Applications of Graph Theory for Reuse of MBSE Design Data

RESEARCH TEAM

Mr. Daniel Herrington is a Doctoral candidate in the Systems Engineering Department at the Naval Postgraduate School. Daniel's research areas of interest include MBSE and cost assessment, with an emphasis on tools and methods that improve engineering efficiency through reuse of past work.

RESEARCH TASK & OVERVIEW

A gap in existing Systems Engineering (SE) research exists between the available tools that to enable reuse of SE design knowledge (i.e., design repositories) and the form that SE design knowledge takes when generated using modern MBSE methods and tools. The intent of this research effort was to develop a tool and a set of enabling methods that allow system models created using a heterogeneous set of MBSE tools to be leveraged as a coalesced body of SE design knowledge.

DATA & ANALYSIS

System model data used for this research includes a Small Unmanned Aircraft System (SUAS) Government Reference Architecture (GRA) developed at the Air Force Institute of Technology (AFIT)[1] using Cameo Enterprise Architecture, as well as a series of UAV system models developed to support this effort using SPEC Innovation's Innoslate tool. Portions of the free and open *Wikidata Knowledge Base* are used as a semantic ontology to aid in the identification of equivalent or similar modeled concepts that appear in multiple systems.

GOALS & OBJECTIVES

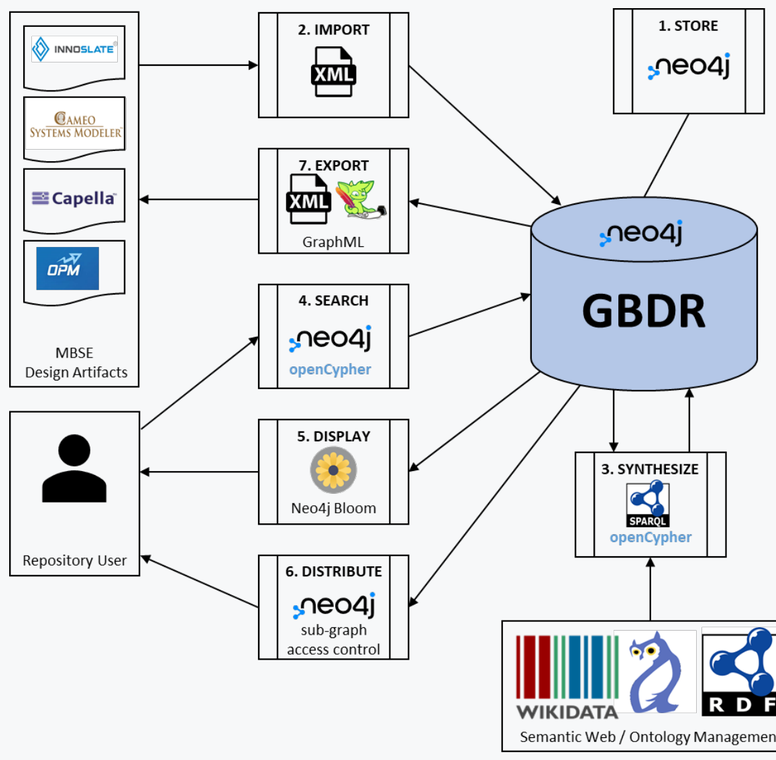
Develop and demonstrate a novel design repository that can:

- Interpret and transform disconnected system design data sets (digital system models from a heterogeneous set of modern MBSE tools) into a coalesced body of SE design knowledge; and
- enable design reuse by providing the core functionality of existing design repositories (store, import, synthesize, search, display, distribute, and export)

Free and publicly available software was used for all developed and demonstrated tools and functions to reduce barriers to adoption.

Core Functions

1 Store
2 Import
3 Synthesize
4 Search
5 Display
6 Distribute
7 Export



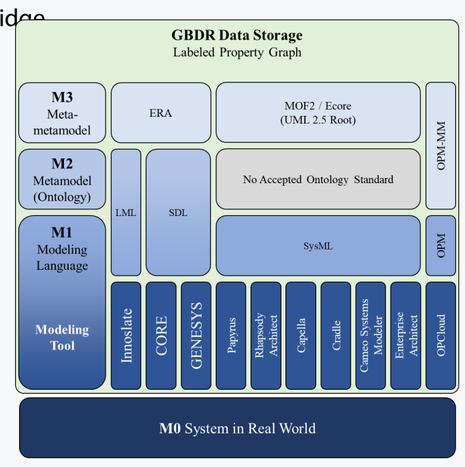
GBDR can process system models from MBSE tools with XML-compliant model files

METHODOLOGY

A novel design repository was created using a Neo4j graph database. The graph-based design repository (GBDR) expands the state-of-the-art for systems engineering by leveraging graph-enabled import, synthesis, search, and export algorithms that allow MBSE system models to be stored and utilized as a coalesced body of systems design knowledge.

