Linking UAF and SysML Models:

Achieving Alignment Between Enterprise and System Architectures

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MBSE Seminar
24 March 2023

OMG Object Management Group

Modeling Languages

OMG-Developed Modeling Standards

For modeling complex **Software Architectures** and applications

For modeling complex **System Architectures** that may include hardware, software, personnel, processes and facilities

For modeling complex **Business Processes**

For modeling complex **Enterprise Architectures** that includes strategy, capabilities, operations, programs/projects, services, resources, security, personnel, organizations and standards

Standardized Architecture Views in UAF

Architecture View Types

Stakeholder Viewpoints

UAF	Motivation Mv	Taxonomy Tx	Structure Sr	Connectivity Cn	Processes Pr	States St	Sequences Sq	Information If	Parameters Pm	Constraints Ct	Roadmap Rm	Traceability Tr
Architecture Management Am	Architecture Principles Am-Mv	Architecture Extensions Am-Tx	Architecture Views Am-Sr	Architectural References Am-Cn	Architecture Development Method Am-Pr	-	-	Dictionary Am-If	Architecture Parameters Am-Pm	Architecture Constraints Am-Ct	Architecture Roadmap Am-Rm	Architecture Traceability Am-Tr
Summary & Overview Sm-Ov												
Strategic St	Strategic Motivation St-Mv	Strategic Taxonomy St-Tx	Strategic Structure St-Sr	Strategic Connectivity St-Cn	Strategic Processes St-Pr	Strategic States St-St	-	Strategic Information St-If	Environment En-Pm and Measurements Me-Pm and Risks Rk-Pm	Strategic Constraints St-Ct	Strategic Roadmaps: Deployment, Phasing St-Rm-D, -P	Strategic Traceability St-Tr
Operational Op	Requirements Rq-Mv	Operational Taxonomy Op-Tx	Operational Structure Op-Sr	Operational Connectivity Op-Cn	Operational Processes Op-Pr	Operational States Op-St	Operational Sequences Op-Sq	Operational Information Model Op-If		Operational Constraints Op-Ct	-	Operational Traceability Op-Tr
Services Sv		Services Taxonomy Sv-Tx	Services Structure Sv-Sr	Services Connectivity Sv-Cn	Services Processes Sv-Pr	Services States Sv-St	Services Sequences Sv-Sq			Services Constraints Sv-Ct	Services Roadmap Sv-Rm	Services Traceability Sv-Tr
Personnel Ps		Personnel Taxonomy Ps-Tx	Personnel Structure Ps-Sr	Personnel Connectivity Ps-Cn	Personnel Processes Ps-Pr	Personnel States Ps-St	Personnel Sequences Ps-Sq	Resources Information Model Rs-If		Competence, Drivers, Performance Ps-Ct-C, -D, -P	Availability, Evolution, Forecast PS-Rm-A,-E,-F	Personnel Traceability Ps-Tr
Resources Rs		Resources Taxonomy Rs-Tx	Resources Structure Rs-Sr	Resources Connectivity Rs-Cn	Resources Processes Rs-Pr	Resources States Rs-St	Resources Sequences Rs-Sq			Resources Constraints Rs-Ct	Resources Roadmaps: Evolution, Forecast Rs-Rm-E, -F	Resources Traceability Rs-Tr
Security Sc	Security Controls Sc-Mv	Security Taxonomy Sc-Tx	Security Structure Sc-Sr	Security Connectivity Sc-Cn	Security Processes Sc-Pr	-	-			Security Constraints Sc-Ct	-	Security Traceability Sc-Tr
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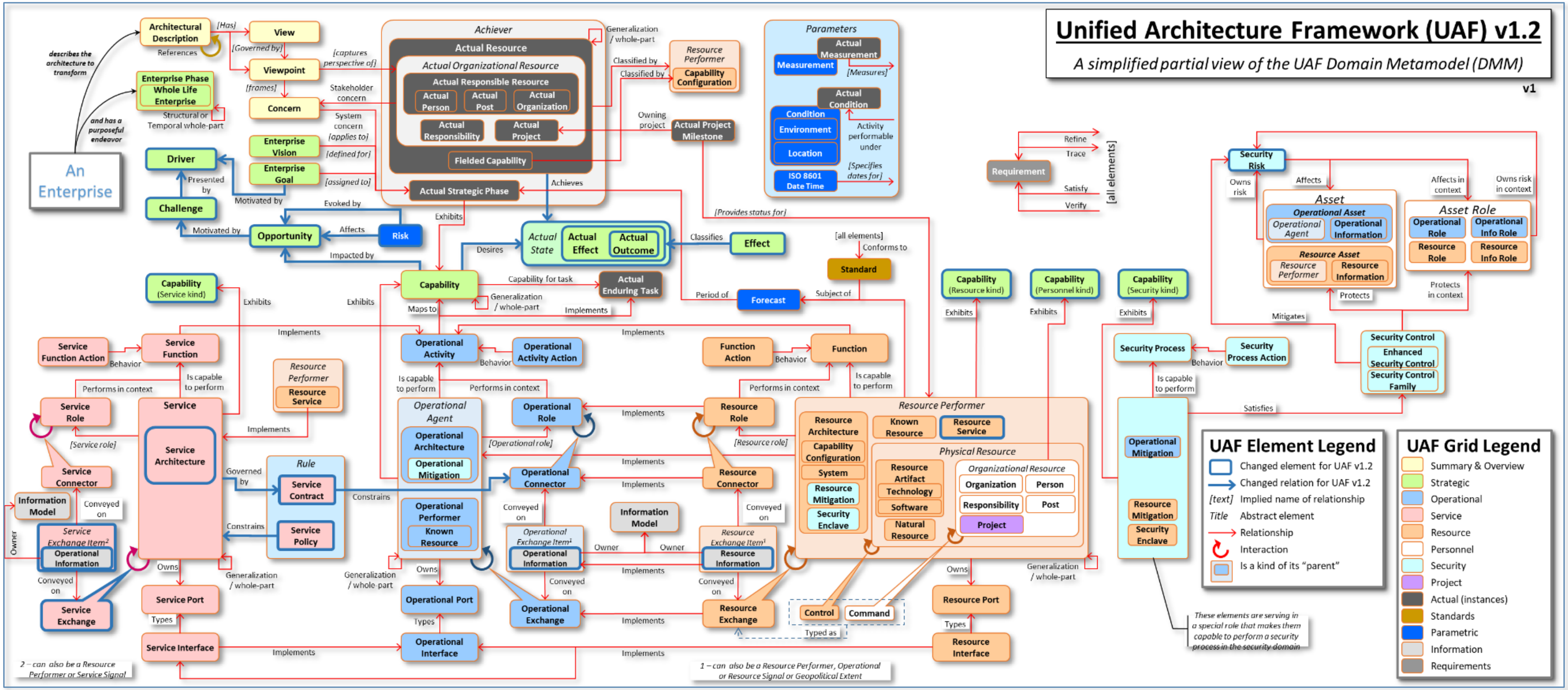
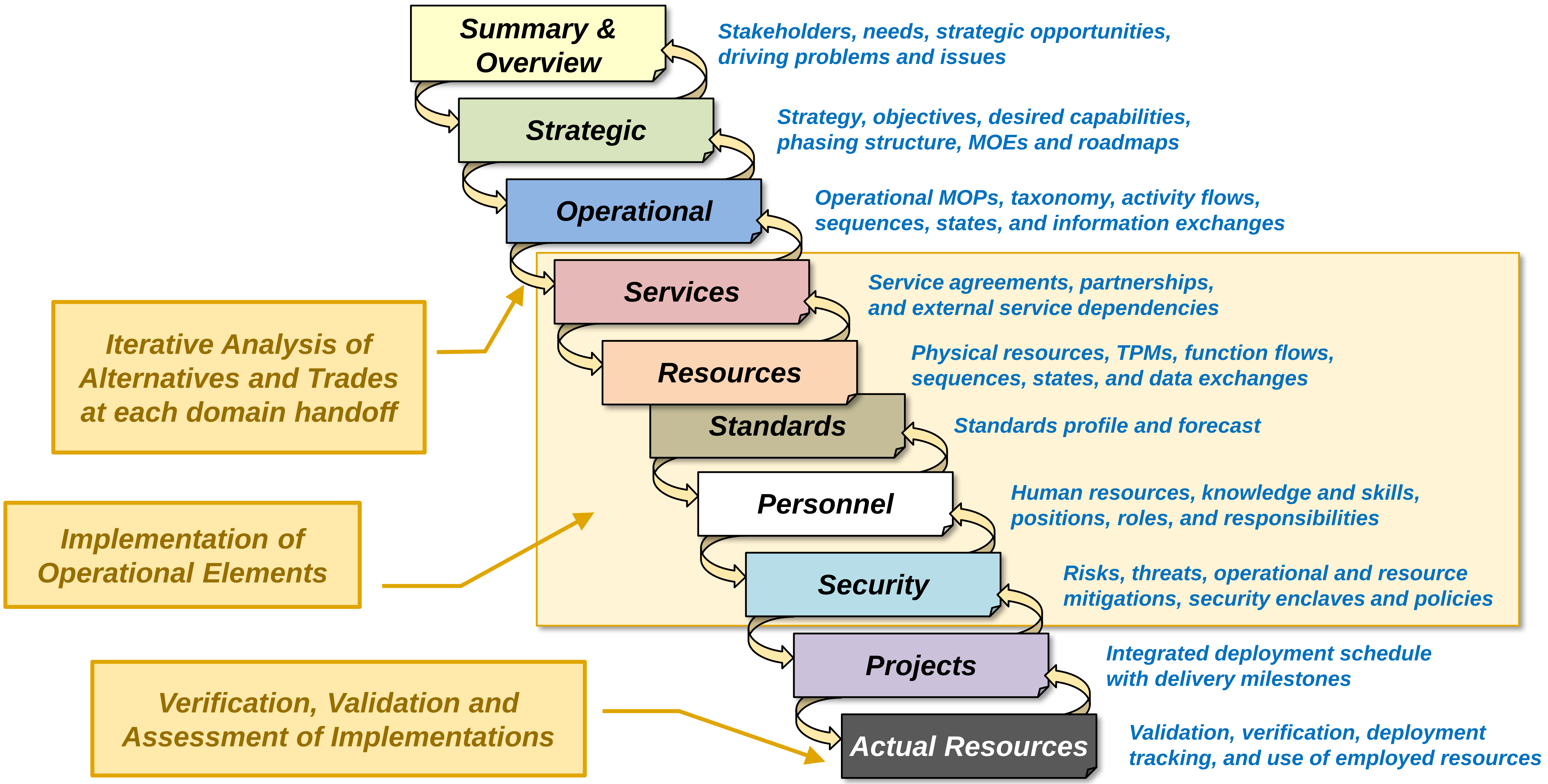
Actual Resources Ar	-	-	Actual Resources Structure, Ar-Sr	Actual Resources Connectivity, Ar-Cn	Simulation			-	-	Parametric Execution/ Evaluation	-	-

