Expériences et défis scientifiques des jumeaux numériques

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mostly borrowed from A. Wortmann

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Full Professor of Software Engineering @ University of Rennes
Computer Science Department (former head) @ Engineering School ESIR
Co-head of the DiverSE team @ IRISA & Inria

Agility and safety in the development of complex software-intensive systems

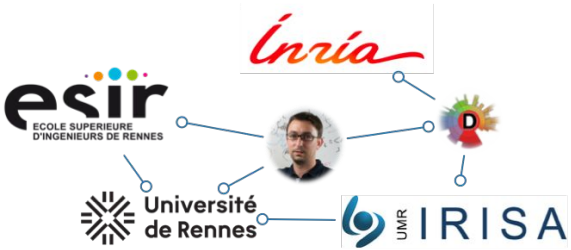
Research interest in Software and Systems Engineering, incl.: Model-Driven Engineering, Software Language Engineering, Domain-Specific Languages, Software-Product Lines, Software Validation & Verification, Resilience Engineering, Scientific Computing, Sustainable Digitalization, ICT for Sustainability.

Application domains: (smart) cyber-physical systems (transport, defense), internet of things (telecommunication, cities/farming, industry 5.0) and environmental sciences (climate change, sustainability).

Editor-in-Chief of the Journal on Software and Systems Modeling (SoSyM), Spring Nature
Editor for the JOT (former Deputy Editor-in-Chief) and SQL Journals
Steering Committee member of the MODELS, SLE and ICT4S conferences

Chief Science Advisor at TwiinIT
Scientific Advisor in Software and Systems Engineering
Collaborations with Airbus, Safran, Thales, Orange, CEA, DGA, Obeo, Akka...

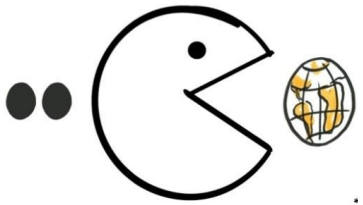
Working group and open-source project leader at the Eclipse Foundation



“Software Is Eating the World”

Digitalization of our society

- personal context (health, music, video, social networks…)
- professional context (digitalization of numerous processes and activities)



THE WALL STREET JOURNAL.
WSJ.com

ESSAY | AUGUST 20, 2011

Why Software Is Eating The World

By MARC ANDREESSEN

This week, Hewlett-Packard (where I am on the board) announced that it is exploring jettisoning its struggling PC business in favor of investing more heavily in software, where it sees better potential for growth. Meanwhile, Google plans to buy up the cellphone handset maker Motorola Mobility. Both moves surprised the tech world. But both moves are also in line with a trend I've observed, one that makes me optimistic about the future growth of the American and world economies, despite the recent turmoil in the stock market.

In short, software is eating the world.

More than 10 years after the peak of the 1990s dot-com bubble, a dozen or so new Internet companies like Facebook and Twitter are sparking controversy in Silicon Valley, due to their rapidly growing private market valuations, and even the occasional successful IPO. With scars from the heyday of Webvan and Pets.com still fresh in the investor psyche, people are asking, "Isn't this just a dangerous new bubble?"

I, along with others, have been arguing the other side of the case. (I am co-founder and general partner of venture capital firm Andreessen-Horowitz, which has invested in Facebook, pon, Skype, Twitter, Zynga, and Foursquare, among others. I am also personally an investor in LinkedIn.) elieve that many of the prominent new Internet companies are building real, high-growth, high-margin, ly defensible businesses.

h interview with WSJ's Kevin Delaney, Groupon and edIn investor Marc Andreessen insists that the nt popularity of tech companies does not constitute bble. He also stressed that both Apple and Google undervalued and that "the market doesn't like tech."

