STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY®

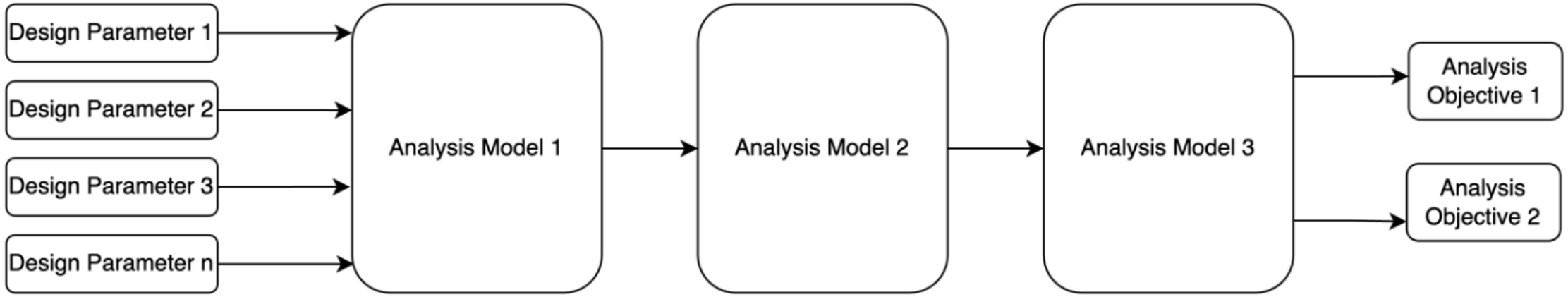
Reuse of Digital Engineering Models via Semantic Component Libraries

AI4SE Workshop

Dr. Daniel Dunbar
Dr. Thomas Hagedorn
Dr. Mark Blackburn
Mr. Steve Hespelt

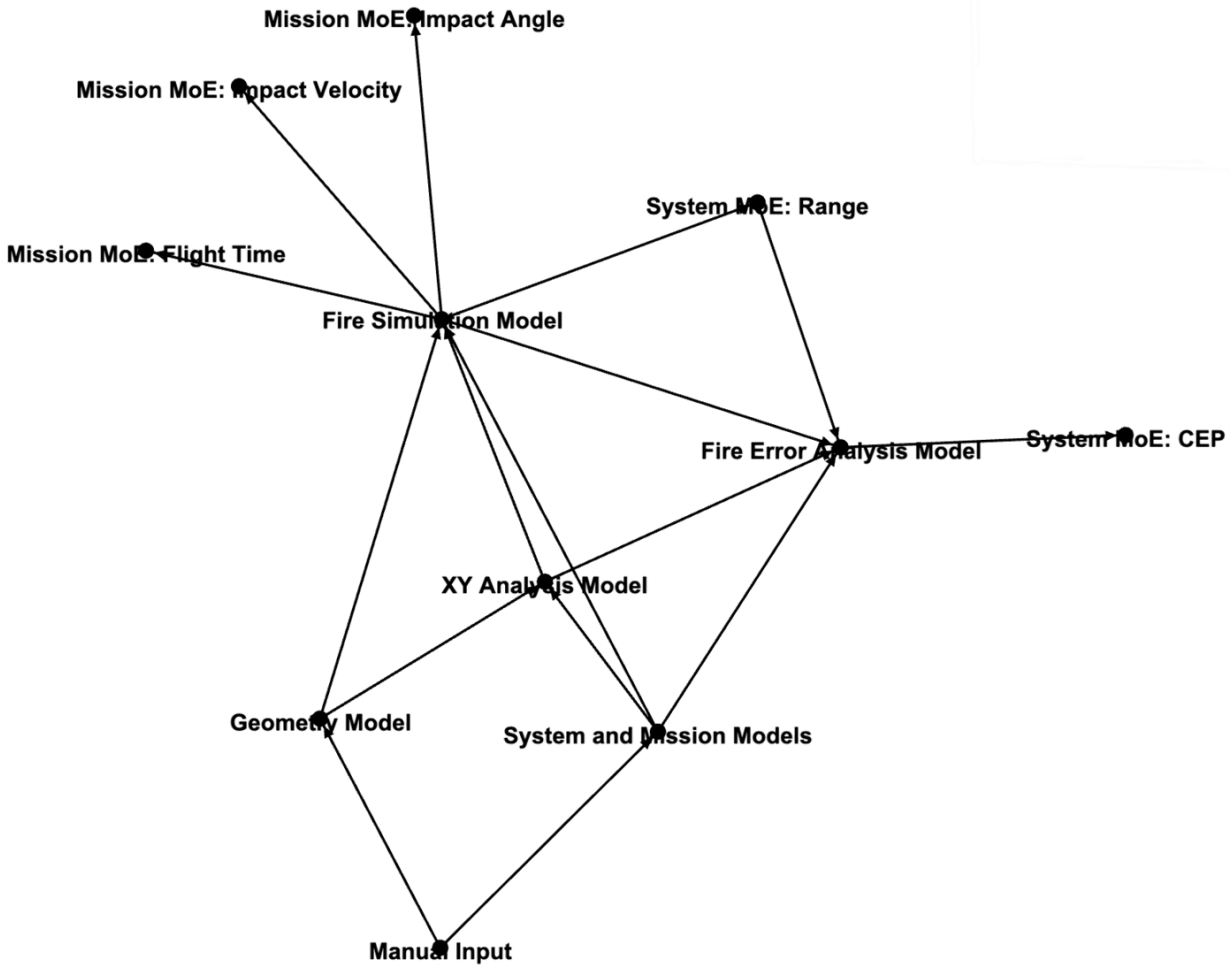
System of Analysis (SoA) – A kind of Digital Thread

- Model representation of the system involved in data analysis, storage, etc. relating to some system or mission
- Analyses often involve multiple models, simulations, domains, etc.
- Multiple models can interact in different ways (share common parameters, inform one another, etc.)
- Different levels of abstraction can occur in a broad analysis context
  - Domain, System, and Mission models and Measures of Effectiveness (MoE) can be used in the same analysis context
- As an analysis increases in complication, the ability to verify analysis structure increases in difficulty

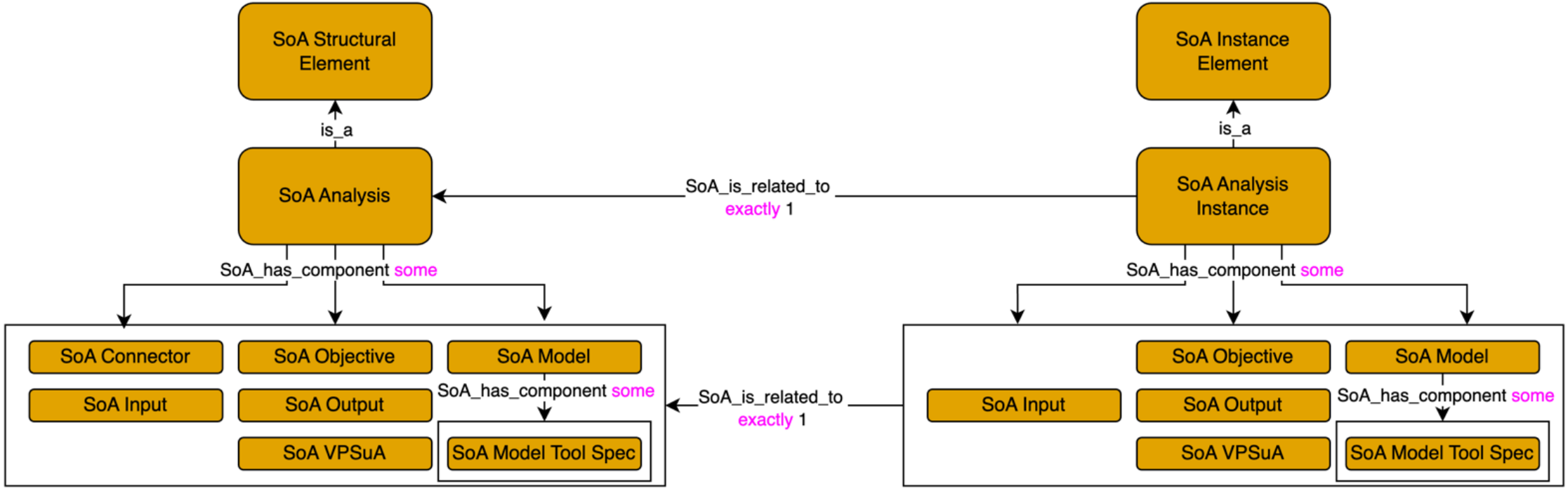


System of Analysis is a Graph

- (Partial) representation of a digital thread as simple, **directed graph**
  - Edges represent sequencing information
- System of Analysis (SoA) – A directed graph representation of data flow through intermediate models to high level analysis objectives
- Graph-Based Analysis can provide insight:
  - Cycles in the directed graph
  - Order for automation
  - Complexity
- Simple graph analysis only looks at simple edges



