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STEVENS INSTITUTE of TECHNOLOGY
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Ontologies for Engineering: A Pragmatic Perspective

Presented by: Mark Blackburn, Ph.D. – Senior Research Scientist
Systems Engineering Research Center (SERC)
Stevens Institute of Technology
Co-Authors: Dr. Tom Hagedorn, Daniel Dunbar, Dr. Annie Yu, Dr. Benjamin Kruise

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- Eirik Hole - Stevens
- Gary Witus – Wayne State

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- Jake Sisavath – Georgia Tech
- Gabriel Rizzo – Georgia Tech

Abstract

- The talks discusses fundamental aspects of ontologies, and how they enable technologies referred to as semantic web technologies (SWT). This is a key enabler for realizing the intent of the Digital Engineering Strategy. Given that tool-to-tool integration is fragile and cannot be sustained, Ontologies allow us to realize semantically consistent and rich interoperability at the data level.
- Accordingly, Ontologies for digital engineering need to be interoperable to allow design reasoning across multiple domains (e.g., cyber security, aeronautics, communications) and to support model “integration” through “interoperability” across domains and disciplines. The core elements of ontologies for engineering are often hidden as part of the Digital Engineering infrastructure, allowing SWT to automate reasoning to help engineers understand consistency and completeness of their models in the context of other related models across the domains using their modeling tool of choice.
- The talk closes with an example of a Cyber Ontology Pilot demonstration that uses SWT to associate potential cyber vulnerabilities with a simple computer network modeled in System Modeling Language (SysML).

Outline

- **What:** Ontologies for Engineering
- **Why:** Ontologies and Semantic Web Technologies are enablers for DoD Digital Engineering Strategic Goals
- **How:** Semantic Web Technologies
  - —Engineering Ontologies are defined using Semantic Web Technologies
  - —Both are formalized for engineering using software methods and tools
- Case Study for Cyber Ontology Pilot for Vulnerability Detection

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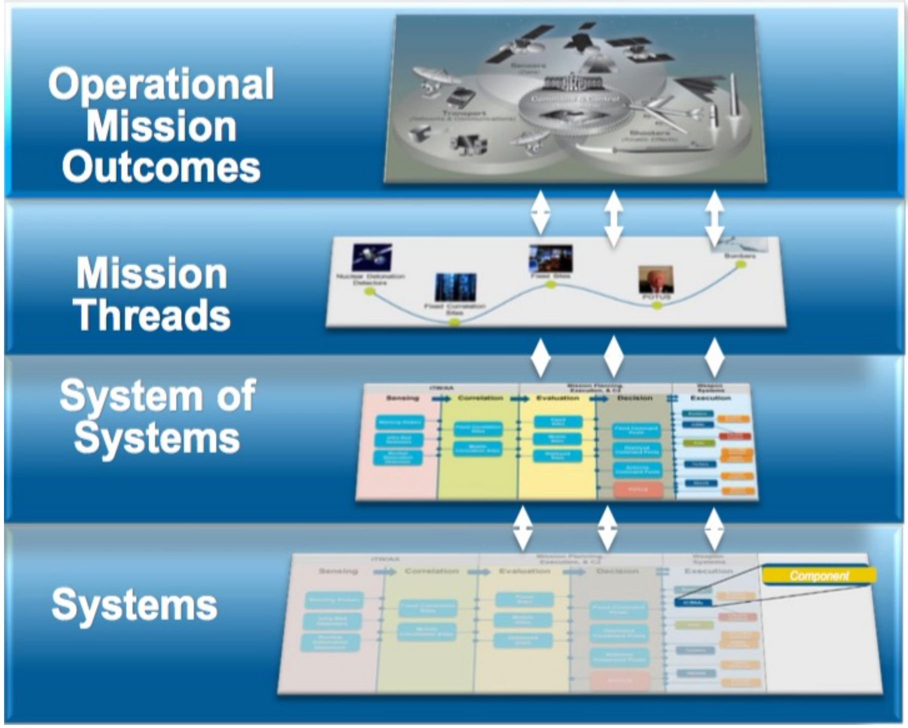
Ontologies for Engineering Concepts and Terms

- What – an ontology is somewhat similar to a database schema
  - —Ontologies focused on concepts & relationships (knowledge representation) formalized using OWL (Web Ontology Language)
  - —Database schema focused on structure of data for storage and querying
  - —Ontology uses a repository called a triple store
  - —Data stored as triples, subject-predicate-object in a triple store resulting in a graph of linked data formalized using RDF (Resource Description Framework)
  - —SPARQL is a standard query language that is notionally similar to SQL
  - —Databases and ontologies can be thought about as part of infrastructure
- Why – provides a means to semantically “integrate” models across different domains using **Interoperability**
  - —Tool-to-tool integration is brittle
  - —Ontologies most often evolve over time
- How - map different types of modeling artifacts to data stored in a triple store repository

