

Visualization of MBSE Datasets in an Interactive 3D Game Engine

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Abstract

Sandia National Laboratories (SNL) plays a role as a systems integrator in numerous national security applications. Supporting such national security missions requires SNL to explore capabilities that will span multiple decades, generations, sites, etc. Effective interactions and engagement across a varied terrain of tools, models, and capabilities require flexibility in the system engineering approach. We have developed a Resource Description Framework (RDF) exporter for Vitech's GENESYS model-based systems engineering (MBSE) tool to support and connect systems engineering models into a virtual reality environment. The MBSE models were integrated with mechanical computer aided design (CAD) models from Creo, which is a family of CAD applications developed by PTC. When integrated with standard systems engineering tools, we expect these capabilities to address and solve complex multidisciplinary product design and development challenges worldwide.

Introduction

Sandia National Labs is pursuing a Digital Engineering Ecosystem (DEE) to enable a more agile and rapid approach to national security applications. This approach consists of four key digital transformation goals: 1) digital exploration, 2) digital prototype, 3) digital twin, all of which are connected using 4) digital thread. To achieve these goals, several model-based approaches are being implemented, including Model Based Systems Engineering (MBSE), Model Based Design (MBD), Model Based Enterprise (MBE), and Model Based Analysis (MBA). Each of these model-based approaches makes use of specific and specialized tools to support its role in the digital engineering process. This work explores opportunities to connect aspects of MBSE, MBD, and MBE by demonstrating data connectivity between modeled systems engineering (SE) requirements and CAD. The blue nodes in Figure 1 below illustrates the relationships explored between these tools and approaches in the present work, as well as a notional "digital thread" shown in red.

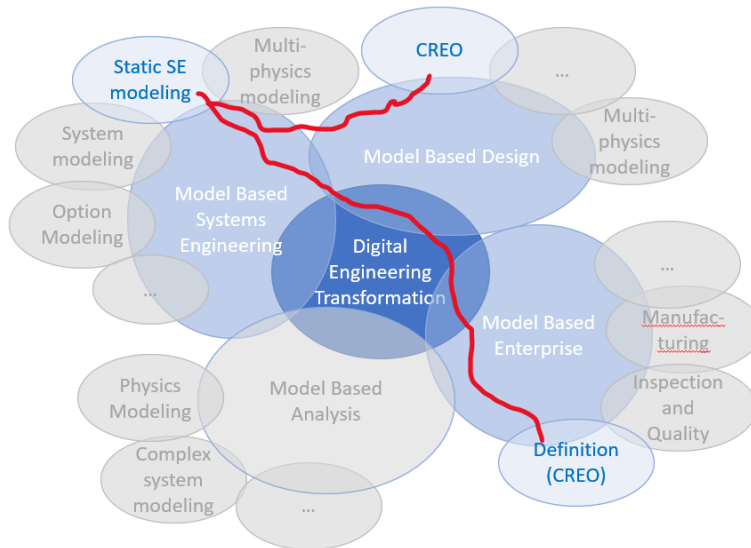


Figure 1. Model-based approaches make use of different tools that support the role of each approach. The red “digital thread” demonstrates the data connectivity discussed in the current work.

Model Based Systems Engineering (MBSE) is a model-based alternative to the conventional document-based approach for engineering a system [1]. MBSE facilitates a coherent and formalized approach over the entire lifecycle of complex and interdisciplinary systems [2]. MBSE further enables better data connectivity and agility for option-modeling analyses, system-level modeling, and paradigm-specific analyses. Although MBSE is useful in the roles described above, a digital thread to domain-specific applications needs to be established to fully and effectively connect all aspects of the system lifecycle.

Virtual Reality (VR) and Augmented Reality (AR) form an impactful conduit of a digital thread and provide unique and powerful ways to connect many disparate data types across domains and life cycles. When presenting information to stakeholders and key decision makers, design reviews are conventionally accomplished using slide decks. Although slide decks can be effective visual tools for communicating certain types of information, the format is frequently inadequate for describing the detail and nuance inherent to complex, modern systems design. The leap to digital engineering requires tools that enable better data connectivity across engineering domains to clearly and effectively communicate information, knowledge, and wisdom. A further compelling reason to explore AR/VR applications is that decision-making is significantly improved when driven visually [3]. Therefore, AR/VR applications can provide a way to arrive at multidisciplinary convergence sooner, enable better-informed decision making, enhance training, and maintain knowledge.

