VR-SysML:
SysML Model Visualization and Immersion in Virtual Reality

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Based on the conference paper in MODERN SYSTEMS 2022:
"VR-SysML: SysML Model Visualization and Immersion in Virtual Reality"

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- Worked for 14 years in the software industry in the Silicon Valley and in Germany doing research and development.
- Since 2004 he has been a Professor of Computer Science at Aalen University in Germany, teaching in the areas of software engineering.
- His research interest is to leverage technologies and techniques to innovate, automate, support, and improve the production and quality of software for society.

Contents

- Current challenge & problem
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- Implementation
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Introduction

- Systems engineering (SysE) is an interdisciplinary collaborative engineering field dealing with the design, integration, and management of complex system solutions over their lifecycle.
- The field faces a continuous challenge of growing system complexity, an increasing share of functionality shifted to software, system resource constraints, while coping with compressed development timeframes and project budget and resource constraints.
- Furthermore, the interdisciplinary nature of SysE means that diverse stakeholder types and groups with their specialty competencies and concerns are involved and who may not be readily acquainted with the model types and modeling languages involved.
- Any models may be digitally isolated or practically inaccessible to all stakeholder types, "hidden" within "cryptic" modeling tools that certain modeling specialists may understand.
- Due to the interdisciplinary nature of SysE, the inaccessibility and lack of model comprehension can hamper collaboration and affect overall system validity and correctness with regard to requirements.

Background

- While SysE can involve various models including physical, mechanical, electrical, thermodynamic, and electronic, the focus of this paper is on the Systems Modeling Language (SysML®).
- SysML is a general-purpose architecture modeling language for systems and systems-of-systems, supporting their specification, analysis, design, verification, and validation
- SysML is a dialect of the Unified Modeling Language (UML®) and defined as a UML 2 Profile.
- Out of UML 2's diagrams, it reuses seven (modifying four of these) while adding two additional ones.

Motivation & Challenges

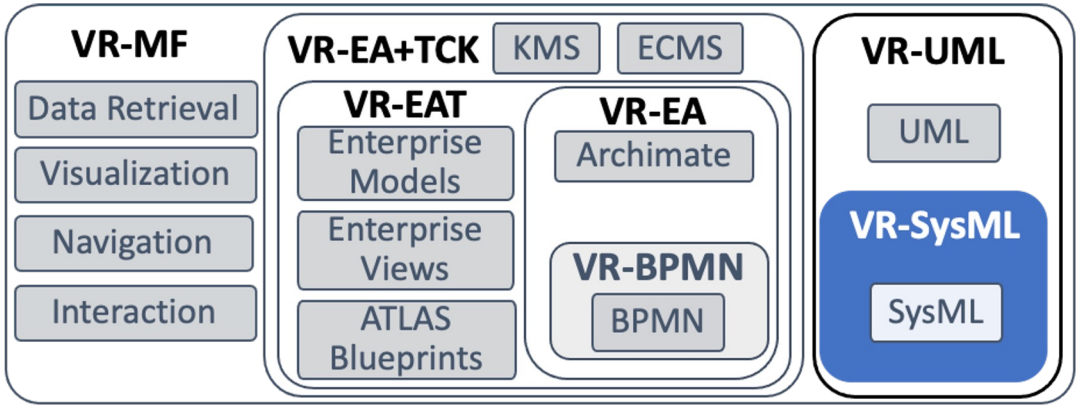
- Model access and collaboration
  - The interdisciplinary nature of SysE means that diverse stakeholder types and groups with their specialty competencies and concerns are involved and who may not be readily acquainted with the model types and modeling languages involved.
  - Any models may be digitally isolated or practically inaccessible to all stakeholder types, "hidden" within "cryptic" modeling tools that certain modeling specialists may understand.
  - Due to the interdisciplinary nature of SysE, the inaccessibility and lack of model comprehension can hamper collaboration and affect overall system validity and correctness with regard to requirements.
- Disparate views
  - Views and their associated diagrams can help reduce cognitive overload, yet their divided nature also risks overlooking a relation or element and comprehending the overall model.
  - Ideally, a model should be whole and complete to the appropriate degree for the reality it is depicting and simplifying.
- Model immersion
  - Yet the modeling languages and associated tooling typically assumes a 2D display and portrays portions of models sliced onto 2D diagrams. Although 3D models can be portrayed on 2D displays, they lack an immersion quality.

Solution Approach

- VR provides an unlimited immersive space for visualizing and analyzing a growing and complex set of system models and their interrelationships simultaneously in a 3D spatial structure viewable from different perspectives.
- Lacking a proper 3D system modeling notation, in the interim we propose retaining the well-known SysML notation and interconnecting 2D SysML diagrams in VR, which can suffice for depicting the relations between elements across diagrams and assist with navigating and validating complex models.
- As system models grow in complexity and reflect the deeper integration and portrayal of their system reality and environment, an immersive digital environment provides an additional visualization capability to comprehend the “big picture” model for structurally and hierarchically complex system models via interconnected diagrams and associated digital elements.

VR-SysML Solution Concept in Relation to our other Solutions

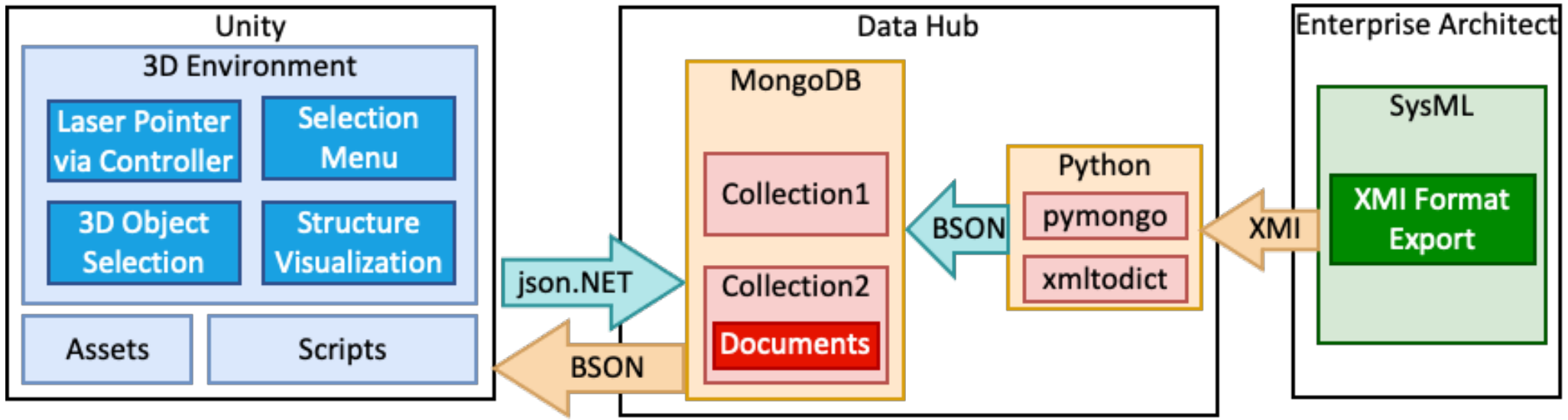
- Extended our VR-UML [2] solution concept, which is based on our generalized VR Modeling Framework (VR-MF) (detailed in [4]).
- VR-MF provides a VR-based domain-independent hypermodeling framework addressing four aspects requiring special attention when modeling in VR: visualization, navigation, interaction, and data retrieval.
- Our other VR modeling solutions include VR-BPMN [3], VR-EA [4], and VR-EAT, which integrates the EA tool Atlas to provide dynamically-generated EA diagrams in VR.
- VR-EA+TCK adds additional capabilities, integrating enterprise Tool, Content, and Knowledge such as a Knowledge Management Systems (KMS) and/or Enterprise Content Management Systems (ECMS).
- While SysML is popular for embedded and model-based systems, it is also applicable to domains such as EA.