UAF Conceptual Schema

(i.e. an Enterprise Ontology!)



The Strategic and Operational Layers at the Enterprise Level should Drive the System Implementation Layers Below



Modeling Languages for Different Levels

Using Modeling Languages to characterize the Problem and Solution Spaces

- **Enterprise Modeling**
  - ***Unified Profile for DODAF & MODAF (UPDM)***
    - High-level modeling language based on UML and SoaML modeling constructs applied to DODAF views
  - ***Unified Architecture Framework (UAF) Modeling Language (UAFML)***
    - Based on SysML, BPMN, SoaML applied to UAF views (including DODAF views)
    - Includes Domain Metamodel (DMM) that fixes various DODAF shortcomings
    - Evolved from UPDM and was originally designated as UPDM v3
- **Systems Modeling**
  - ***Systems Modeling Language (SysML)***
  - ***Architecture & Analysis Design Language (AADL)***
- **Software Modeling**
  - ***Unified Modeling Language (UML)***
  - *Various extensions to UML*
    - MARTE profile for real-time and embedded systems
    - And other UML profiles for XSD schema definition, web modeling, business process modeling, open distributed processing, etc

Modeling Languages are key enablers for Digital Engineering and for Architecture and other SE practices

Benefits of Traceability Between SA Models and the EA Model

- ✓ Traceability **from SA to its EA context** within which the system will be operated that helps define the motivation for the system's features and functions and ensures better system support for mission execution
- ✓ Traceability improves **accountability to stakeholders** and also helps validate other features that are unrelated to any particular stakeholder needs
- ✓ Enable **more comprehensive and accurate change impact analysis** via traceability between the EA and SA when changes inevitably occur
- ✓ Support **navigation of relationships between System Architecture and EA** for a better understanding of the two models with respect to each other
- ✓ Utilize design information created in the EA as an initial set of **enterprise-wide features and properties informing the System Architecture**
- ✓ **Re-use of model elements** created in EA to seed the System Architecture

Flowing Down from the Enterprise to Systems

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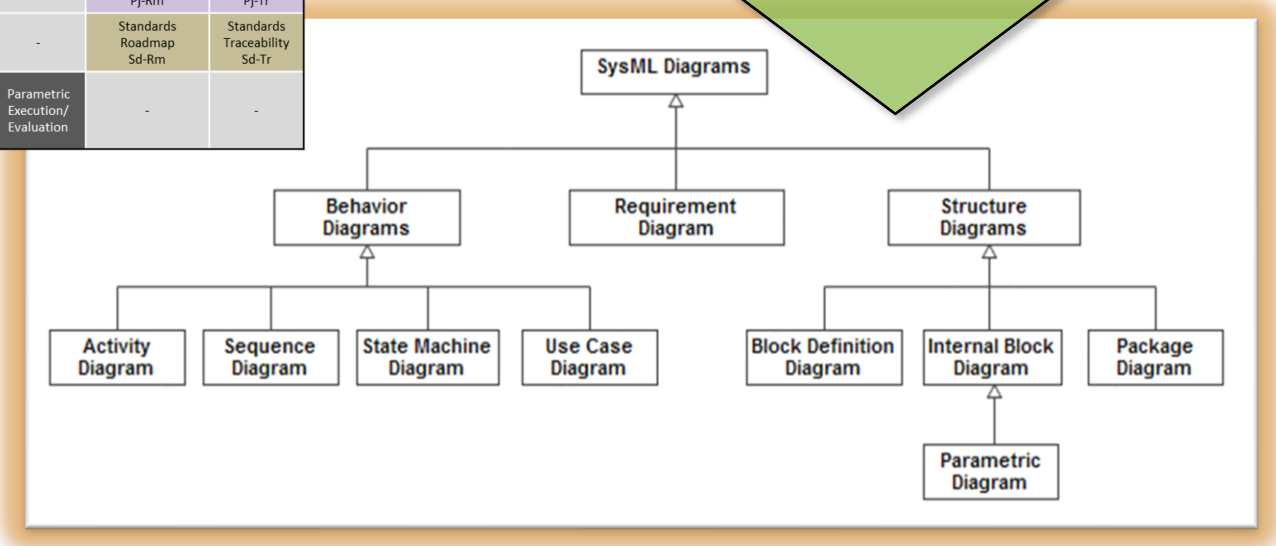


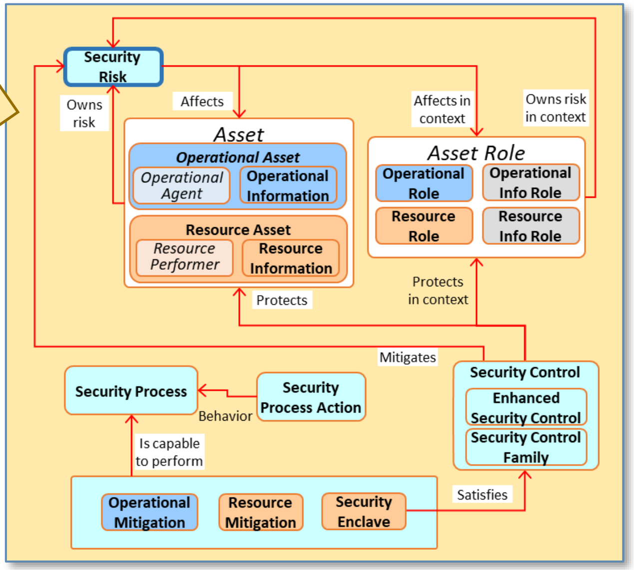
Why Not Just Use SysML?

