Applications of Graph Theory for Reuse of MBSE Design Data

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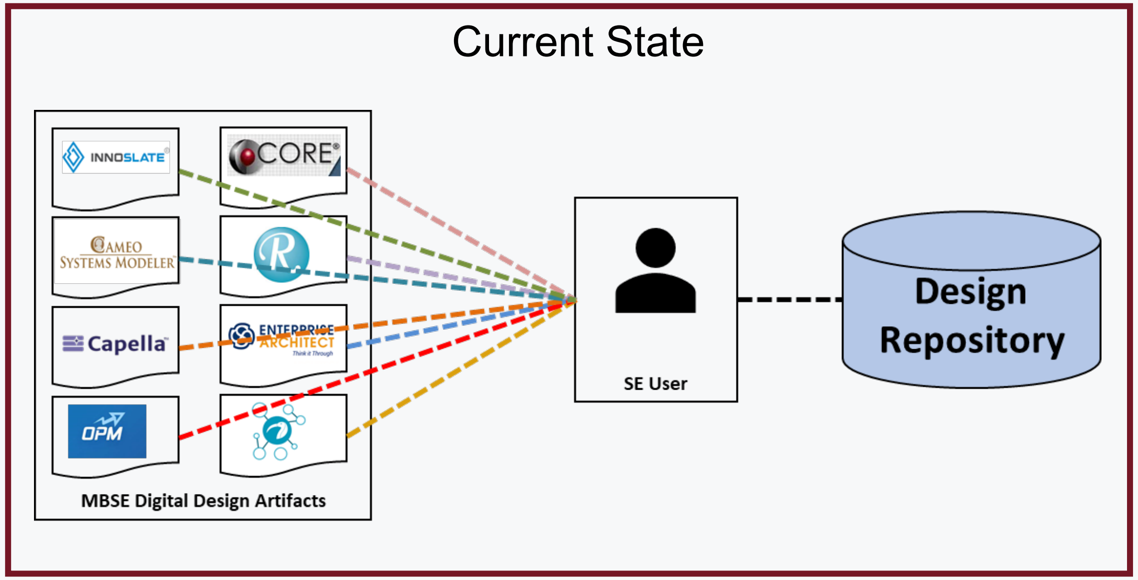
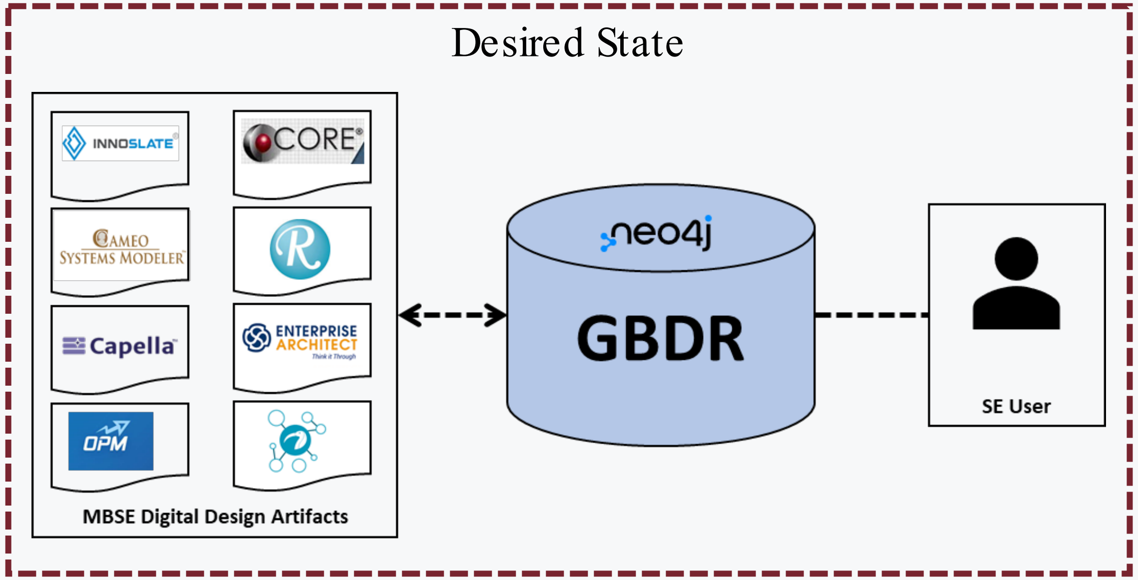
Motivation and Background

