not provide specific guidance for technical implementation. However, in the context of simulation, the Levels of Conceptual Interoperability Model (LCIM) has been proposed. Also, the semantic web initiative has been introduced to provide description logic information to web pages. This presentation investigates how these two concepts can be combined into a general approach for SoS interoperability. It also expands on the LCIM model by providing more details about the world models of a system and its content on the higher levels of interoperability, and discusses experiences from applications.

Download recording from the Library at www.incose.org/enchantment

NOTE: This meeting will be recorded

Speaker Bio

Dr. Jakob Axelsson received an MSc in computer science in 1993, followed by a PhD in computer systems in 1997, both from Linköping University, Sweden. He was in the automotive industry with Volvo Group and Volvo Cars 1997-2010. He is now a full professor of computer science at Mälardalen University, Sweden and a senior research leader in systems-of-systems at RISE Research Institutes of Sweden. His research interests are focused on all aspects of systems-of-systems engineering, and in particular system architecture. Prof. Axelsson is a member of INCOSE and has served as chairman of the Swedish chapter.

Today’s Presentation

Things to think about

- How can this be applied in your work environment?
- What did you hear that will influence your thinking?
- What is your take away from this presentation?

Achieving System-of-Systems Interoperability Levels Using Linked Data and Ontologies

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SoS common concerns

Klein and van Vliet (2013): Survey of 200 research papers on SoS architecture.

- **Interoperability** (45)
- Security (14)
- Evolution (13)
- Performance (9)
- Safety (8)
- Testability (6)
- Quality of service (5)
- Reusability (5)
- Risk (5)

Bianchi et al. (2015): Survey of 40 research papers on SoS quality attributes.

- **Interoperability** (14)
- Security (14)
- Performance (14)
- Reliability (13)
- Safety (10)
- Availability (8)
- Maintainability (6)
- Complexity (5)
- Dependability (5)

Interoperability

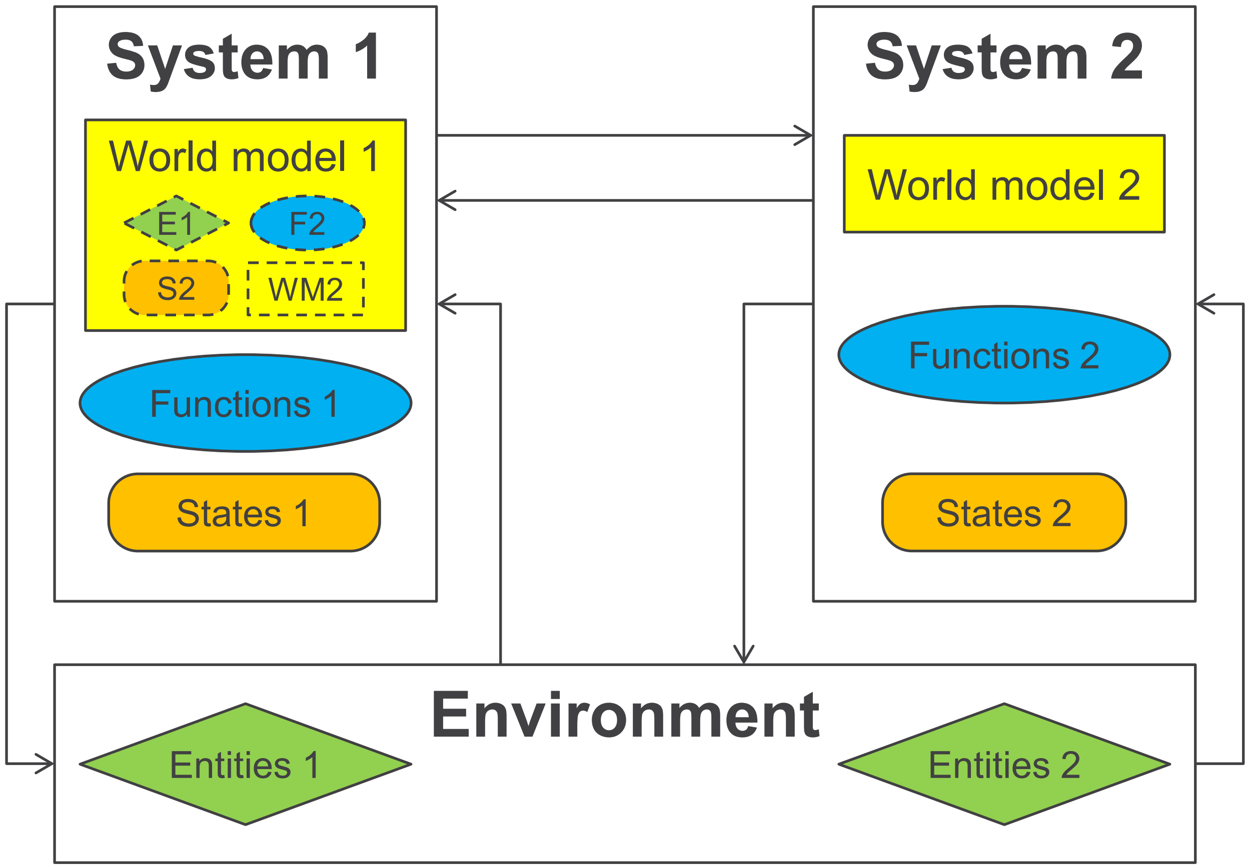
"The ability of two or more systems or components to exchange information and to use the information that has been exchanged."

