Federal Register Notice: 89 FR 51554, Federal Register :: Networking and Information Technology Research and Development Request for Information on Digital Twins Research and Development, June 18, 2024.

Request for Information on the National Digital Twins R&D Strategic Plan

Synopsys

SYNOPSYS® | [redacted]

28 July 2024

Melissa Cornelius
Technical Coordinator, National Coordination Office (NCO)
Networking and Information Technology Research Development Program (NITRD)
[redacted]

RFI Response: Digital Twins R&D Plan

Dear Ms. Cornelius,

Synopsys, an American company, and core component of the chip design value chain, has extensive capabilities in process simulation and systems emulation. We are pleased to have the opportunity to respond to the Networking and Information Technology Research and Development Request for Information on Digital Twins Research and Development, and to inform the development of the Digital Twins R&D Strategic Plan. Our response to this RFI is contained in the following pages.

A Digital Twins R&D Strategic Plan is critical to align and encourage advancement of digital twin technology, acceleration of use, and early adoption of models. Thoughtful review of substantial existing investments in proprietary digital twin technologies as well as the challenges will increase innovation in digital twins and provide significant benefits to the U.S., such as virtual manufacturing floors to discover ways to improve products and expedite processes. Currently, the U.S. lacks a comprehensive lab environment for developing and validating digital twin technology (something that the CHIPS Manufacturing USA Digital Twin Institute seeks to develop).

This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Digital Twins R&D Strategic Plan and associated documents without attribution.

Thank you for the opportunity to share our perspective on digital twin technology development and enhancement. Please alert us to opportunities where our expertise can help move this initiative forward.

Best,
Dale

Dale Donchin

Dale Donchin
Principal Engineer
Synopsys
[redacted]

Introduction

Digital twins, as virtual stand-ins for their physical counterparts, enable essential requirements of simulation, verification, compliance, optimization, performance, functionality, exploration, and several other types of analysis without perturbation of the process or object they represent. This capability provides valuable knowledge of the physical entity without needing to manipulate it directly. For example, digital twins can predict how an aircraft will behave during a catastrophic failure without destroying the plane.

As stated in the 2024 National Academies Report, Foundational Research Gaps and Future Directions for Digital Twins, "Digital twins are emerging as enablers for significant, sustainable progress across industries." The wide range of applications include medical (treatment efficacy), climate (correlation of weather, emissions, and other factors), business (ROI analysis), and microelectronics (manufacturing yield). As noted in the RFI, a variety of factors must be considered that are common to all digital twin instantiations.

The focus for Synopsys is on digital twins for semiconductor manufacturing through in-field products, covering the wide spectrum from atoms to systems. Synopsys has expertise in several of these areas, notably **Data, Ecosystem**, and **Standards**.

About Synopsys

Synopsys is an electronic design automation (EDA) company providing chip design and verification, silicon intellectual property, and software security and quality. Synopsys delivers the most trusted and comprehensive silicon-to-systems design solutions, from electronic design automation to silicon IP and systems, that accelerate technology innovation. We partner closely with semiconductor manufacturing and design customers across a wide range of vertical markets to maximize their R&D capability and productivity, powering innovation today that ignites the ingenuity of tomorrow. In a world where the pace and complexity of innovation is accelerating, the entire silicon ecosystem trusts Synopsys to pioneer new technologies and help them get to market faster without compromise. Our products support chip design, manufacturing, and product digital twin development and utilization. Digital twin capabilities are already present in many of the Synopsys tools, including Sentaurus TCAD, Fab.da, and Silicon.da ("da" is an acronym for "data analysis").

Data

There are many methods for data representation and without proper thought and practice, incompatibilities arise as do implementation of proprietary formats. This is of utmost concern to digital twins since the intention from the outset is interoperability and use across a wide ecosystem and virtual models of many physical properties. Synopsys suggests consideration of the following data-related topics and provides recommended best practices.