Overall, it can be challenging to understand and successfully communicate system requirements in relation to the physical world to non-experts tasked with key decision making [4]. SNL has explored leveraging various types of digital threads to help communicate complex system requirements from a more physical perspective that will connect to a broader audience

of multidisciplinary collaborators. The present work focuses on exploring capabilities to connect systems engineering data to CAD models in VR to better communicate multidisciplinary datasets in a collaborative environment.

Methods and Results

General Approach

Unity is a game engine and game development platform created by Unity Technologies. The goal of the present work is to leverage Unity as a visualization tool to connect disparate data types and enable coherent connections between data originating from multiple disciplines and a variety of tools. The Unreal engine was also explored for visualization applications. Unity was selected due to availability of resources at the time of the decision; however, a similar workflow could be developed based on the Unreal engine. The diagram in Figure 2 introduces the data connectivity that we have demonstrated (solid lines) and the connections that are currently being explored (dashed lines). Long-term efforts are oriented toward creating generalized model interoperability workflows that enable data transfer between a variety of tools; the scope of the present work is limited to establishing connections between GENESYS and Creo that support in-depth analysis of multidisciplinary data. The architecture is being built such that future connections will allow extension to verification and validation type efforts and datasets.

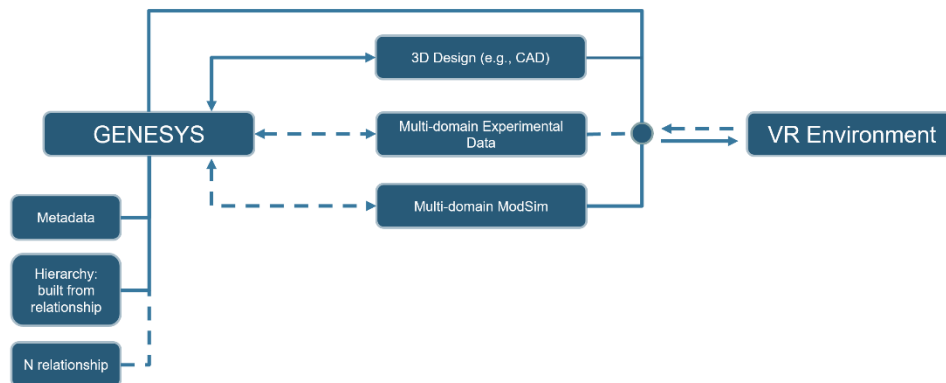


Figure 2. High-level data connectivity being explored for MBSE data. Solid lines indicate connections pursued in the current work and dashed lines indicate future data connectivity.

A Research and Sounding Rocket (RASR) was used as an exemplar to demonstrate the current capability. The RASR is an instrument-carrying rocket designed to take measurements and perform scientific experiments during its sub-orbital flight. The payloads for these research rockets are provided by HONEYWELL FM&T, which establishes an avenue for connectivity between a Design Agency (SNL) and a Production Agency (HONEYWELL FM&T). The RASR is shown in Figure 3.



Figure 3. RASR exemplar used to demonstrate the visualization workflow.

Model InteroperabilityFigure 4

In order to ensure modularity and extensibility in our solution, we have developed a hub-and-spoke interoperability system for sharing model data between the modeling tools used in all the model-based approaches described above. This system is based on the Resource Description Framework (RDF) as the centralized model representation format. RDF is an open standard data format published and maintained by the W3C organization [5]. RDF was originally developed for exchanging data on the World Wide Web; however, because it is based on a directed graph structure, RDF is an excellent format for representing engineering models as well. By using RDF as a common central model representation, we have been able to construct a flexible system for model data connectivity as illustrated in Figure 4. Any modeling tool that is able to read and/or write RDF can exchange model data with any other tool via the central RDF representation. While most modeling tools do not include native functionality for importing and exporting RDF, many of these same tools do include an API through which a suitable connector can be written.