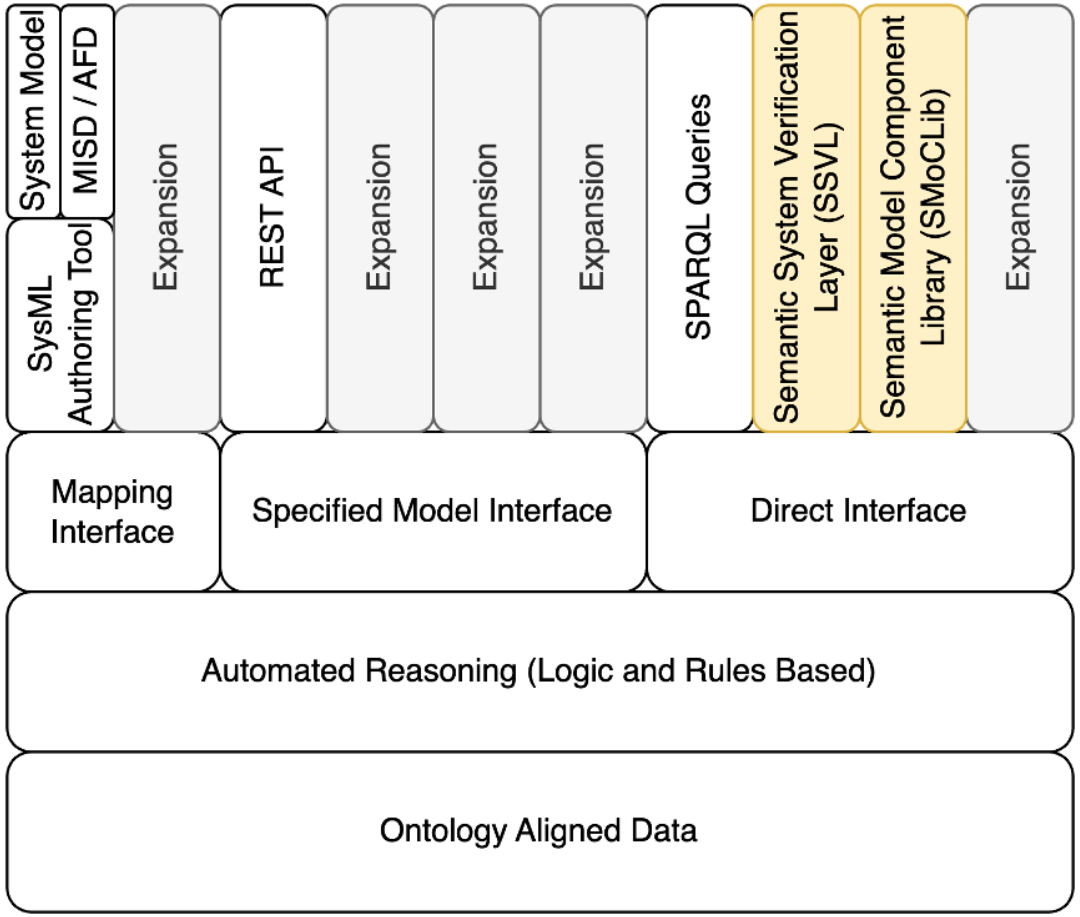
SoA Ontology - Reusable markup to tag an SoA graph



Digital Engineering Framework for Integration and Interoperability (DEFII)

Digital Engineering Framework for Integration and Interoperability (DEFII)[1]

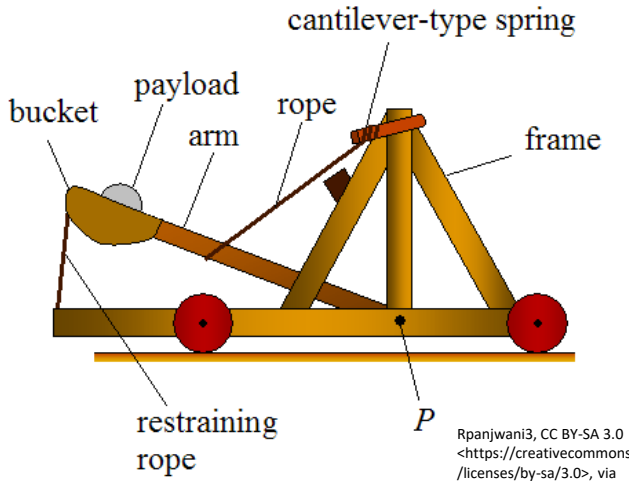
- Supports **interoperable, linked data across** system and analysis **models, repositories, visualizations**, etc.
- Built on semantic web technolgoy (SWT) toolchain – ontology-aligned data representation accessed and modified via supported interfaces
  - Mapping: rule-based data mining from a tool
  - Specified Model: **Pre-configured data and metadata payloads defined via SoA models**
  - Direct: Access via SWT interfaces like query engines, verification shapes, etc.



[1] Dunbar, D., Hagedorn, T., Blackburn, M., Dzielski, J., Hespelt, S., Kruse, B., Verma, D., & Yu, Z. (2023). Driving digital engineering integration and interoperability through semantic integration of models with ontologies. Systems Engineering, sys.21662. https://doi.org/10.1002/sys.21662

[2] Dunbar, D., Hagedorn, T., Blackburn, M., & Verma, D. (2024). A Three-Pronged Verification Approach to Higher-Level Verification Using Graph Data Structures. *Systems*, *12*(1), 27. https://doi.org/10.3390/systems12010027

The Problem – Large Scale Multi Model Analysis & Reuse



Rpanjwani3, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

Catapult Use Case

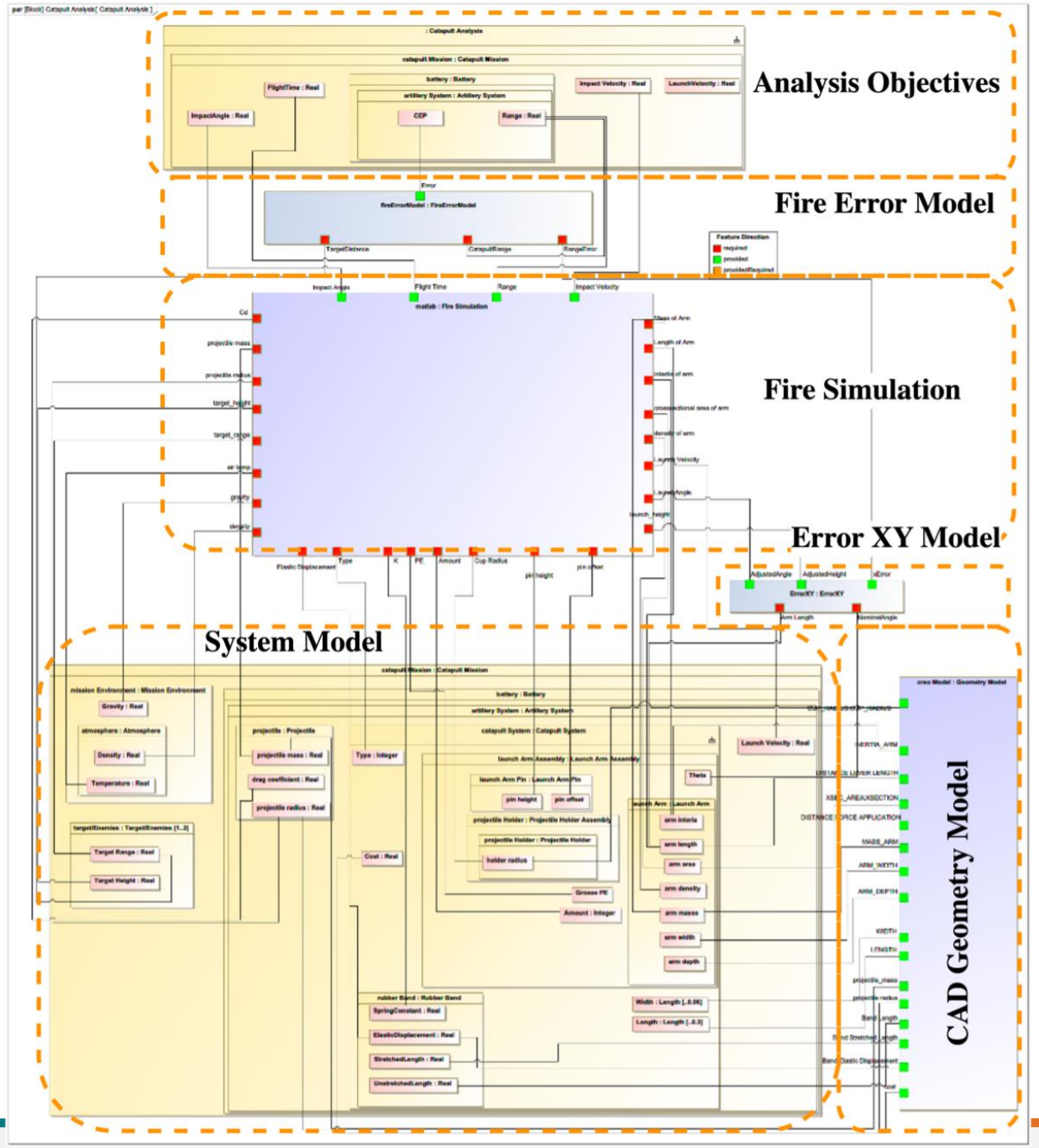
- Five Models
  - Descriptive (SysML)
  - Geometry (CAD Model using CREO)
  - Fire Simulation (MATLAB)
  - XY Error Model (Python)
  - Fire Error Model (Python)
- Models are connected in a non-linear fashion

Catapult Analysis System of Analysis

The Assessment Flow Diagram (AFD) has the System Under Analysis, the analysis models, and the Analysis Objectives.