VR-SysML Solution Concept VR Aspects

- Visualization in VR
  - A hyperplane is used to intuitively represent a diagram.
  - Stacked hyperplanes are used to support viewing multiple diagrams at once, while permitting a user to readily have an overview of the number and types of diagrams.
  - Hyperplanes serve a grouping function and allow us to utilize the concept of a common **transparent backplane** to indicate common elements across diagrams via **multi-colored inter-diagram followers**.
  - Versus side-by-side, stacked diagrams are a scalable approach for larger projects since the distance to the VR camera is shorter.
  - Multiple stacks can be used to group diagrams or delineate heterogeneous models.
  - Diagrams of interest can still be viewed side-by-side by moving them from the stack via an anchor sphere affordance on a diagram corner, which is also used to hide or collapse diagrams to reduce visual clutter.
  - To distinguish SysML elements types, 2D icon images can be placed on generic (e.g., block) model elements, in order to reduce the effort of modeling each SysML element type as a separate 3D form for VR.
- Navigation in VR
  - Besides flythrough, also teleporting offered to reduce likelihood of potential VR sickness symptoms
- Interaction in VR
  - Since interaction with VR elements has not yet become standardized or intuitive, in our VR concept, user-element interaction is handled primarily via the VR controllers and a virtual tablet.
  - A VR-Tablet provides detailed element information and context-specific Create, Retrieve, Update, Delete (CRUD) capabilities including a virtual keyboard for text entry via laser pointer key selection.
  - Anchor affordances as ball on corner of hyperplane and plates can be used for moving or collapsing/expanding it.

VR-ProcessMine Realization



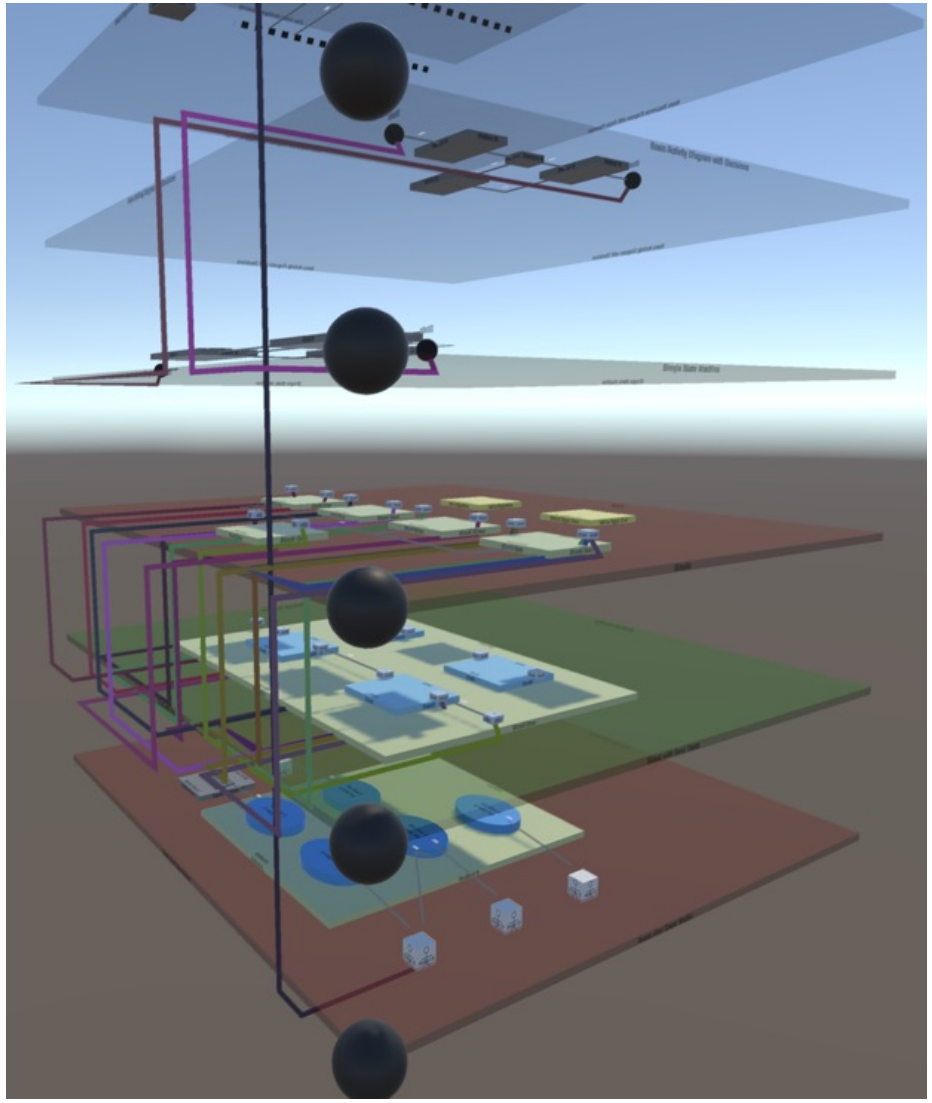
- Our prototype currently does not consider the Allocation Table (relationship matrices).
- CRUD capabilities in the VR-Tablet are not yet fully implemented.

Evaluation

- The evaluation of our solution concept is based on the design science method and principles [11], in particular, a viable artifact, problem relevance, and design evaluation (utility, quality, efficacy).
- A case study is used with an emphasis on SysML diagram type support, how these are visualized in VR, and additional capabilities in VR.
- A sample SysML project with all 9 SysML diagram types is used to compare the visualization in Enterprise Architect to that in VR-SysML, grouped as requirement, behavior, or structure diagram types

