SystemC and Digital Twin: Good match or Not?

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Outline

- Introduction
- Introduction to the Digital Twin
- Digital Twin commercial offerings
- Open source initiatives
- Simulation concepts
- Q&A
- Conclusions and recommendations
- Proposed next steps

Introduction

- This talk will present the opportunities and challenges of bringing the SystemC and Digital Twin worlds together
  - Is it feasible to integrate a SystemC eco-system with a Digital Twin ecosystem?
  - Is the SystemC language suitable to model a complete product or systems-of-systems?
  - Does it actually make sense to combine the SystemC and Digital Twin worlds?
- Explore SystemC standardization opportunities to address seamless integration of these (still separated) ecosystems

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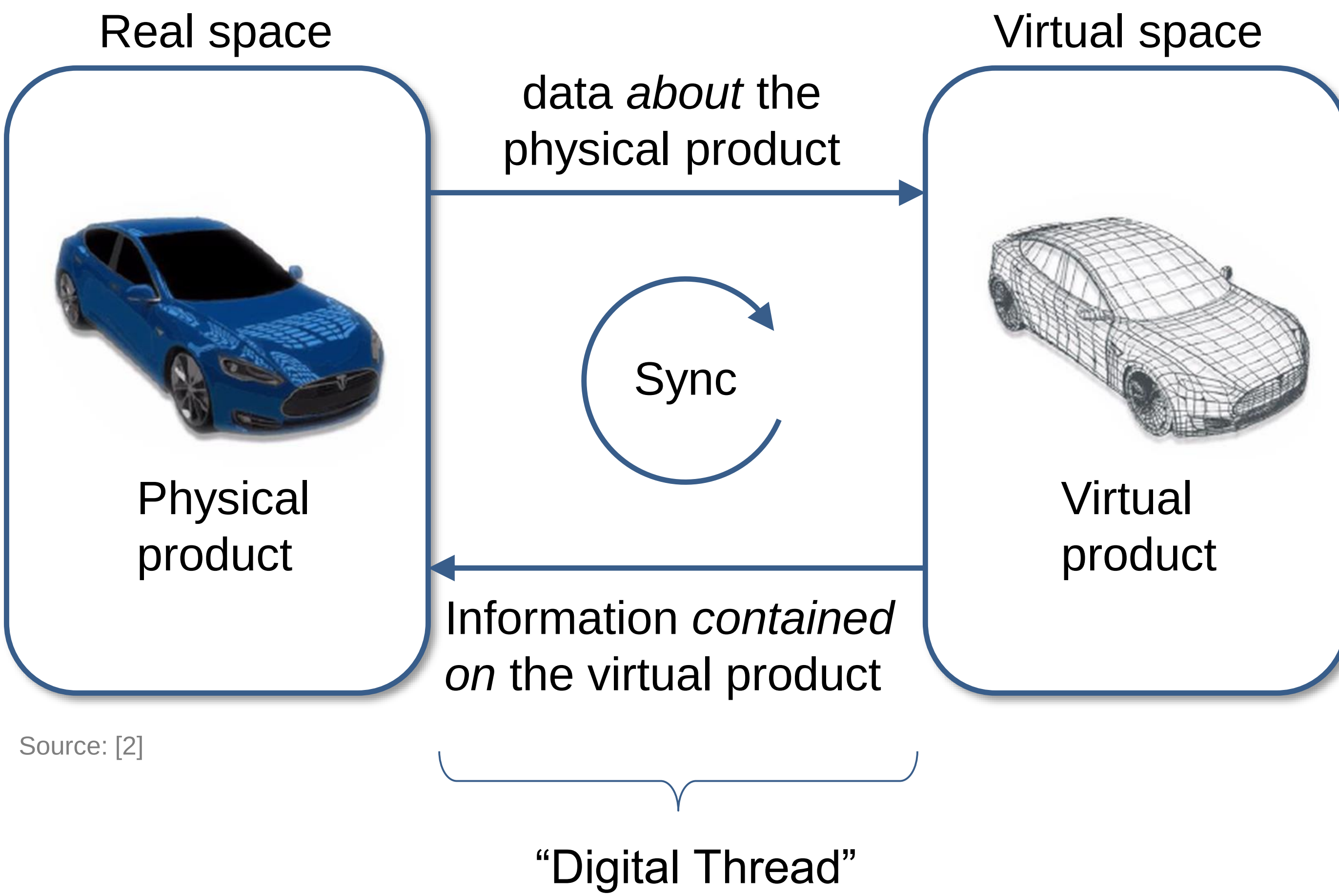
What is a Digital Twin?