- Design knowledge from previous engineering projects is an asset for engineering teams
  - Value of existing knowledge is realized through the process of reuse
- Model Based Systems Engineering (MBSE) tools store design knowledge in a form that makes cross-model reuse cumbersome and limited by:
  - A lack of consistent data standards or a standard modeling language
  - Costly licenses required to use proprietary MBSE tools
  - 'Siloed' data in separate models for each system developed
- Design repositories presented in existing literature serve as a tool to enable reuse, but do not support the reuse of data from MBSE tools





Research Direction: Current Gap and Intended Outcomes

- A gap in the SE state-of-the-art exists due to differences between:
  - the ways that system design knowledge is generated and captured (system models created in MBSE tools); and
  - the tools available to enable reuse of system design knowledge (design repositories)

- To resolve this gap, my dissertation research pursued answers to the following research questions:
  - How can system models from a heterogeneous set of MBSE tools be coalesced into a body of knowledge for SE design?
  - How can differences between MBSE tool data standards and modeling languages be bridged to support reuse of information from a heterogenous set of MBSE tools?

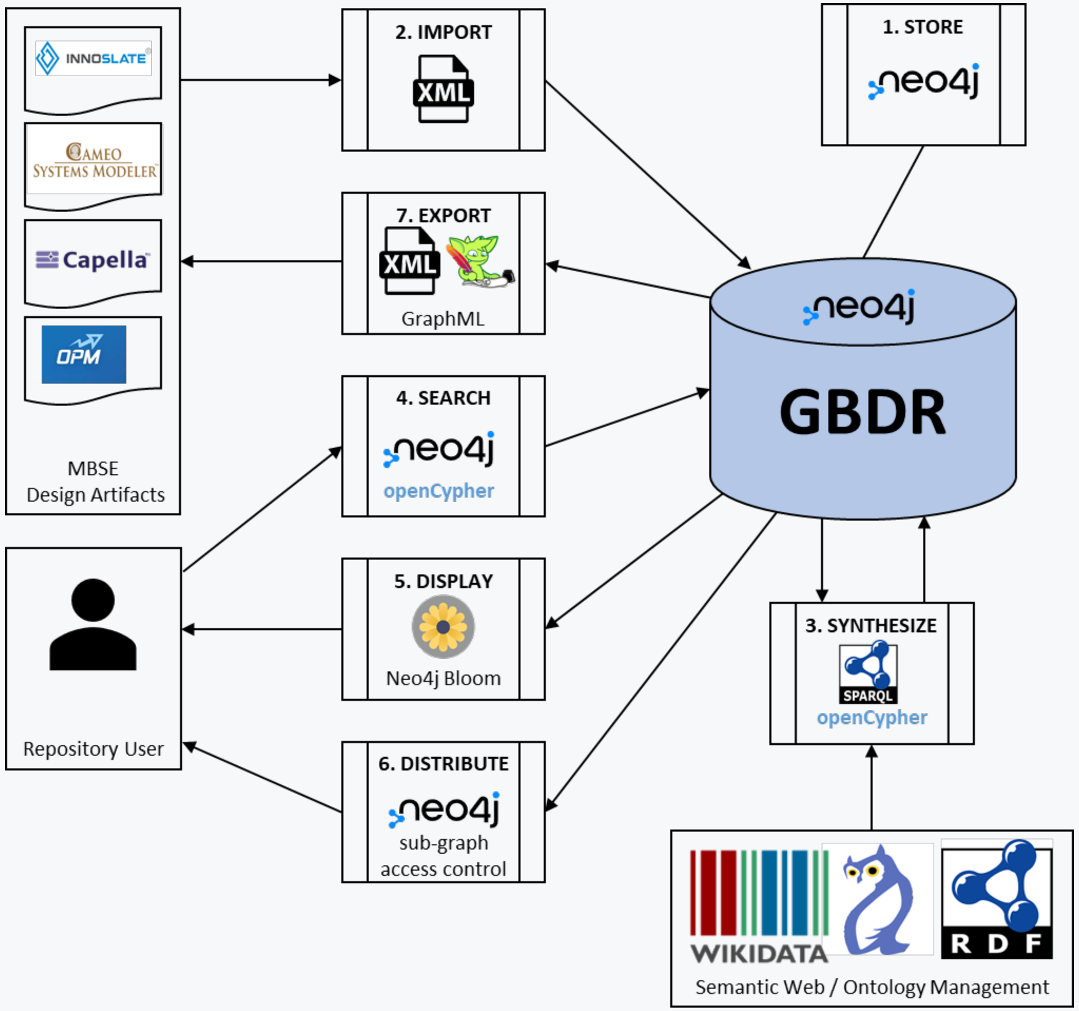
- The research effort resulted in a novel graph-based design repository (GBDR) that can:
  - interpret and transform disparate system design data sets (digital system models from multiple modern MBSE tools) into a coalesced body of SE design knowledge; and
  - enable design reuse by providing and enhancing the core functionality of existing design repositories