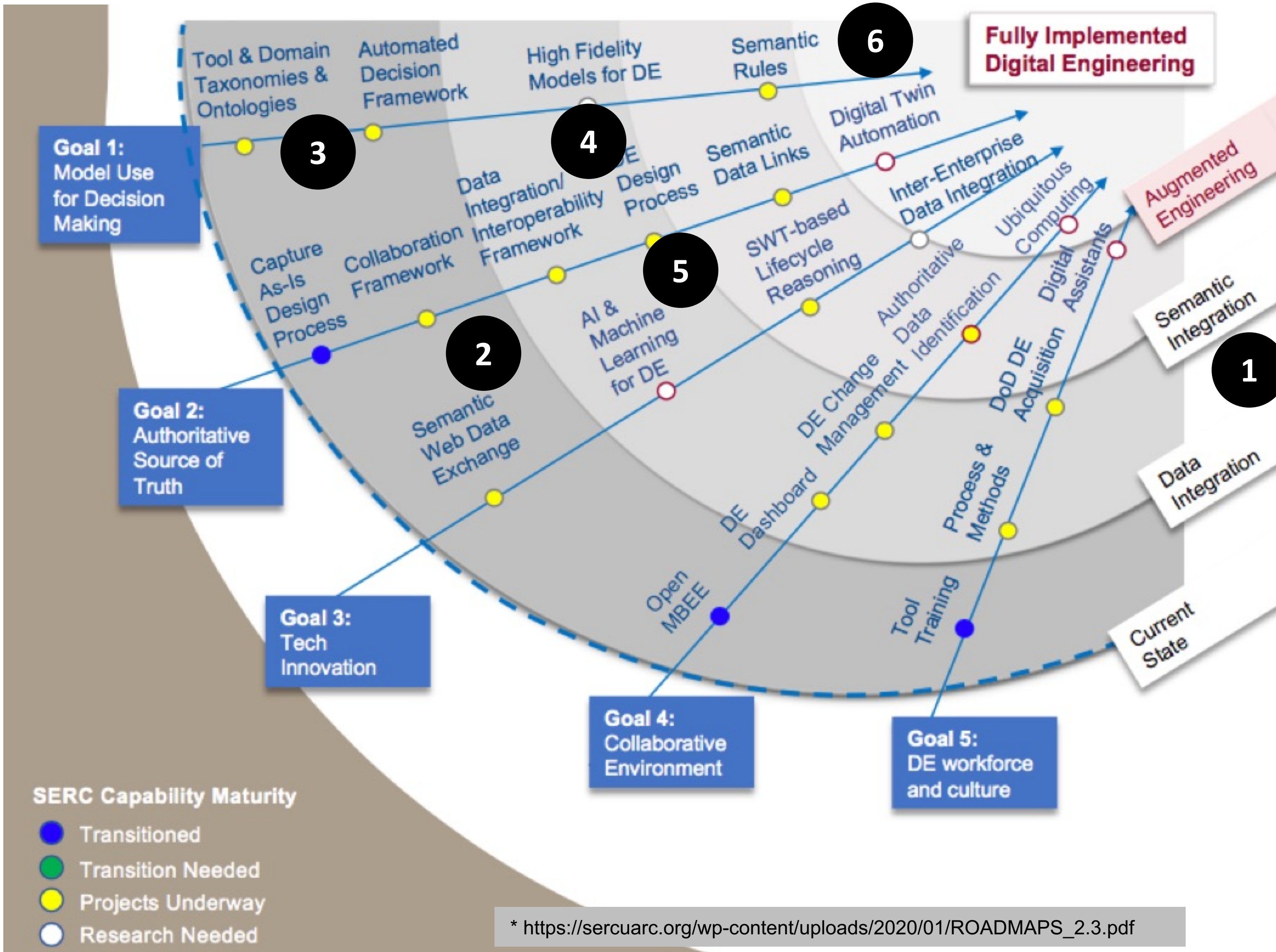
DoD DE Strategy – Discussion Framework

- DE/MBSE helps refactor and strengthen implementation of Systems Engineering principles (Goal 3)
  - Represent Structure, Behavior, Interfaces, Requirements and related interactions
  - Can characterize different levels of abstraction – Mission, System, Subsystem where different
    types of methods are needed
- DE requires a formalized system/design representation that links information in an Authoritative Source of Truth (Goal 2)
- Semantically linked system/design information to enable tradespace analyses and decision making (Goal 1)
- Need computation and methodological infrastructure to access and visualize on need-to-know basis (Goal 4)



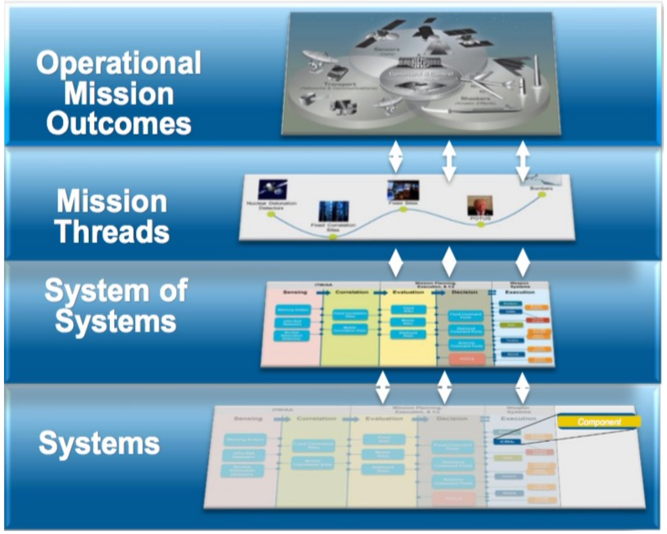
Extending the DoD Digital Engineering Strategy to Missions, Systems of Systems, and Portfolios
P. Zimmerman, T. Gilbert, J. Dahmann
22nd Annual NDIA Systems and Mission Engineering Conference
Tampa, FL| 23 October 2019

Digital Engineering for Systems Engineering Roadmap: Goals are Mutually Supportive not Orthogonal



Conceptual Examples

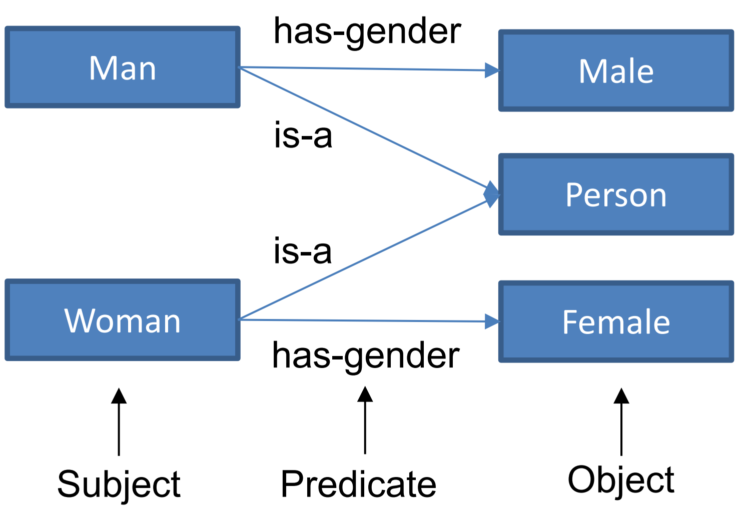
- Person ontology and RDF (data)
  - —Example of data: Subject – Predicate - Object
- Navy mission use case
  - —Mission objective: continuous surveillance
  - —System capabilities: UAV and Refueler
  - —System focus: refueling subsystem



- Cyber ontology pilot use case
  - —Computer network
  - —Vulnerability analysis using ontology and semantic

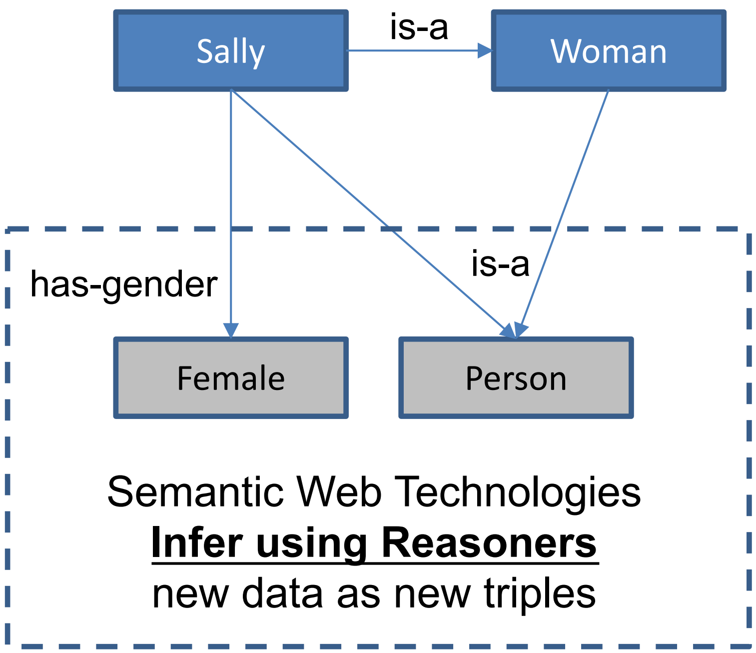
Basic Concepts of Ontologies and Semantic Technologies