Separation of data and access: Digital twin data contains the information necessary to model the digital twin's corresponding physical object and storage and access methods that present its interface to its compute environment, including API protocols and how information flows bi-directionally (ex. to/from sensors and simulation models). The access methods enable extensibility and portability of digital twins as the type of information, or the type of interface, changes. The separation of data and access also enables the model and its interoperability to evolve independently. Changes to the model, for example, to correct or enhance its performance, can replace the instantiation of a prior version of the digital twin. Meanwhile, changes to the interface, for example, to extend it to be used for future analysis tools, doesn't jeopardize how the model performs. This guidance has its roots in user interface architecture ("MVC"), where the Model of the data is distinct from how it's presented (View) and the interface (Controller) that supports the information transfer. The differentiation of these aspects enables the same information to be easily ported between, for example, different mobile phone models and orientations (vertically/horizontally held) and input styles (ex. keyboard, stylus).

Synopsys recommends that this best practice from the user interface domain carry forward to digital twin data. The model information and how it's connected to its consumer/provider must be defined separately. This suggestion protects confidentiality in that the interface can hide the implementation.

Methods for preserving confidentiality: Confidentiality is a concern with digital twins, as the processes they model may be proprietary, and can represent sensitive recipes, trade secrets, or contain anomalies not intended for public disclosure. There are several methods to mitigate this concern. One approach is to encrypt the digital twin data or employ homographic computation. However, in some instances, this might not provide sufficient protection if enough of the proprietary behavior is observable at the interface level. In this case, the interface itself may need to be encrypted or tied to a specific data "owner." This approach requires secure management of a decryption key, which raises issues of its own. An alternative option is to share only low fidelity digital twins that limit reverse engineering attempts.

Distributed data access: Data is also distributed, with different players in the value chain that have their own data. Access to data across the value chain makes the digital twins useful for end users. Training models on this distributed data without one entity having access to all the data, like federated learning, would be beneficial.

Benefits of varied model fidelity: Fidelity, the accuracy of the digital twin's representation of its physical manifestation, is a critical data aspect. While high fidelity is encouraged, as noted earlier, there are reasons to have models of varied fidelity. In fact, initial models may be low fidelity with their accuracy increasing as more experimentation and tuning occurs. The digital twin's fidelity must have a method for measurement, an understanding of the factors that may impact it (ex. aging), and a way to associate and document the accuracy of a digital twin.

Digital twins that mimic physical effects prone to change need a calibration procedure and recommendations for how often that process should be performed. For example, digital twins of climate behavior must adapt to and be calibrated at different temperatures, levels of humidity, air particulates, and similar real-world phenomenon. This is also true of AI-enabled digital twins that require training data. Using digital twins properly entails knowledge of their calibration requirements and how recently they were met.

Importance of unique identifiers: Since digital twins differ in their maturation stage, fidelity, modelling approach, enhancements and optimizations, and other attributes, a version identifier must be associated with each of them. This implies that a digital twin model has companion metadata that, at a minimum, specifies its version. Other metadata should include its author, its fidelity and calibration data mentioned earlier, and other aspects that describe it. The JSON format is a recommended format for the metadata file since it's human-readable, well-supported, easily parsed, and extensible.

Accounting for external factors: In the physical world, various entities interact with each other. Often, this interaction entails the behavior of one entity affecting the behavior of another. For example, when billiard balls collide, the direction and velocity of both changes. If this event were to be modelled using a billiard ball digital twin, mimicking the behavior of each requires bi-directional data transfer between them. Therefore, digital twins must be capable of not only modeling their physical counterpart but also reacting to external conditions. Implementation of digital twins requires inputs at their "outside" interface that affect the processing of the model "inside." For some ecosystems, the exchange of information between digital twins is continuous vs. one-time. Analysis of digital twin output must consider waiting for the digital twins to reach their steady-state values, which isn't a guaranteed outcome. This situation has consequences for both digital twins and the tools that perform their analysis.