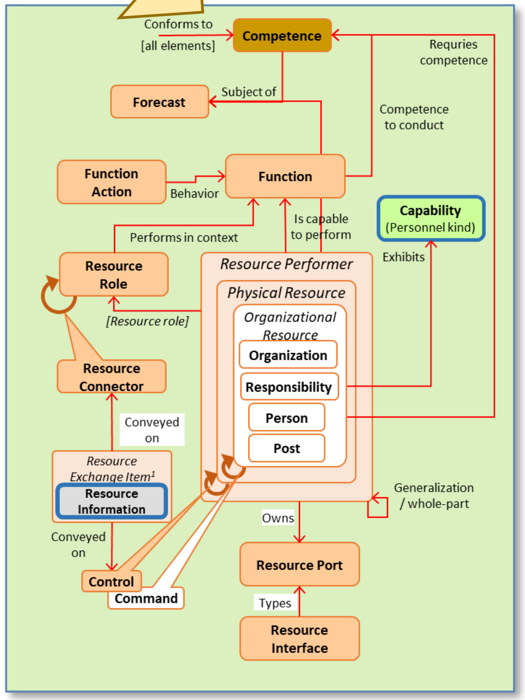
- **SysML is great for:**
  - *Modeling Systems and for doing Systems Engineering*
  - *Defining and tracing between levels of abstraction within a System*
  - *Defining the **RFLP** for a System – Requirements, Functions, Logic & Physical aspects*
- **The UAF Modeling Language (UAFML) provides all this, plus more:**
  - ***Capability and Enterprise concepts:** more comprehensive definition of the "why" and "what" before the "how" (such as enterprise drivers, capabilities, goals, effects, outcomes)*
  - ***Services :** definition of Enterprise services (both producing and consuming) and traceability to capabilities, operations, and implementing resources*
  - ***Personnel:** How People and Systems interact, and their requisite knowledge & skills*
  - ***Security:** Identifying risks and mitigations, and integrating security into the Architecture*
  - ***Standards:** definition of and compliance with standards in the Architecture*
  - ***Project Deliveries:** phased milestone approach to Capability deployment*
  - ***System Configurations over time:** deployment timelines and changes*
  - ***Requirements for the Total Solution:** Allowances for linking Requirements to non-system Solution Elements and to overarching Enterprise, Mission and Business elements*
  - ***Built-in Traceability between views** – Between layers of abstraction & across layers*
  - ***Automatic Generation of DODAF and Other Standard Views –** DODAF-compliant views (which would otherwise require custom extensions in SysML)*

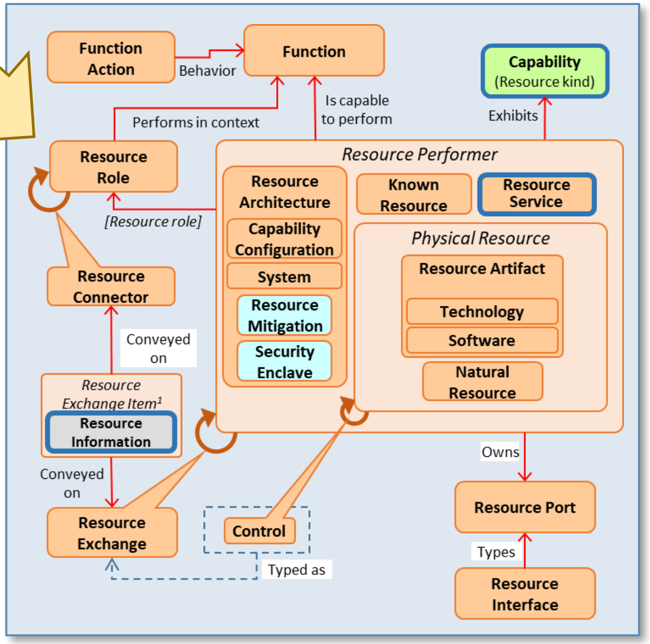
UAF Provides Additional Features Beyond DODAF…

New viewpoints to address other important stakeholders and their concerns

- **Security Views:** rules and constraints, enclaves and levels, threat analysis, security weaknesses and strongpoints
- **Personnel Views:** roles and responsibilities, knowledge and skills, organizational constructs, role dependencies
- **Resources Views:** kinds of resources (including Systems) that can implement functions and activities, interactions and dependencies, mapping to requirements





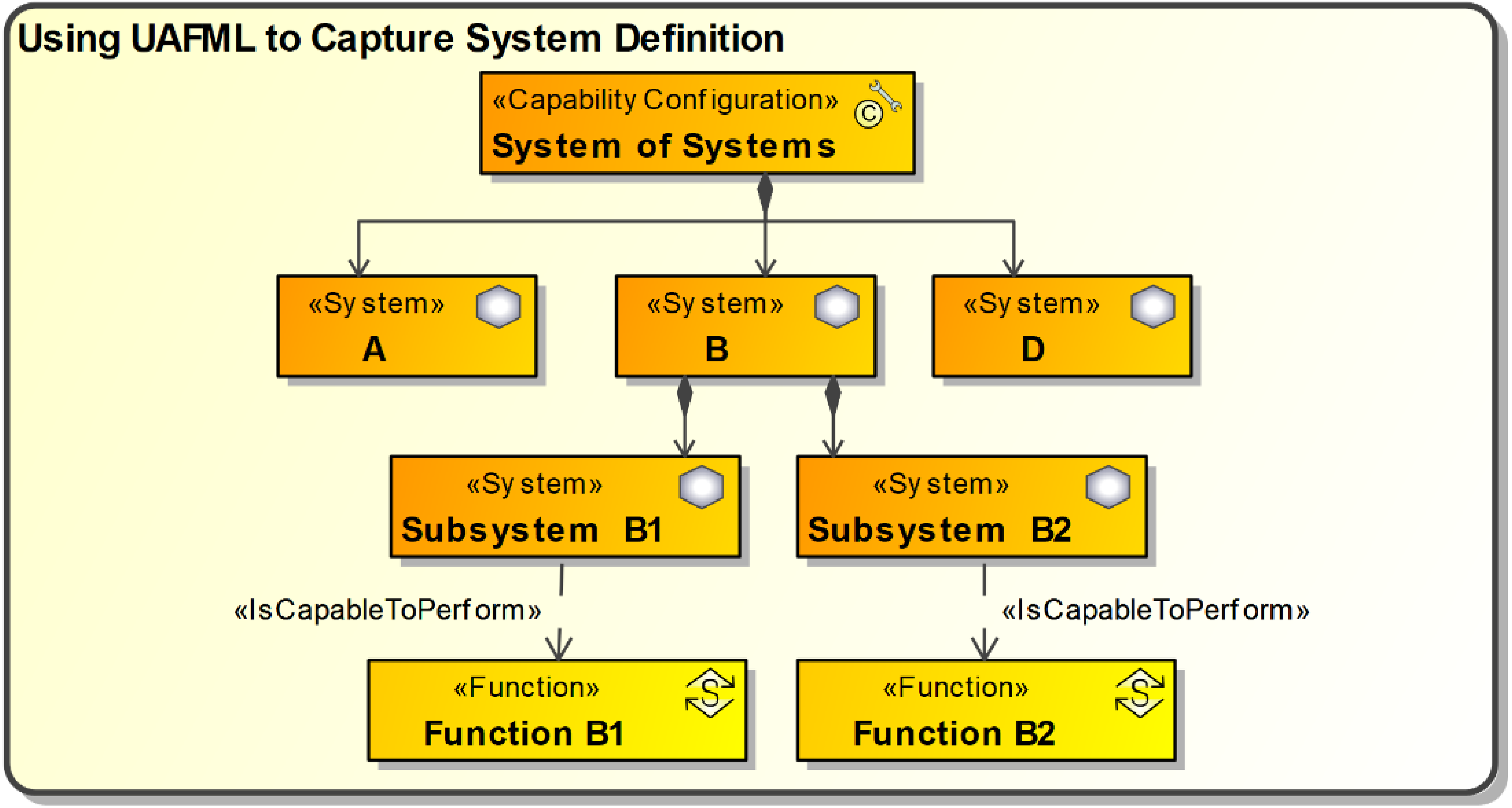


Four Methods Examined and Compared

Methods chosen since they are the most commonly used basic approaches

1. Enterprise model encapsulates the system definition
2. Specialization of EA by SA and redefinition
3. Allocation from EA to SA
4. Requirements traceability between enterprise and system elements