(IEEE standard glossary of software engineering terminology, 1990)

SoS engineering considerations

- Analysis: Levels of Conceptual Interoperability Model (LCIM).
- Technology: Linked data and ontologies.
- Trade-offs: Functionality vs. performance and lifecycle cost.

A basic system(-of-systems) model

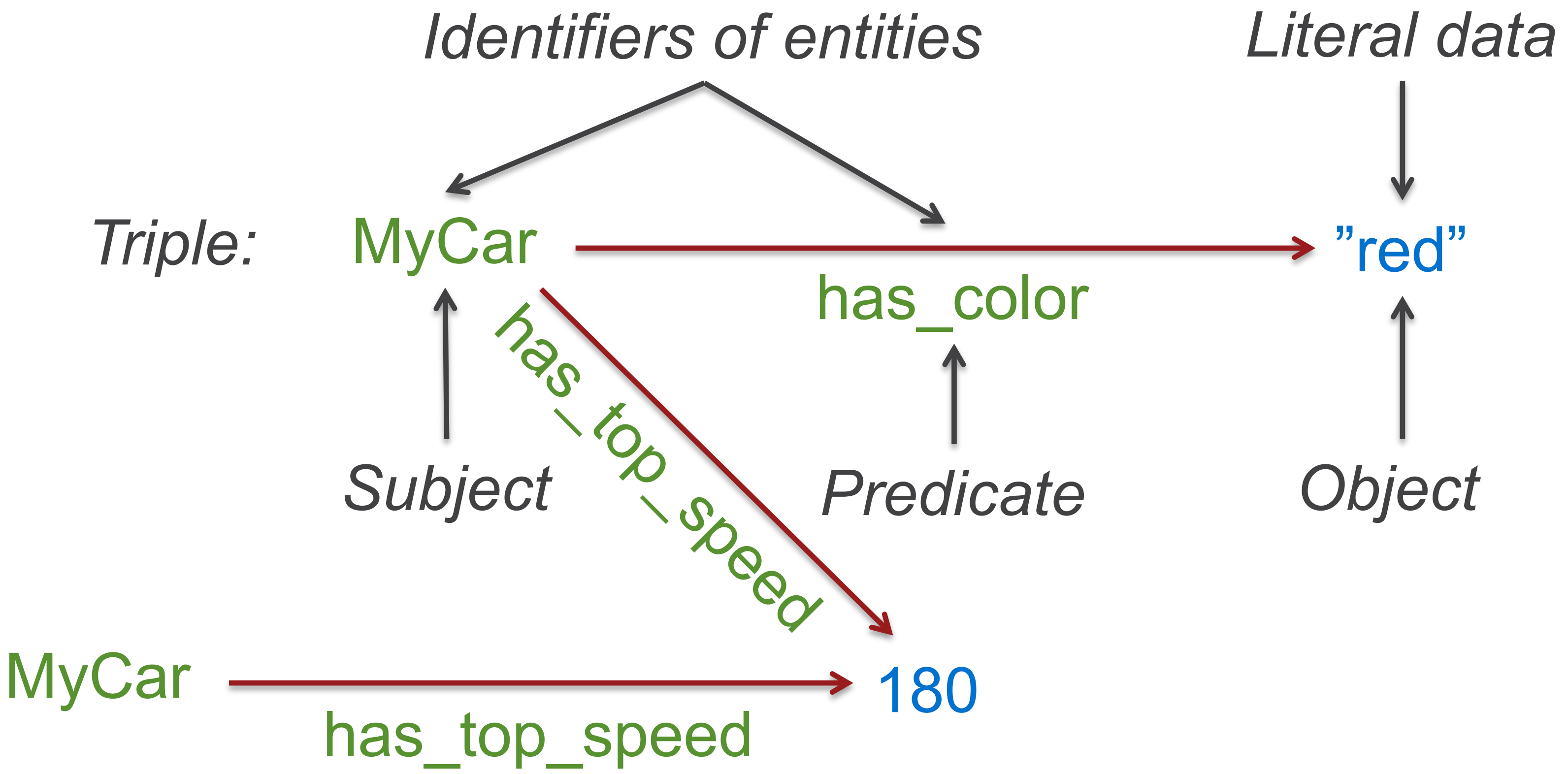