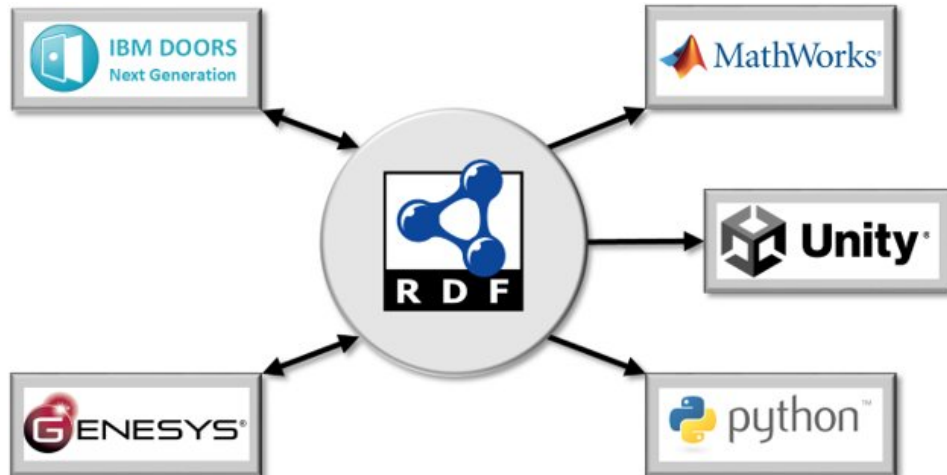


Figure 4. RDF provides a centralized, standard data format that facilitates sharing model data between modeling tools.

The data contained in an RDF graph is based on one or more ontologies. An ontology is similar to a schema or metamodel and defines the terms used to describe the data elements, their properties or attributes, and the relationships between them. For the present work, we created an ontology based on a modified version of the GENESYS schema, which proved sufficiently detailed for demonstrating our interoperability process.

We developed a custom connector to export GENESYS model data to RDF, including all entities, attributes, and relationships. Using similar connectors for other tools, we have demonstrated the capability to access and make use of the exported model data on the other platforms and tools shown in Figure 4. The present work focuses on our efforts to use this data within a Unity scene.

Visualization of GENESYS Attribute Data in Unity

To visualize GENESYS attribute data in Unity, we developed a custom Unity package capable of reading the data stored in RDF files. This custom package converts each entity in the RDF file to a Unity game object containing its associated attribute data. These game objects were then systematically connected to a corresponding, previously imported CAD game object using a string search to match the unique base number contained in both the CAD part number and the RDF requirements/descriptions. Once correspondence between the CAD part number and the RDF base number had been established, the remaining RDF attribute data could be attached to the individual CAD components. The result is a user-interactive capability to visualize the attribute data associated with each CAD model, as shown in Figure 5 below.

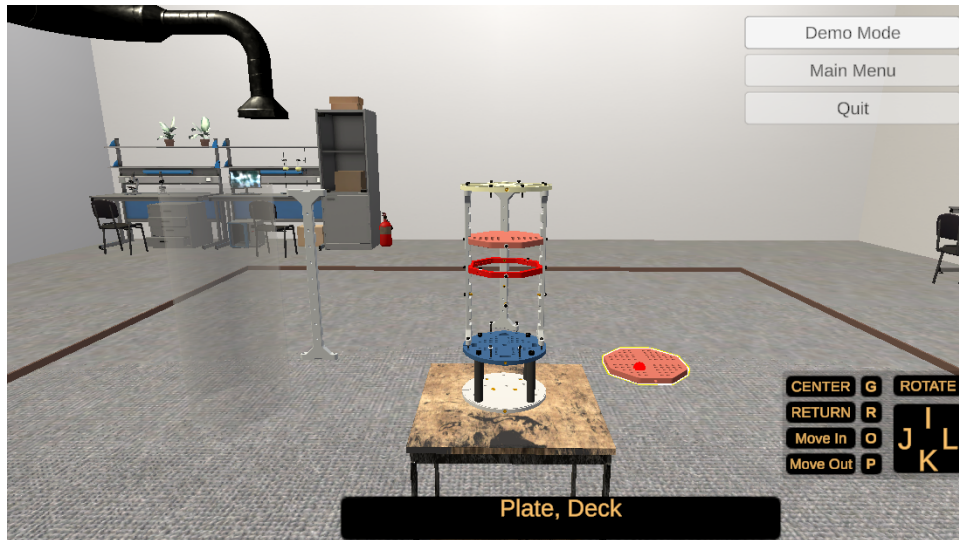


Figure 5. Example of Unity desktop interaction demonstrating that selection of specific CAD objects results in the display of associated part metadata modeled in GENESYS.

Visualization of GENESYS Relationships in Unity

The systems engineering model data exported from GENESYS to RDF, as described above, contains information about the relationships between model entities, in addition to entity attributes. As a result, we can generate a variety of graph visualizations to clearly illustrate the various relationships between the different entities that comprise the model.