Graph-based Design Repository Overview

- GBDR utilize principles from graph theory to transform disparate system model files from MBSE tools into a single body of SE design knowledge stored in a graph database.

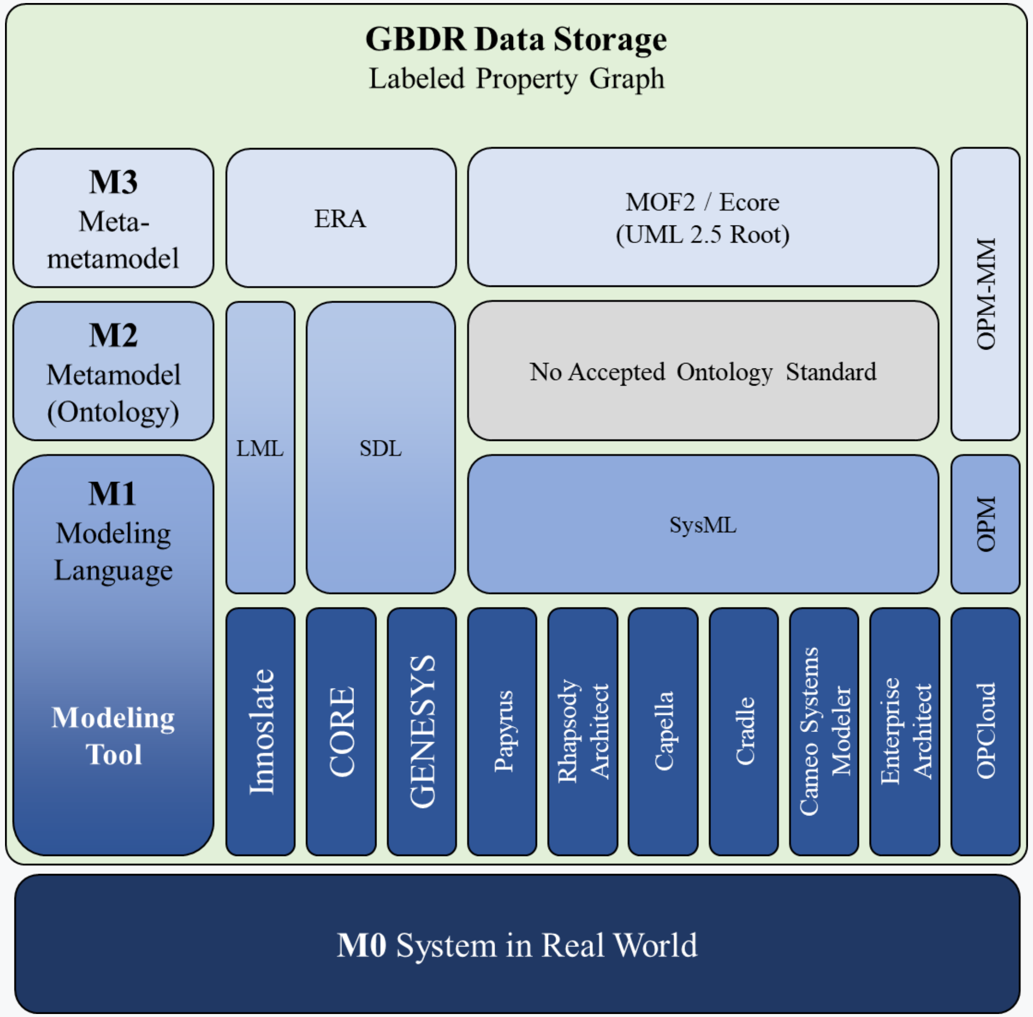
- GBDR leverage data from system models to fulfill the core functions of design repositories from previous literature:
  - Store
  - Import
  - Synthesize
  - Search
  - Display
  - Distribute
  - Export