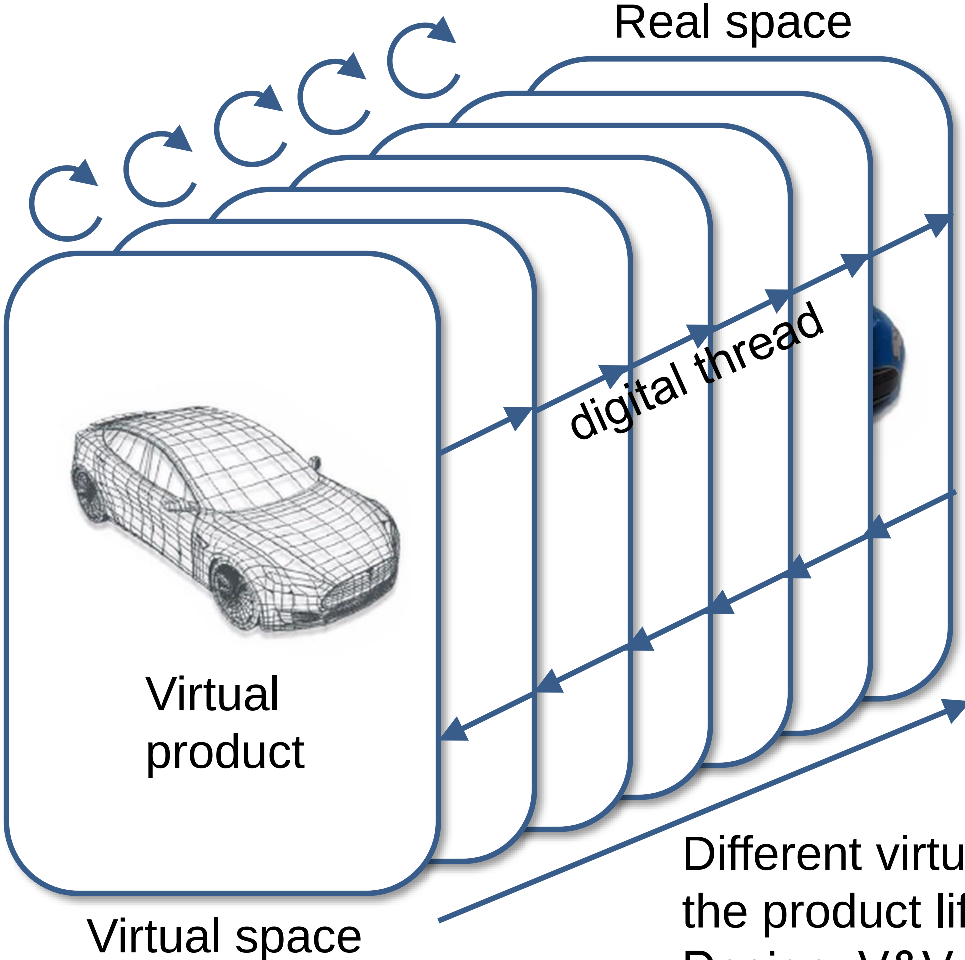
- Concept introduced in 2003 by Dr. Michael Grieves at the University of Michigan, as part of the Product Lifecycle Management (PLM) curriculum
- The Digital Twin is a dynamic virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning [1]
- The Digital Twin concept contains three parts [2]
  1. Physical product in real space
  2. Virtual product in virtual space, and
  3. Data and information flow between these worlds

What is a Digital Twin?