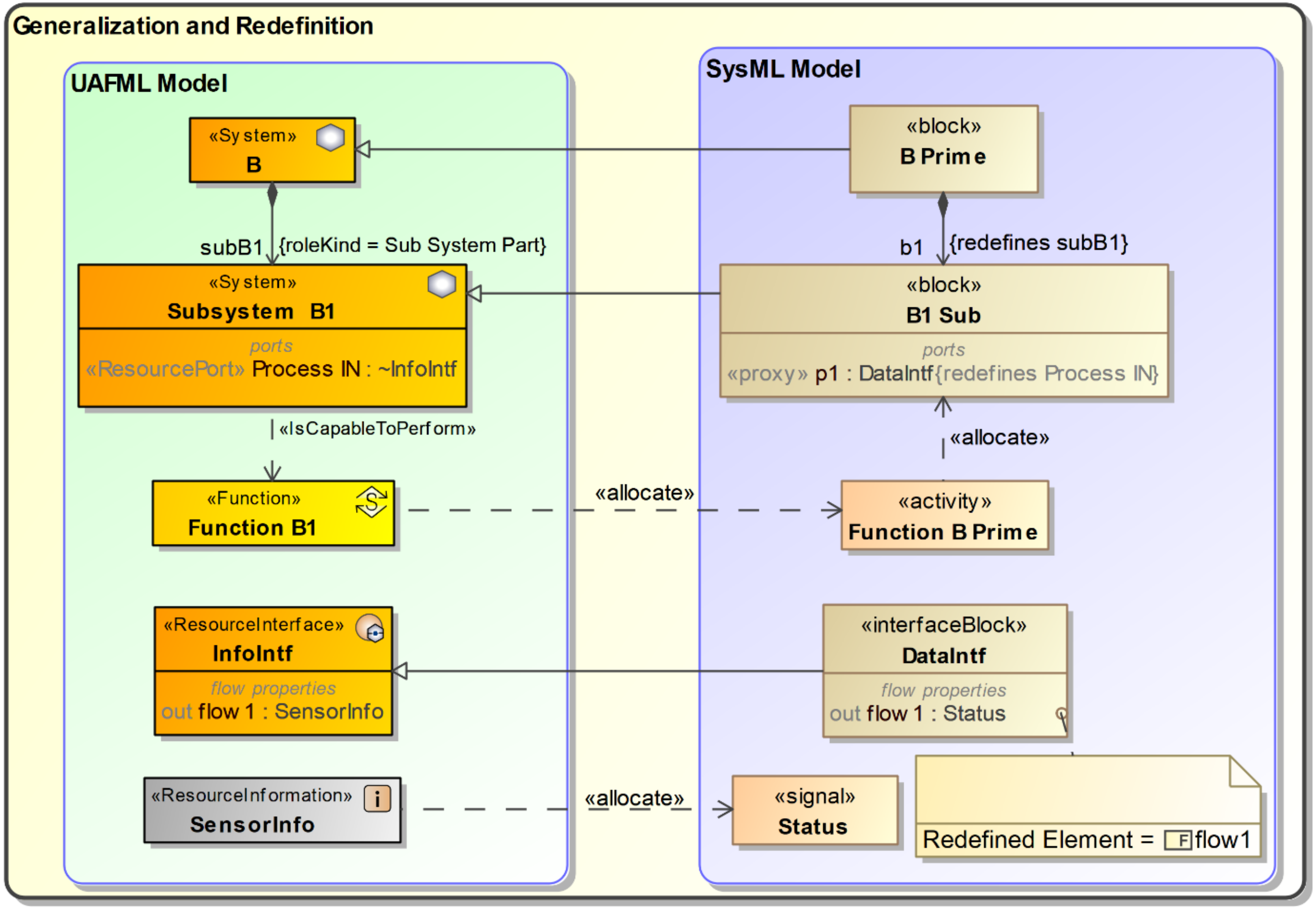
Solution 1 – Enterprise Model Encapsulates the System Definition



Solution 1 – Enterprise Model Encapsulates the System Definition

Advantages	Disadvantages
✓ **No separate SysML model to create and map, thereby reducing the amount of modeling work that would have entailed** ✓ **Less duplication of data** ✓ **Very reasonable solution for COTS solutions that do not require detailed designs**	× This approach is not applicable when a complex SA model is required (eg, for detailed analysis of the systems without customizations or for complicated integrations that need to occur) × System Architects and Systems Engineers need to understand how to use UAFML concepts × A challenge when two or more organizations with differing processes, scheduling, and intellectual property concerns are working within the same model × The system’s internal details, such as subsystems, components, etc, must be exposed and captured in EA. The EA must be updated each time the system internal subsystems, and component changes

Solution 2 – Specialization of EA by SA and Redefinition



Solution 2 – Specialization of EA by SA and Redefinition

Mapping from UAF to SysML Models When Using this Approach

Name	Element	Direction	Element
Allocate			
	C Prime [SysML Design]	←- - - - -	Function B Prime [SysML Design]
Inherited Is Capable To Perform			
	C [Systems Viewpoint::SV-1]	- - - - -→	Function B [Systems Viewpoint::SV-4]
Inherited Resource Association			
	C [Systems Viewpoint::SV-1]	←——◆	B [Systems Viewpoint::SV-1]
Association			
	C Prime [SysML Design]	←——◆	B Prime [SysML Design]
Generalization			
	C Prime [SysML Design]	——→	C [Systems Viewpoint::SV-1]

Solution 2 – Specialization of EA by SA and Redefinition

Advantages	Disadvantages
✓ **Reduces rework of SA definition when base elements in UAF are identically described in SysML (eg, inherited structures, properties, etc)** ✓ **Many elements in a UAF model can be redefined in the SysML model to align to the necessary types used and fidelity of the SA model** ✓ **Traceability of structural elements of EA to structural elements of SysML is readily done** ✓ **Mapped EA elements cannot change without impact to the SA model** ✓ **If the EA model can be simulated, then the SA model will also be so, with reduced effort and similar results**	× Redefinition of UAFML elements is required which has several issues × The EA and SA model elements are tightly coupled × The EA model must be loaded for the inherited context for most kinds of analysis to occur × Pre-existing SysML models can be used, but this adds complexity × Possible performance issues caused by EA model needing to be available for simulation and analysis (further complicated in federated models) × Generalization is limited to structure, necessitating other methods to map behavior like allocation (see example below) × Can lead to a solution forced into a tightly coupled designs rather than loosely coupled components