Allows for explicit connection between individual parameters, intermediate models, and final objectives.

The AFD is the basis for the graph-based representation of the SoA.



SSVL Verification Applied to SoA Well-Formedness (Three Prongs)

Prong 1: Description Logic Reasoner

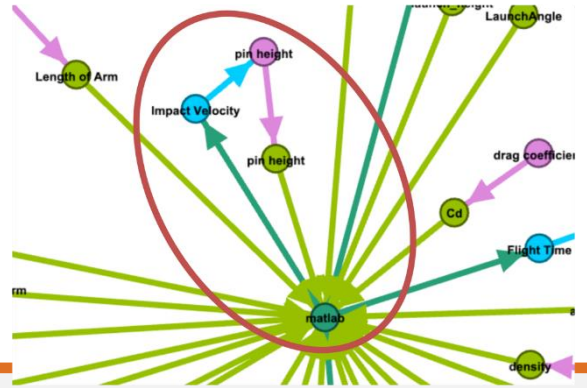
Scenario Name	Scenario Description	Failure	Pellet Message
C10	Gravity to Air Temp Inputs on Fire Simulation Model	Description Logic Reasoner	1) Functional SoA_terminated_to_target 09de70c2-0dfd-4599-8ebe-1dfaab9b7d61_SoA SoA_terminated_to_target 69ec40fc-3edd-4635-8e56-f21431071a86_SoA 09de70c2-0dfd-4599-8ebe-1dfaab9b7d61_SoA SoA_terminated_to_target a4f578a8-ce36-4417-ad15-81f982ebf855_SoA

Prong 2: Closed World Constraint Analysis

Scenario Name	Scenario Description	Failure	SHACL Messages
C16	Removed CircularErrorProbability (CEP) from objective	Closed World Constraint Analysis	Violation: Requirement 7 - Value Property: 'CEP' is not tagged with a loaded ontology term

Prong 3: Graph Based Analysis

Scenario Name	Scenario Description	Failure	Graph Failure
C26	Cycle from Impact Velocity to Pin Height	Graph Based Analysis	Cycle Detected

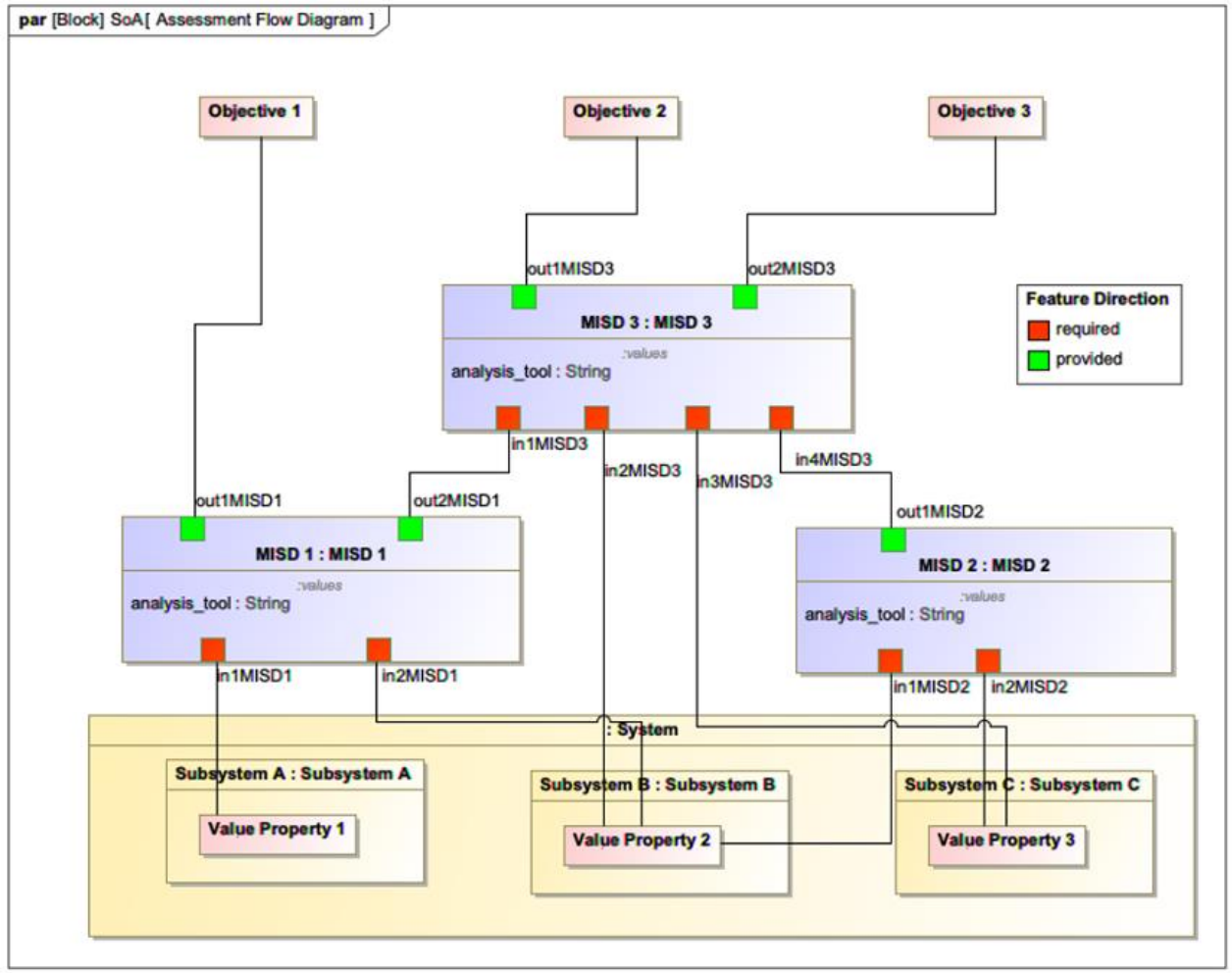


Abstract System of Analysis (SoA)

Value Properties identified as Objectives of the SoA

Intermediate Analyses defined through model interface specifications within SysML

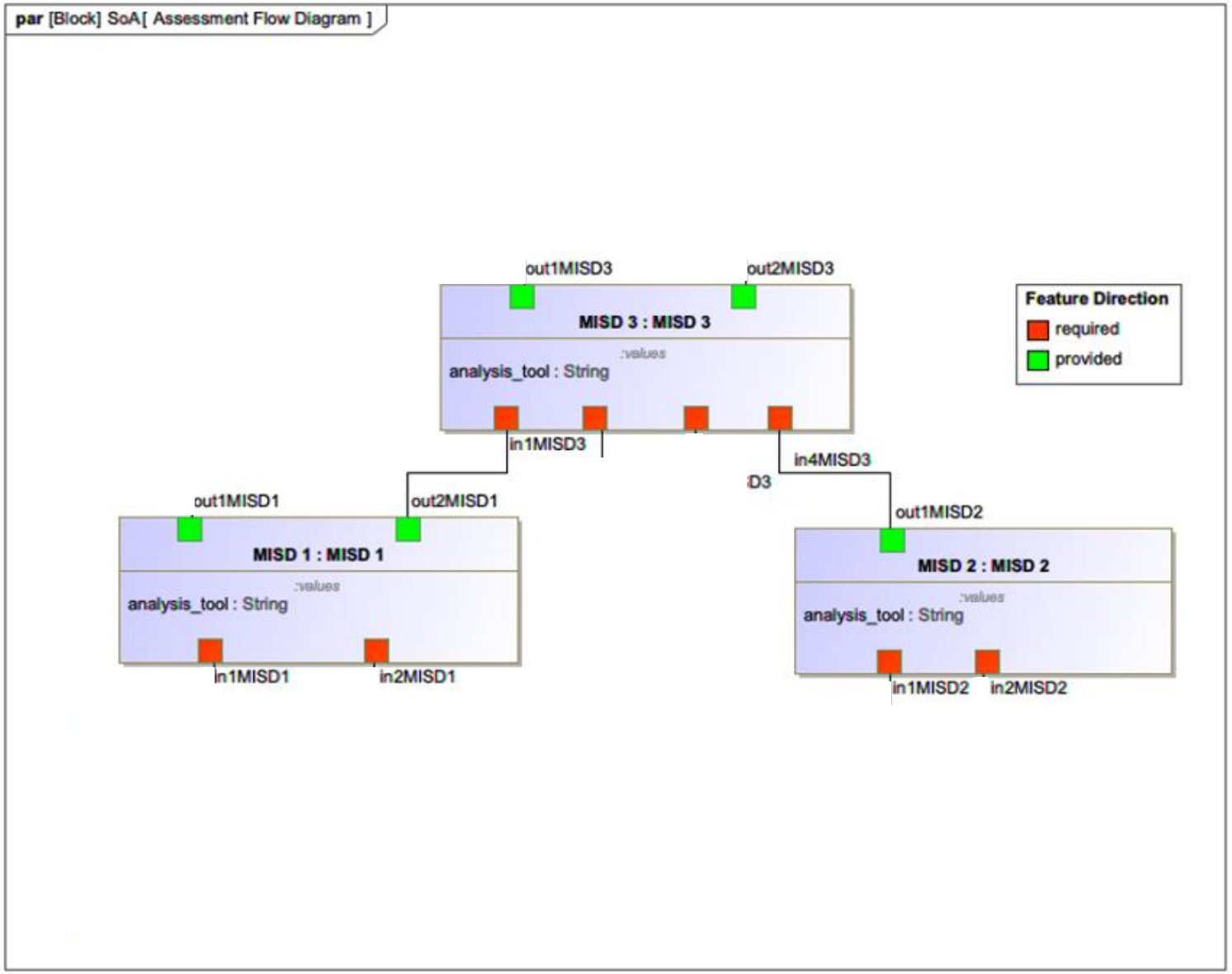
Value Properties of System Under Analysis