- The presented GBDR utilizes an open-access knowledge graph as a system-agnostic ontology to enable the identification of equivalent modeled concepts within different system models.



Storing Data from Multiple MBSE Tools/Modeling Languages

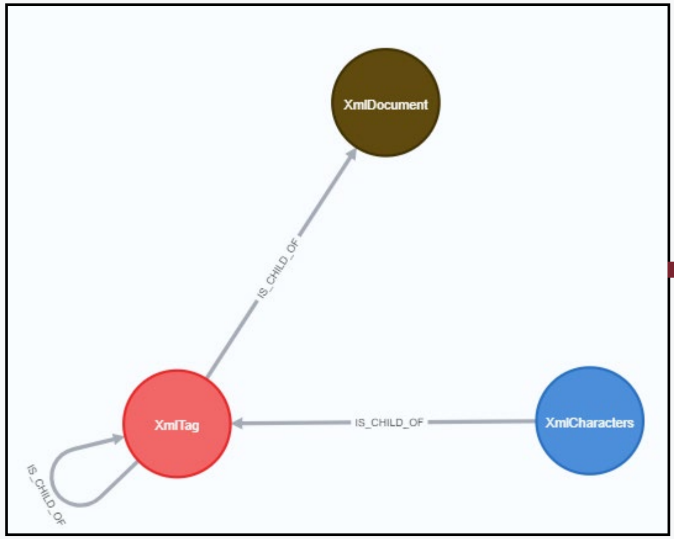
- The GBDR presented in this dissertation accounts for both explicit and implicit information stored in MBSE tools by storing data for all levels of abstraction within the system model/tool.
- System design information from MBSE tools is represented in:
  - The system model itself (M_1)
  - The leveraged ontology/metamodel (M_2), if one exists.
  - The meta-metamodel that is used to define the base semantics of the modeling language (M_3).
- The data stored for each of these three levels of abstraction are organized into layers, called the System Model Data Layer (SMDL) for M_1, the Ontology Data Layer (ODL) for M_2, and the Meta-metamodel Data Layer (MMDL) for M_3.
- A common meta-metamodel (GOPPRR) is used as a bridge between base semantic concepts from different meta-metamodels.



Importing Data from Multiple MBSE Tools

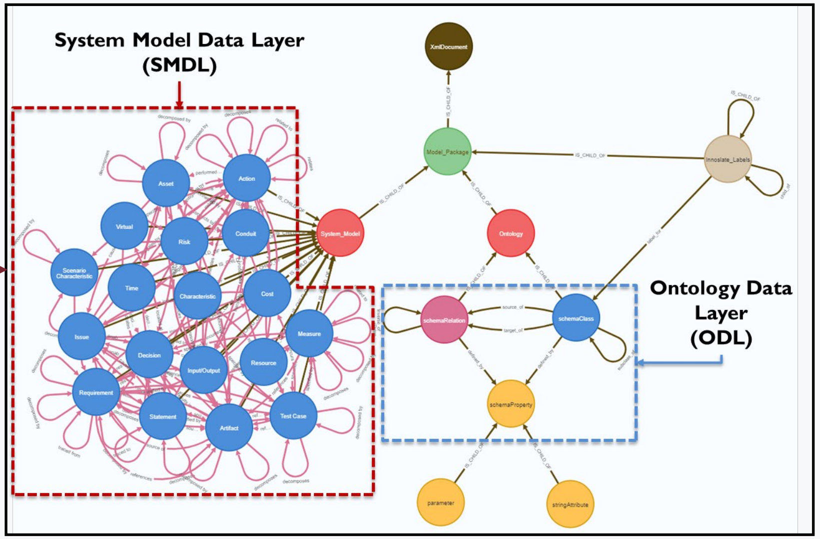
- The value of design repositories as a source of information for reuse increases as the quantity of system information stored in the repository grows.
  - The time associated with adding each system model can be a barrier to populating a design repository with a large number of models.
  - Primary obstacle to automating the import process for MBSE design artifacts is the variability of data structures between source tools.
- Fortunately, most commonly-used system modeling tools can generate XML-compliant interchange files that represent all information stored in the system model.
- The presented GBDR can transform XML data from interchange files into a labeled property graph of modeled concepts