Ontology (Classes and Properties)



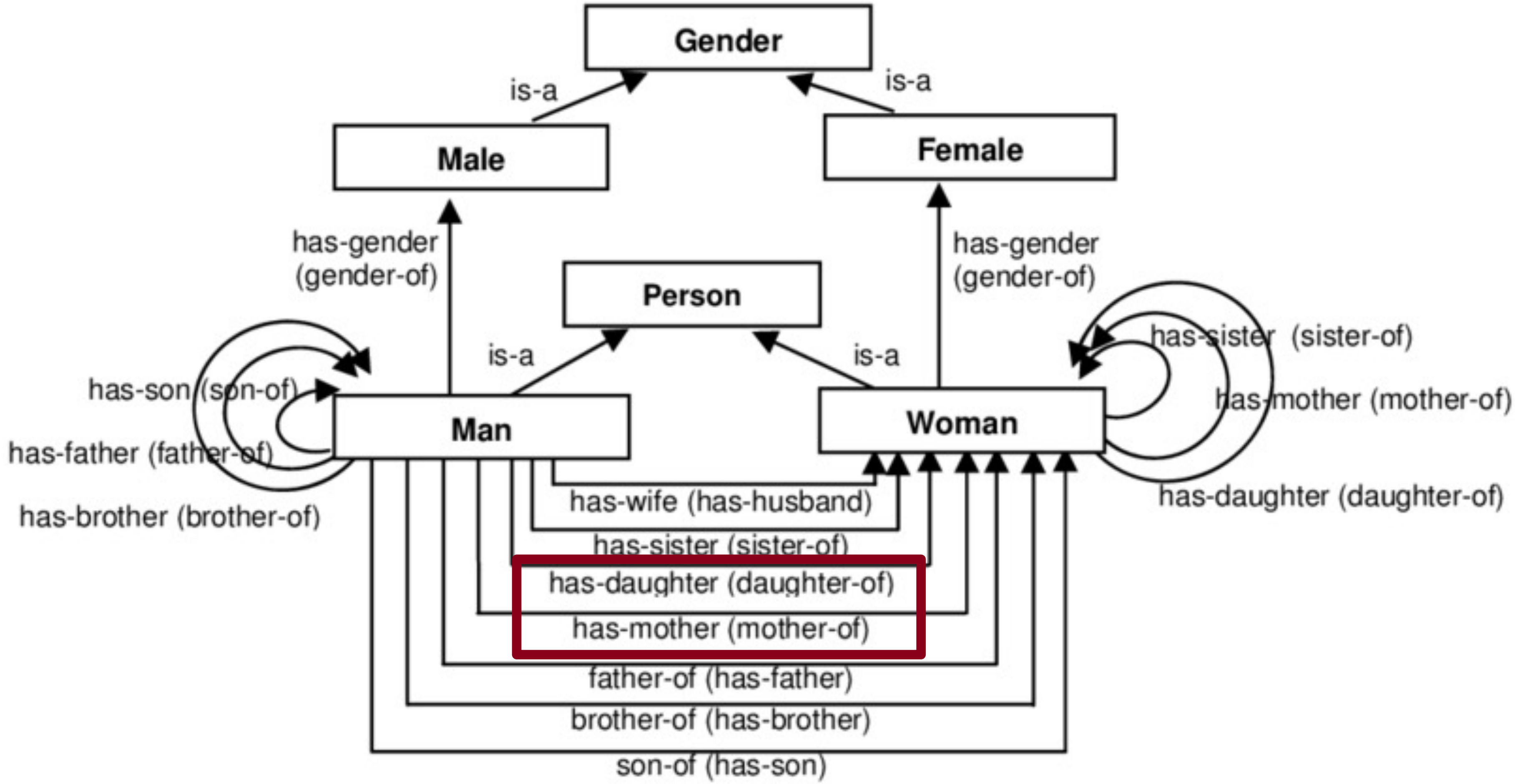
Data (RDF) (Referred to as Instances)

If we assert



Everything is Represented as Linked Data as: Subject - Predicate - Object

Ontology: Classes and Properties



https://www.researchgate.net/figure/A-graphically-reproduced-segment-of-the-example-Family-ontology_fig13_234059795

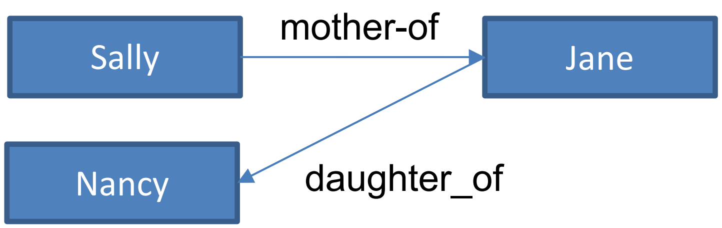
Automated Reasoning from Property Constraints Identifies Data Issues

Ontology
(Property Constraints)

- Mother has 1 or more children
- Daughter has only 1 mother

Data (RDF)
(Referred to as Instances)

If we assert



Semantic Web Technologies
Reasoners
will identify this as not possible
because Jane cannot have two mothers

Example: Cross Domain Relationships Needed for System Trades, Analysis and Design

- Mission objective: continuous surveillance
- Capability Refueling UAV
- Systems: UAV and Refueler
- **Valve** – Cross-domain Object
- Mechanical Domain
  - Valve connects to Pipe
- Electrical Domain
  - Switch opens/closes Value
  - Maybe software
- Operator Domain
  - Pilot remotely sends message to control value
- Communication Domain
  - Message sent through network
- Fire control Domain
  - Independent detection to shut off valve
- Safety Domain