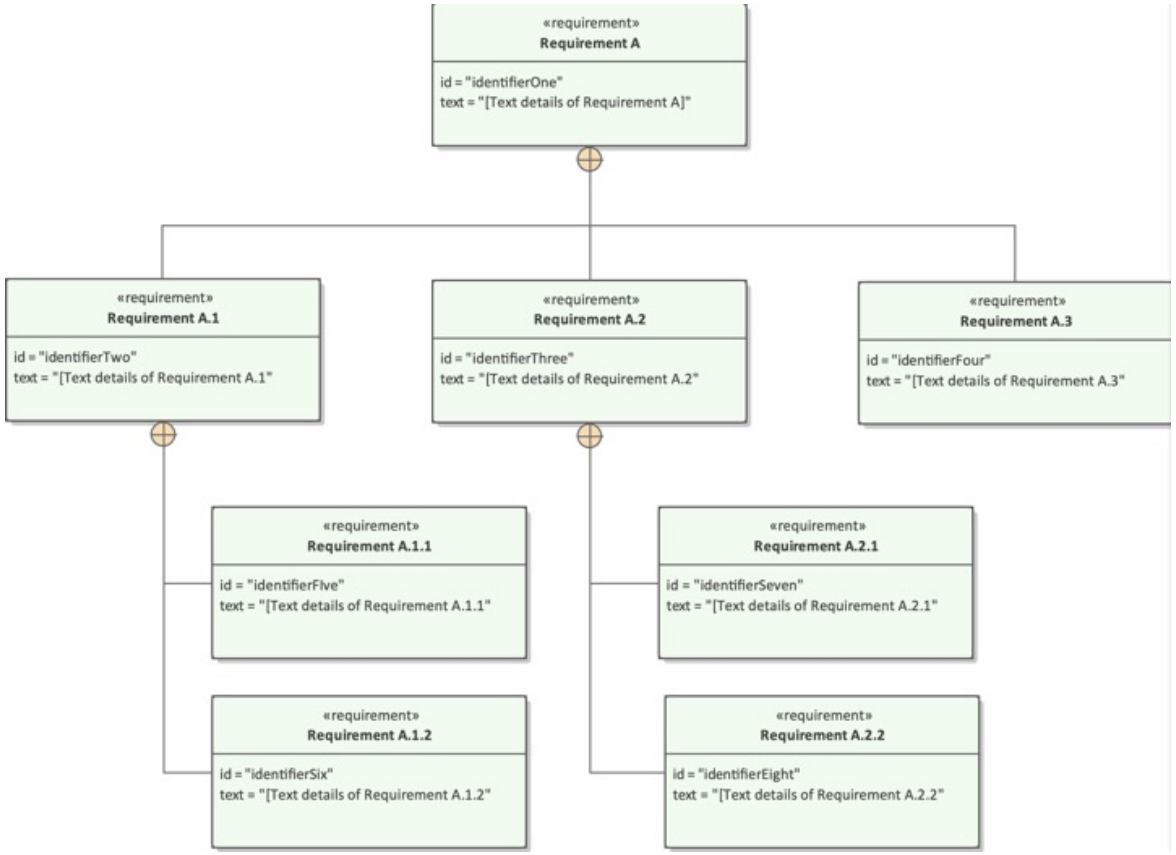
Evaluation

- SysML diagrams are mapped to stacked hyperplanes that provide an anchor affordance (black sphere) with which to expand, collapse, or move a diagram.
- Planes and elements have a shallow 3D depth with labeled edges to support recognition from different viewing angles.
- The colors of the planes can be configured to help with differentiation or grouping.
- Our backplane concept creates followers that allow one to quickly find the same element across different diagrams in the same model, to readily see in which diagrams that element participates, or to determine that the element is only shown on one diagram (it not having a follower).
- The colored followers can be selected (made bold) and the other followers can be hidden if desired to reduce visual clutter for larger models.