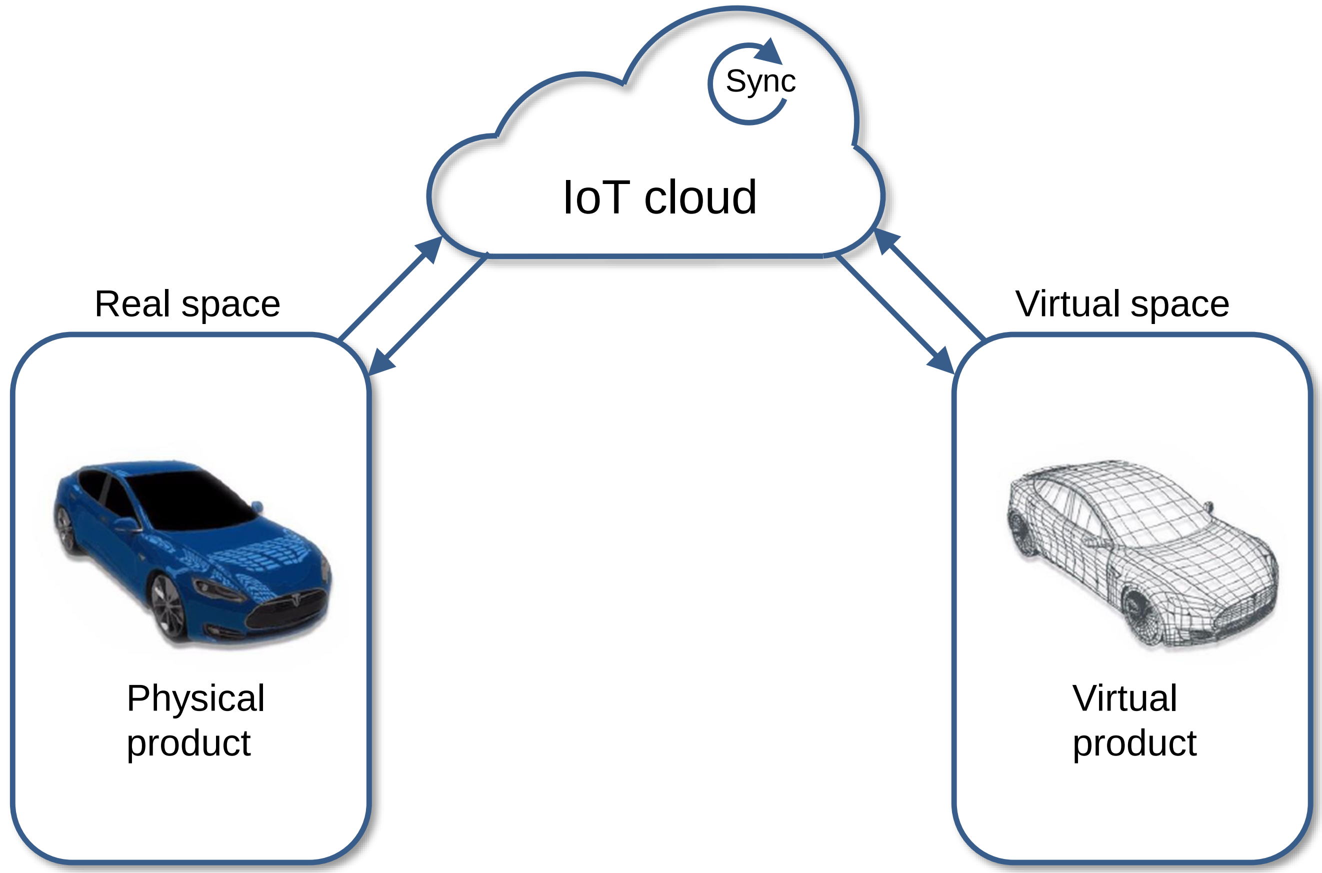
Source: [2]

What is a Digital Twin?