Levels of conceptual interoperability (LCIM)

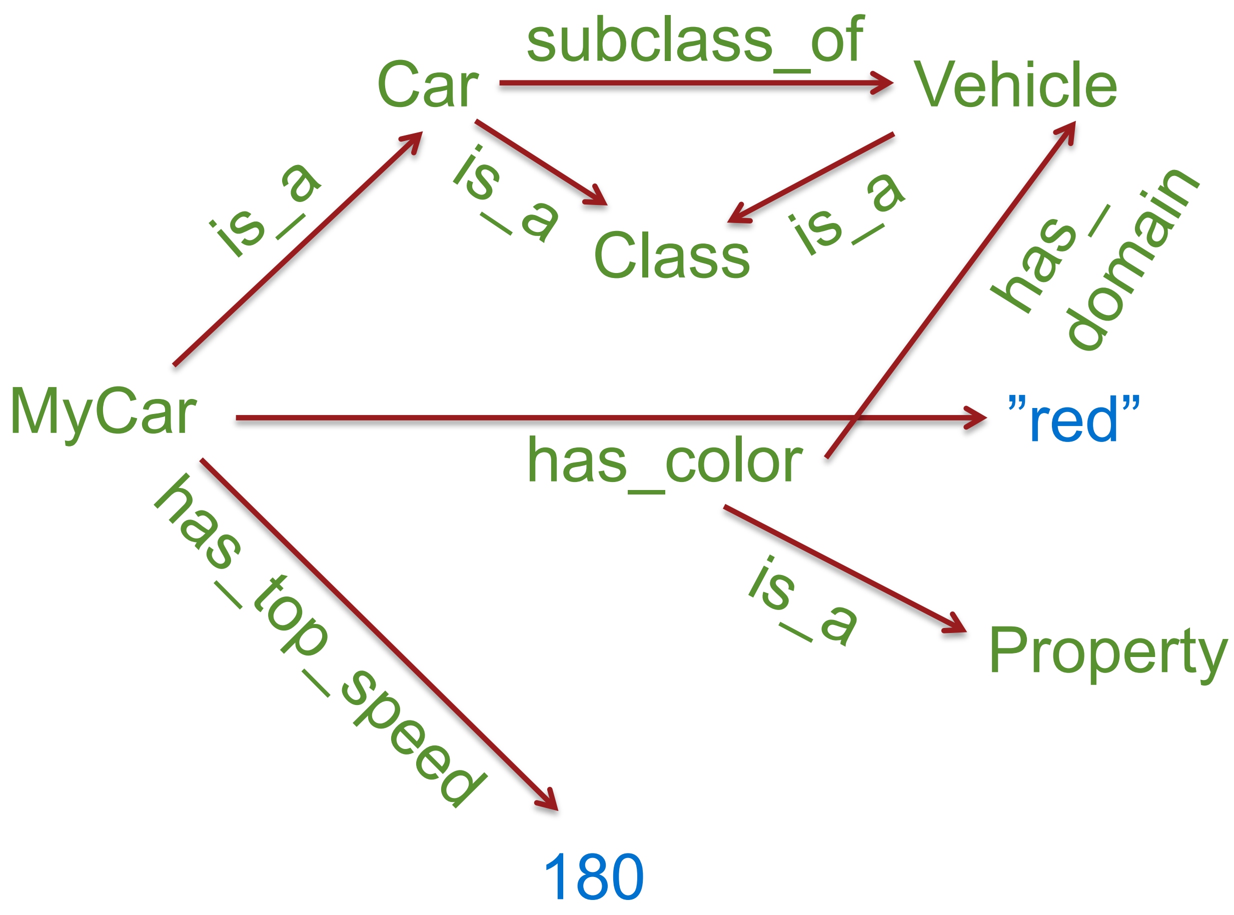
Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Effect of data
4	Pragmatic	Workflow model	Use of data
3	Semantic	Reference model	Meaning of data
2	Syntactic	Data structure	Structured data
1	Technical	Communication protocol	Bits and bytes
0	No	No connection	None