Keeping Pace with an Accelerated World

- Software is revolutionizing the modern world
  - changing ever faster
  - facing a growing uncertainty and recurrence of extreme events
  - limited to planetary boundaries
- Software systems are evolving at an accelerating pace
  - operating in increasingly dynamic environments
  - contending with ever-increasing uncertainty
- These dynamics demand unprecedented levels of adaptability
  - capacity to adapt not just to a fixed space of variable requirements, but to an emerging sequence of requirements, often driven by incoming data

Data-centric software development

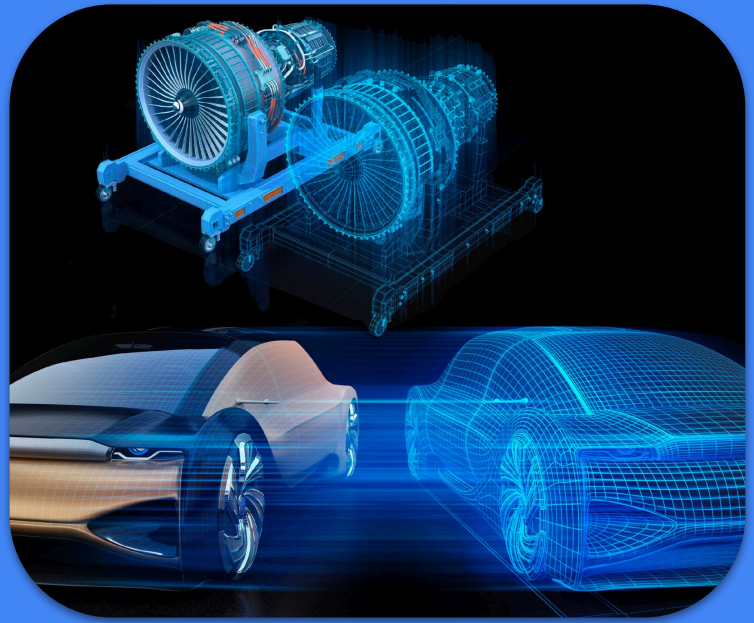
Software engineering community introduced DevOps principles to seamlessly bridge the gap between Ops and Dev.

➔ Includes telemetry and monitoring for informed decision and possibly automation

What about cyber-physical, possible socio-technical, complex systems?

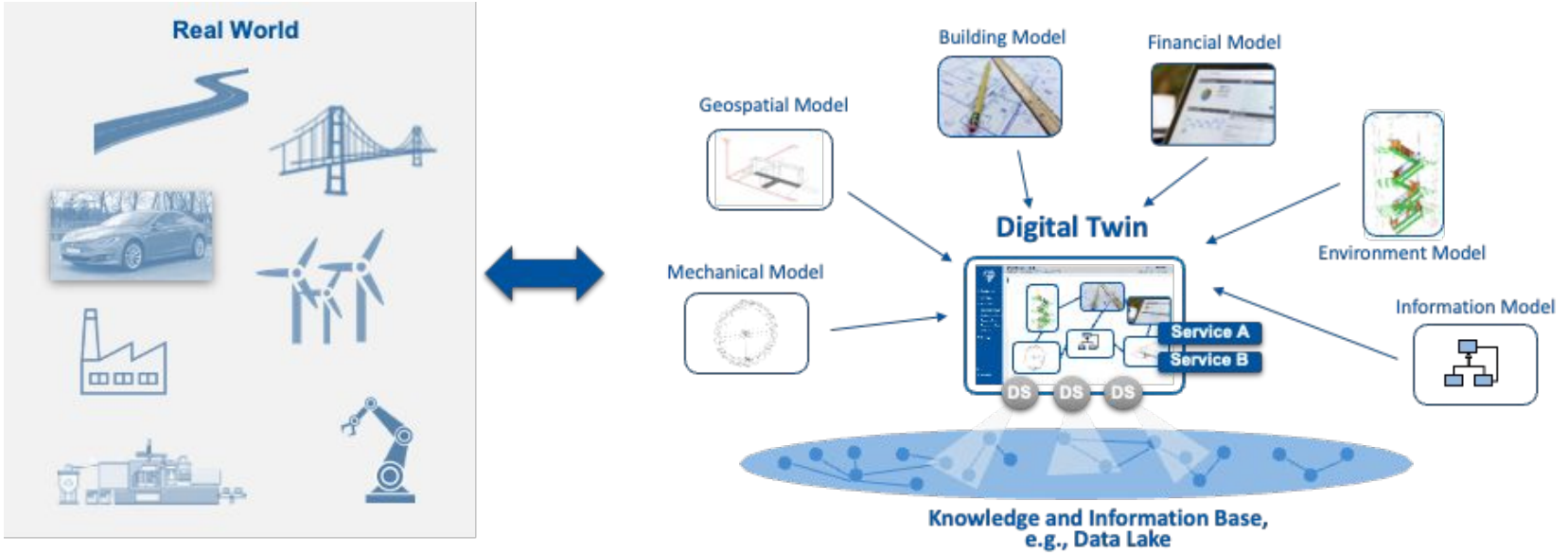
Digital Twins

C’est quoi ?