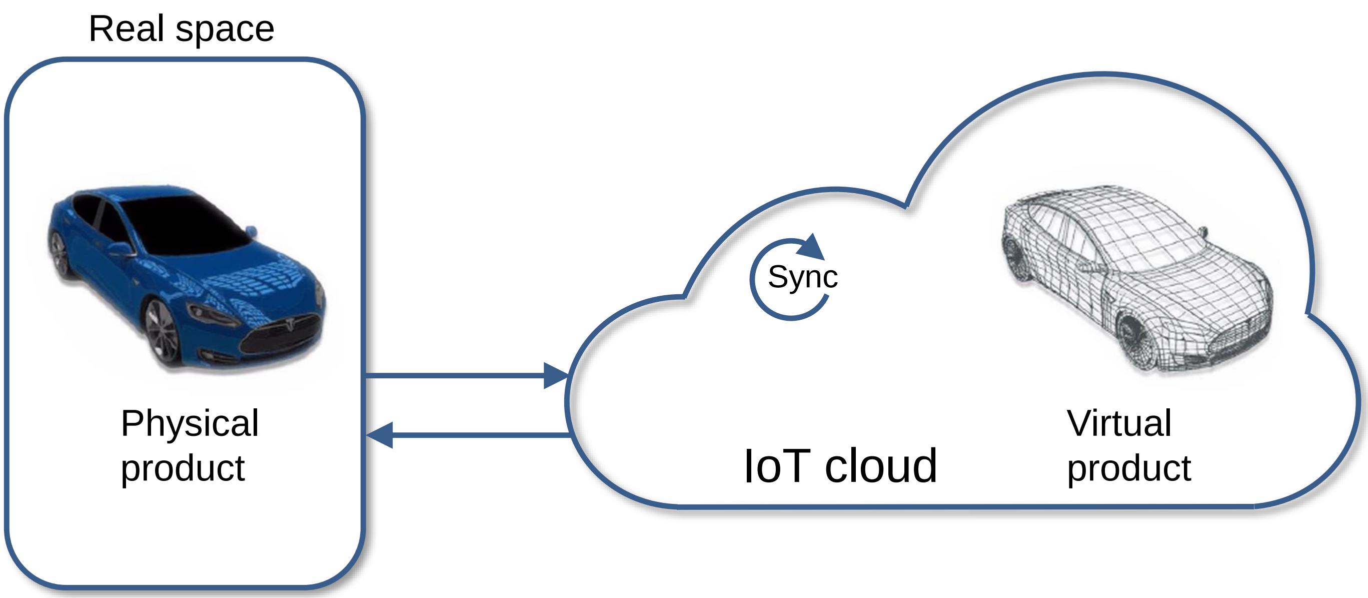
Different virtual representations during the product lifecycle (e.g. Concept, Design, V&V, Test, Manufacturing, …)

What is a Digital Twin?



Variant: IoT and cloud technology enable remote control, monitoring, or analysis even after the delivery of the physical product

What is a Digital Twin?



Variant: The virtual counterpart of the Digital Twin ‘runs’ in the cloud and remains in close contact with its physical counterpart

Benefits of a Digital Twin

- *Unambiguous specification*: Executable descriptions to document the intended behavior of the product
- *What-if analysis:* Interact with the virtual product (model) to simulate various conditions that are impractical or costly to address in the real world
- *Early system validation:* better understanding how the physical product will perform in the real world
- *Traceability*: Link the different PLM phases provided by the digital thread (e.g. IoT / cloud platform)

Digital Twin – Main disciplines

Visualization
3D geometry
Virtual Reality
Augmented Reality

Simulation
Multi-domain
(electronics, mechanics, software, …)
Inter-domain
(MIL, SIL, PIL, HIL)

Communication (IoT)
Data acquisition
Sensor/actuator control
State propagation
Software-of-the-air