(Tolk et al., 2006; Wang et al., 2009)

Semantic web: Linked data



Semantic web: Ontologies



Level 1: Technical interoperability

Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Effect of data
4	Pragmatic	Workflow model	Use of data
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Level 1: Technical interoperability

- Transferability of data
- Open Systems Interconnection (OSI) model
- Internet/WWW protocols:
  – IoT
  – Cloud

Level 2: Syntactic interoperability

Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Effect of data
4	Pragmatic	Workflow model	Use of data
3	Semantic	Reference model	Meaning of data
2	Syntactic	Data structure	Structured data
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Level 2: Syntactic interoperability

- Serialization of linked data:
  - XML, Turtle, Json, etc.
- Triple databases:
  - In memory or persistent.
  - SPARQL query language.

Level 3: Semantic interoperability

Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Effect of data
4	Pragmatic	Workflow model	Use of data
3	Semantic	Reference model	Meaning of data
2	Syntactic	Data structure	Structured data
1	Technical	Communication protocol	Bits and bytes
0	No	No connection	None

Level 3: Semantic interoperability

- Basic ontology concepts (metamodel):
  - Classes, subclasses, instances
  - Properties
- UML and SysML.
- Reasoning.

Levels 4: Pragmatic interoperability

Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Effect of data
4	Pragmatic	Workflow model	Use of data
3	Semantic	Reference model	Meaning of data
2	Syntactic	Data structure	Structured data
1	Technical	Communication protocol	Bits and bytes
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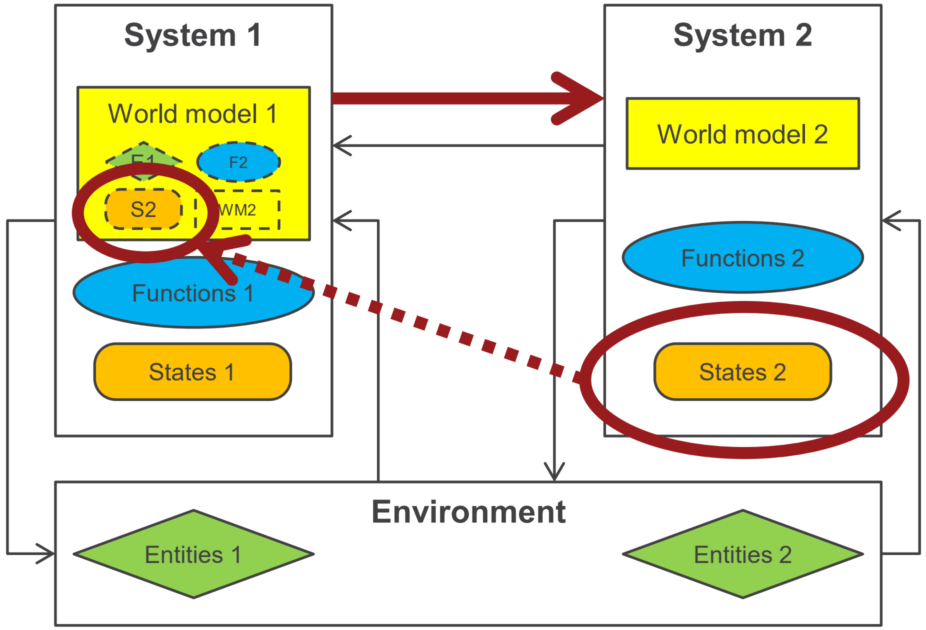
Level 4: Pragmatic interoperability

World model:

- States and transitions
- Workflows
- Modes
- Configurations
- Services offered



Levels 5: Dynamic interoperability

Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Effect of data
4	Pragmatic	Workflow model	Use of data
3	Semantic	Reference model	Meaning of data
2	Syntactic	Data structure	Structured data
1	Technical	Communication protocol	Bits and bytes
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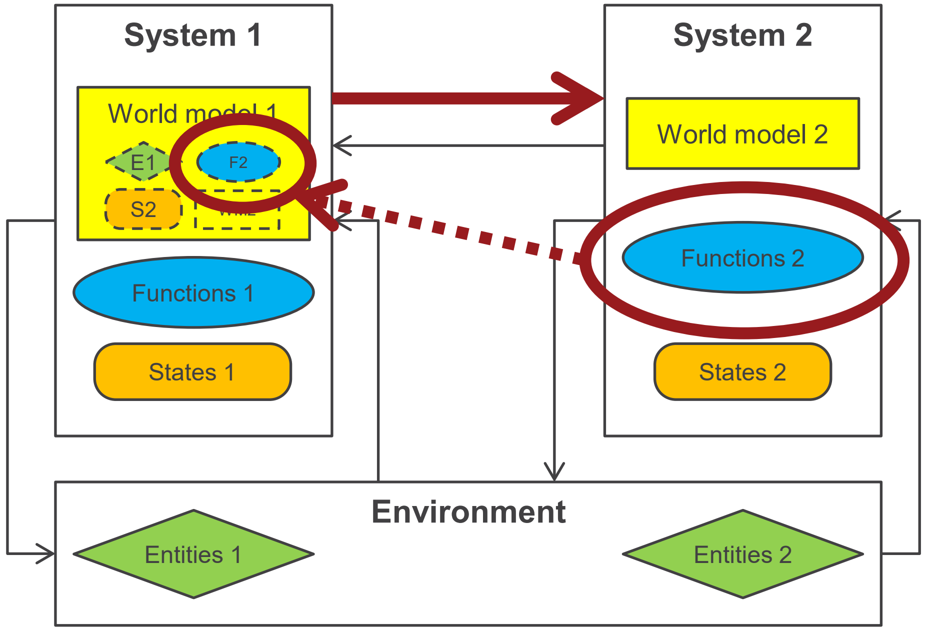
Level 5: Dynamic interoperability

World model:

- Functions
- Missions
- Capabilities
- Properties



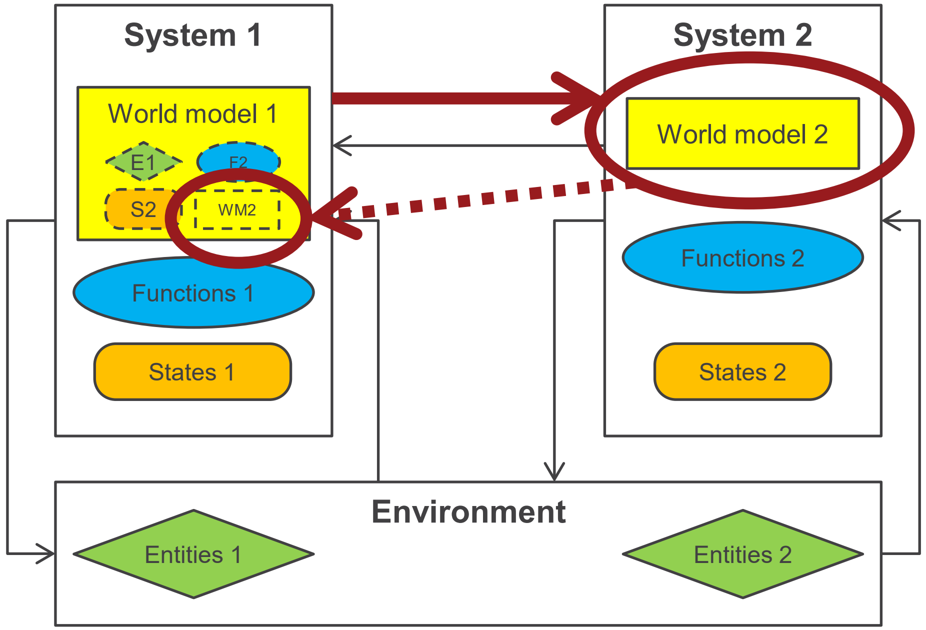
Levels 6: Conceptual interoperability

Level	Layer	Premise	Information defined
6	Conceptual	Conceptual model	Assumptions, constraints
5	Dynamic	Execution model	Effect of data
4	Pragmatic	Workflow model	Use of data
3	Semantic	Reference model	Meaning of data
2	Syntactic	Data structure	Structured data
1	Technical	Communication protocol	Bits and bytes
0	No	No connection	None