Evaluation: SysML Requirement Diagram

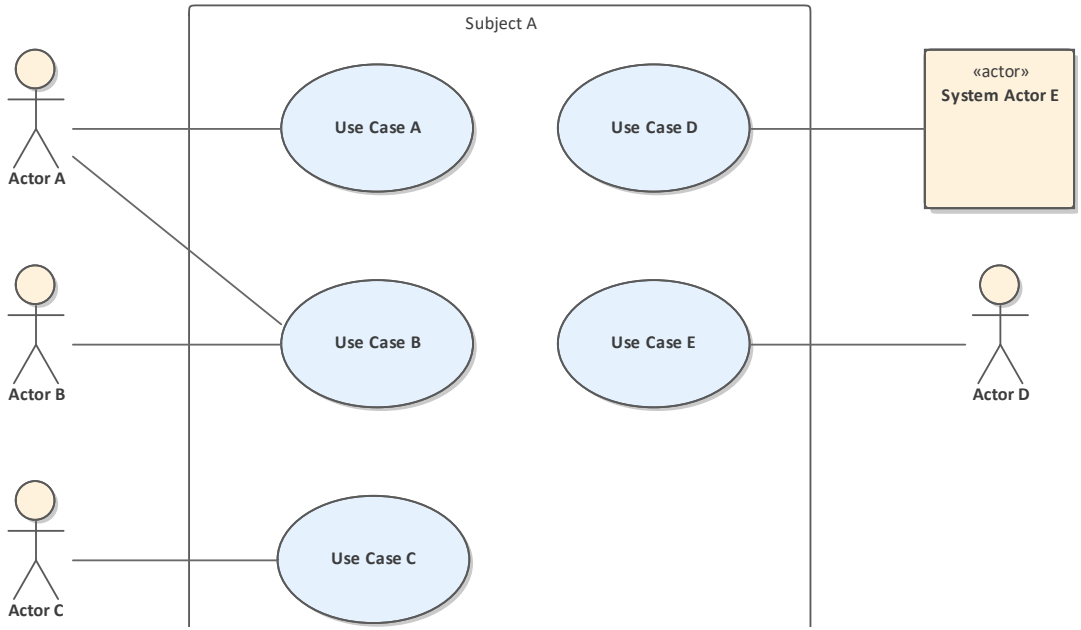
Visualization in Enterprise Architect®



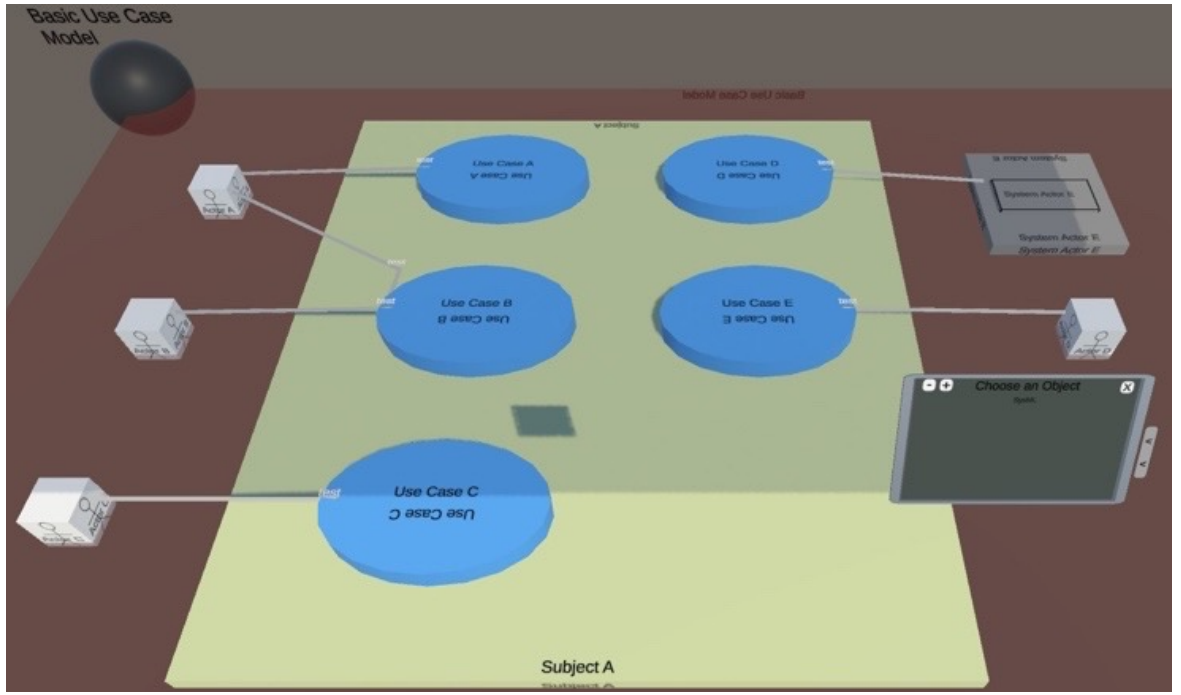
Visualization in VR-SysML

Evaluation: SysML Use Case Diagram

Visualization in Enterprise Architect®

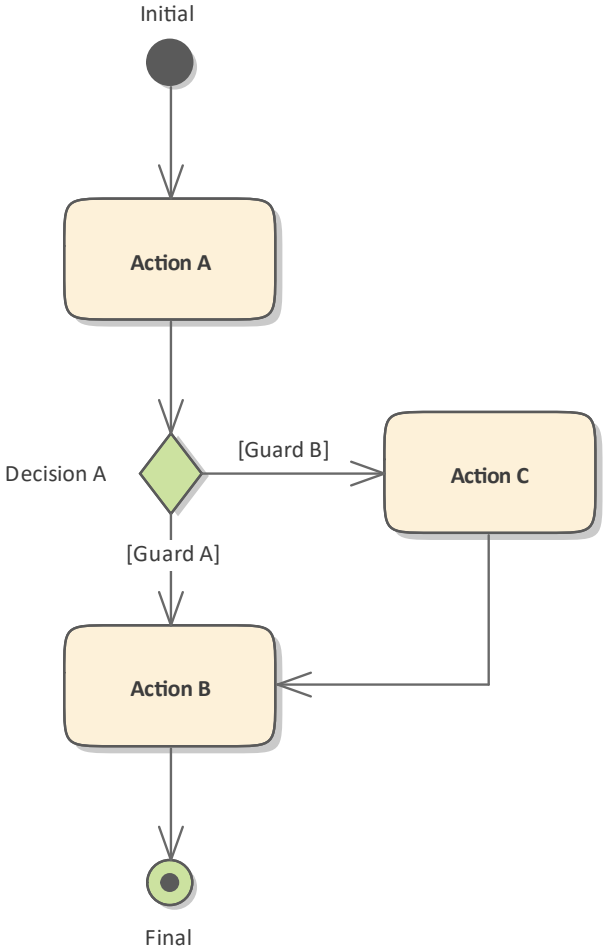


Visualization in VR-SysML