Emerging Markets using Digital Twin

Automotive

Autonomous driving
Electrification
Smart mobility

Industry 4.0

Advanced robotics
Smart factories
Additive manufacturing

Healthcare

Health monitoring
Human body modeling
Therapy and treatment

Smart Cities

Smart power grid
Traffic management
Urban planning

Digital Twin commercial offerings

Siemens	**Simcenter**: 3D CAE modeling platform supporting multi-domain simulation (Amesim), system simulation, MBSE, automotive driving scenarios (Prescan), embedded SW dev tools
Ansys	**Twin Builder**: multidomain systems modeling and simulation incl 3D physics solvers and reduced-order model (ROM) capabilities. Can be combined with embedded SW dev tools
Dassault Systèmes	**3DEXPERIENCE Twin**: Build on top of the 3DEXPERIENCE platform offers virtual simulation, analysis and testing in a 3D virtual reality
PTC	**Creo**: 3D CAD modeling and simulation platform offering capabilities for Additive Manufacturing, IoT, Model-Based Definition and Augmented Reality

Observations

- Many commercial offerings have their origin (and focus) in 3D CAE and mechatronic system simulation
- Each provider offers a rather fragmented mix of tools to address the 3-disciplines of Digital Twins
- Some tools embed multi-physical system simulation
- Most tools support model exchange and/or co-simulation using the Modelica-based Functional Mock-up Interface / Unit (FMI/FMU)
- Integration of embedded systems (HW/SW) is weak

Open Source Initiatives

Open Simulation Platform

The Open Simulation Platform (OSP) initiative develops an open source digital platform to create Digital Twins of ships

Source: [3]

OpenADx

OpenADx is an Eclipse project to accelerate development of autonomous driving through collaboration and open source

Source: [4]

GAZEBO

ROS

Gazebo/ROS is a robot simulation platform combining the 3D rigid body simulator with the Robot Operating System (ROS)

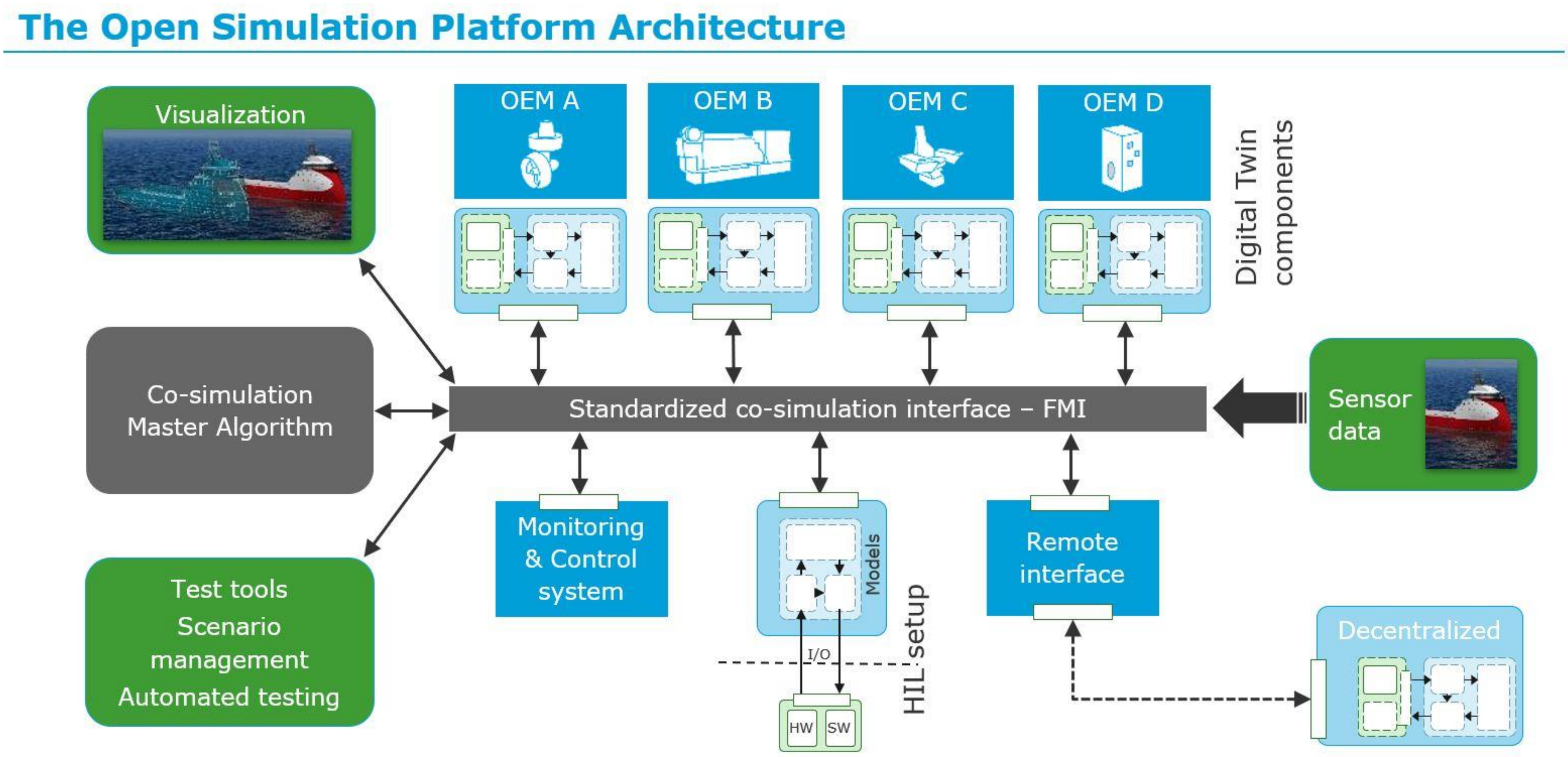
Source: [5]