Level 6: Conceptual interoperability

World model:

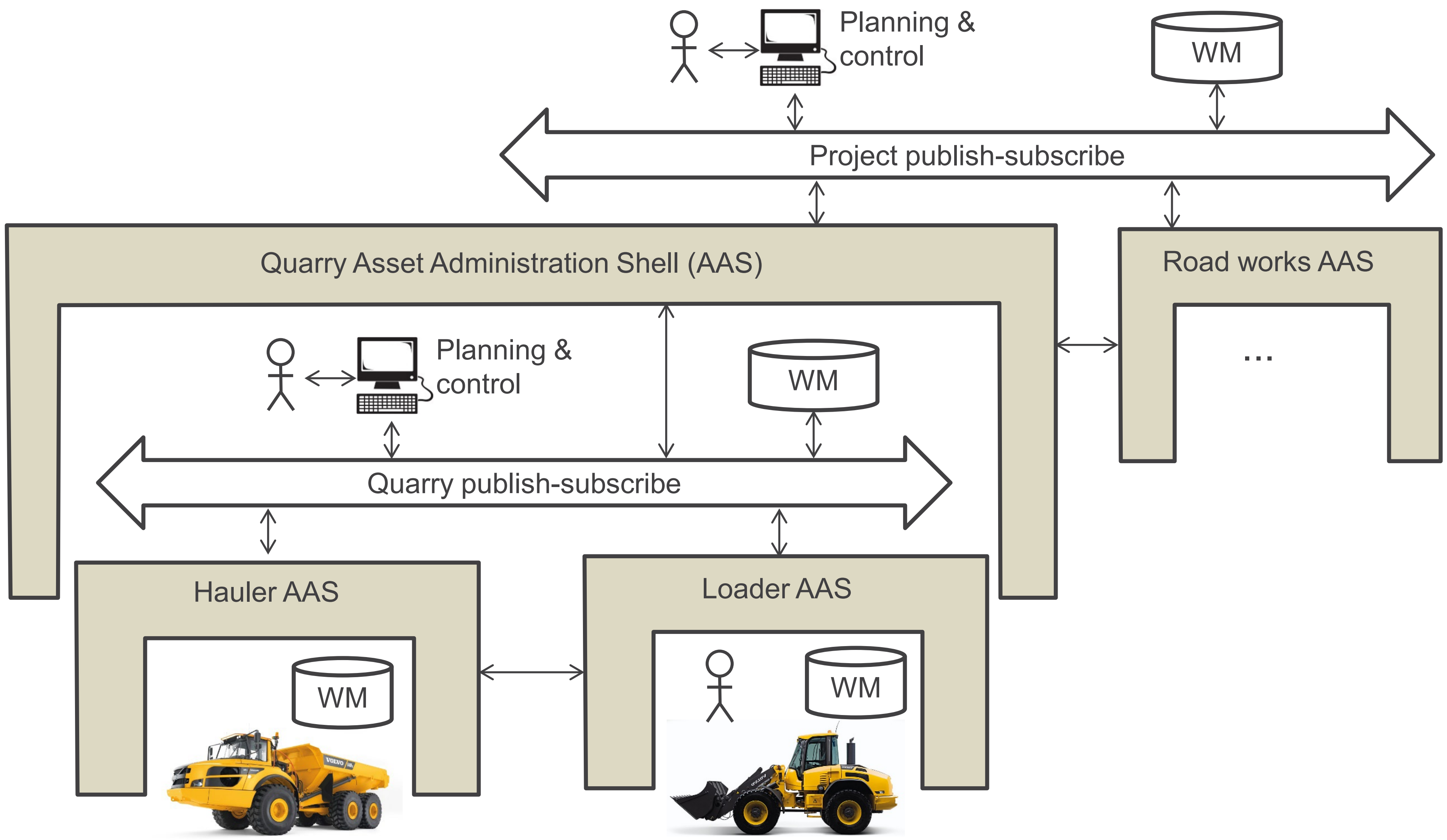
- Mutual awareness of other systems' knowledge.
- If I know that you know my plans, I can expect you to act in a different way.
- Laws of parsimony and requisite variety.