XML file schema graph



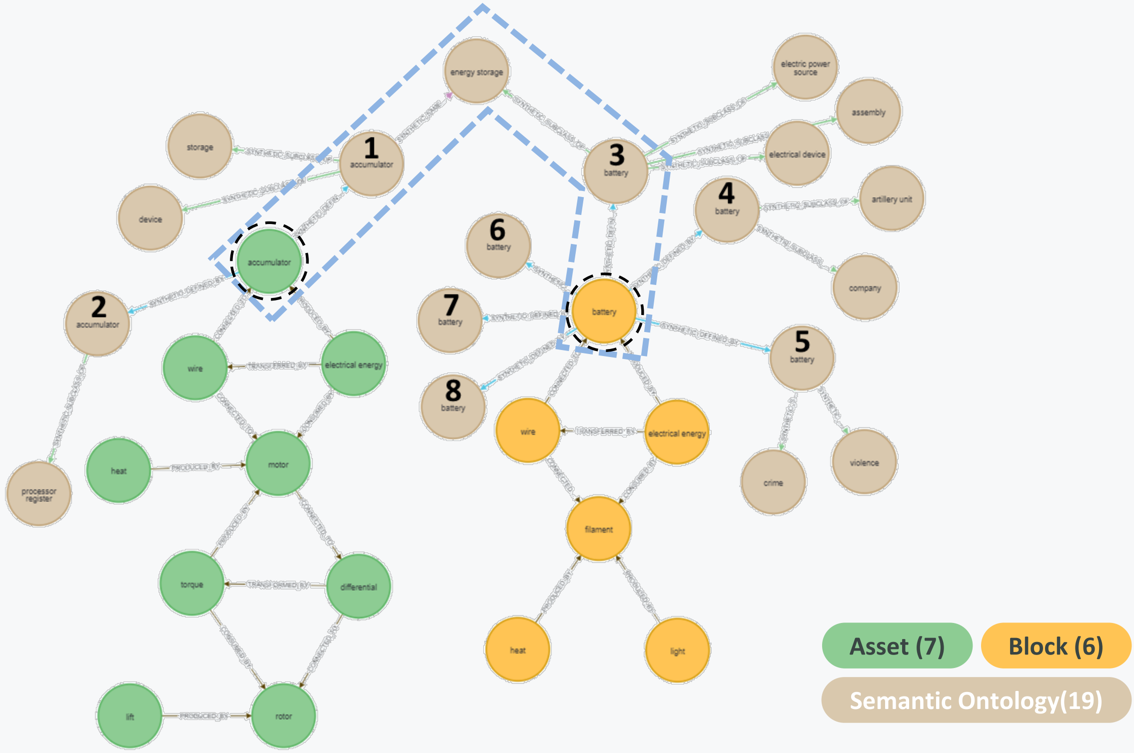
GBDR Import Function

GBDR schema for a system modeled in LML



Synthesizing Data from Multiple MBSE Tools

- The goal of the synthesis function is to turn a disconnected set of system models into a connected body of knowledge.
- Connections are created as relationships between similar modeled concepts from different source system models
  - The presented GBDR uses a semantic knowledge graph (WikiData) to populate an M_1–level ontology.
  - This ontology is used to detect pairs of potentially equivalent concepts found in different system models.
  - Two scoring measures were developed that provide a metric for the similarity of identified pairs of potentially equivalent concepts.