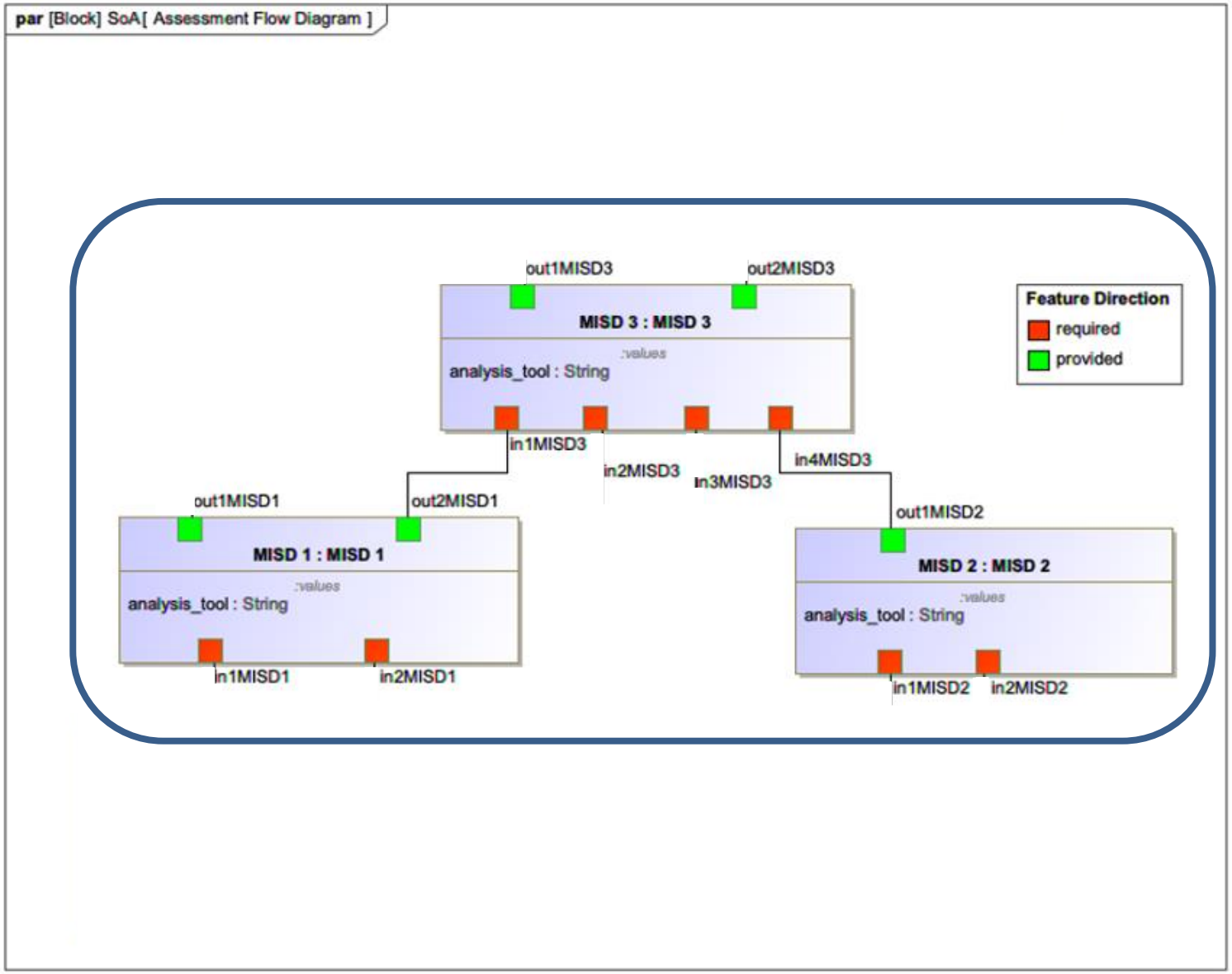
Dunbar, D., Hagedorn, T., Blackburn, M., & Verma, D. (2024). A Three-Pronged Verification Approach to Higher-Level Verification Using Graph Data Structures. *Systems*, *12*(1), 27. https://doi.org/10.3390/systems12010027

Cilli, M. V. (2015). Improving Defense Acquisition Outcomes Using an Integrated Systems Engineering Decision Management (ISEDM) Approach [PhD Thesis]. In *ProQuest Dissertations and Theses*. http://ezproxy.stevens.edu/login?url=https://www.proquest.com/dissertations-theses/improving-defense-acquisition-outcomes-using/docview/1776469856/se-2?accountid=14052