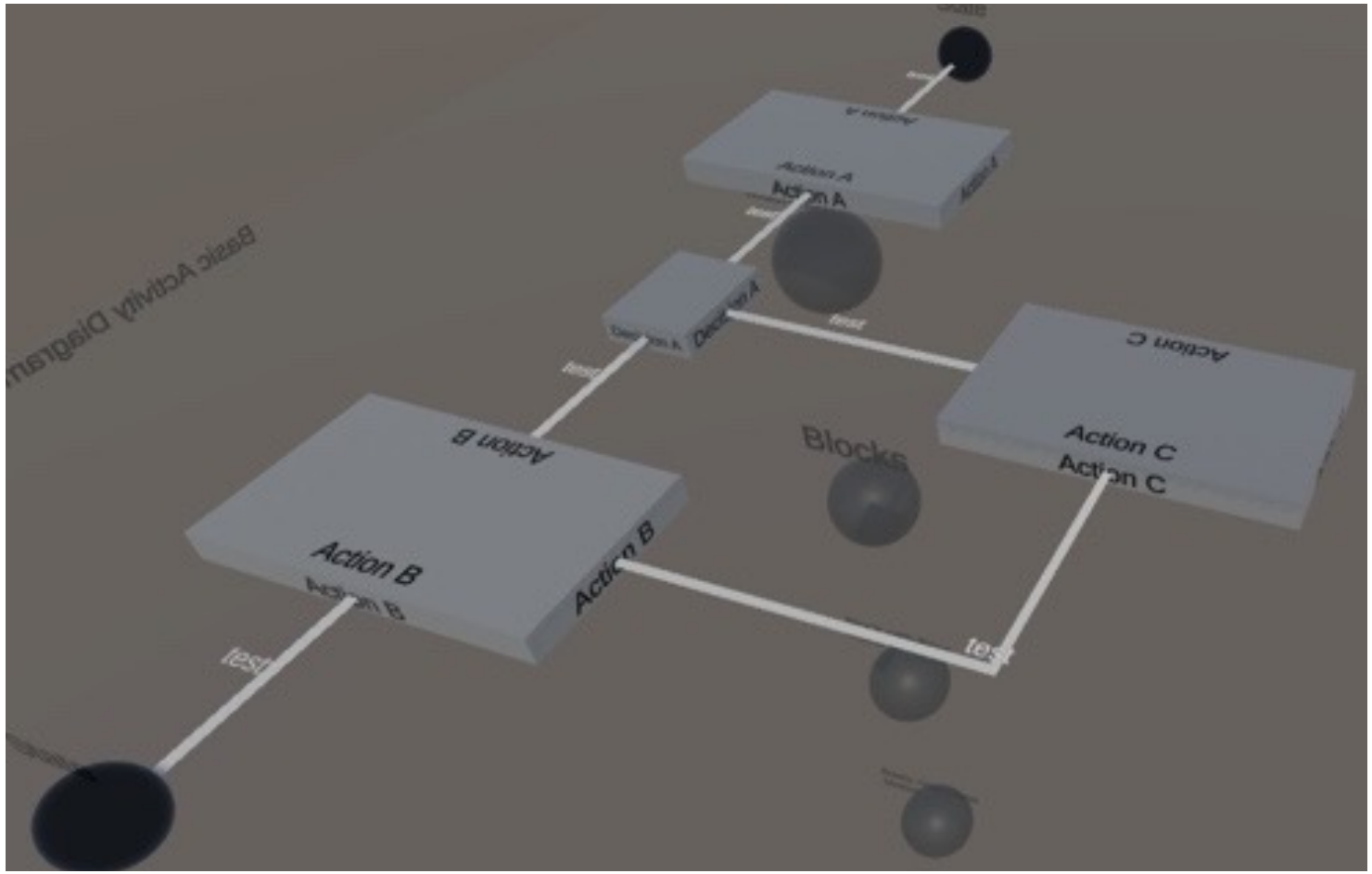


Evaluation: SysML Activity Diagram

Visualization in Enterprise Architect®

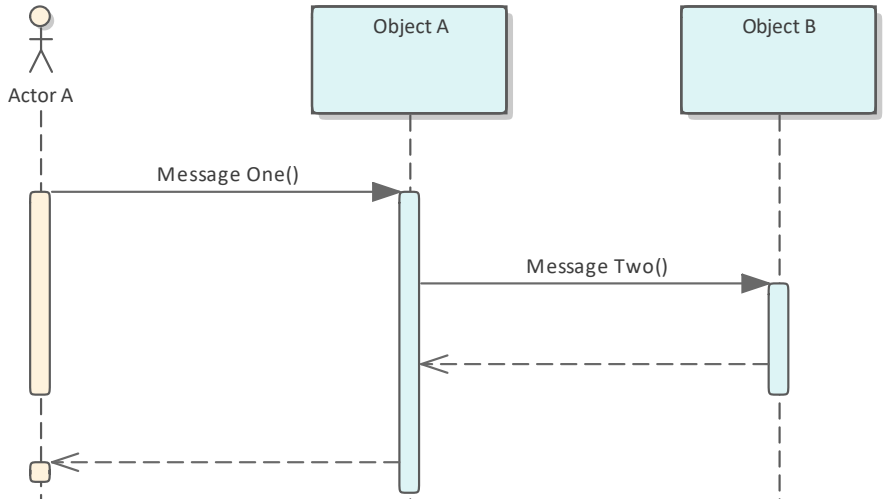


Visualization in VR-SysML

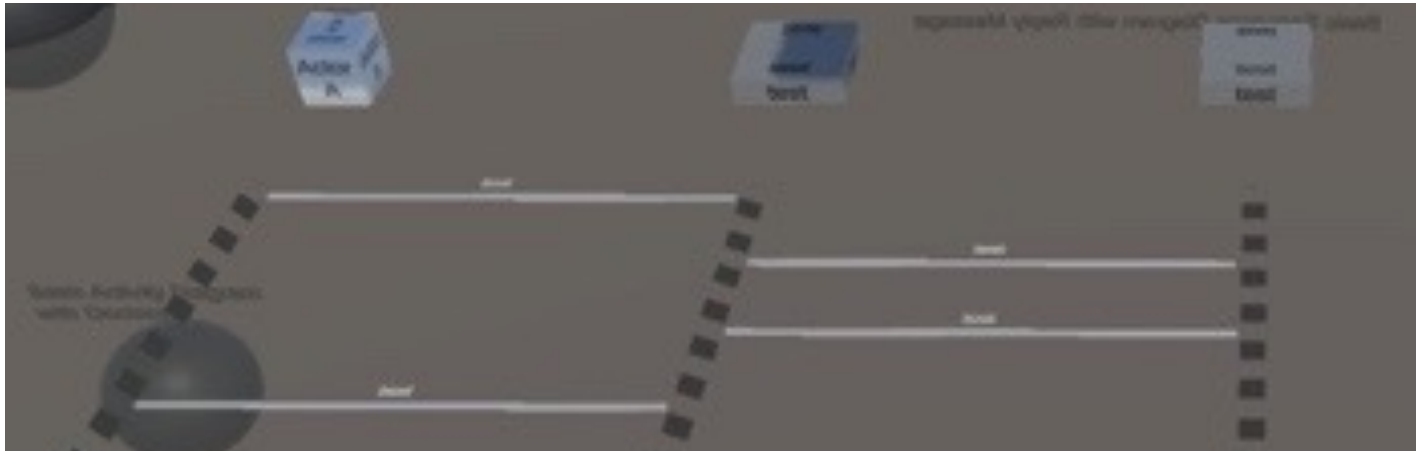


Evaluation: SysML Sequence Diagram

Visualization in Enterprise Architect®

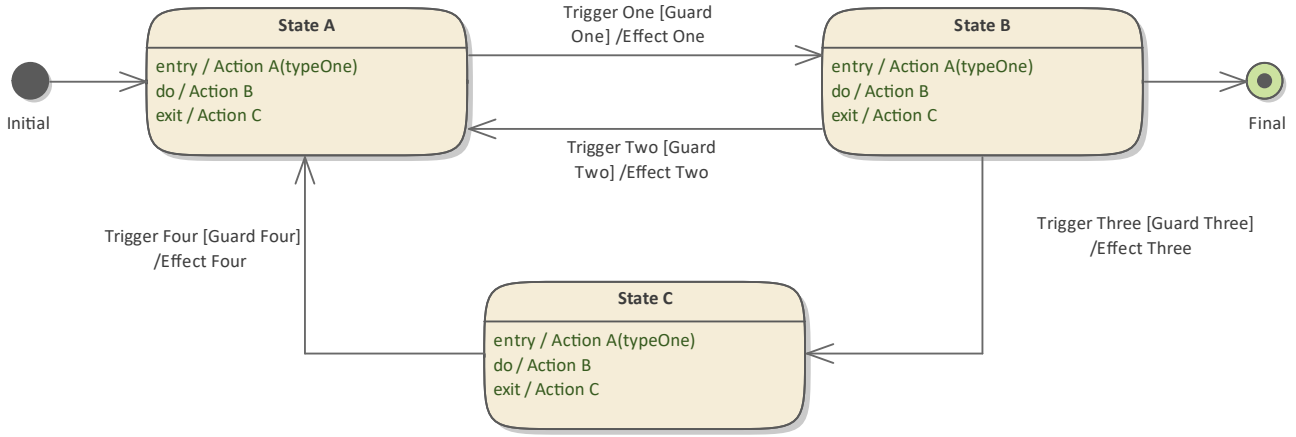