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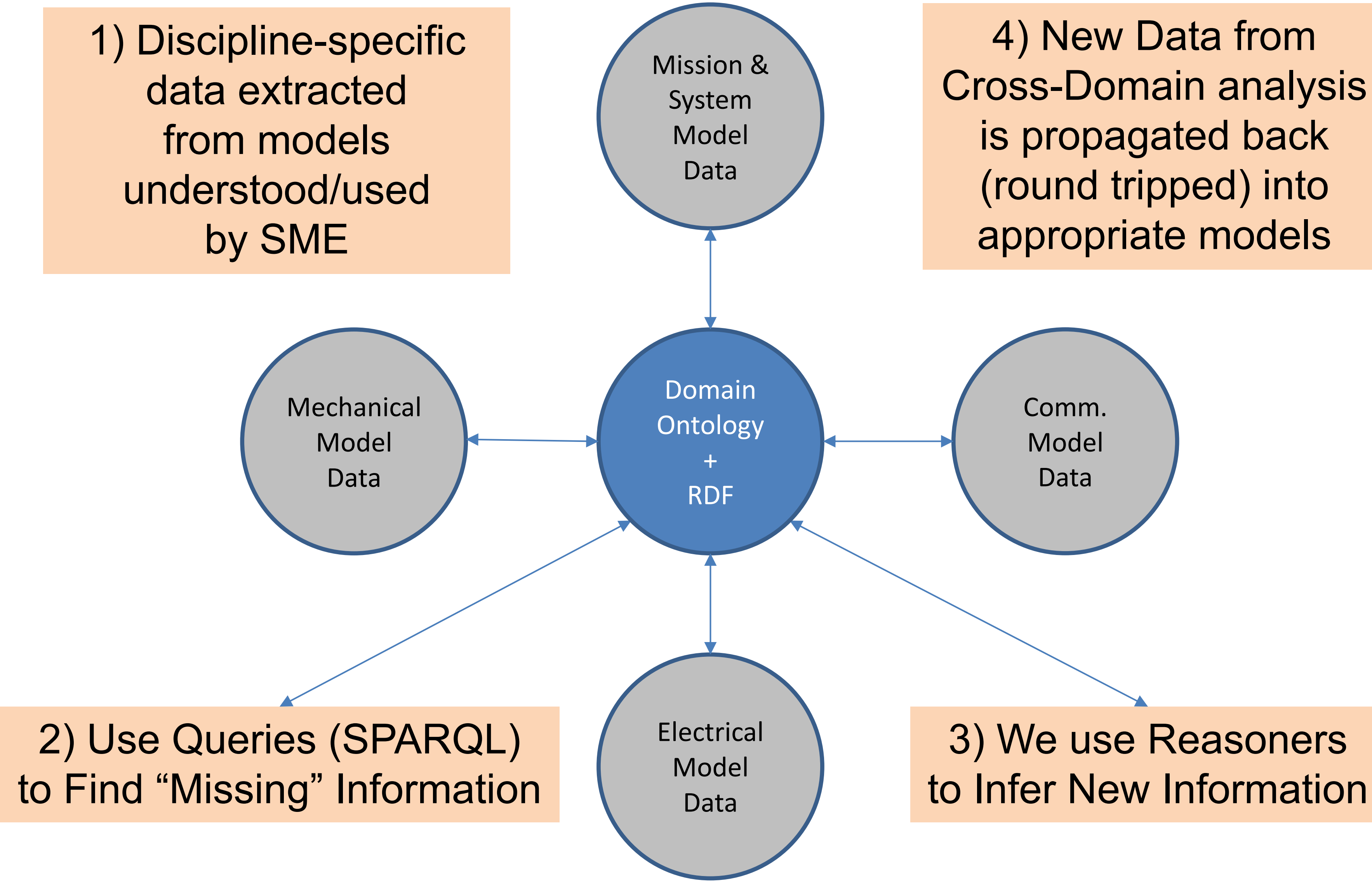
Bring Data Across Disciplines into Linked Data that Complies with Domain Ontology



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How to Develop and Interoperable Ontology

- Recognize that ontology development relies on software development skills, conceptual/information modeling
- Develop in OWL (now OWL2)
  - —Use Ontology Editor such as Protege
- Use an established foundational set of classes
  - —Like "programming libraries"
  - —E.g., Basic Formal Ontology (BFO) – referred to as an upper ontology
  - —May also use extensions of BFO such as the Common Core
- Start from established:
  - —Data dictionaries and lexicon formalizing "terms" that are "programmed" as classes
  - —Taxonomies to understand relationships
  - —Often aligned with Reference Architectures

Cyber Ontology Pilot Case Study

Use Case: transform system model of computer networks represented in SysML into ontology “data” that integrates with NAVSEA ontology (CVAST) to reason about potential vulnerabilities