Potential for SoA model reuse

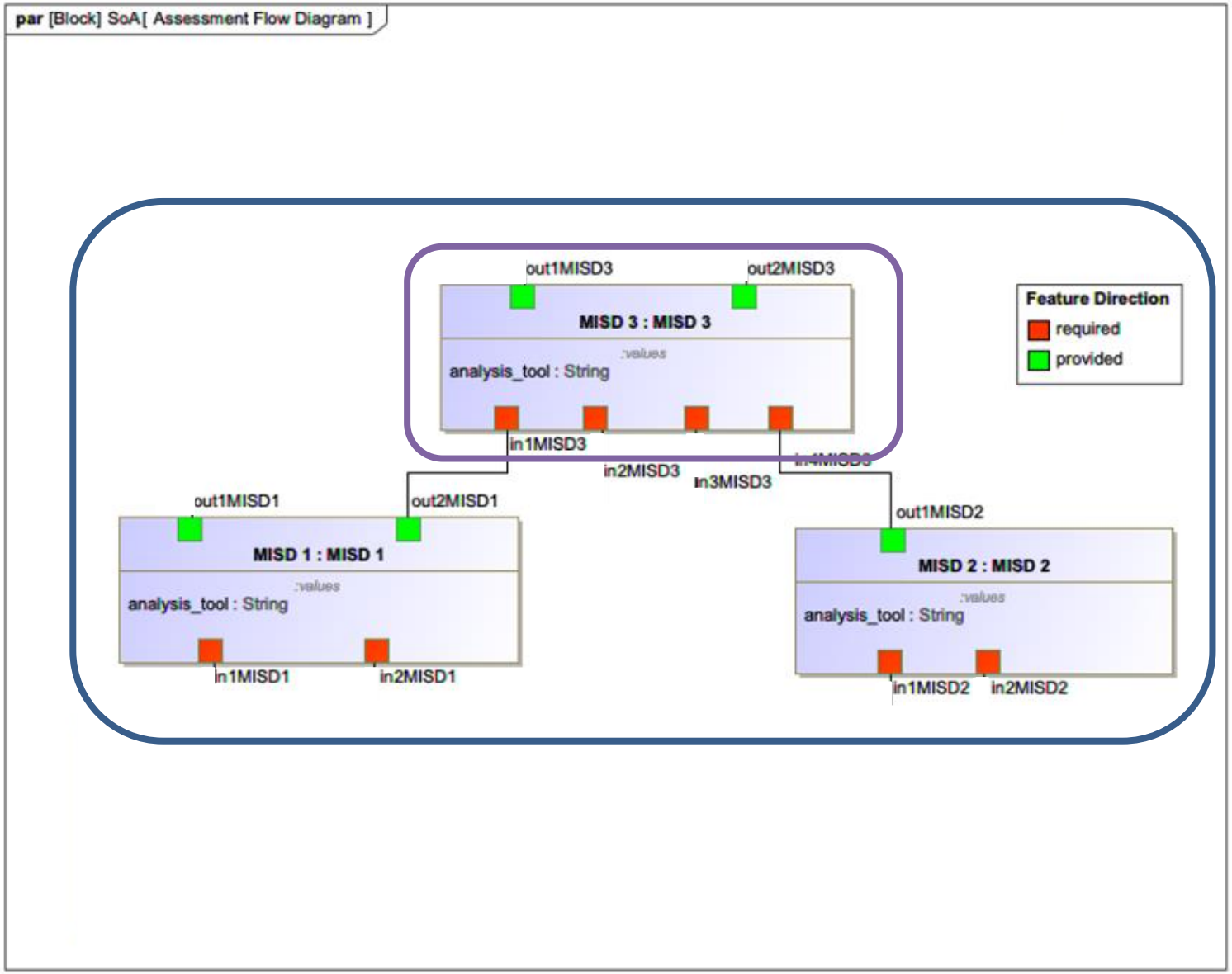


Potential for SoA model reuse



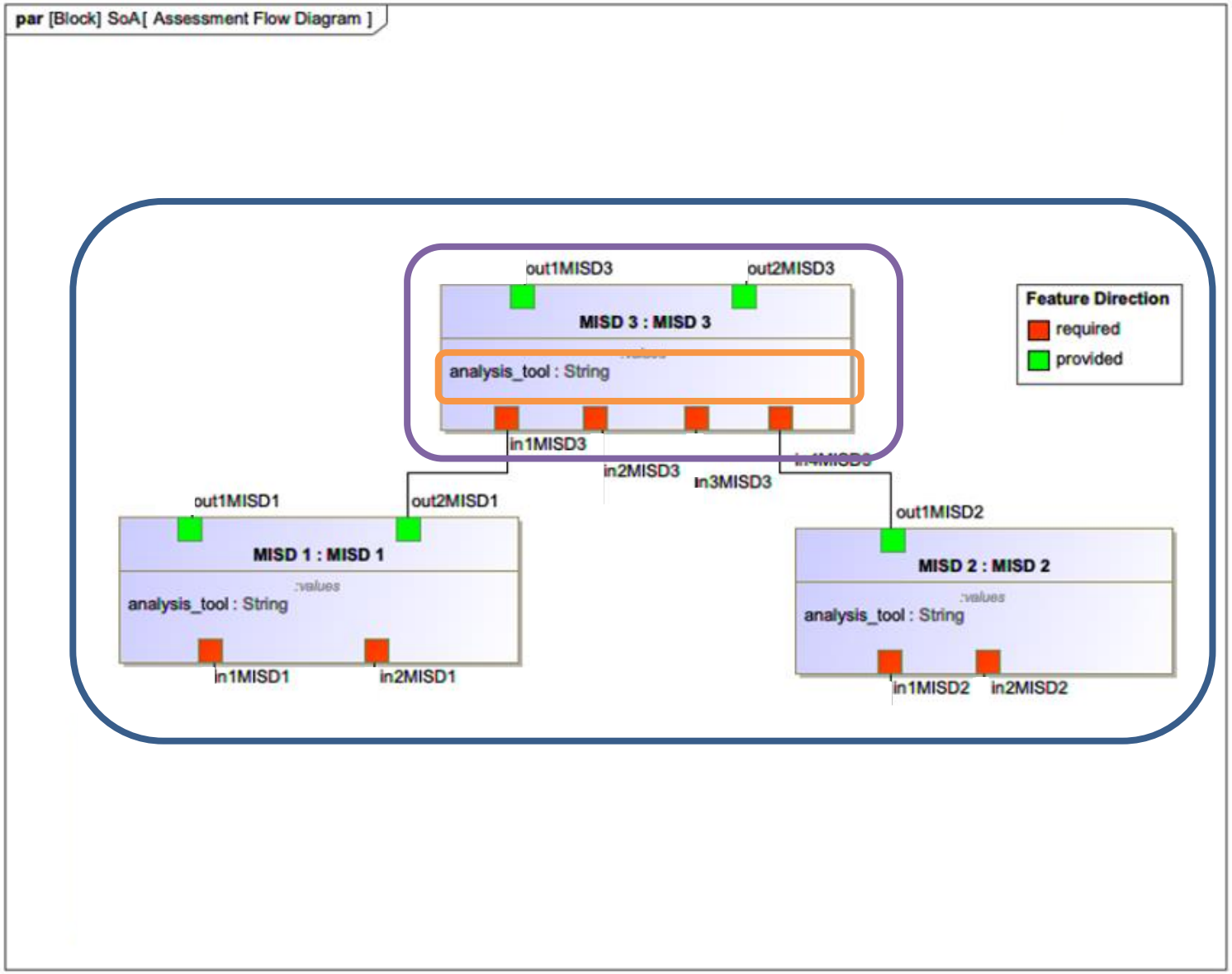
- Full SoA

Potential for SoA model reuse



- Full SoA
- Individual Model

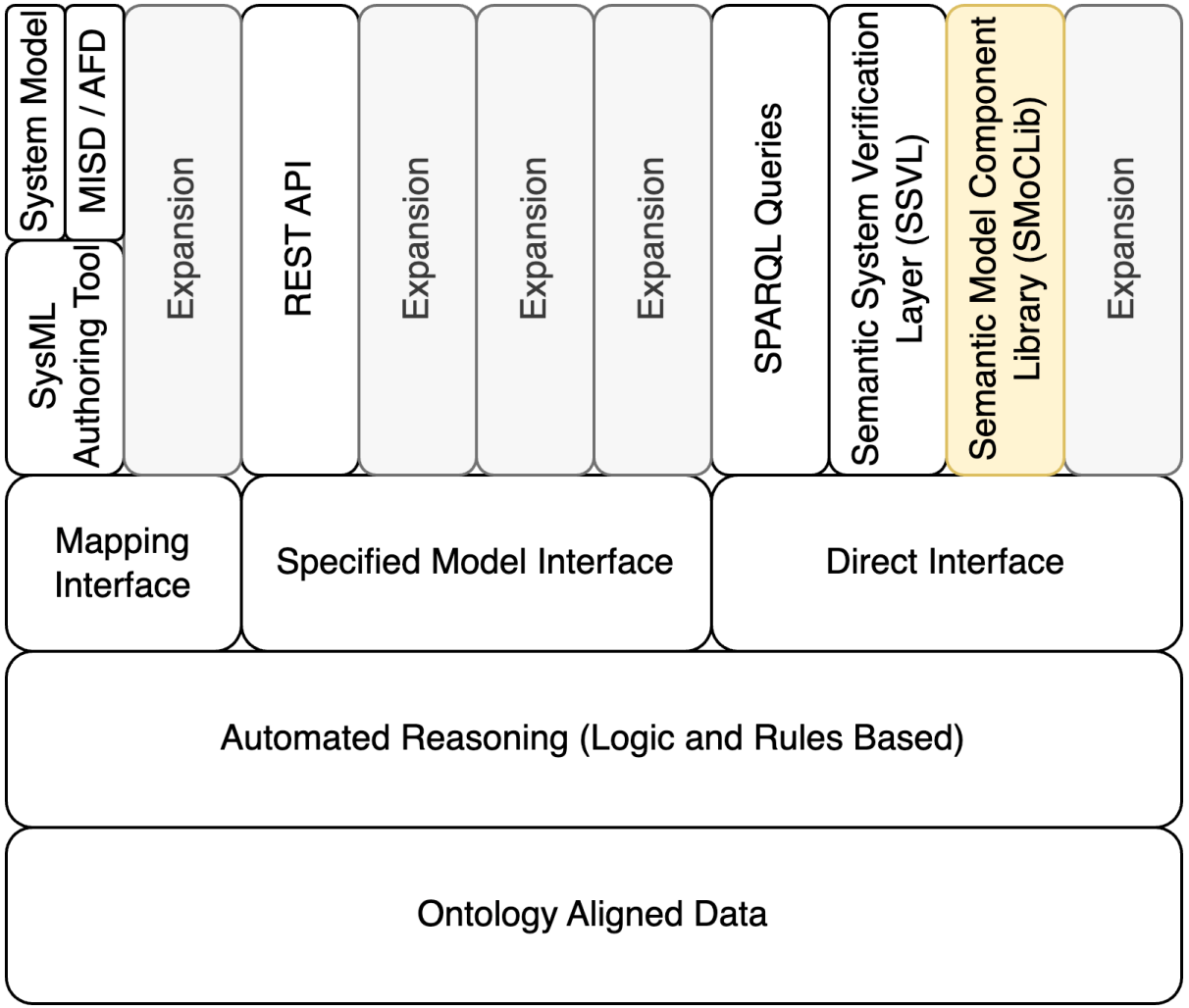
Potential for SoA model reuse



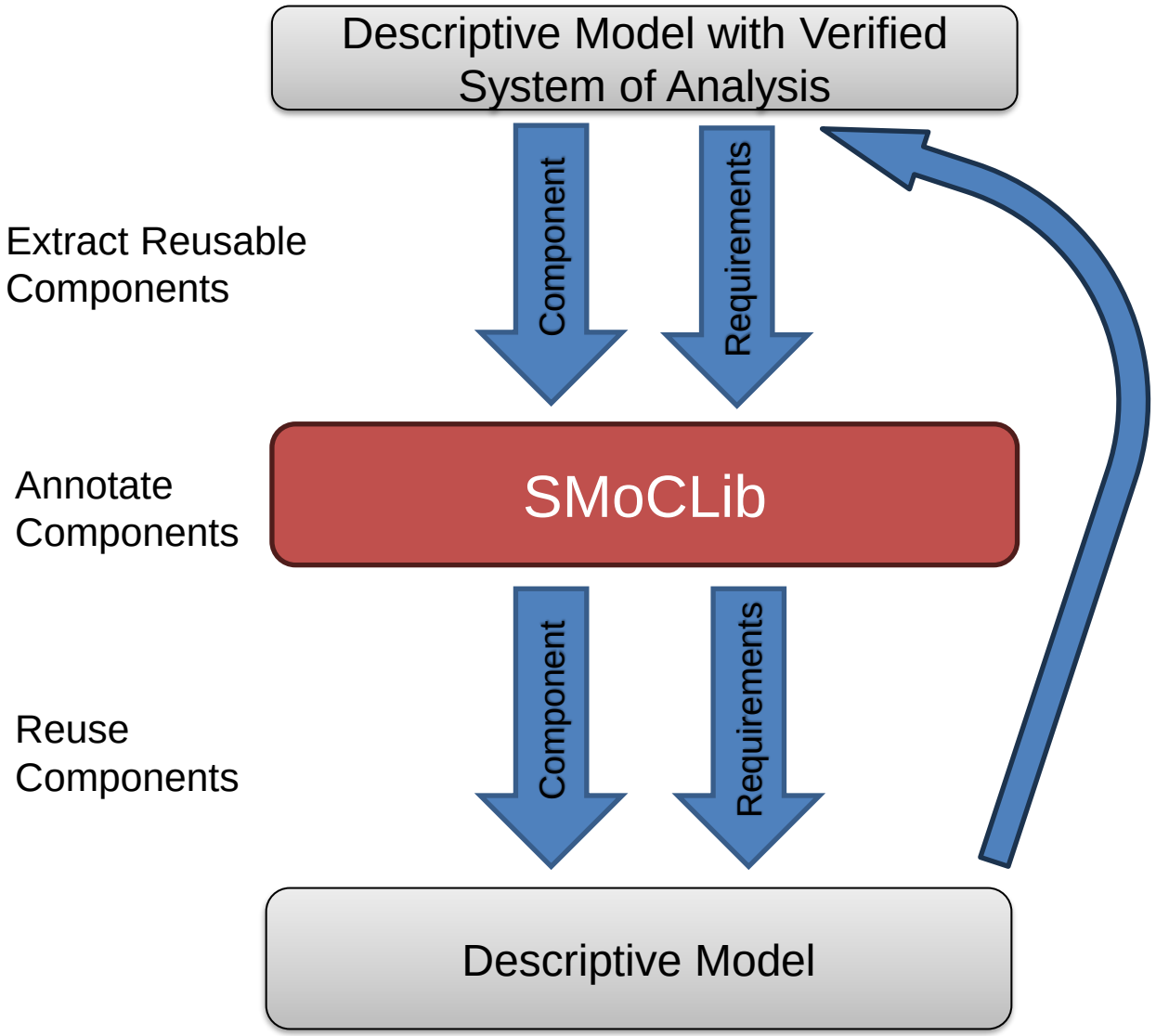
- Full SoA
- Individual Model
- Model Metadata

Semantic Model Component Library (SMoCLib)

- Extends the Digital Engineering Framework for Integration and Interoperability (DEFII)