Open Simulation Platform

- 2-year Joint Industry Project (JIP) initiated by DNV GL, Rolls-Royce Marine, SINTEF and NTNU
  - Project running from September 2018 to Spring 2020
  - Members from 20 maritime industries from Norway, Germany, Netherlands, Austria, Japan, China and Korea
- Objective to establish an ecosystem for collaborative Digital Twin simulations of ships, to solve challenges with designing, commissioning, operating and assuring complex, integrated systems
- Project is developing an open source Core Simulation Environment (CSE) and defining modelling guidelines and interface standards to support model reuse and creation of model libraries

Open Simulation Platform

Open Simulation Platform

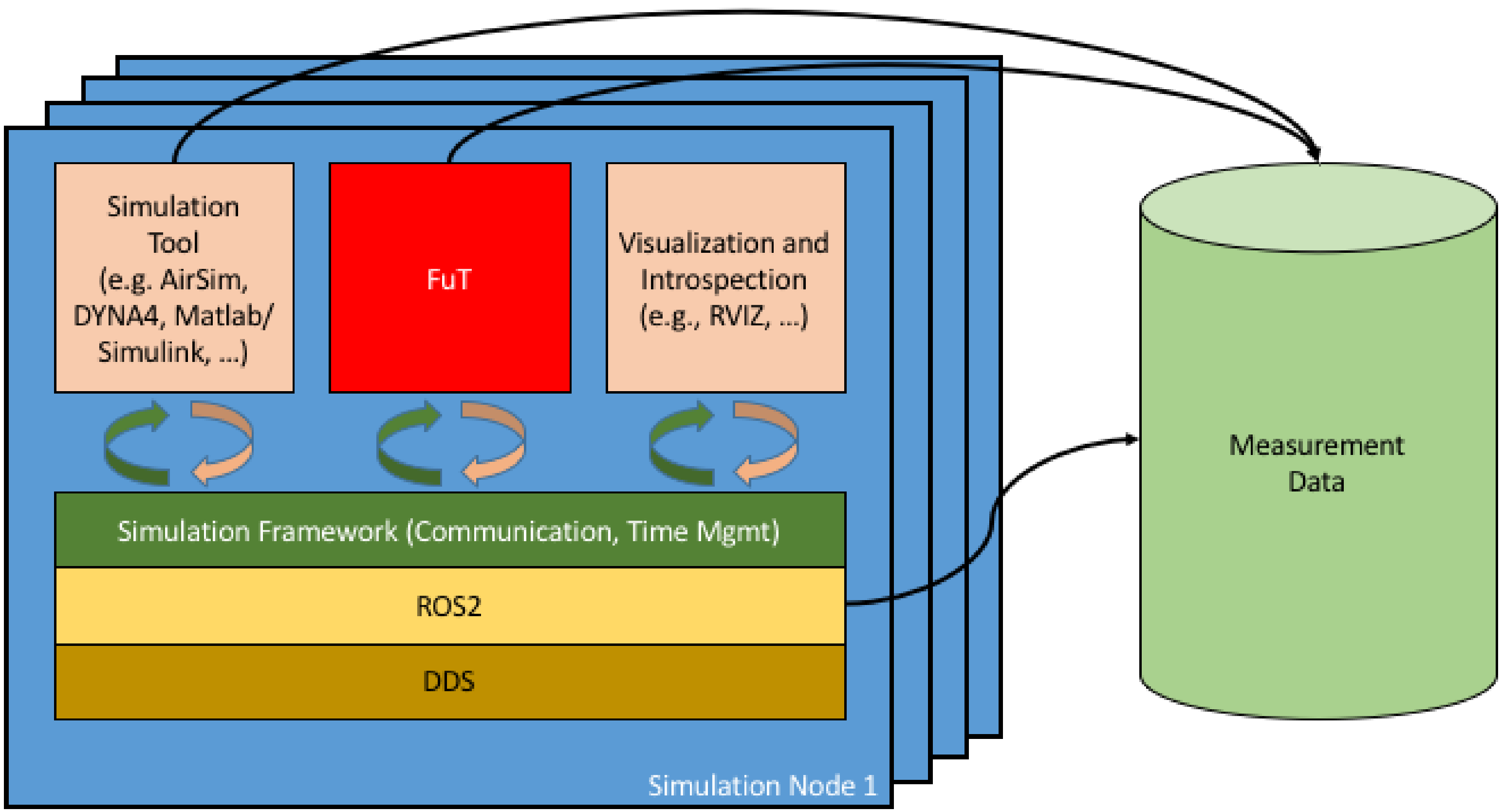