Accumulator Root SAKL Node	Connected SAKL Entry	Battery Root SAKL Node
(2) arithmetic register		
(1) energy storage device	storage	
	device	
	energy storage	**(3)** assembly of one or more electrochemical cells
	electric power source	
	assembly	
	electrical device	
		(4) artillery unit size designation
		(5) criminal offense
		(6) common law act
		(7) chess formation
		(8) baseball term

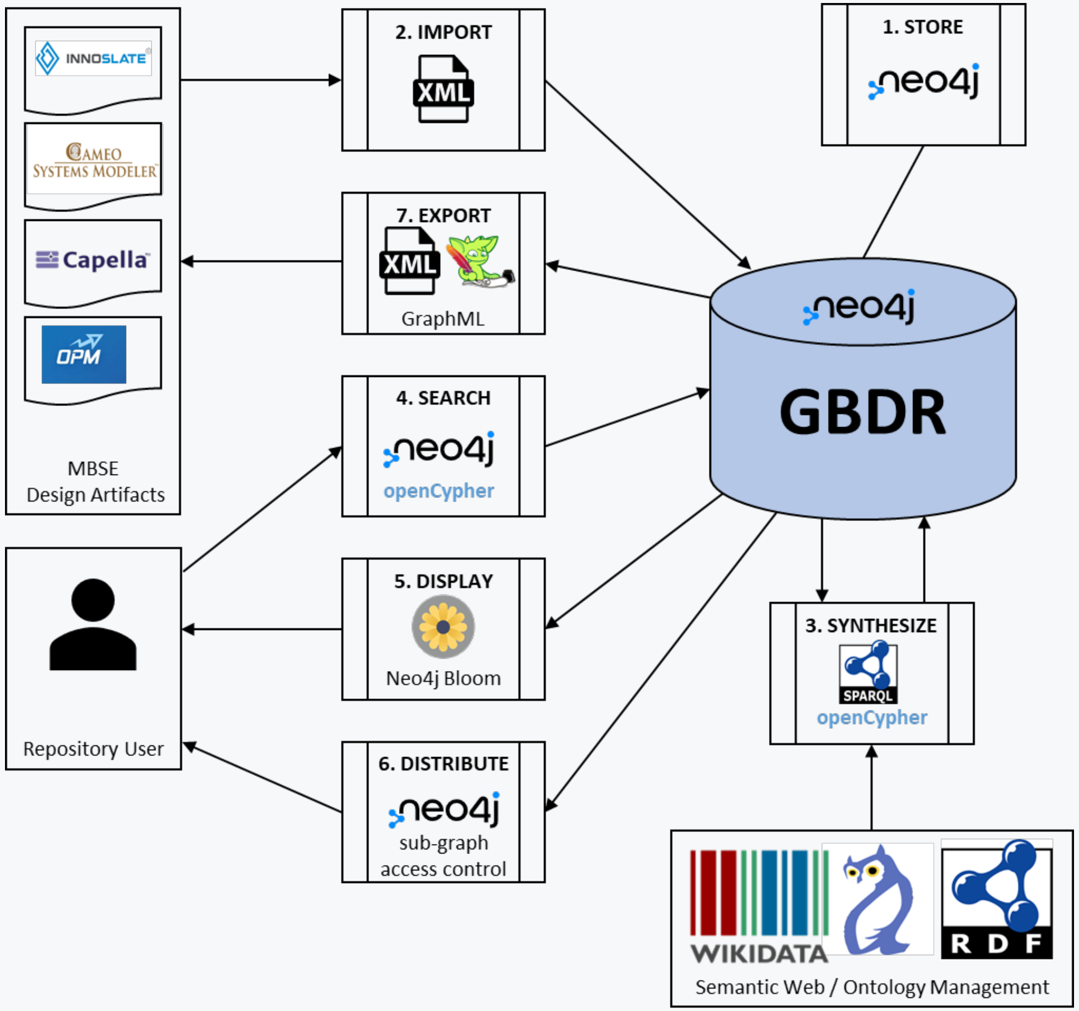
Additional Design Repository Functions

- **Search** is accomplished using graph-enabled pattern and super pattern matching
  - Enables the identification and retrieval concepts modeled at different levels of abstraction across system models