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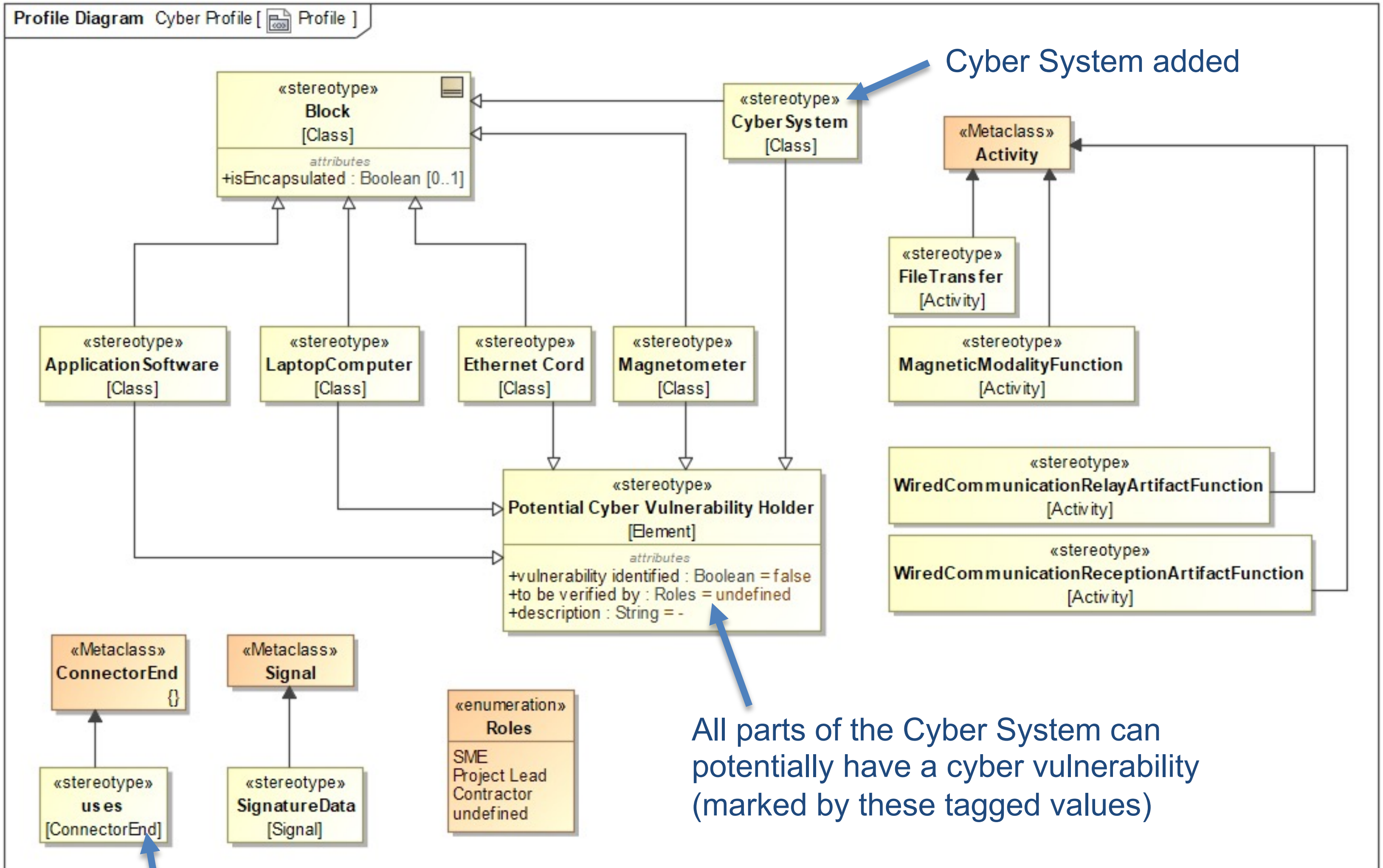
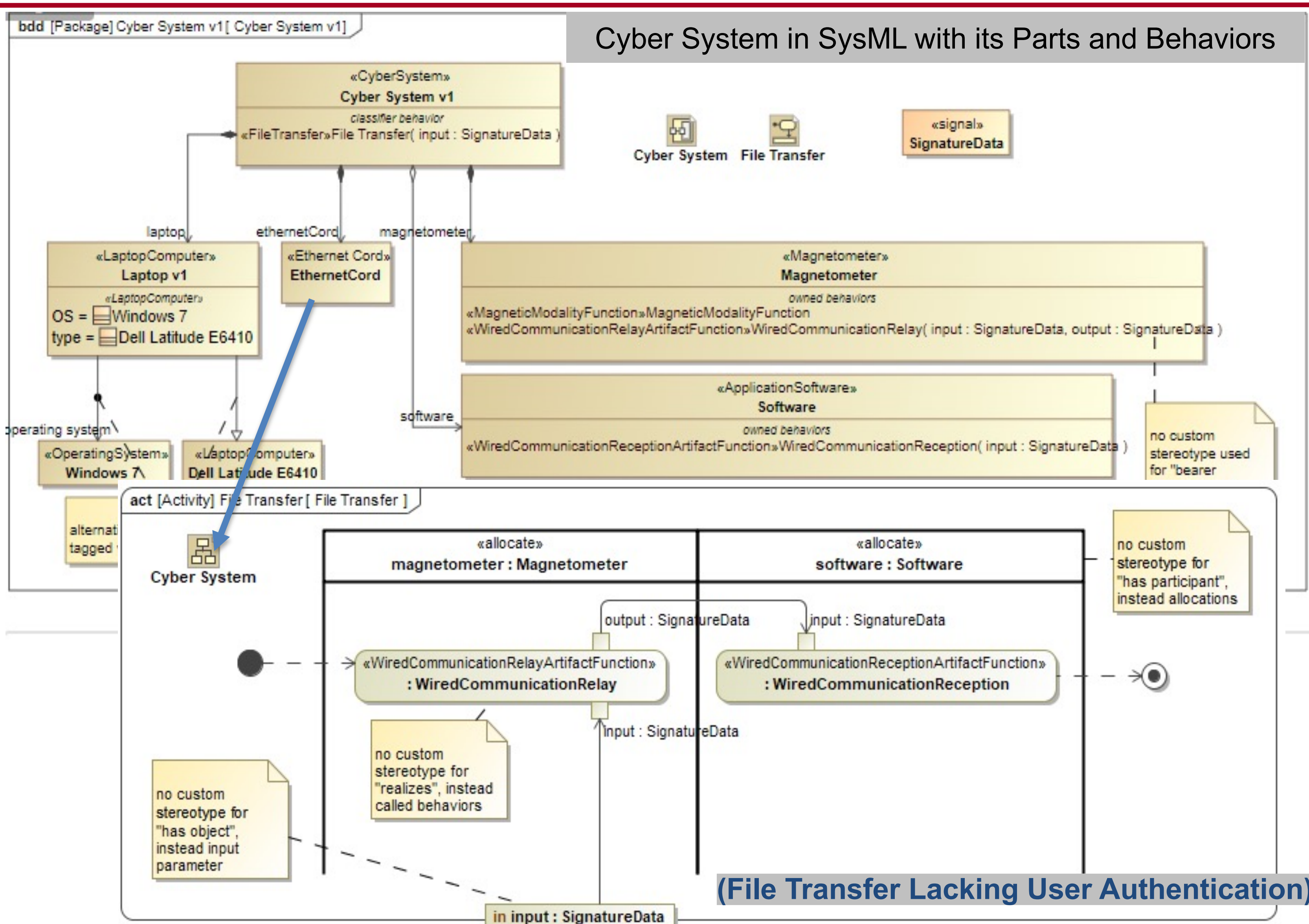
IoIF Cybersecurity Demo: SysML Profile



Almost no relations of ontology defined; Default SysML relations sufficient

Cyber Demo SysML Model with Seeded Vulnerability



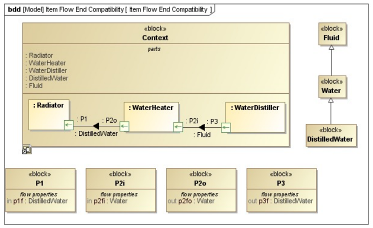
Workflow

1. Cameo / MagicDraw Model(s) synchronized into Model Management System (MMS) (repository for SysML Models)
2. IoIF* requests the model from MMS (also works with Teamwork Cloud)
3. IoIF parses the model into RDF, maps into its semantic model
4. IoIF looks for the vulnerability with a rule
5. IoIF writes documentation back into MMS
6. Synchronize from MMS into Cameo / Magicdraw

*Interoperability and Integration Framework (IoIF) is Semantic Web Technologies developed under SERC Research

IoIF Cyber Ontology-Based Use Case used in Course and Exercise (animated)

Cyber System Model of Computer Network in SysML

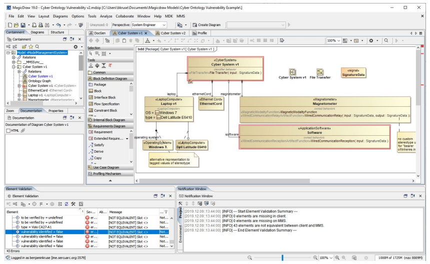


Transform SysML into Ontology "data"

python

Interoperability and Integration Framework (IoIF) supports Loading, Parsing, Mapping and Querying of Linked Data across ontologies (domains)