- Uses the Direct Interface to access component library for model reuse
- Builds on SoA ontology-aligned data that provides structure for strategic reuse
- Attachment to modeling tool via plugin
- Enables approach for “correct-by-construction” approach to SoA development



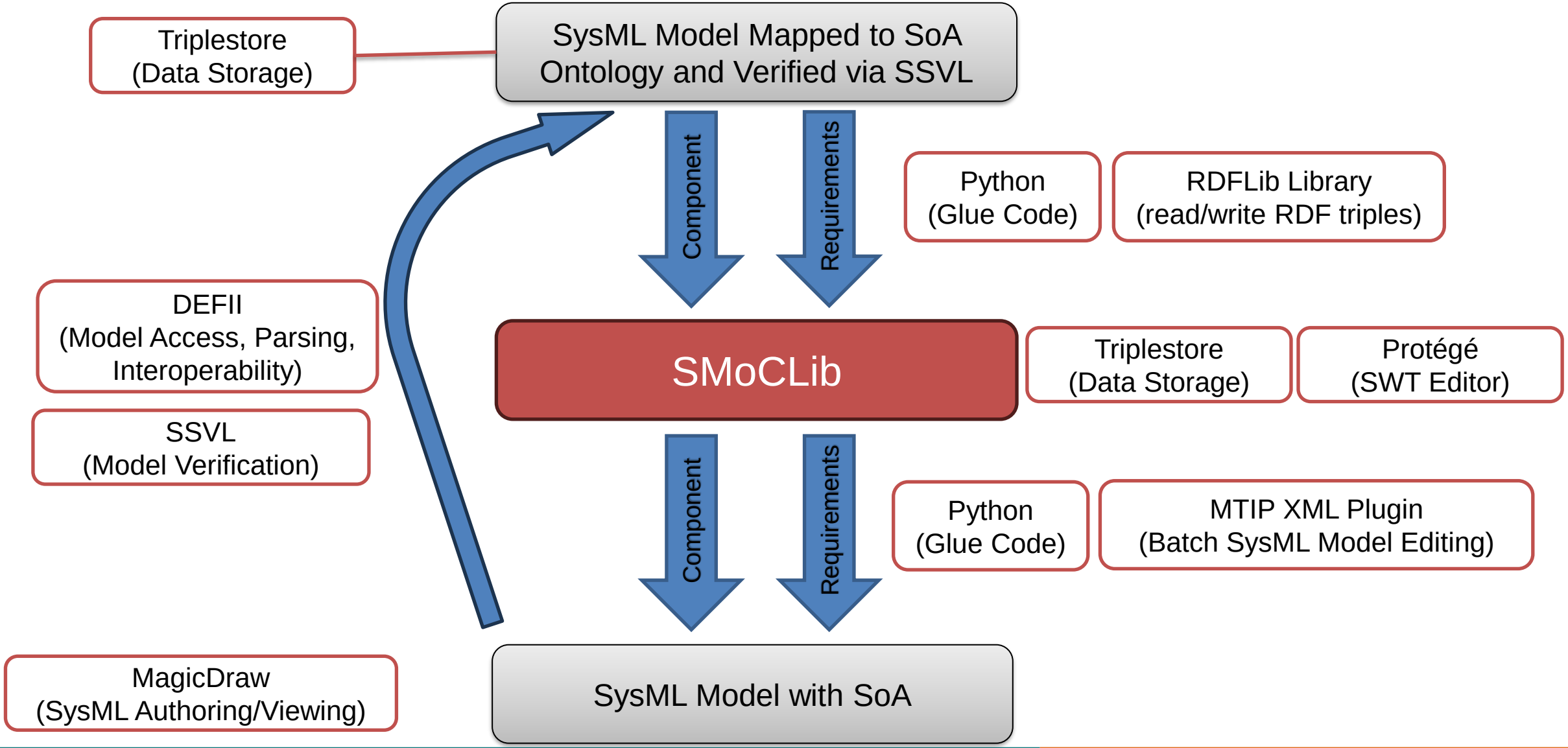
Theoretical SMoCLib Workflow in DEFII



- SoA models can be extracted and stored as ontology-aligned data
- Further annotations can add context to the model for searchability and dynamic model requirement creation
- Models can be imported into a new system model for use