Store

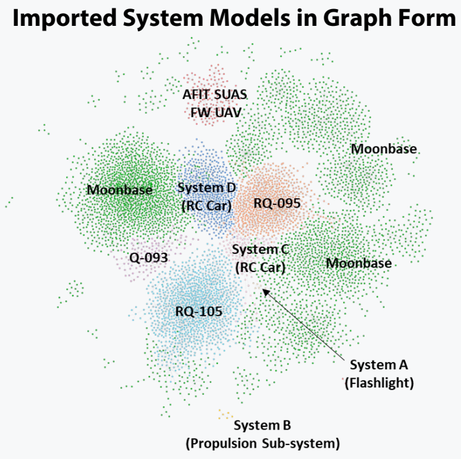
System design data from MBSE models is stored as a graph. Explicitly modeled system concepts (M_1 level of abstraction) and modeling concepts (M_2 and M_3 levels of abstraction) are represented as data layers within the GBDR. A common meta-metamodel (GOPPRR) serves as a semantic bridge.



Import

System model files from MBSE tools that use XML-compliant interchange files can be imported as a hierarchy of XML statements. A series of transformation operations translate XML data into a labeled property graph of system concepts.

Imported System Models in Graph Form

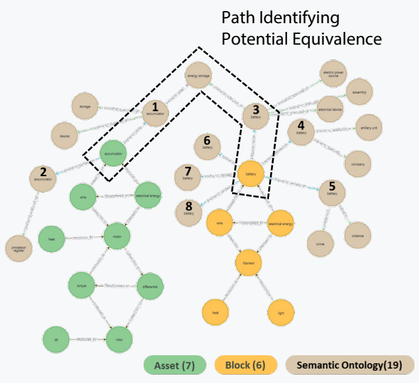


Synthesis

A semantic ontology is imported to the GBDR using the Wikidata SPARQL API. Modeled concepts from system models are matched to the semantic ontology based on concept names.

Potentially equivalent pairs of concepts modeled in different source system models are identified by the existence of connecting paths through the semantic ontology.

Similarity measures are proposed that quantify the similarity of potentially equivalent pairs of system concepts:



Node Similarity Score (SS_N) measures the similarity of the properties of a pair of nodes:

Where:
A_p = the set of property keys on node A

$$SS_N(A,B) = \frac{|A_p \cap B_p|}{|A_p \cup B_p|}$$

Context Similarity Score (SSC) measures the similarity of the system context of nodes identified as potential pairs:

Where:
k = count of neighboring nodes that have a potentially equivalent concept neighboring the other node in the pair
p = assumed probability of successfully identifying a matching concept in the semantic ontology

$$SS_C(A,B) = \sum_{i=0}^{|k|} \binom{n}{i} p^i (1-p)^{n-i}$$

Search

The presented GBDR provides both strict and flexible search approaches to allow users to identify relevant data from the system models stored in the system.

- Strict search accomplished using pattern matching and results meet a fixed subgraph structure
- Flexible search accomplished using super-pattern matching and results meet a subgraph structure with bounded variability.

Search criteria can be tailored to allow the return of subgraphs composed of modeled concepts from multiple source system models, where equivalent concepts between models are used to cross system boundaries. The resulting **synthetic system models** can be exported to a target MBSE tool.

Display Distribute Export

Satisficing solutions for the display, distribute, and export functions were developed using native Neo4j functions and a FOSS tool-chain to demonstrate that a GBDR is a complete and usable tool.

FUTURE RESEARCH

By transforming disparate system models from MBSE tools into a single coalesced data set, a GBDR may be an ideal data set to enable further research into computer aided systems engineering and design automation. Potential applications of GBDR for management of systems engineering intellectual property may feasibly be enabled through the integration of digital ledger technologies.

CONTACTS & REFERENCES

The lead researcher can be reached at djherrin@nps.edu. Dr. Paul Beery served as committee chair and primary advisor for this research.

[1] D. Jacques and A. Cox, "The use of mbse and a reference architecture in a rapid prototyping environment," 2019 MBSE Cyber Experience Symposium, May 2019.

SYSTEMS ENGINEERING RESEARCH CENTER
SERC DOCTORAL STUDENT FORUM 2022
NOVEMBER 17