Advantages of hierarchy simulation: Digital twins can stand in for very granular physical entities, such as one of the hundreds of manufacturing steps in the production of a semiconductor wafer or represent the entire wafer creation process. In the latter case, virtual simulation at a top-level may be implemented by utilizing lower-level digital twins. This is commonly called hierarchy. Digital twin creation should consider its use within another digital twin, or twins, forming a hierarchy of virtual representation. This consideration affects the "outside" of the digital twin, since the API must not only be bidirectional for input/output source/result transfer but also support data coming from/going to another digital twin. Hierarchy is a popular method of simulation. It's advantageous to isolate behavior to a low-level module that's referenced from higher-level routines. A change (bug fix or enhancement) in the low-level digital twin is reflected in all higher-level instances where it's referenced. Without hierarchy, that same change must be made in multiple places, introducing potentials for error in making the change and propagating it to all necessary instances.

Data management, provenance, and verification: Finally, digital twin models, the metadata referenced earlier, and the data they produce are valuable and require management, including backup and access controls. The storage system must enable provenance and integrity verification, providing authentication and anti-tamper assurance.

Ecosystem

A collaborative and open approach to digital twins is necessary to interoperate with the many current and future suppliers of the physical entities that jointly create physical processes and products. For example, a manufacturing plant contains equipment and consumes components from diverse companies and relies on a complex and global supply chain. Modelling that environment using digital twins requires flexible and common methods supporting companies individually and collectively as the final product depends on the contribution of each step and their interactions.

Synopsys offers several recommendations to create a harmonious digital twin ecosystem that spans multiple use cases.

Importance of interface interoperability: It's envisioned that several digital twins can be part of an end-to-end flow that model a broad ecosystem. This can be achieved through a series of hierarchical digital twins as mentioned earlier in this response (vertical ecosystem) or through an end-to-end connection (horizontal ecosystem). The prior section's discussion of digital twin data recommendations provides requirements for their use in an ecosystem.

Chief among digital twin requirements for use in an ecosystem is interoperability of its interface. An ecosystem typically involves different digital twin authors and must support stitching them, and any analysis tools, together. Thus, digital twin ecosystems are only possible when their interfaces are vendor agnostic and well-documented (see Standards section below). Note that this doesn't prevent the data representation from being proprietary.

Hardware emulation to mitigate compute requirements: Synopsys is especially interested in the digital twin ecosystem that's required as components scale from atoms to systems and beyond. EDA tools can simulate the many digital twin models that comprise an end-to-end flow from parts to products but trade-offs between computation and wall clock must be considered.

The performance of such a flow may suffer if a great amount of compute resources is required. Creation of an environment containing the stimulus for the digital twins, for example, varying their inputs and analyzing their outputs, is required. The use of digital twins doesn't stop with just having them – something must measure how they behave when subjected to the same conditions experienced by their physical counterpart. The ecosystem is thus beyond having the digital twin virtual representations. An environment is necessary that provides inputs, collects outputs, and performs analysis. As noted previously, that environment must consider the time requirements for digital twin processing, which is likely much slower than their physical counterparts. Training of AI-based models may also be required. These considerations amplify the compute processing needed.

Synopsys recommends the use of hardware emulation to mitigate high processing requirements. Hardware emulation uses hardware-based systems for concurrent software and hardware processing. As a result, they can be multiple orders of magnitude faster than software-based simulation. The hardware emulator (ZeBu™ is the Synopsys hardware emulator product) can also connect to many types of other hardware. This capability enables simulation of an entire ecosystem comprising both physical and digital twin elements.

Establishing a digital twin repository: The entity creating a digital twin ecosystem must source those models from a diverse community of digital twin authors. Availability and support are key factors. Synopsys recommends that a digital twin "store" is established to address these aspects of ecosystems. There are multiple methods to create this "store." A simple approach is the creation of a "Git" repository, which is commonly used to expedite shared content. Digital twins and support may also be provided by their authors as products and services. A collaborative consortium of digital twin providers is another possible mechanism. None of these methods are mutually exclusive. Whichever approach is undertaken, it's important that security concerns including authentication and integrity are considered. Similarly, digital twins should always be supplied from a trusted source.