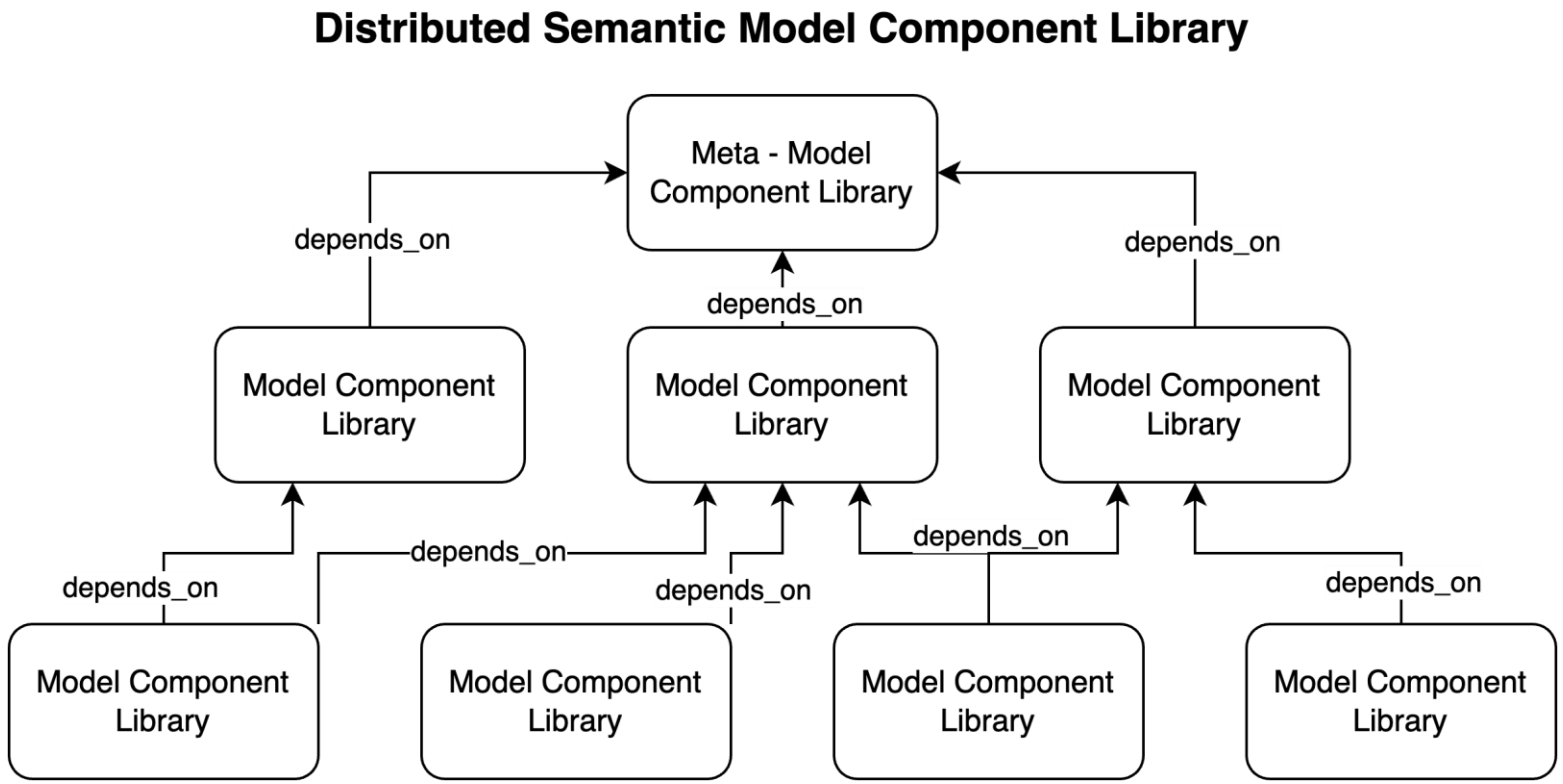
- Authoring is not limited to Descriptive Model – displayed this way to emphasize reuse
- Model is extracted as a full SoA
- Reuse can happen at multiple levels of abstraction

Implemented SMoCLib Workflow in DEFII



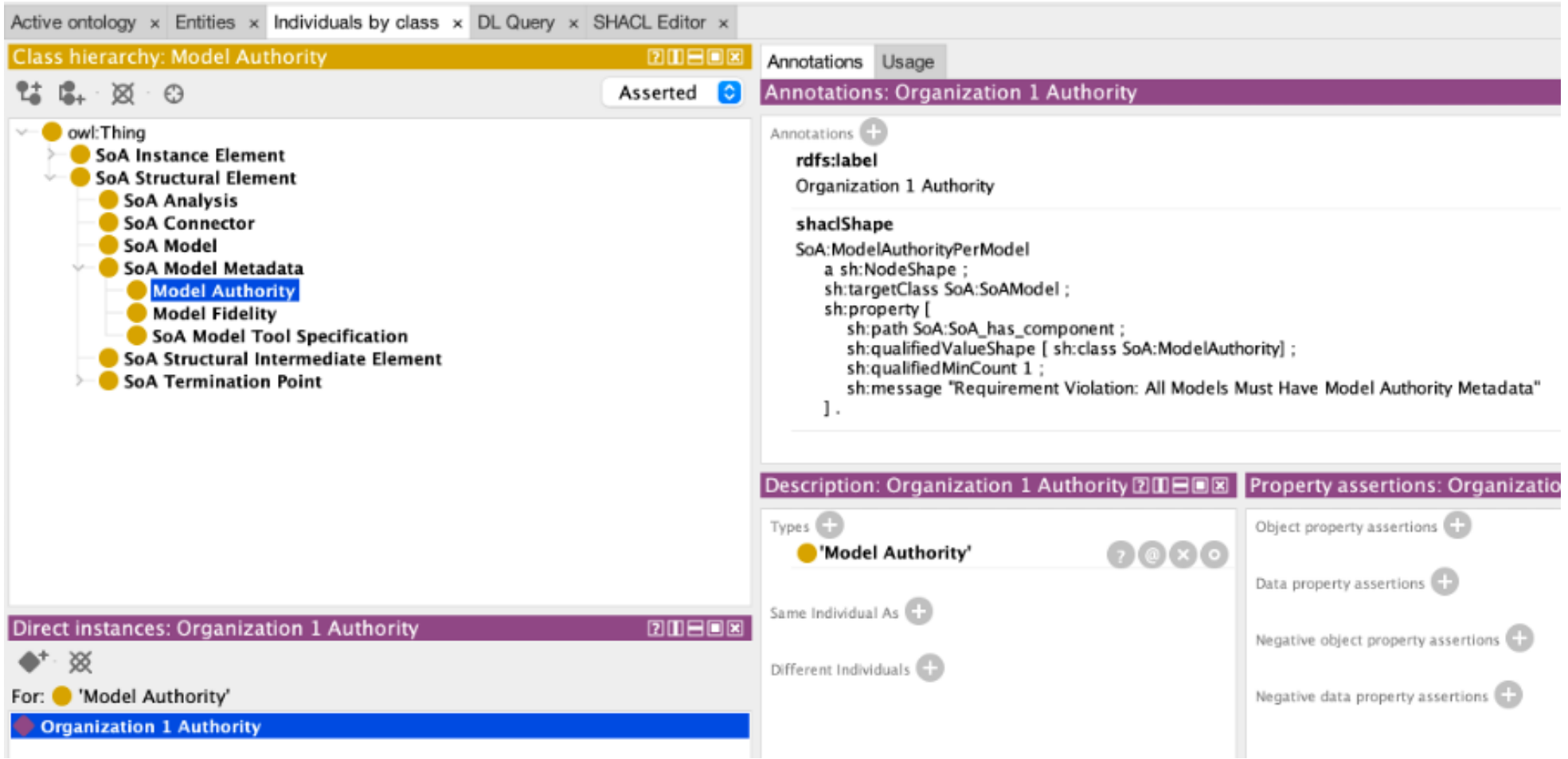
Models Stored in SMoCLib

- Can be distributed - Segment out sensitive materials or into separate repositories
- Extensible – can always add more facts
- Tool Agnostic – Need only add proxy to new authoring tools
- Can be versioned via git (text based)
- Searchable via linked data
  - Graph and logical queries