Creating digital twins for …

… elements in the physical world
that can be monitored, sensed, actuated and controlled



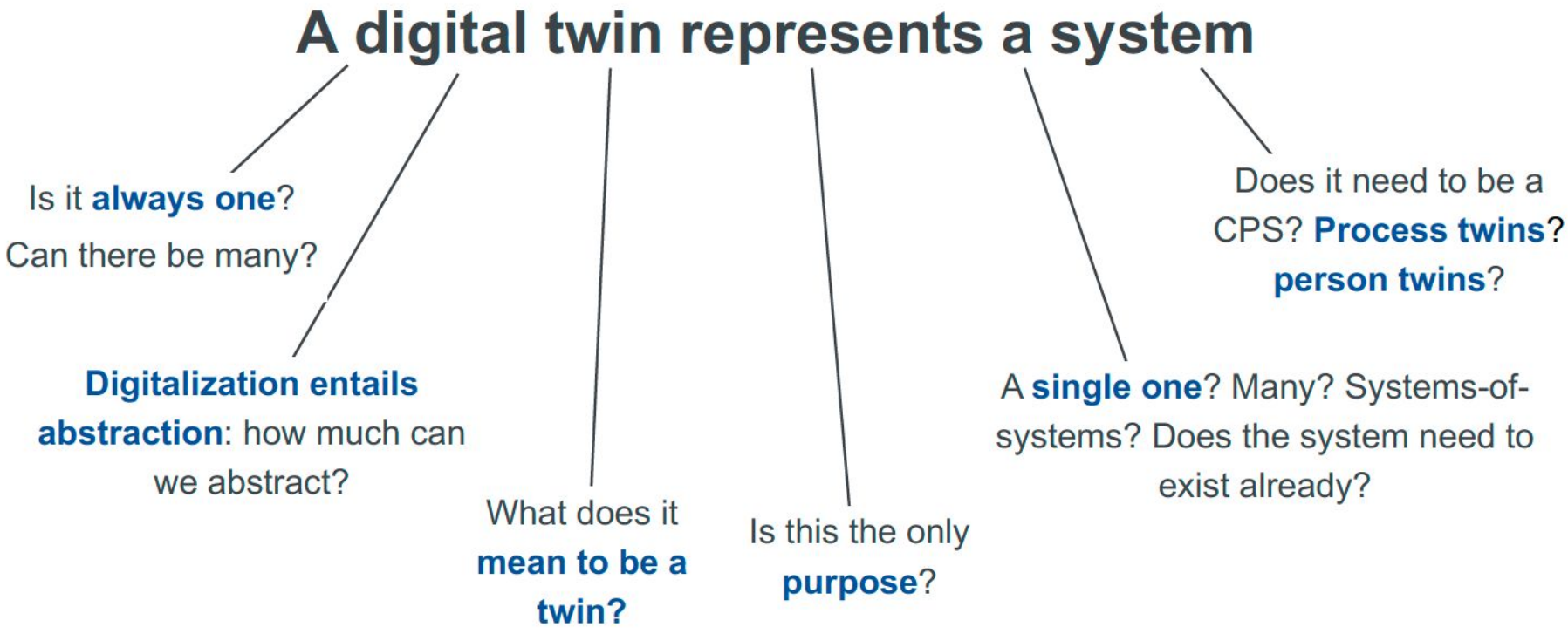
A Bit of History

- Goal: Increase system availability and performance of systems by
  - Analyzing physical processes and judging, predicting and optimizing virtually
  - Providing data from physical system to complete simulations, validate settings and dynamically adjust
  - Analyzing results and feeding back to respond to the changes
- Term “twin” originates from NASA: Build a physical copy of aircrafts to simulate and test control scenarios
- Today: Digital Twins normally are virtual representations of physical things
  - digital models about the physical thing
  - data about/of the physical twin
- Realizing new technologies requires close collaboration of experts and connecting various models