- **Display** is accomplished using existing standalone graph visualization tools or embeddable tools (e.g., Python or JavaScript packages)

- **Distribute** is accomplished using native Neo4j roles, privileges, and fine-grained security

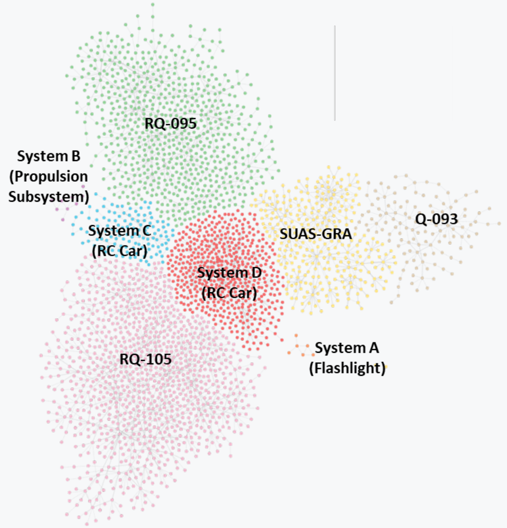
- **Export** is accomplished using a tool-chain composed of free and open-source software
  - Neo4j generation of exportable output subgraph
  - Neo4j export of XML-compliant GraphML file
  - Transformation to MBSE tool interchange format using XSLT



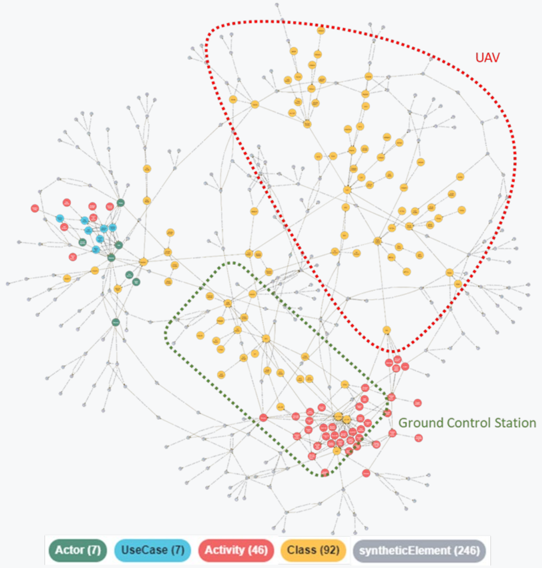
Practical Demonstration of GBDR Applications

- A Small Unmanned Aircraft System (SUAS) Government Reference Architecture (GRA) was used to demonstrate GBDR functionality using a practically representative model.
  - ➢ SUAS GRA was created as a Cameo Enterprise Architecture model without knowledge it would be used to demonstrate the GBDR
- Practical demonstration identified alternative components for the GRA from within a set of UAV systems represented by Innoslate models.

System Models in GBDR



SUAS GRA w/ Local Semantic Concepts



Demonstration Results

Identification Method	Alternatives Identifed
Component Name Matching	17
Similarity Score*	27
Superpattern matching*	17

*novel method enabled by GBDR

Conclusions and Future Work

- A graph-based design repository provides multiple novel contributions and novel applications:
  - Contributions
    - Enables the reuse of design data from multiple modeling tools and modeling languages in a single tool.
    - Provides a method to identify similar concepts across system models that are modeled at different levels of abstraction.
    - Provides a method to generate synthetic system and subsystem designs composed of details from multiple source systems.
  - Novel Applications
    - Integrates a semantic ontology for use in the identification of equivalent concepts found in different system models.
    - Demonstrates the application of graph-enabled search on a set of practically-representative models from multiple MBSE tools.

- Opportunities for Future Work:
  - By transforming disparate system models from MBSE tools into a single data set, a GBDR may enable further research into computer aided systems engineering (CASE) and design automation.
  - Potential applications of GBDR as a tool to manage systems engineering intellectual property may be enabled through the integration of digital ledger technologies with a GBDR.

SYSTEMS ENGINEERING RESEARCH CENTER

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