Round Trip and Visualization of Reasoning Results



Compute Vulnerability Score

MATLAB

Uses Tool Proxy & IoIF Service

Analysis associates Vulnerabilities with Model

Visualize Score in Dashboard

python

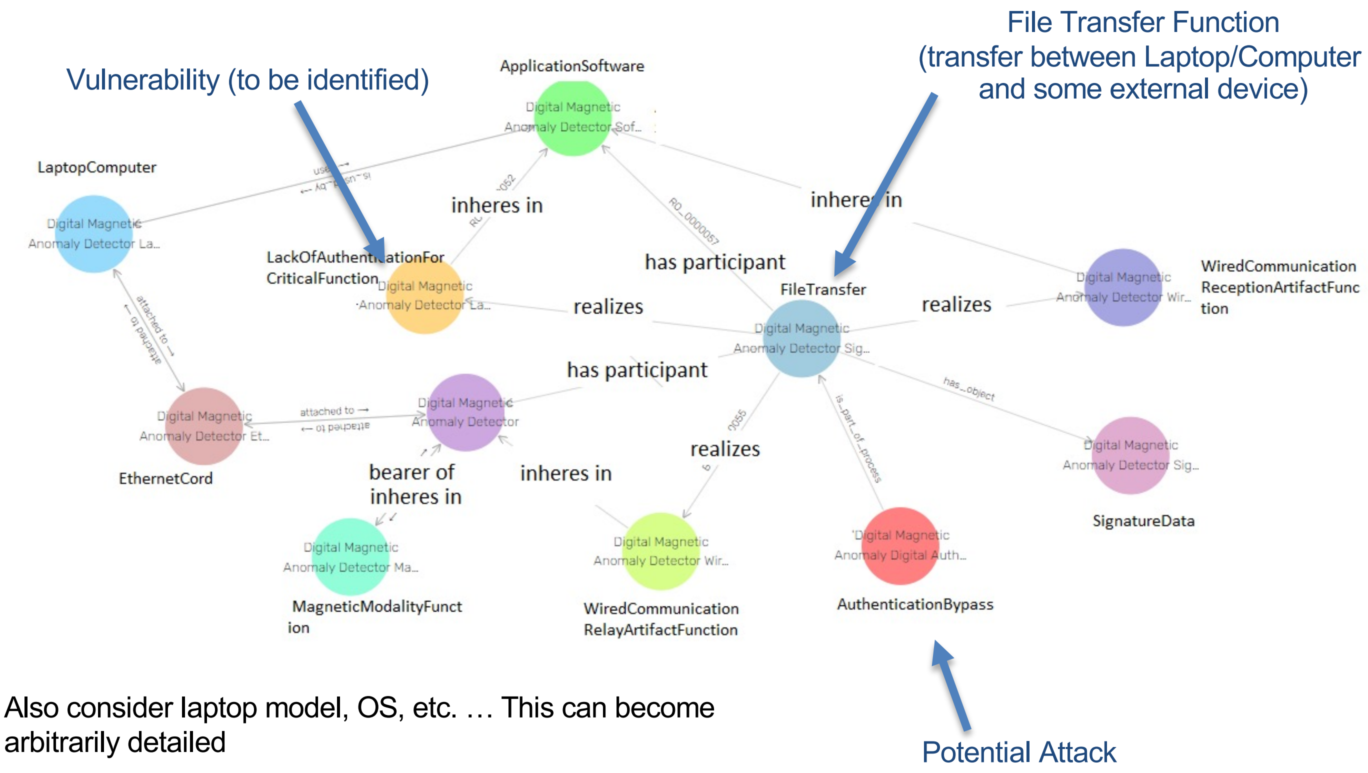
Uses Tool Proxy & IoIF Service

Triple Store Repository for Linked Data from Different Ontologies Initialized

rdf4j Compliant

IoIF Cybersecurity Demo: Ontology

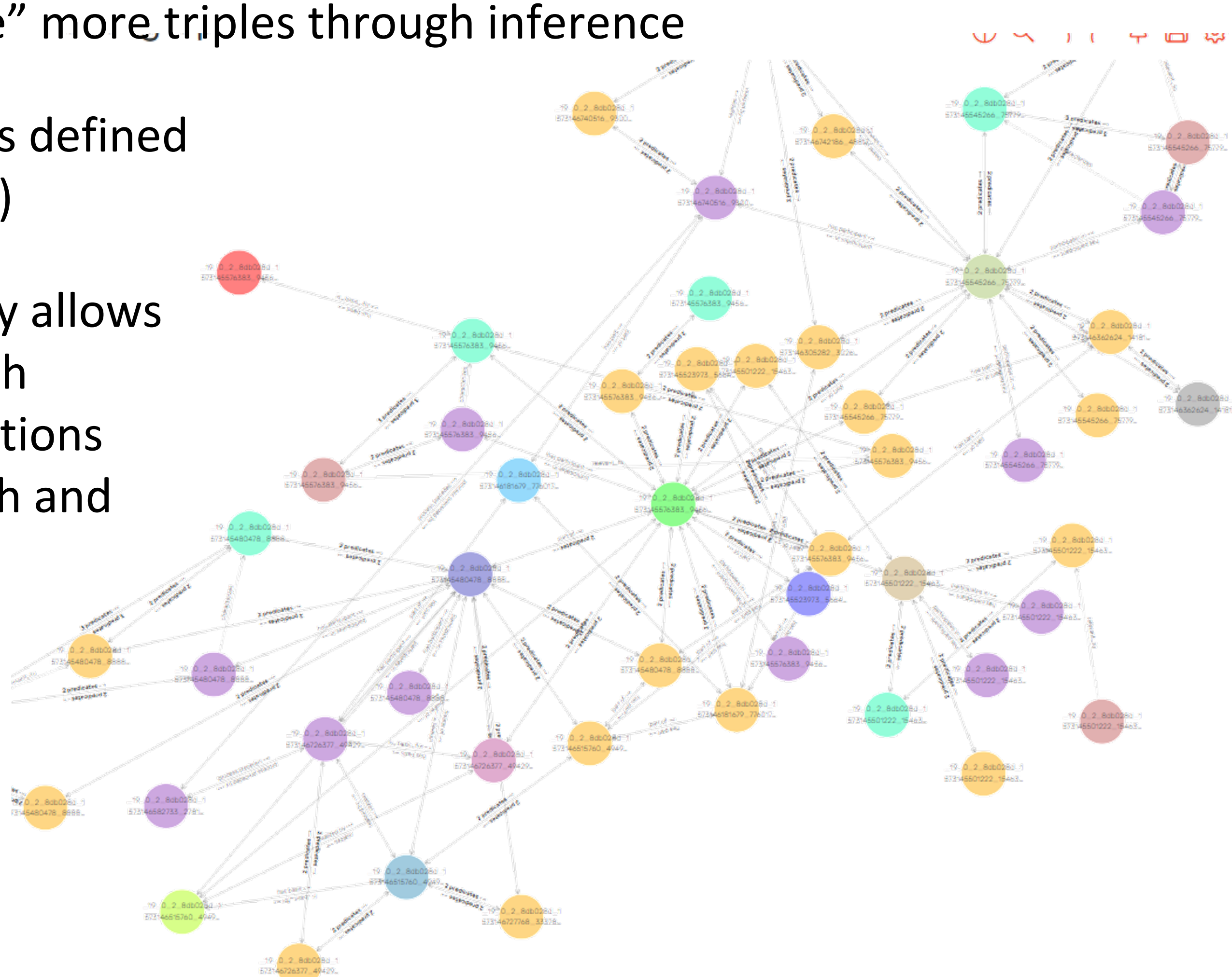
- Ontology data (RDF) is store as triples (Subject Predicate Object) as a graph in a Triplestore Repository