Source: [6]

OpenADx

- OpenADx Working Group started under the Eclipse Foundation in August 2019
- Objective is to develop an industry-wide accepted definition of the toolchain for Autonomous Driving
  - Supported by a reference architecture and open source software
- First members: AVL, Bosch, Eteration, IBM, itemis, JCIM, Red Hat, and Siemens
- Eclipse Cloe (Closed Loop Simulation Environment for Automated Driving) is the first pilot project
  - Focus on defining a standard for interoperability between various simulation tools and the software in development with support for multiple autonomous driving software architectures

OpenADx – Base Architecture

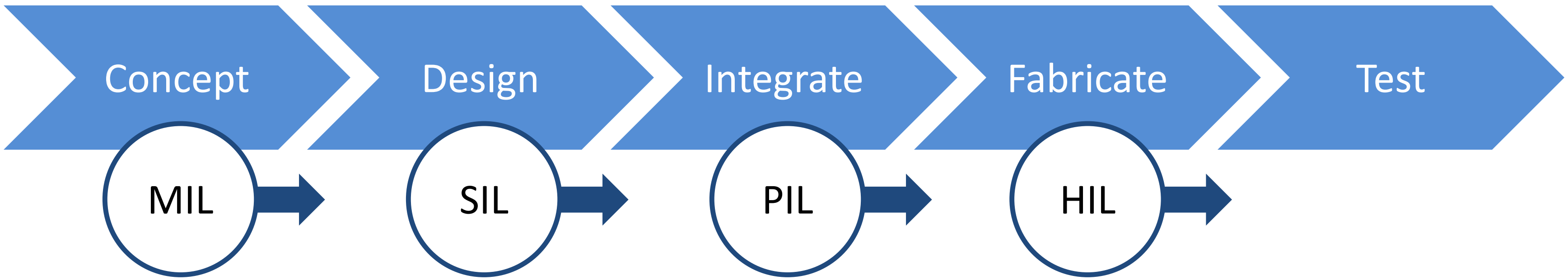


Source: [4]