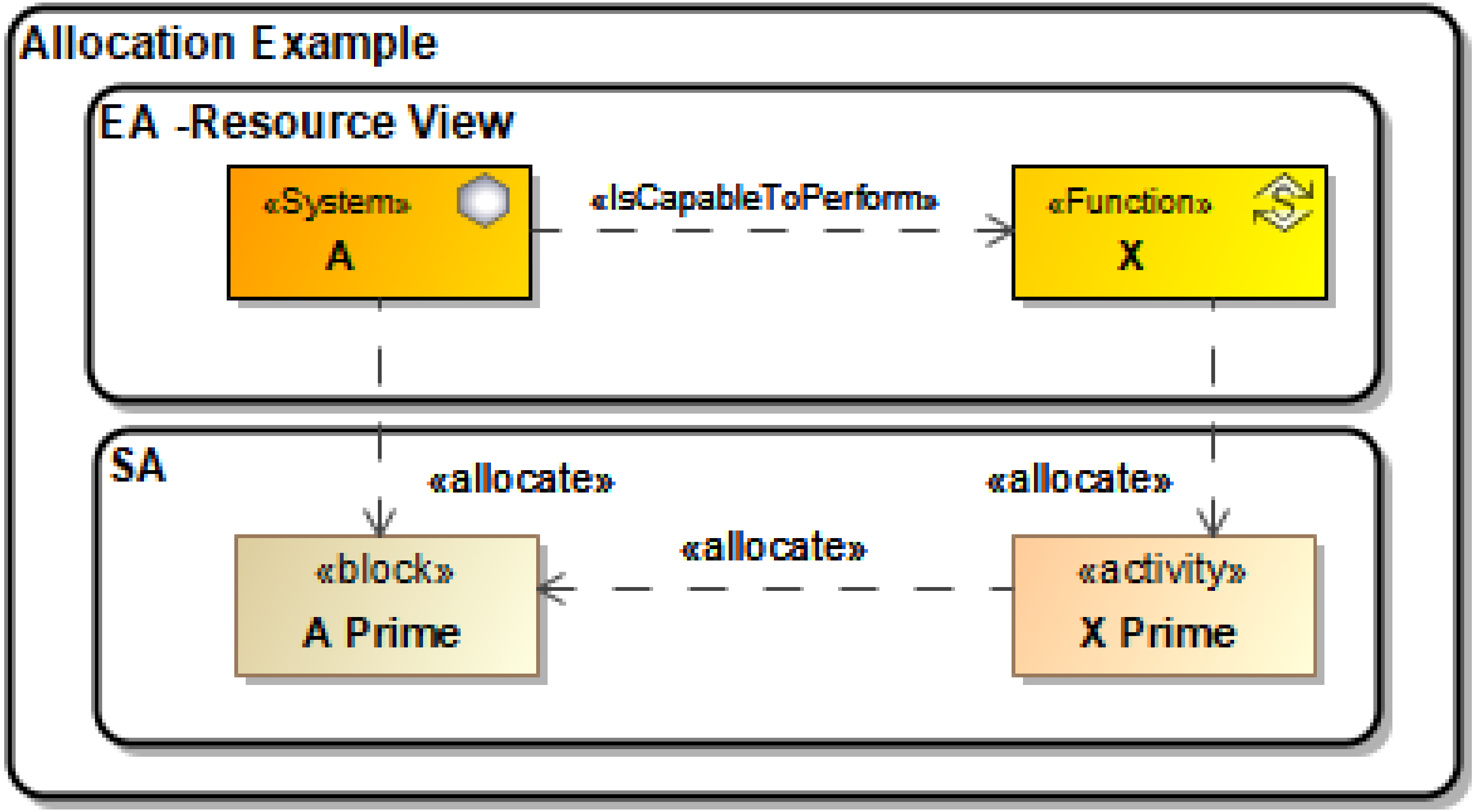
Solution 2 – Specialization of EA by SA and Redefinition

Disadvantages *(More Details…)*

- × **Redefinition of UAFML elements is required which has several issues**
  - – Generalization and redefinition approach adds complexity
  - – Inheritance of Activities and State Machines are not well supported by tools for redefinition (e.g., when needed to add specificity and granularity at the system level)
  - – There is no support for the deletion of inherited properties that are not used
  - – Excess dependency relationships to the SA model like IsCapableToPerform are inherited and cannot be redefined or deleted from the SysML model
- × **The EA and SA model elements are tightly coupled**
- × **The EA model must be loaded for the inherited context for most kinds of analysis to occur (cannot dynamically load the referenced EA model) but the scope of the data is likely much more than required for most SA analyses or usage**
- × **Pre-existing SysML models can be used, but this adds complexity**
  - – Multiple-inheritance and redefinition of both EA and existing SysML models
  - – Complex reporting to distinguish mapping to EA versus pre-existing SysML
  - – Change management complicated by dependent libraries, generalizations, and redefinitions
- × **Etcetera…**

Solution 3 – Allocation from EA to SA

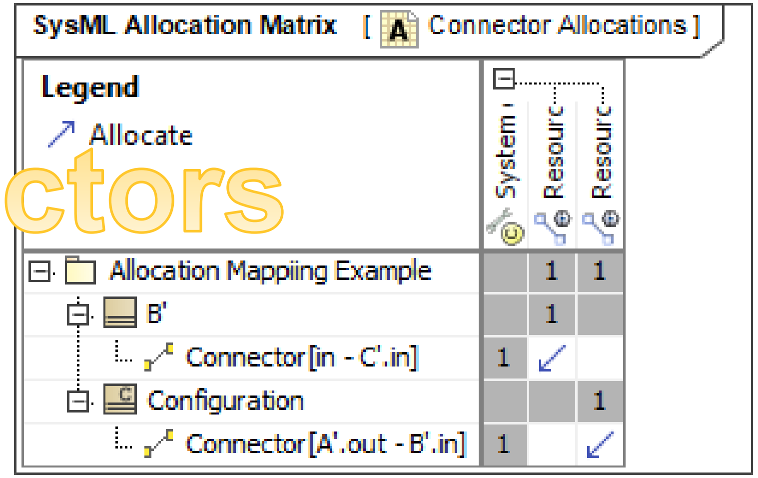
Using the Allocate Relationship from UAF to SysML Models