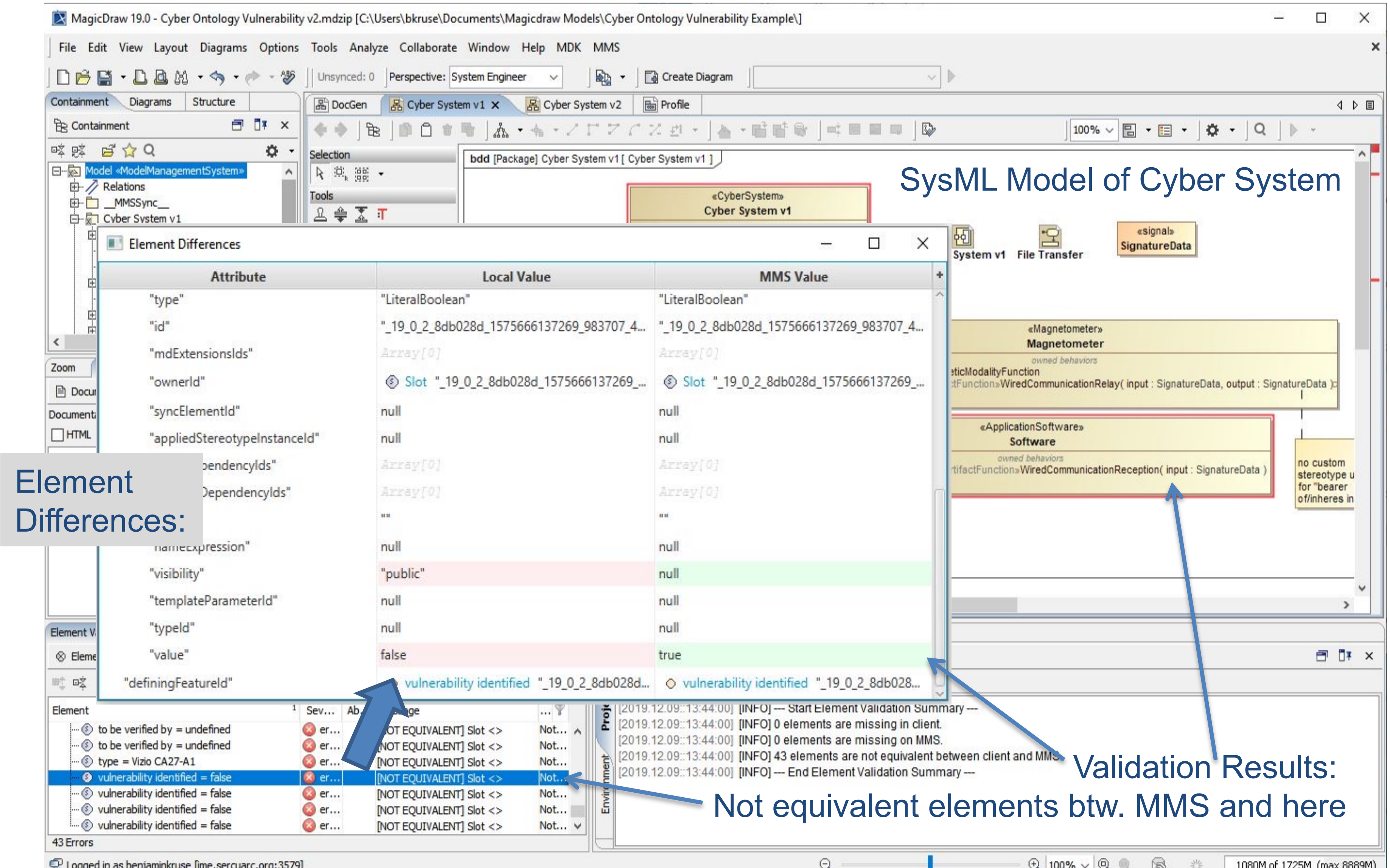
Also consider laptop model, OS, etc. … This can become arbitrarily detailed

IoIF Conducts Reasoning to Expand Graph

- Reasoners “generate” more triples through inference
- Search vulnerabilities defined in RDF graph (CVAST)
- IoIF + Cyber Ontology allows us to rapidly find such vulnerable configurations and update the graph and synchronize back into model