Gazebo / ROS

- Gazebo and ROS are hosted under the Open Source Robotics Foundation since 2012
  - Gazebo development started in 2002 at the University of Southern California. First ROS code was submitted to SourceForge in 2007
- Gazebo is a 3D dynamic simulator incl. multiple physics engines, models for sensors, robots and environments (‘worlds’) models. ROS API is available to get/set various aspects from the simulated world
- Established applications: Robots, Drones, Rovers
- Gazebo/ROS not developed for Digital Twin, but offers technologies compatible with the Digital Twin concept

Simulation concepts



- Model-in-the-Loop (MIL): The product and its environment are simulated in the modeling framework without any physical hardware components
- Software-in-the-Loop (SIL): Embedded software is executed in the modeling framework representing the application without any hardware
- Processor-in-the-Loop (PIL): The embedded software is executed on the processor hardware which is connected to the modeling framework representing the application
- Hardware-in-the-Loop (HIL): The product in hardware is validated which is connected to the modeling framework representing the application

Observations

- Disjoint simulation flow from MIL to HIL
  - Different models (abstraction-levels), languages and tools (simulation or hardware) are used, limiting reuse
  - No standardized interfaces
- Fast (co)simulation is crucial, but not always achieved
  - Required to run 1000s of 'real-life' test scenarios, replacing and extending traditional 'field trails'
  - Achieve simulation-based run-times within real-time constraints (essential for hybrid setups such as PIL and HIL)
  - Current WoW: C-code generation to dedicated OS/platforms
- Limited adoption of SystemC in these domains

Q&A

- Q1: Is it feasible to integrate a SystemC eco-system with a Digital Twin ecosystem?

- A1: Yes, it is feasible, but it requires a more *top-down* approach rather than a *bottom-up* approach for standardization and API development

- Approach: What is needed (API) to embed SystemC (models) *in the bigger* system?
  - Instead of: How can we model *everything* in SystemC?

Q&A

- Q2: Is the SystemC language suitable to model a complete product or systems-of-systems?

- A2: In its current form, probably not, and should be avoided (see A1)
- Missing concepts
  - Distributed simulation / co-simulation API
  - DDS and/or ROS2 interface
  - (Meta)Model encapsulation / interoperability standard

Q&A

- Q3: Does it actually make sense to combine the SystemC and Digital Twin worlds?

- A3: Yes. There are several initiatives which would benefit by introducing or expanding towards ESL based simulation and modeling
  - Encapsulation using FMU/FMI not efficient for all type of models
  - Not many commercial offerings support systems-of-systems modeling and simulation under real-time conditions

Conclusions & Recommendations

- Digital Twin is an emerging domain
  - Different interpretations, concepts and solutions proposed (addressing different use cases and problems)
  - Complex and scattered tool landscape (PLM)
  - Integration strategy of embedded HW/SW systems in Digital Twins still an open topic
- SystemC could become an important *piece of the puzzle*
  - Mindset change: How to embed SystemC in the bigger system
  - Prerequisite: distributed simulation and model encapsulation
  - Consider participation in other community initiatives: Broaden collaboration to develop an open and standardized simulation and tool framework

Proposed next steps

- Revitalize SystemC Evolution WG
  - Explore interfaces and APIs to focusing on standards for tool and/or model interoperability
    - DDS and/or ROS2 interface
    - (Meta)Model encapsulation / interoperability
- Explore standardization partnership or collaboration with other organizations
  - Select matching consortiums and initiatives: OpenADx, AVCC, Autoware, Apollo, …

References

[1] IBM, https://www.ibm.com/internet-of-things/trending/digital-twin

[2] Michael W. Grieves, *Digital Twin: Manufacturing Excellence through Virtual Factory Replication*, 2014

[3] Open Simulation Platform, https://opensimulationplatform.com/

[4] OpenADx, https://openadx.eclipse.org/

[5] Gazebo Simulator, http://gazebosim.org/

[6] DNVGL, https://www.dnvgl.com/feature/open-simulation-platform-osp.html

[6] Apollo, http://apollo.auto/

[7] The Autoware foundation, https://www.autoware.org/

[8] The Autonomous Vehicle Computing Consortium (AVCC), https://www.avcconsortium.org/