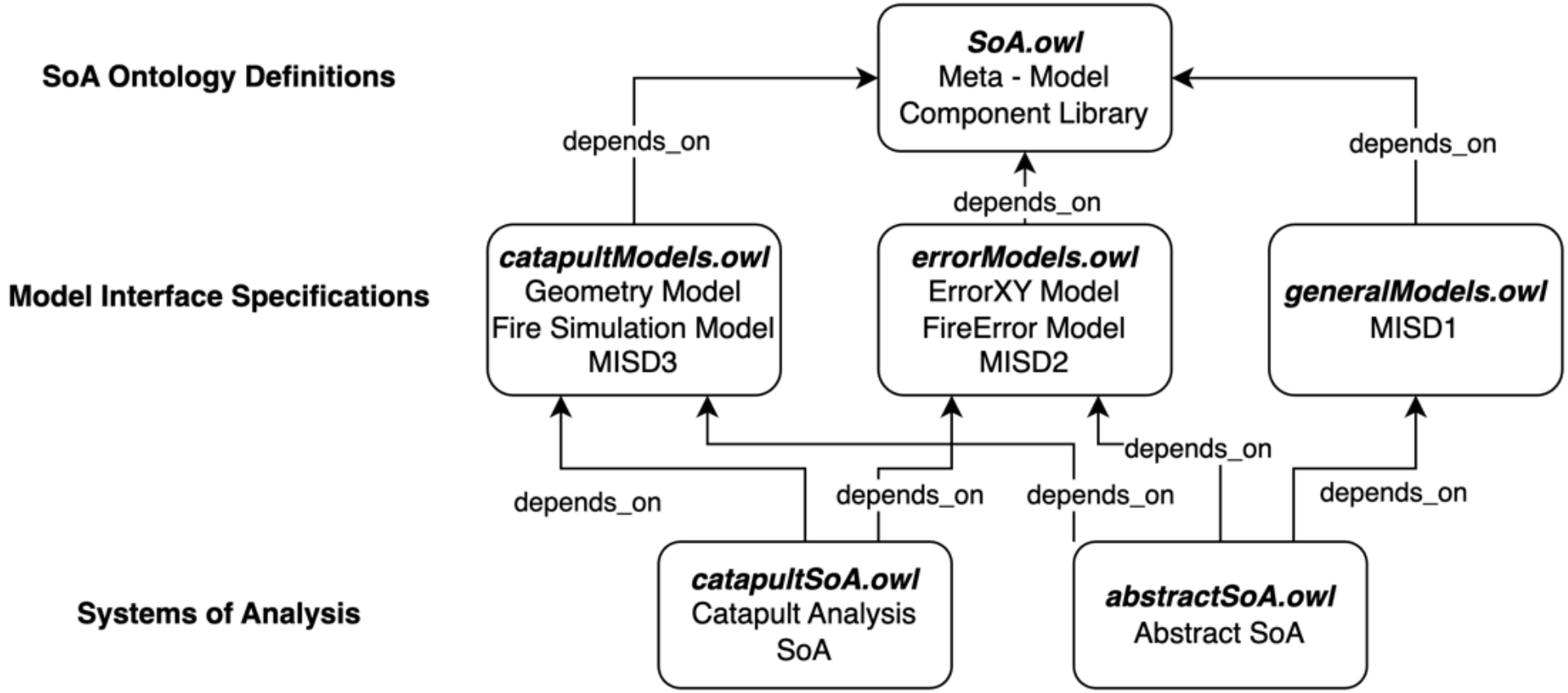


Distribute models in SMocLib and use graph to track dependencies

Ontology View of Components with Tailored Requirement

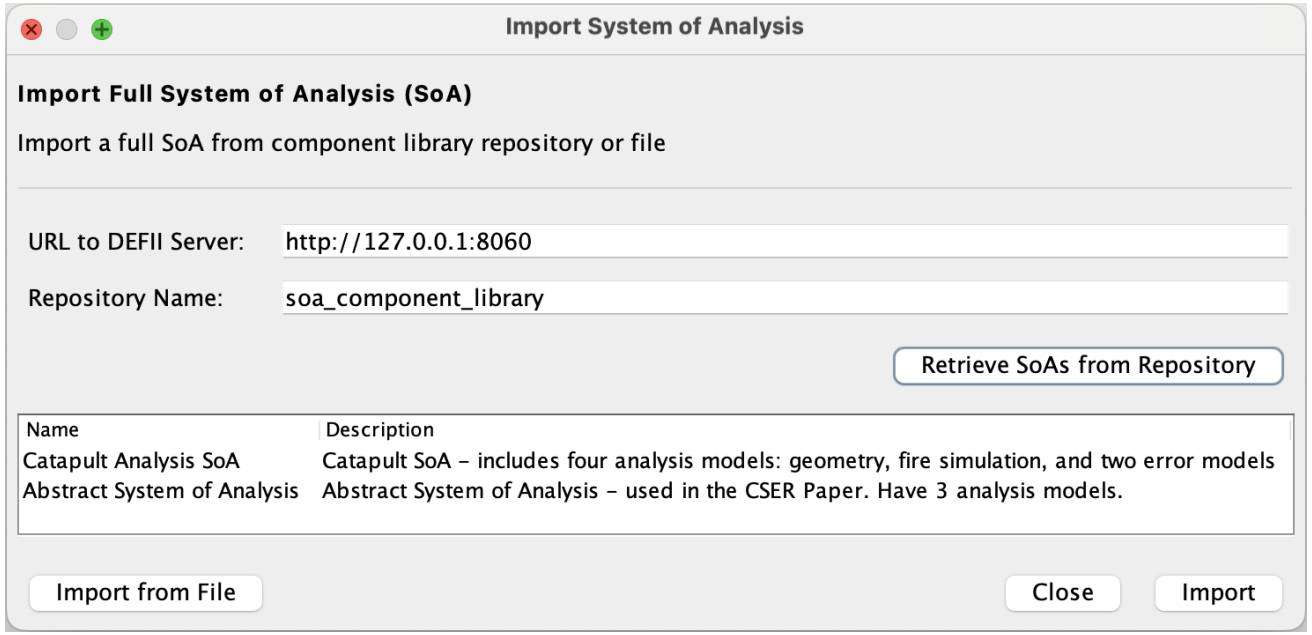


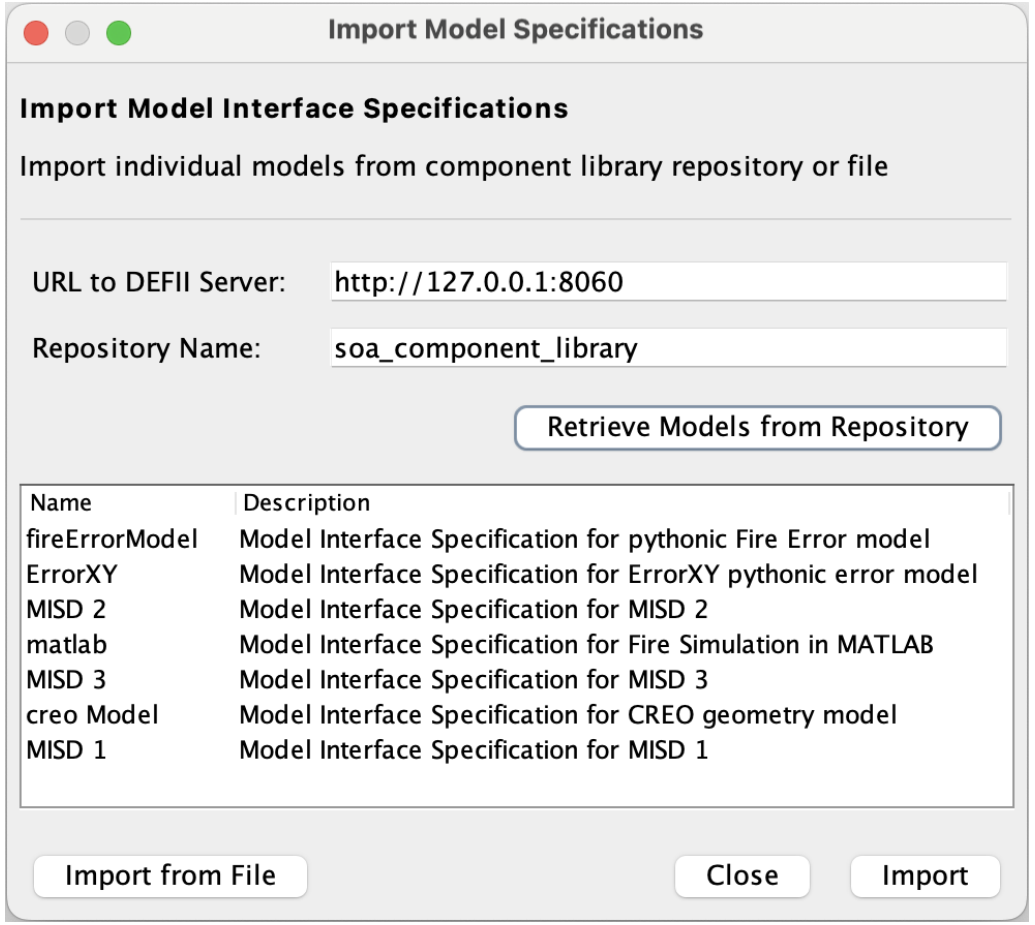
Distributed Component Library for Catapult SoA



SMoCLib – Cameo Plugin

- Automated construction of SoA within a SysML system model
- Correctly stereotypes elements based on implementation of DEFII
- Enables mix/match of different elements from previous analyses





Verification of Method – Import Components

Import full SoA, model metadata, and an additional model interface specification

Dynamically add requirements to global set

Verify seeded defects are detected and remedy model

Order	Type	Details
1	Full SoA Import	Import Catapult SoA
2	Model Metadata Import	Model Authority Metadata
3	Model Interface Specification Import	MISD1 Model Interface Specification

Number	Requirement
1	All Model Interface Specifications shall have Model Authority information
2	Model Fidelity attached to Model Interface Specifications shall be specified as “Low,” “Medium,” or “High”

Scenario Description	Failure	Constraint Violation Messages (via SHACL)
Ill Formed Version of SMoCLib Imported Model	Closed World Constraint	Requirement Violation: All Models Must Have Model Authority Metadata Value does not match pattern '^Low$\|^Medium$|^High$'
SMoCLib Imported Model with Violations Corrected	Pass	None

Conclusion

- Three-Pronged Verification in expanded SSVL gives opportunity for robust analysis
  - Previous use in Well-formedness analysis
  - Can be extended to provide verification functionality to many problem spaces
- SMoCLIB extends SSVL approach by permitting efficient reuse of models
  - Allows association of metadata, rules, etc. for reuse with each model
  - Distributed storage of model data, import into models as needed