Visualization in VR-SysML

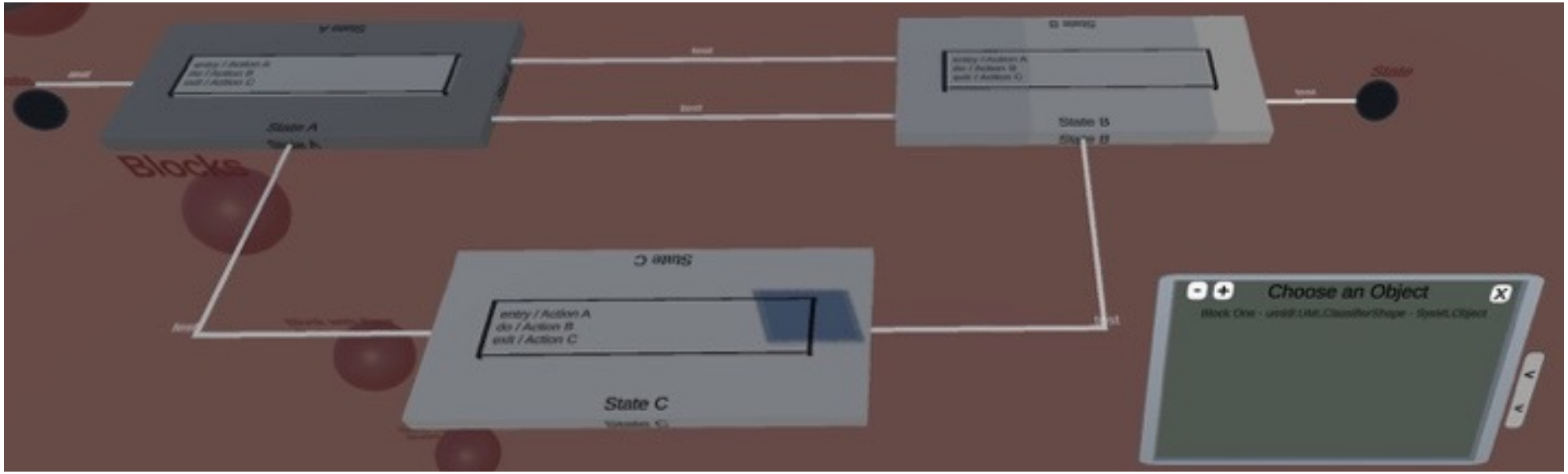


Evaluation: SysML State Machine Diagram

Visualization in Enterprise Architect®

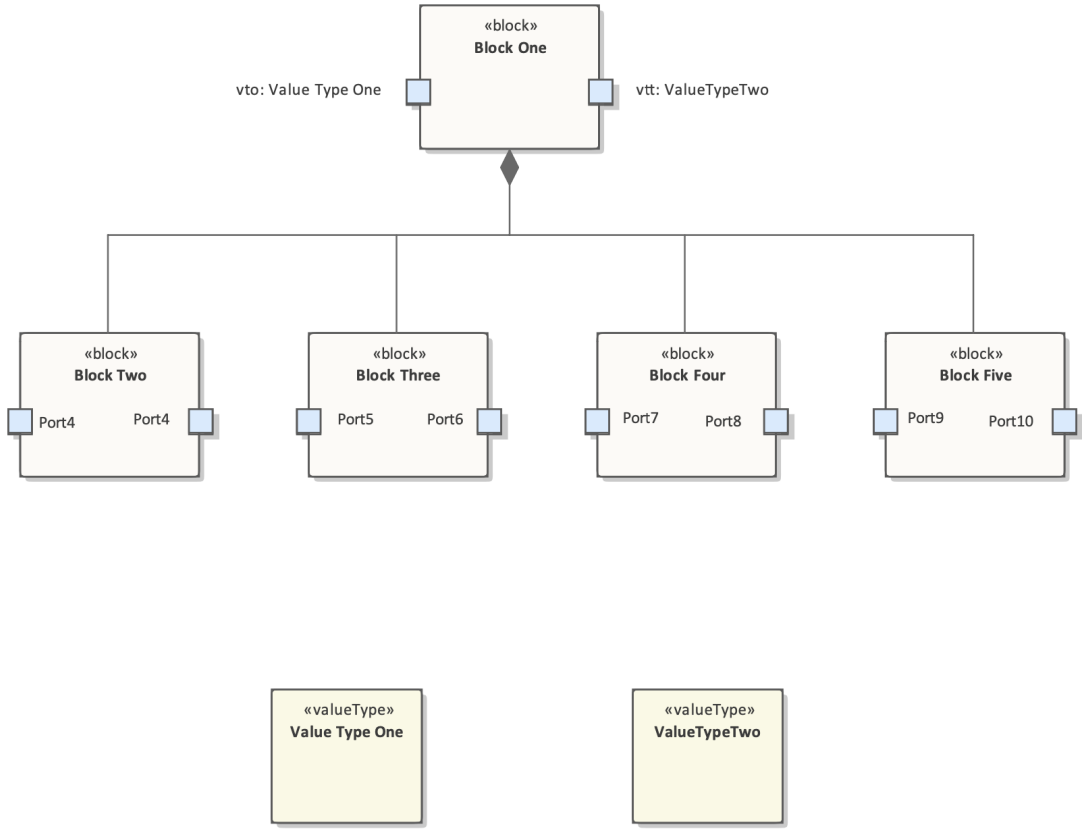


Visualization in VR-SysML

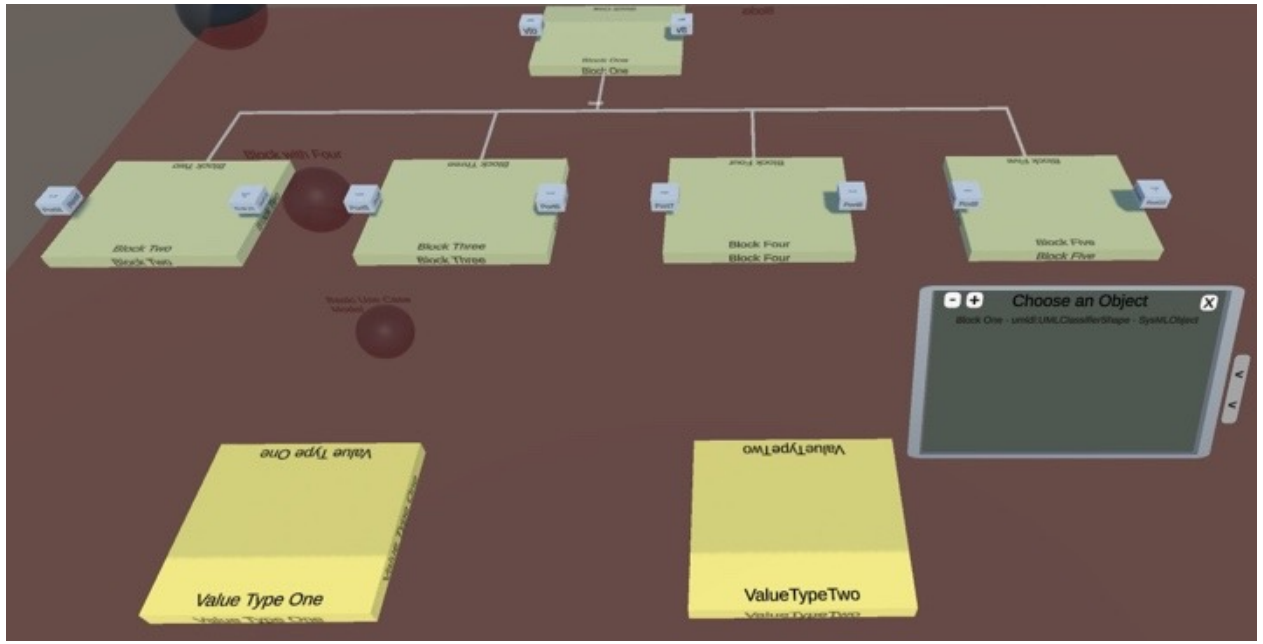


Evaluation: SysML Block Definition Diagram (BDD)