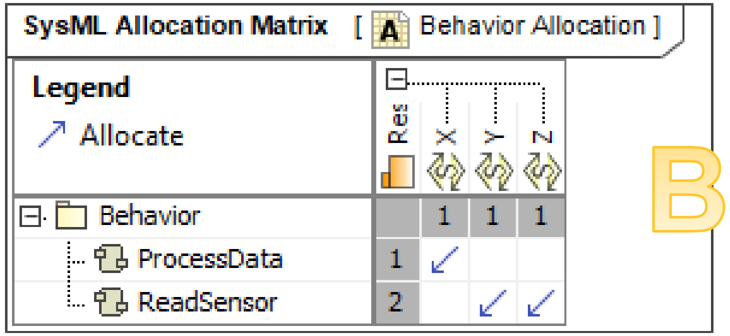
Solution 3 – Allocation from EA to SA

Allocation Matrices of Paired Modeling Concepts

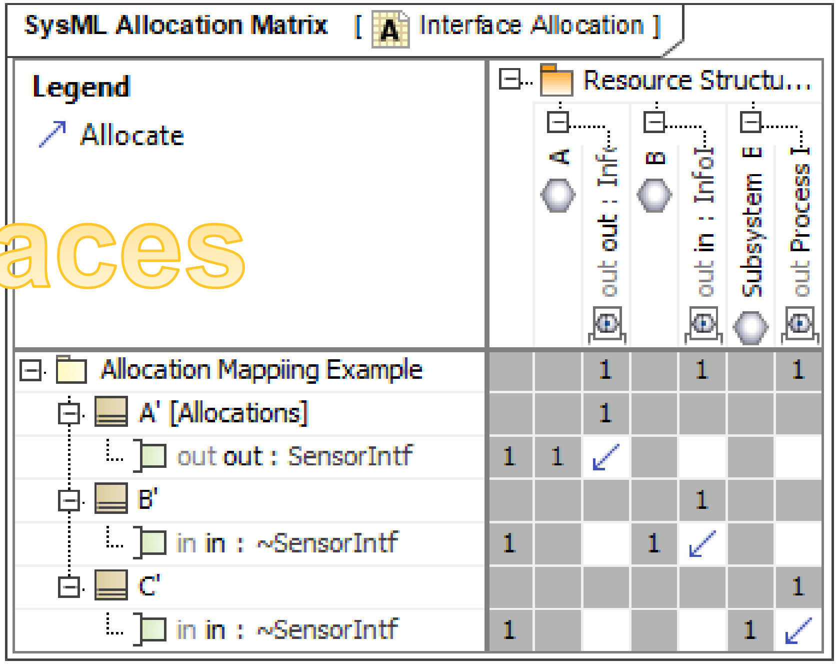
Connectors



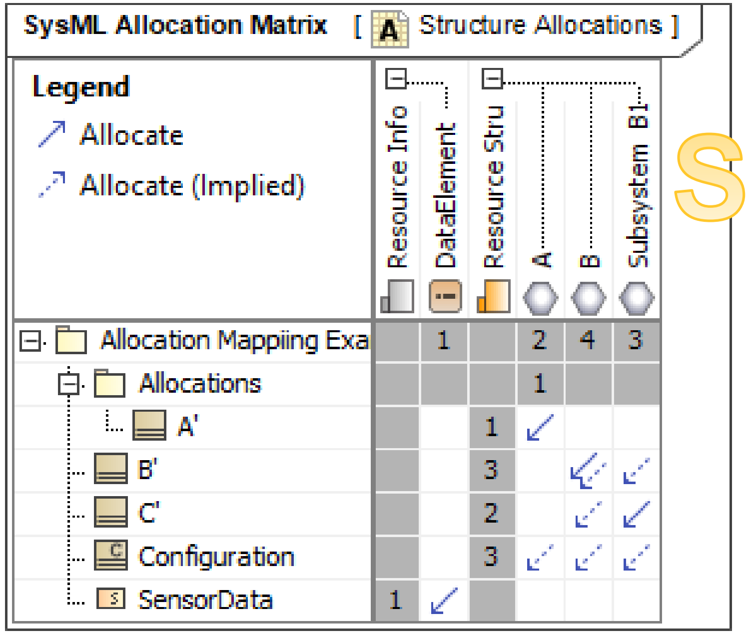
Behavior



Interfaces



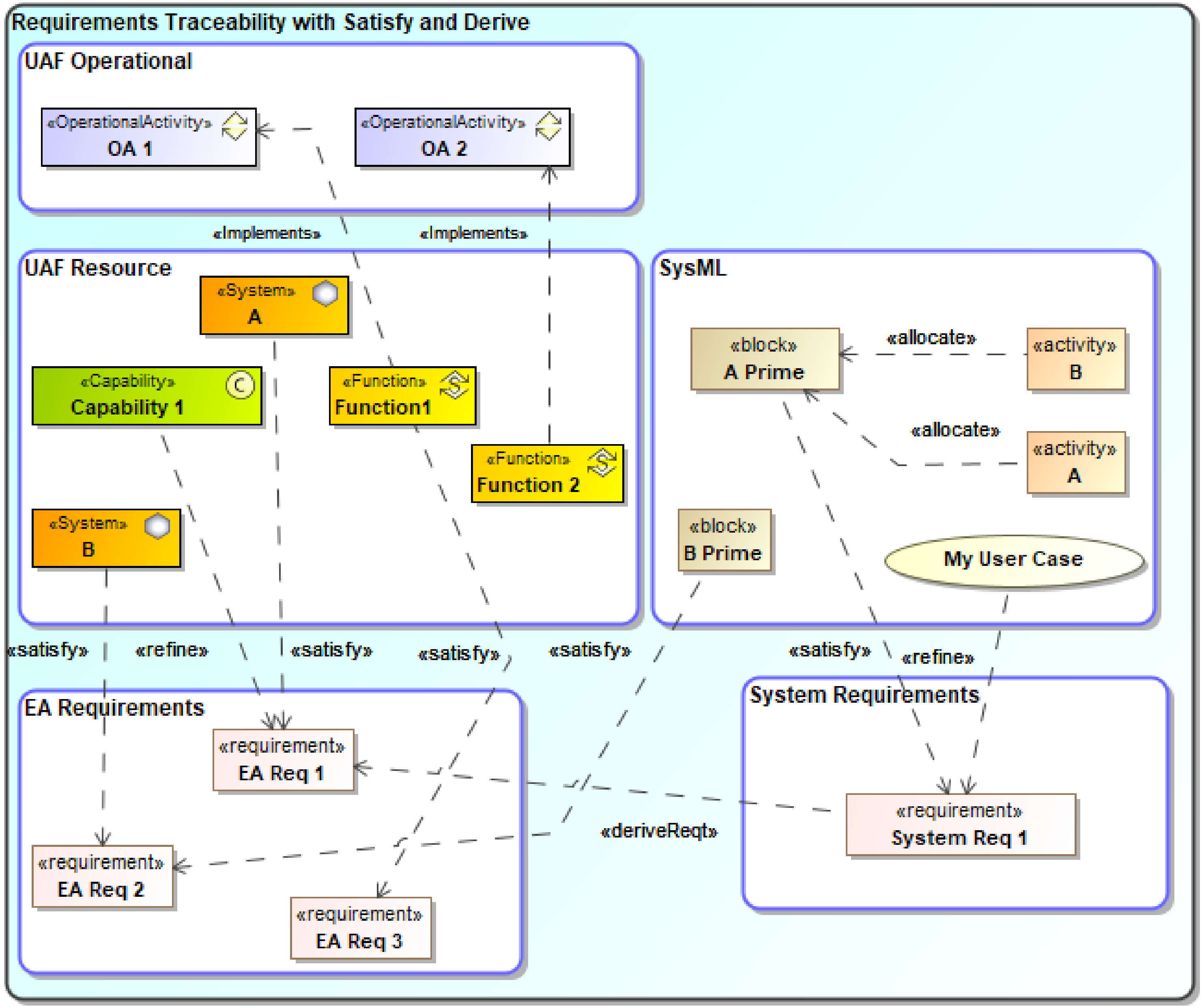
Structure



Solution 3 – Allocation from EA to SA

Advantages	Disadvantages
✓ **Models are loosely coupled, minimizing the impact of downstream changes to the integrity of the SA model** ✓ **Elements in EA and SA models are normally modeled at different levels of detail and specificity, so mapping can be better than reuse** ✓ **EA model does not need to be loaded into the execution context for many types of analysis and model execution** ✓ **Some mappings can be derived from context** ✓ **Compatible with elements in existing libraries and federated models** ✓ **Reuse can use common libraries without resulting in tight coupling**	× Allocation is very generic and subject to inappropriately mapped elements ○ However, it is usually overcome with the use of simple patterns and constraints… ○ And by explicitly defining the semantics of the assertion (ie, the assignment of responsibility) that the model is intended to capture × No re-use of the EA model elements or simulation × Changes in EA are not automatically propagated so manual change is required (similar to requirement impact, but also includes the EA's SOI changes)