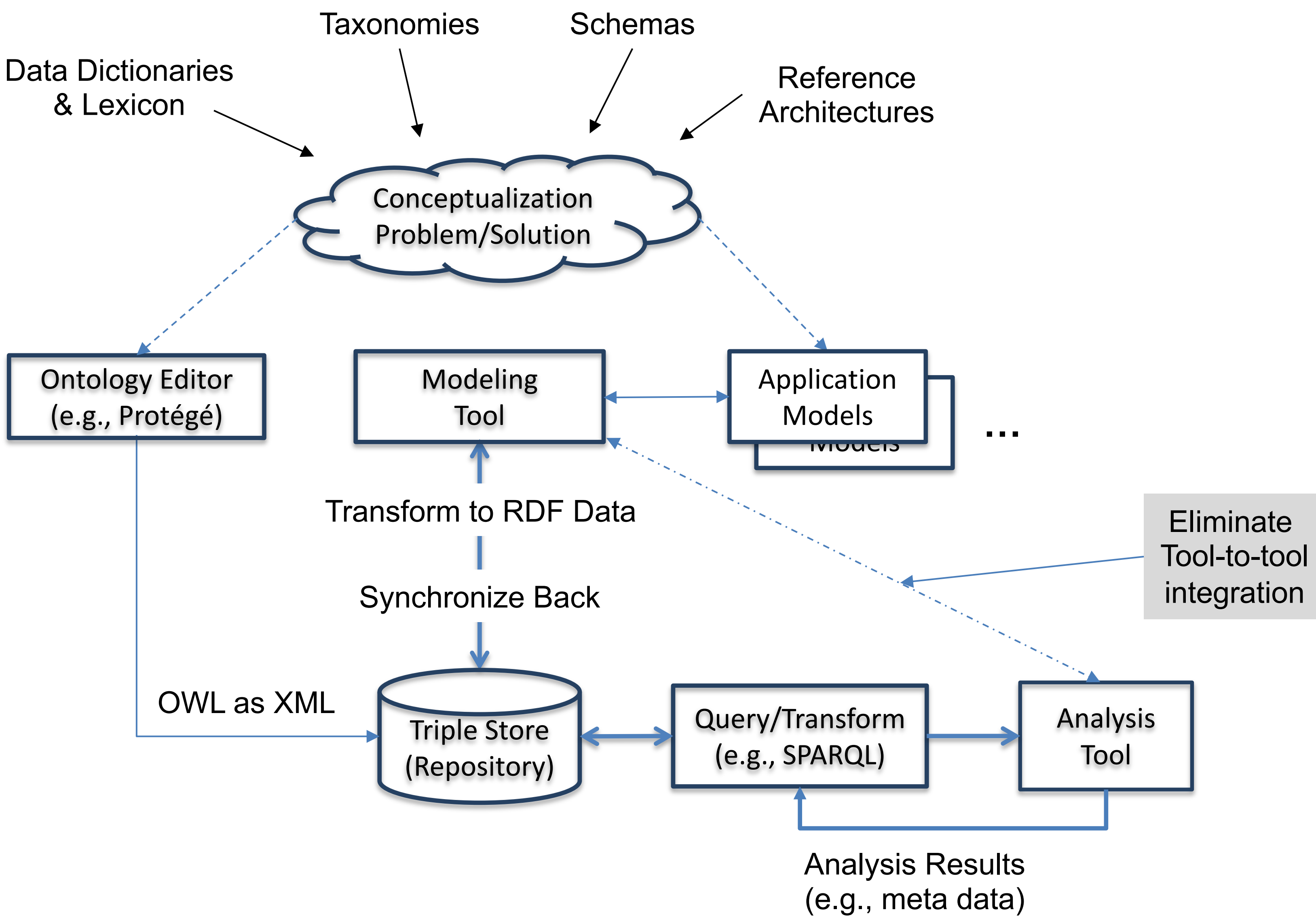


Magicdraw/Cameo Systems Modeler – Data Pushed Back



Summary and How Ontologies and Semantic Technologies Enable DE Infrastructure

Generalization for Mapping for Using Ontologies to support Interoperability vs. Tool-to-tool Integration



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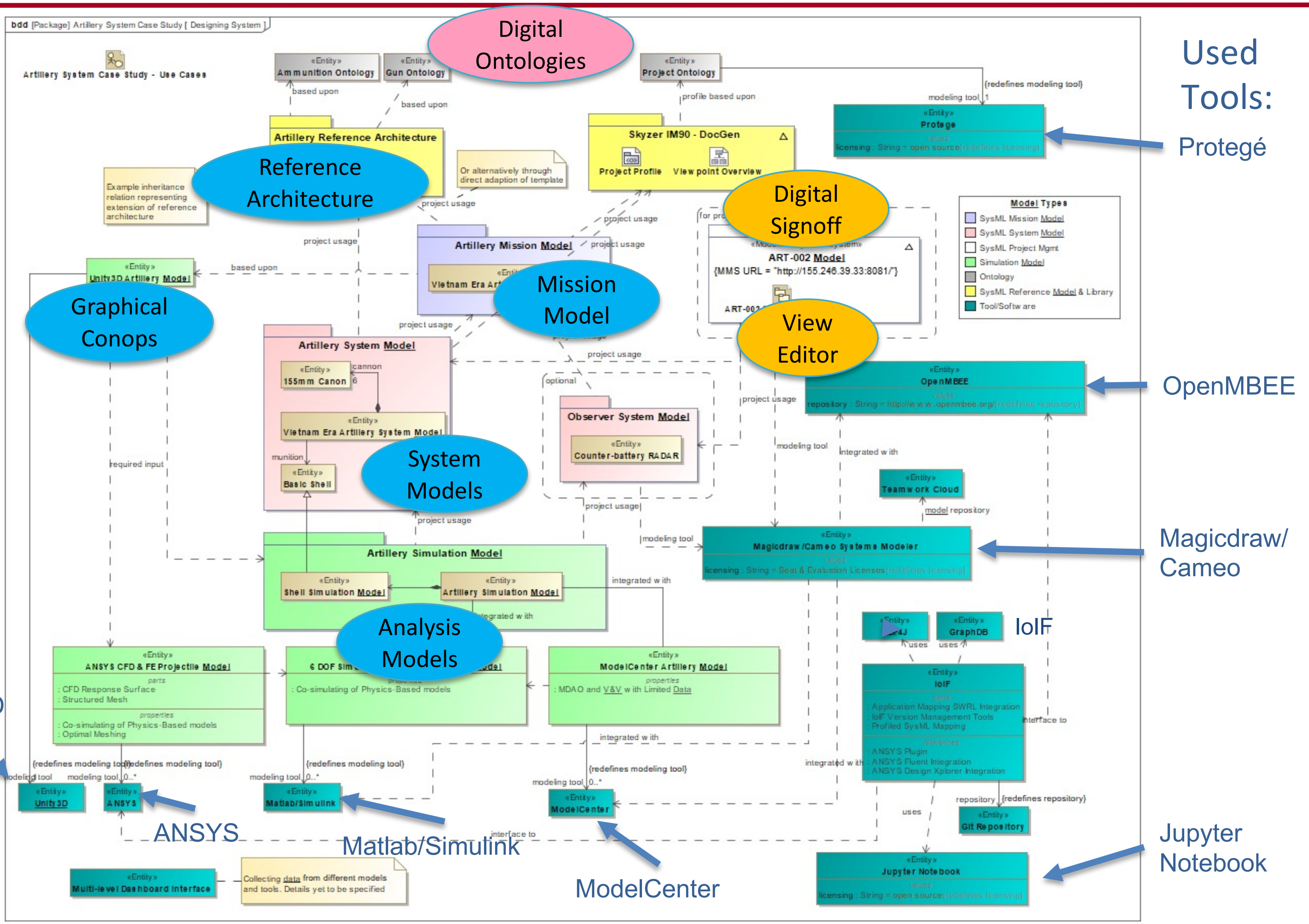
Example Reference Architecture “Full Stack”



Primary Takeaways

- This approach has been readily adapted to other Application Domains
- We are looking for opportunities to scale this to a Program of Record to understand any impedance factors to full scale transition
- We plan to have follow on briefings on other Use Cases and additional deep dives into the enabling technologies and concepts

Thank you!

- Dr. Mark Blackburn
- Senior Research Scientist
- Principal Investigator
- Member of SERC Research Council
- Member of OpenMBEE Leadership Team
- School of Systems & Enterprises
- Systems Engineering Research Center
- Stevens Institute of Technology