Visualization in Enterprise Architect®

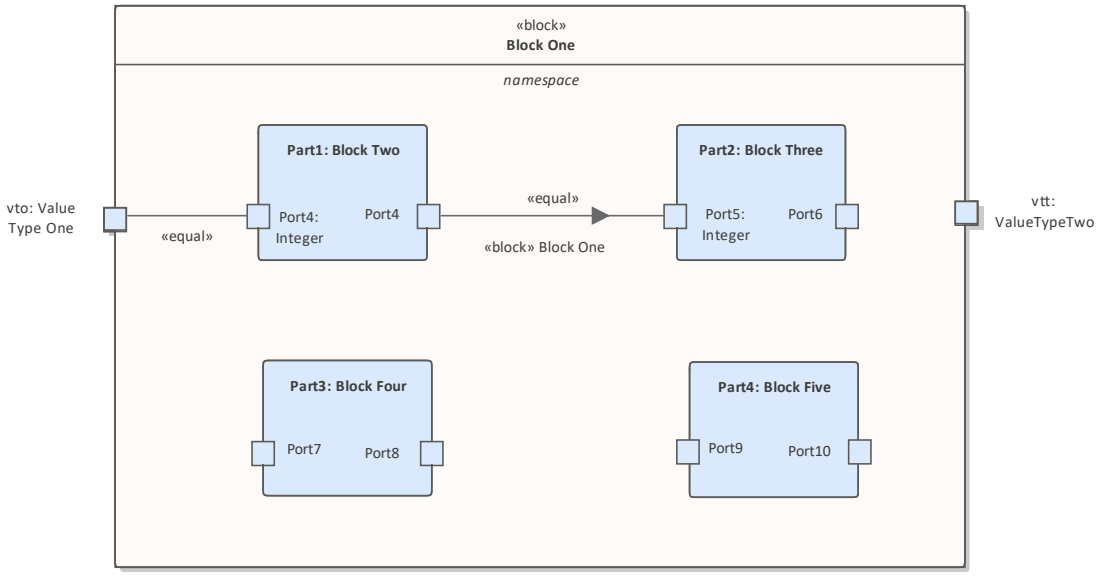


Visualization in VR-SysML

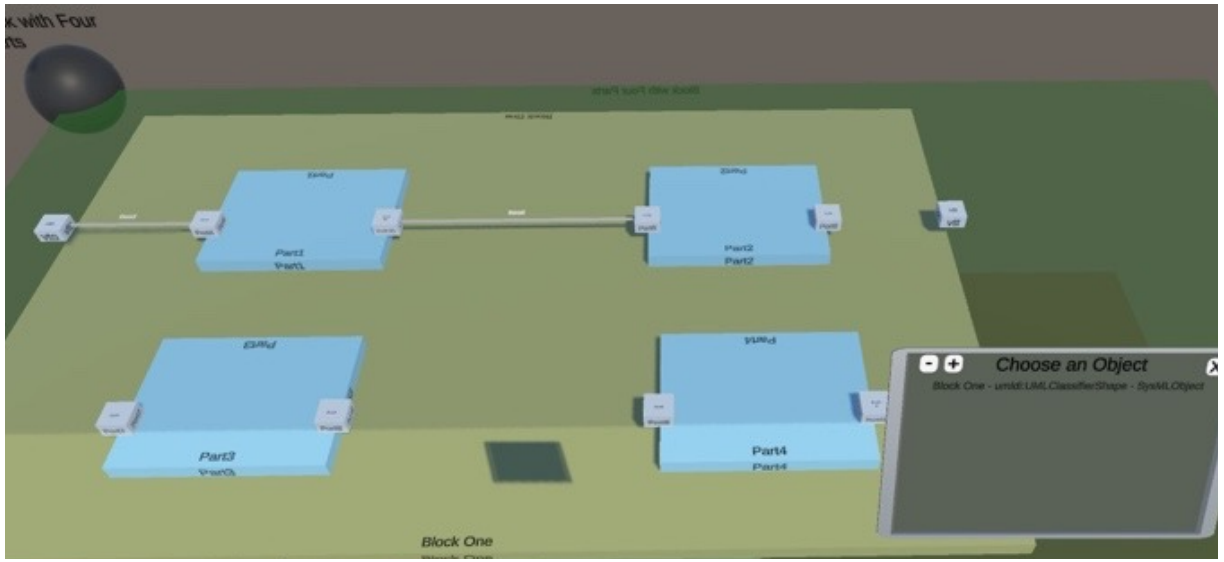


Evaluation: SysML Internal Block Diagram (IBD)