Solution 4 – Reqts Traceability Between Enterprise & System Elements



Solution 4 – Rqts Traceability Between Enterprise & System Elements

Mapping from SysML Elements to UAF Elements

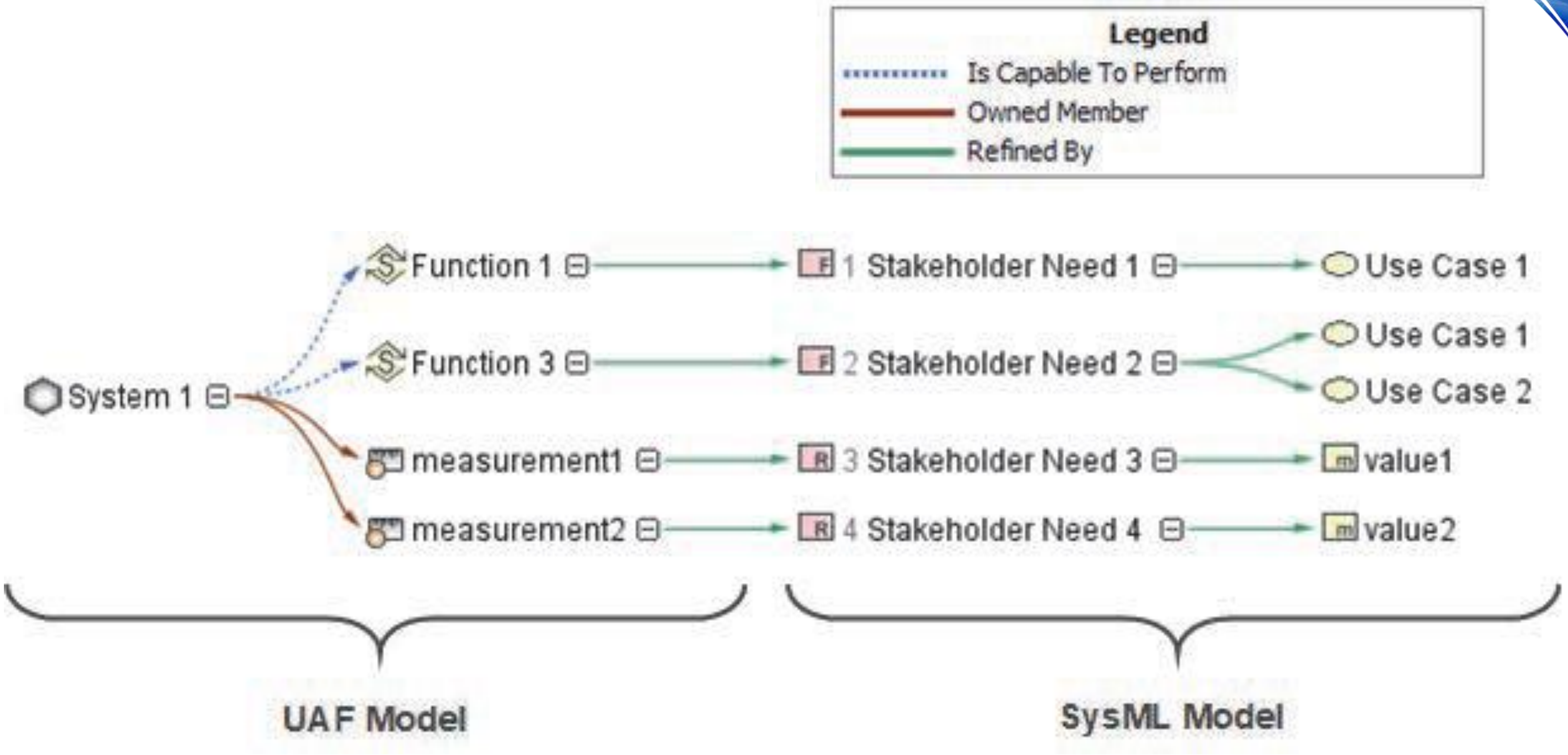
#	Name	Refining Use Case	Satisfies	Requirements Derived in SV	Derived Satisfied By In UAF	UAF Satisfied By	Exhibits Capability
1	B Prime		4 EA Req 2			B	Capability 1 Capability 2
2	A Prime	My User Case	3 System Requirement	2 EA Req 1	A		Capability 1

Solution 4 – Rqts Traceability Between Enterprise & System Elements

Advantages	Disadvantages
✓ Mapping is enriched by requirements and the associated relationships ✓ Mapping to related elements can be easily navigated manually or by query ✓ Isolation and low-coupling of models (which is improved when limiting this to Refine, Copy, and Derive) ✓ Coupling is only in one direction and can be owned by the SA model (allows for dynamic loading of EA model only when mapping is navigated for analysis)	× Need to have sufficiently developed requirements × Mapping directly to a requirement is not always possible, so additional mapping is likely needed (such as the Allocation approach) × Navigating the mapping is more complex × No re-use of the EA model elements or simulation × Changes in EA are not automatically propagated so manual change is required (similar to the requirements impact, but also includes the EA's system of interest changes)

The SysML MagicGrid Process

Combination of Methods 2, 3 and 4



Comparison of Approaches

Scoring Criteria Used to Assess Alternative Solutions

Criteria	Description
Coverage	***Does the method provide a good mapping between EA and SA?*** **High** involves maximum coverage, while **Low** would entail minimal coverage
Simplicity	***How easy can modelers and stakeholders create and understand traceability?*** **High** is simple to do traceability, while **Low** is complex and relies on good understanding of complex modeling details
Maintain-ability	***When changes are made to EA model, how easy is it to establish and maintain correct traceability in SA model?*** **High** involves simple maintenance (e.g., suspect links), while **Low** requires rework of system model and redo of tests and analysis
Isolation	***Do changes in EA cause downstream structural or behavioral changes?*** Good isolation would mitigate issues caused by automatic effects that require one to do testing and debugging (if they are even detected). **High** is no impact, while **Low** would entail large impact

Comparison of Approaches

Scoring Results

Criteria	Solution 1	Solution 2	Solution 3	Solution 4
Coverage	High	High	Medium	High
Simplicity	Medium	Low	High	Medium
Maintainability	Low	Medium	High	High
Isolation	Low	Low	High	High
Scores →	7	7	11	11

Obviously, there is no clear winner. After considering the consequences of your choice, capture the approach in your modeling methodology and ensure those modeling rules are consistently applied

Conclusions

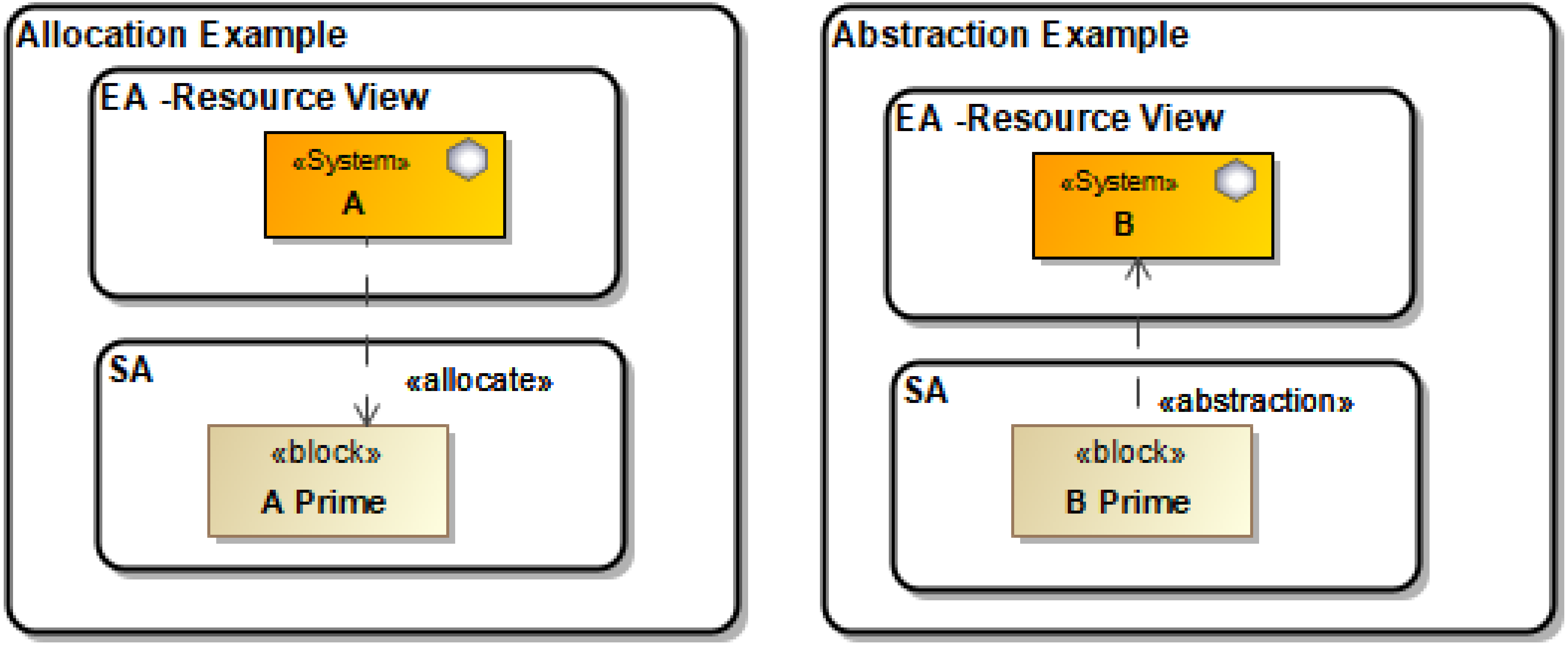
- **Systems will usually be modeled using SysML**
  - *However, UAFML needs to also be used to address the complete context of the Enterprise that influences what the Systems must do to satisfy enterprise objectives*
  - *As a result, this strategy requires a good way to link from your System models to the Enterprise model to ensure alignment is properly established and maintained*