Digital twin licensing: Digital twins have value, require access controls, and may be updated or revoked. Licensing is a means to respond to these digital twin properties. Licenses, which are granted, enforced, and tracked by license management applications, enable a digital twin supplier to specify the user, user's access type, usage permitted, and access duration, among other aspects. IP licensing is well-established in the semiconductor industry; however, it may not resolve all issues associated with digital twin usage. This is due to license controls placed outside of the IP.

Technical documentation: Comprehensive documentation is necessary to tie disparate digital twins together. This is analogous to integration guides that accompany semiconductor IP products, illustrating how they are configured, validated, and connected to other components in the ecosystem. Like the digital twins themselves, the documentation must be version controlled and provide a means to associate it with the corresponding IP version.

Identifying use case and audience: An important ecosystem consideration is defining the use case and audience. For example, the ecosystem may be intended for observation and analysis of the process that creates a product or the behavior of the product itself. Those interested in the results may be equipment vendors, operators, or application users. The degree of fidelity required may be minimal or of high accuracy. The audience could be university researchers, commercial firms, defense contractors, or end users of the product or function. The diversity of the audience impacts the cost, value, and benefit. Thus, there could be several ecosystems for the same or similar set of digital twins, each appropriate for who the audience is, their expectations, and intended benefit. Addressing reliability and security are primary requirements.

Standards

Synopsys enjoys a long tenure chairing and participating in many industrial standards committees and forums and is eager to share our experience for the benefit of digital twin standardization.

All ecosystems require industry standardization to be viable. Compilation, agreement, adoption, and compliance to common practice enable existing and new entrants to effectively communicate and interchange content. For digital twins, this includes data exchange protocols, tutorials and examples, community engagement and discussion, oversight, and public dissemination.

Standardizing communication through backplanes: As noted earlier in this document, the interface allowing digital twins to communicate with each other must be standardized. One implementation approach is to have each digital twin interact with a "backplane" instead of each other. An advantage of this method is that the digital twins only need to talk to one type of interface. The digital twin backplane can be the entity that supports different digital twin communication channels. A backplane also enables tracking and management of the digital twins collectively since it's the bridge over which all digital twin communication occurs. Backplanes are common interface technology. Synopsys suggests the same approach for digital twin communication.

Interface heterogeneity between digital twins and physical counterparts: Digital twins may communicate with its corresponding physical entity. The twin may receive data, perhaps needed to train an AI model, and/or transmit data, for example to affect a change in the ecosystem. Synopsys believes that standardizing interfaces to equipment will be difficult due to the vast diversity of equipment types, vendors, data and operational sensitivity, and other concerns. We recommend that the interface between the physical entity and its digital twin counterpart be free of standards and compliance restraints, with communication to/from the digital twin and the rest of its ecosystem achieved through the backplane approach mentioned above.

Benefits of initial voluntary standards: Standards can be of the "should" type or the "must" type. The former suggests adherence to a standard whereas the latter demands it. Digital twin development, while not at its infancy, has much room to grow. Accordingly, the "should" type is recommended at this stage of maturation.

Once "should" standards evolve to the "must" type, compliance tests need to be created by the standards body and certification given to those digital twin developments that can demonstrate adherence to the standard's dictates. Compliance test generation and validation of meeting requirements is a large undertaking. This is another reason why Synopsys suggests "should" terminology at standardization outset.

User group involvement: User groups aren't standards committees, but they serve a valuable role supporting them and helping others understand, debug, and comply with them. There are countless user group forums that exist in almost every domain, technology and otherwise. Synopsys recommends a similar notion to build a digital twin community.

Conclusion

Digital twins are becoming increasingly prevalent across multiple industries for virtual representation of physical behaviors. Synopsys welcomes this opportunity to share expertise and suggestions toward the successful deployment and use of this technology in all their applications, given our role in atoms to systems microelectronics.

A Digital Twins R&D Strategic Plan is critical to align and encourage advancement of digital twin technology, acceleration of use, and early adoption of models. Thoughtful review of substantial existing investments in proprietary digital twin technologies as well as the challenges will increase innovation in digital twins and provide significant benefits to the U.S.