Visualization in Enterprise Architect®

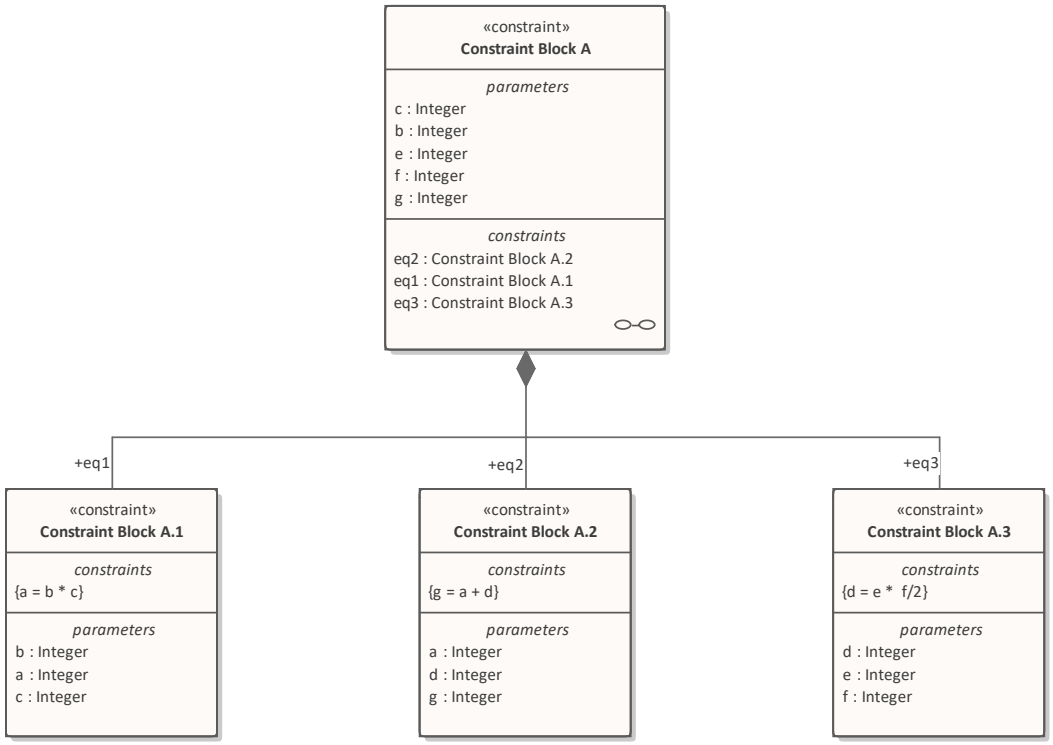


Visualization in VR-SysML

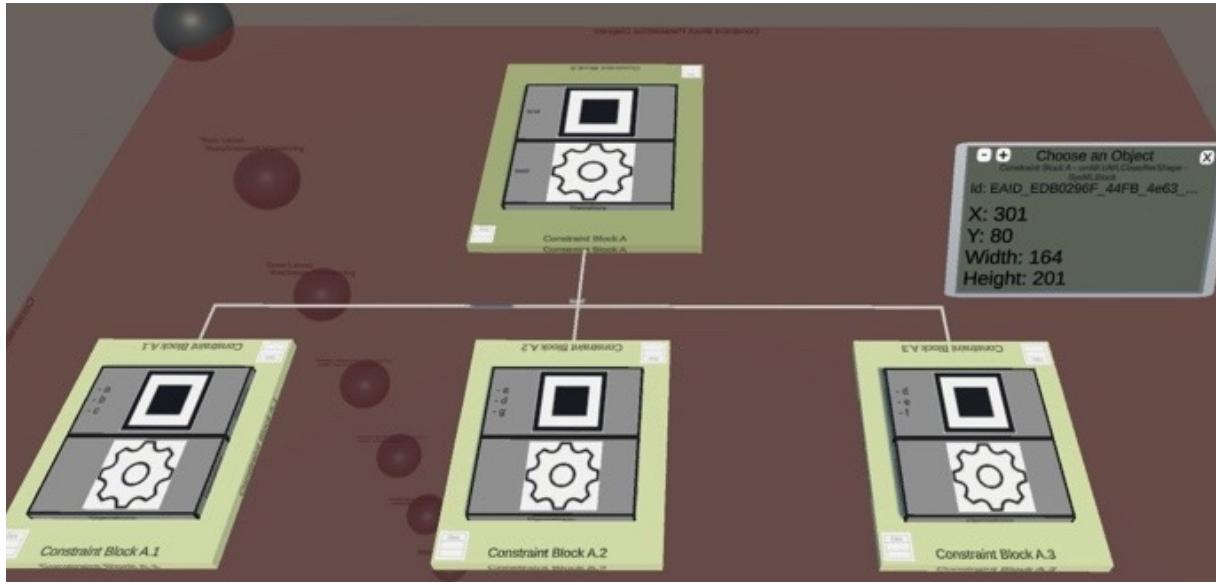


Evaluation: SysML Parametric Diagram

Visualization in Enterprise Architect®

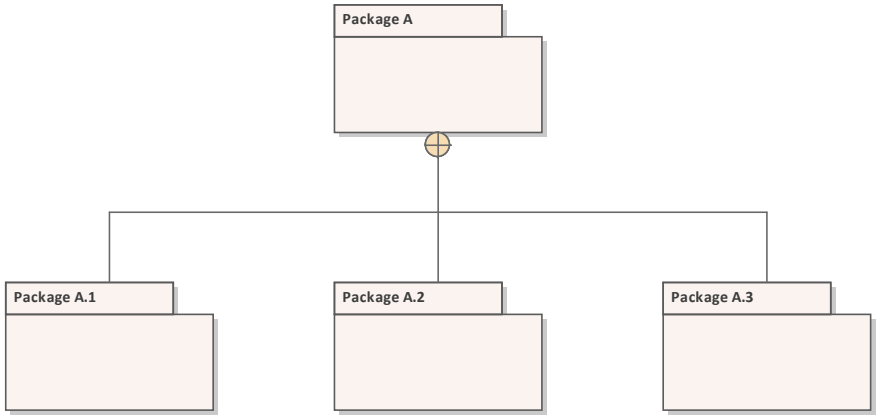


Visualization in VR-SysML

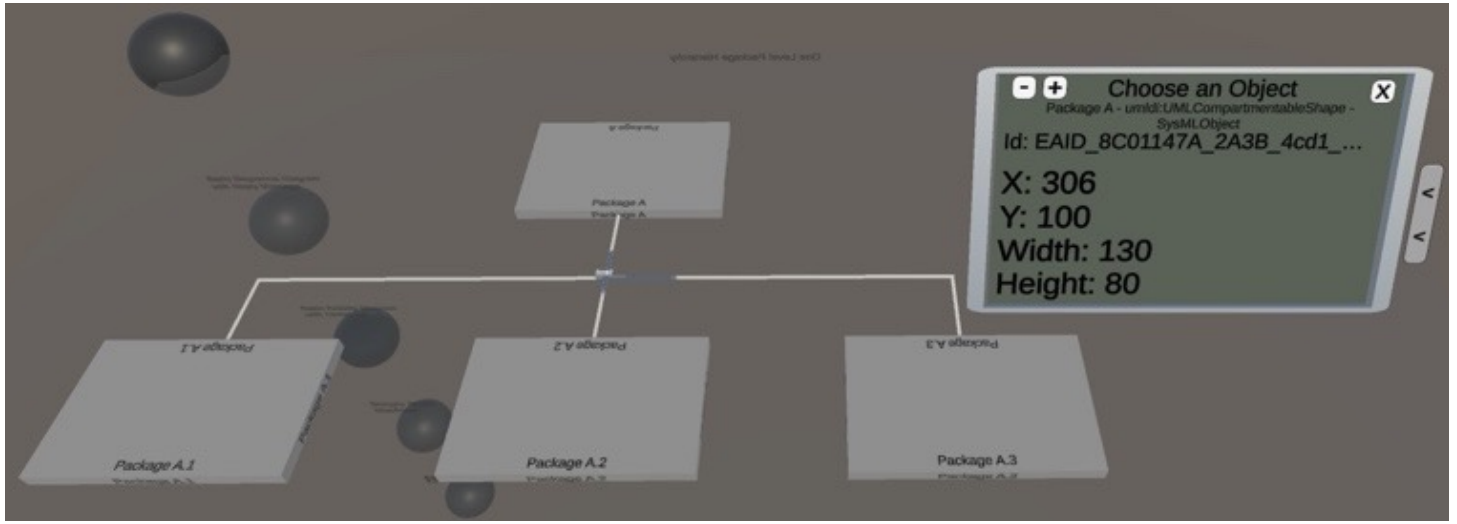


Evaluation: SysML Package Diagram

Visualization in Enterprise Architect®

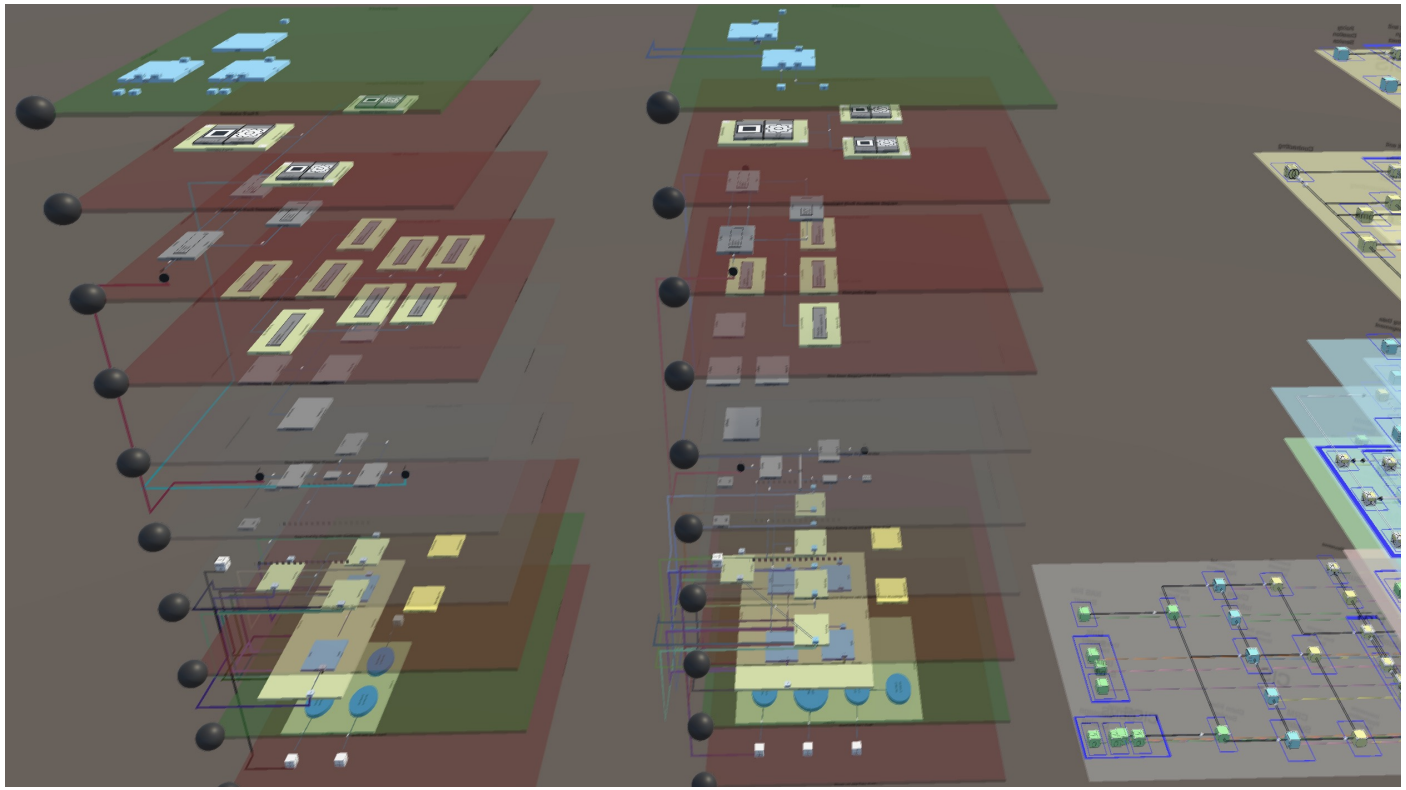


Visualization in VR-SysML



Evaluation: Multi- and Heterogeneous Model Depiction in VR

- VR's unlimited virtual space provides the potential to view, compare, and analyze multiple SysML models (left)
- Heterogeneous models can also be viewed side-by-side (exemplified with an ArchiMate enterprise architecture model on the right).
- For SysE, this immersive approach also has the potential to support interdisciplinary collaboration between specialization experts for complex systems



Conclusion

- VR-SysML contributes an immersive SysML model experience for visually depicting and navigating SysML diagrams of models in VR.
- The solution concept was described and a VR prototype demonstrated its feasibility using a case study.
- Based on our VR hyperplane principle, SysML diagrams are enhanced with 3D depth, color, and automatically-generated inter-diagram element followers based on our back-plane concept. Interaction is supported via a virtual tablet and keyboard.
- The unlimited space in VR facilitates the depiction and visual navigation of large models, while relations within and between elements, diagrams, and models can be analyzed.
- Furthermore, in VR additional related (SysML or non-SysML) models can be visualized and analyzed simultaneously and benefit complex systems-of-systems architectures or collaboration.
- The sensory immersion of VR can support task focus during model comprehension and increase modeling enjoyment, while limiting the visual distractions that typical 2D display surroundings incur.

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