Although Unity does not provide built-in support for drawing structures like graphs and the resources available in the Unity Asset Store are somewhat limited in this regard, the Unity engine does provide an excellent platform for rendering custom 2D and 3D structures of any type. This means that it is not only possible to recreate the various GENESYS data views within Unity, but also to create highly specialized custom views of relationships between a variety of different model entities.

To demonstrate this capability, we created a Unity asset for generating hierarchy diagrams of systems engineering elements that are related by a specified parent-child relationship. For traditional hierarchy diagrams, our Unity asset implements Walker's algorithm to generate aesthetically pleasing layouts that also conserve space [6]. This algorithm operates in $O(N)$ time, and node positions are computed recursively from the leaf nodes toward the root. For simplicity, each node is represented by a cube; however, any 2D or 3D object could be used instead. The diagram on the left in Figure 6 shows a traditional hierarchy generated by our Unity asset.

For larger hierarchies, it is convenient to arrange the nodes in ways that make more efficient use of screen real estate. One way to do this is by arranging child nodes radially around a

central parent node. Modifications to Walker's algorithm allow our Unity hierarchy asset to generate radial hierarchies, as shown in the diagram on the right in Figure 6.

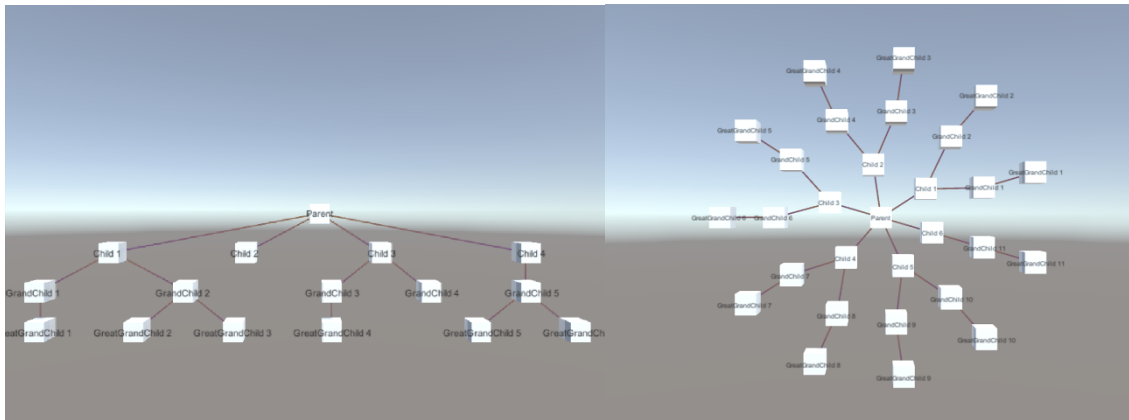


Figure 6. Example of dynamically generated hierarchy diagrams created from GENESYS data using a custom Unity diagramming asset.

Because each node of the hierarchies generated by our custom Unity asset is an interactable Unity game object, it is a straight-forward matter to enhance a Unity scene with such a hierarchy and context-driven data connections to other elements of the scene. For example, Figure 7 demonstrates interactive links between hierarchy diagrams generated from GENESYS systems engineering data and notional CAD objects. While the CAD objects are shown as cubes in this example for simplicity, as with the hierarchy diagrams described above, any 2D or 3D object that can be rendered in Unity could be used. By linking diagrams and 3D representations in this way, we can create Figure 7an additional dimension of intuitiveness when exploring MBSE and CAD data.