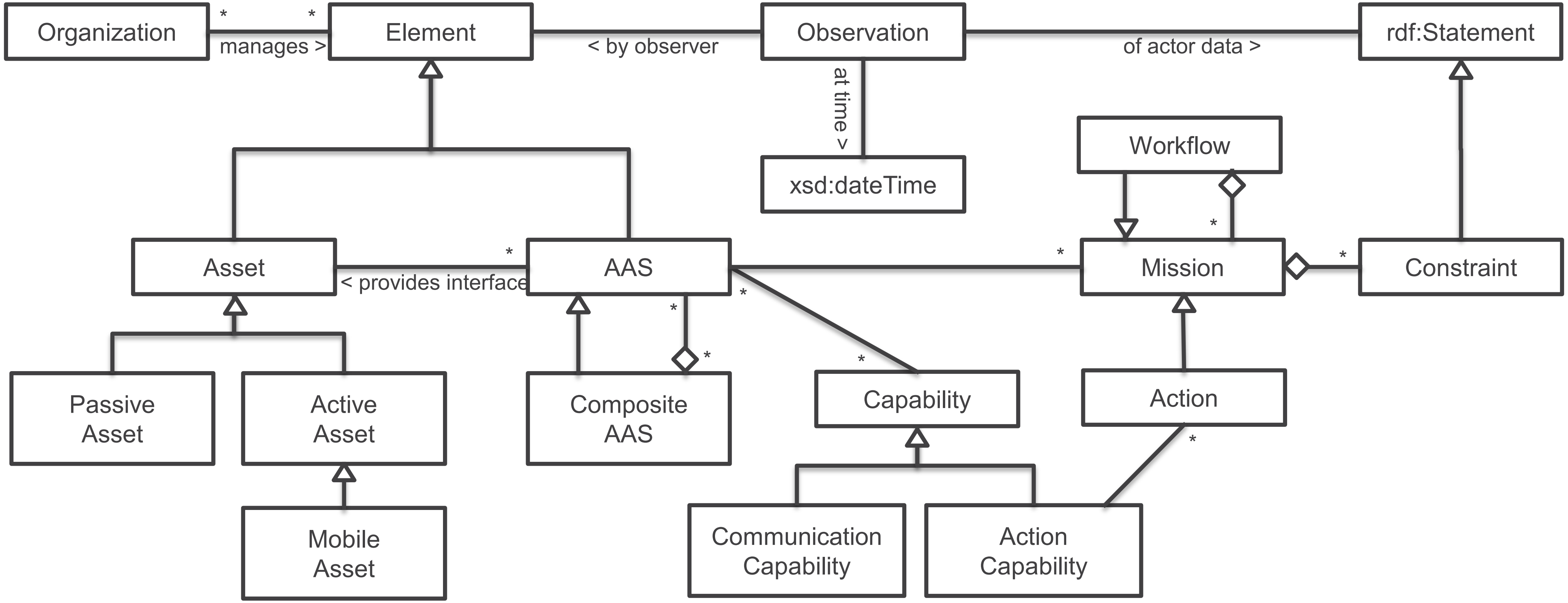
Example: Road construction

- Objective:
  - Improve productivity.
- Hypothesis:
  - Increased coordination of machines, and more access to information in real-time is the key aspect.
- Approach:
  - Industry 4.0 concepts for connectivity.
  - Lean techniques for reducing wastes.
  - Framework for real-time production control on all levels.

Road construction: SoS architecture



Ontology



Organization
*
*
manages >
Element
< by observer
Observation
of actor data >
rdf:Statement
at time >
xsd:dateTime
Workflow
*
Asset
*
< provides interface
AAS
*
Mission
*
Constraint
*
*
*
Passive Asset
Active Asset
Composite AAS
*
Capability
Action
*
Mobile Asset
Communication Capability
Action Capability

Discussion

- Cost of using linked data:
  - Memory, communication, computation.
- Value of data, willingness to share.
- Open Services for Lifecycle Collaboration (OSLC).
- Digital twins.
- Industry 4.0.

Conclusions

- Interoperability is a cornerstone of SoS engineering.
- Trade-off: functionality vs. performance and lifecycle cost.
- Analysis: Levels of conceptual interoperability.
- Technology: Linked data and ontologies.
  - Standardized
  - Reusable software libraries
  - Focus effort on domain ontologies
  - Model-based systems engineering

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Please

The link for the online survey for this meeting is

- www.surveymonkey.com/r/2020_10_MeetingEval

Look in GlobalMeet chat box for cut & paste link

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- The library page at: www.incose.org/enchantment