- **Four basic ways examined for linking Enterprise and System models**
  - *There is no obvious winner for all situations, each one involves trade-offs*
  - *Careful consideration must be given to the pros and cons of each approach*
  - *All approaches need proper model management to be successfully applied*

This investigation is a preliminary look at the issues involved for modeling in an Enterprise context using UAF

Solution 3 – Allocation from EA to SA

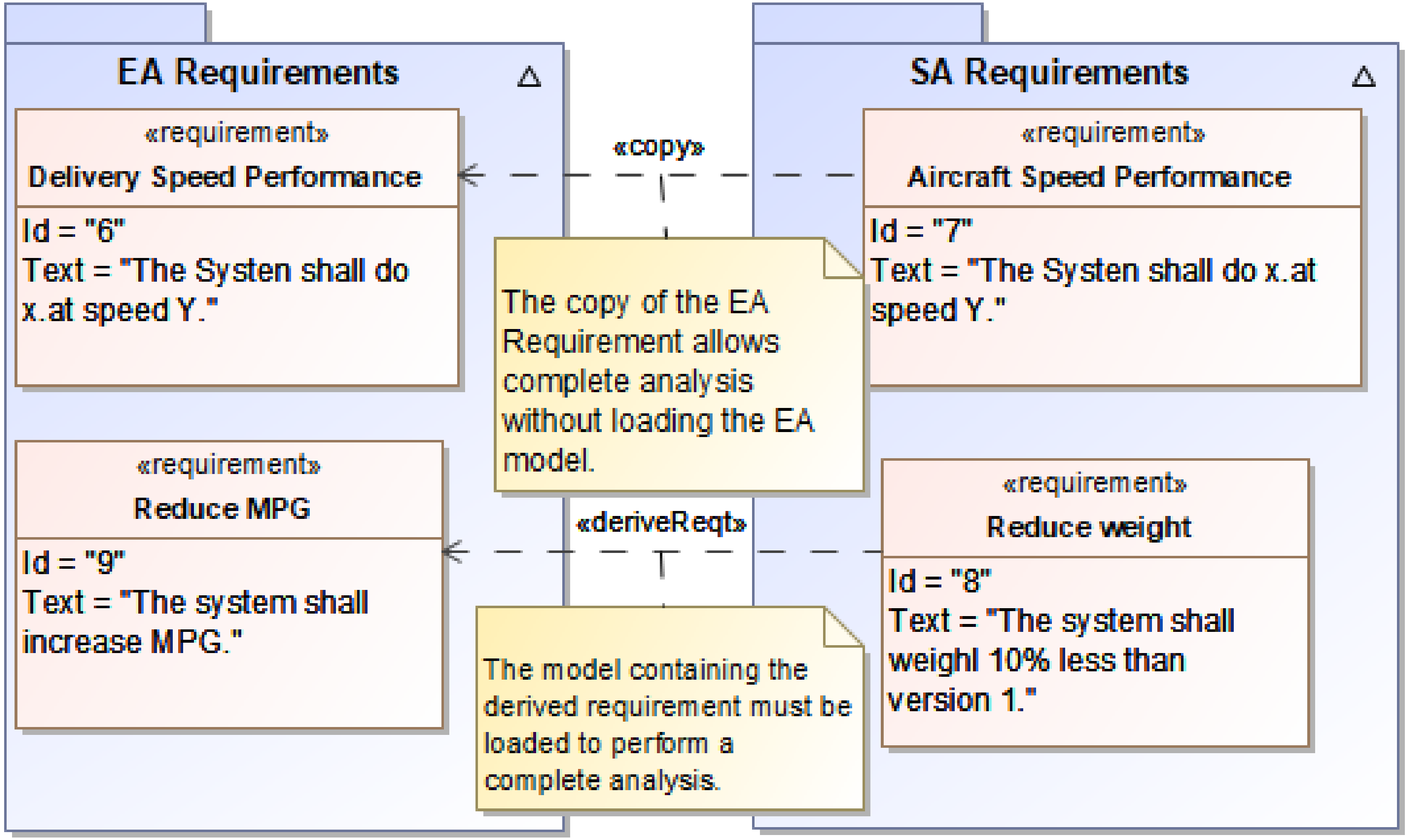
What about using the Abstraction relation?



Allocate in SysML is equivalent to Abstraction in UML. However, the direction is reversed…

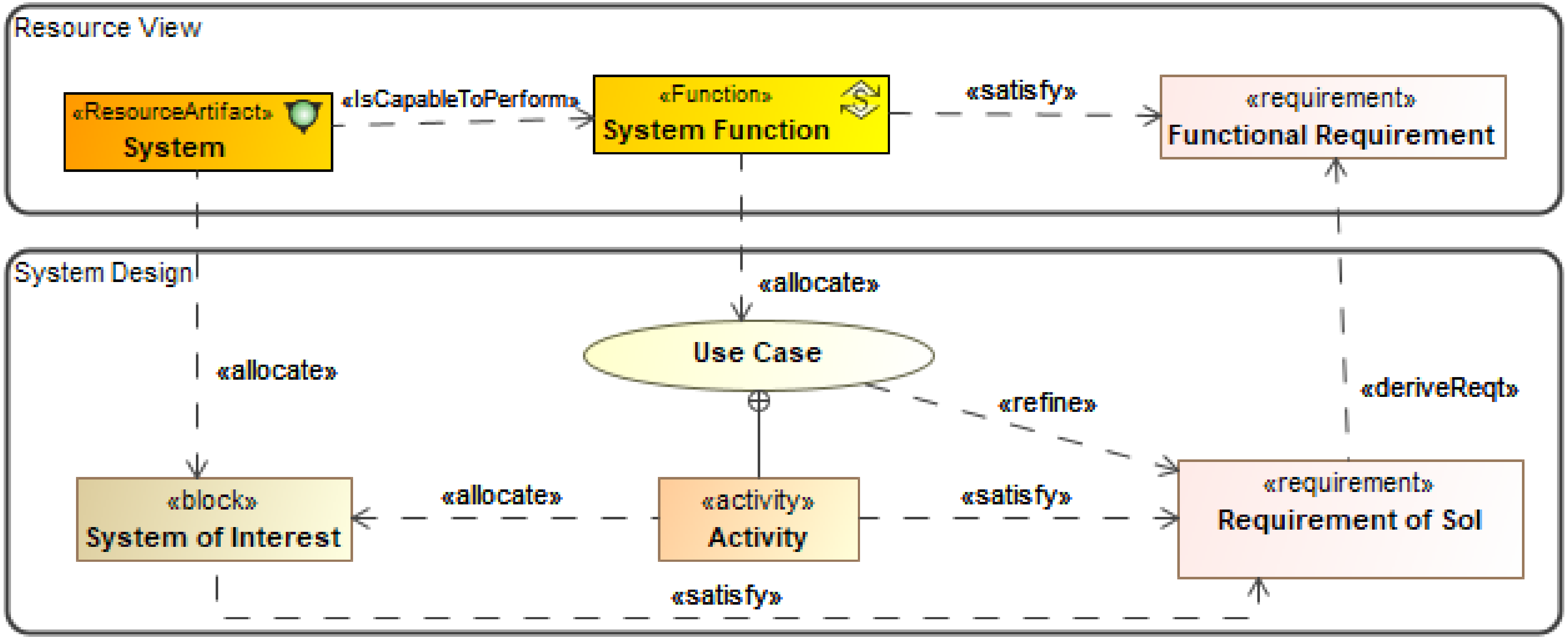
Solution 4 – Rqts Traceability Between Enterprise & System Elements

Example of Separated Requirement Models



Combination of Allocation and Derivation Approach

An alternative method beyond the four basic ones examined above



Combination of Allocation and Derivation Approach

Advantages	Disadvantages
✓ **Simple mapping that covers key elements of both models** ✓ **Isolation and low-coupling of models** ✓ **Coupling owned by the SA model (allows for dynamic loading of EA model only when mapping is navigated for analysis)**	× The complexity of multiple gap/change analysis techniques and reporting × No re-use of the EA model elements