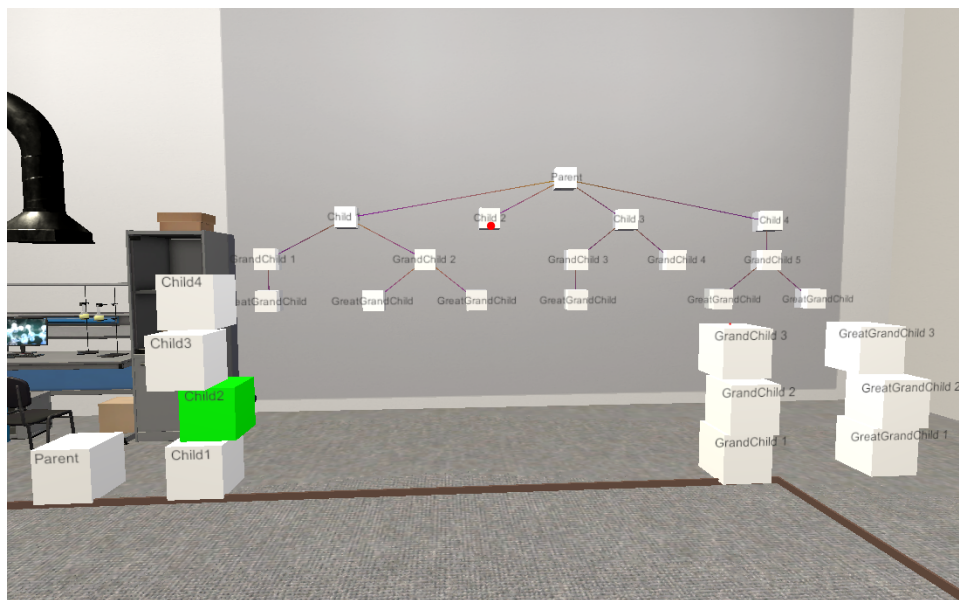


Figure 7. Demonstration of dynamically generated hierarchy diagram. When a user interacts with the hierarchy diagram, the associated CAD model is highlighted, and vice versa.

Discussion

Conventionally, design and product reviews with stakeholders and customers have been accomplished using slide decks with voiceover requiring a knowledgeable team member to be present as an interpreter. Although slide decks can be effective in communicating requirements, context is crucial to communicating and understanding the details of large, complex systems [7]. One way to address this challenge is to employ interactive game-engine based tools to enhance data connectivity across engineering. Such tools can offer intuitive, visual methods for communicating and maintaining data, information, knowledge, and wisdom.

Combining and compiling model-based engineering data across tools and engineering disciplines presents a significant data and tool interoperability challenge. To address this challenge, RDF and the Unity cross-platform game engine were used to develop a visually driven digital thread between CAD and GENESYS tools. CAD by itself is an excellent tool for visualizing and understanding geometry requirements; however, it lacks the ability to effectively visualize and communicate different relationships at the component and system level. On the other hand, MBSE tools enable a user to model and understand different relationships and multidisciplinary requirements but lack a physical context. The Unity game engine allows us to combine information from both types of tools and visualize GENESYS component metadata and GENESYS hierarchical requirements information overlaid onto a CAD model. Although RDF is being used currently as a central, common format solution for data representation and model interoperability, larger efforts are also underway to implement data transformation and tool interoperability solutions on a much larger scale.

In the present work, we have demonstrated an interactive desktop and VR application to help users understand the connections between different disparate and multidisciplinary datasets. This and similar tools will improve data connectivity between disciplines, enabling faster convergence and identification of potential mistakes earlier on in the product development lifecycle. These tools further enable key decision makers to become semi- “experts” in a shorter amount of time, which facilitates better-informed decision making and convergence [8]. In addition, such tools can be leveraged during all aspects of a system lifecycle, including as a knowledge management or training tool. Another key benefit is that users of these tools are not required to have extensive domain-specific knowledge in order to navigate datasets; rather, they can explore pre-connected datasets in a user-friendly environment by using the game engine application (VR or desktop). We are also exploring other types of visualization tools and platforms, including Alteryx, Tableau, and D3.js, in order to better understand how to improve data connectivity and enhance data visualization for different audiences.

Conclusion

The communication of complex system requirements from both abstract and context-driven perspectives is necessary to effectively understand multidisciplinary systems. We have demonstrated visualization of connections between MBSE, MBD, and MBE datasets by leveraging the commercial Unity game engine. Use of AR/VR tools enables immersive 3-dimensional exploration of complex and disparate datasets without the need for in-depth

knowledge of domain-specific tools. Further, extensions to the captivating 3D environments provides an additional layer of intuitiveness and physical context thus enabling non-experts to converge faster and make better informed decisions [9].

Future work will explore the visualization of different types of relationship data from static MBSE tools including functional-flow architectures and specialized, multi-dimensional hierarchies. We are also investigating methods of incorporating additional domain-specific data and contexts (electrical, radiation, thermal, etc.) in a multi-user collaborative environment to enhance connections between tools. Further, we are evaluating ways of expanding these capabilities to different areas of the digital engineering transformation to enable more dynamic connections to data for verification and validation efforts, manufacturing, training, and beyond.

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