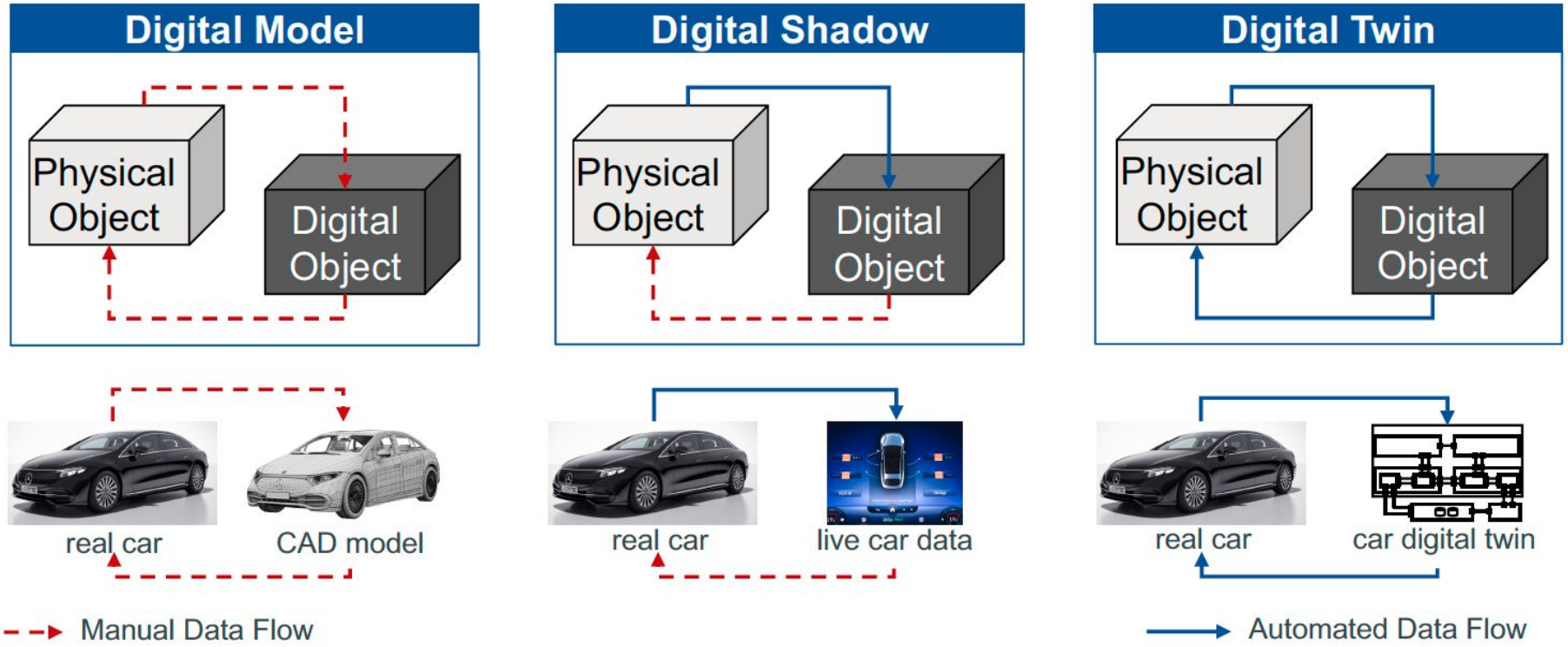
Purposes depend on the application domains

- Health: **monitoring**, **diagnostics**, and prognostics
  - Simulators for medical training and education
- Automotive:
  - **Predicting** driving behavior
  - Monitoring for **predictive maintenance**
- Aerospace: **virtual product** development and **flight test scenarios**
- Construction and Energy Efficiency:
  - **Monitoring** structural health of sensor modules
  - **Process automation** with intelligent sensors and methods for calibration
- Games, Media, and Entertainment:
  - Visual and physical **motion sensing** for three-dimensional motion capture
- Manufacturing: **Automating** production and reacting if necessary

A Simple Truth about Digital Twins

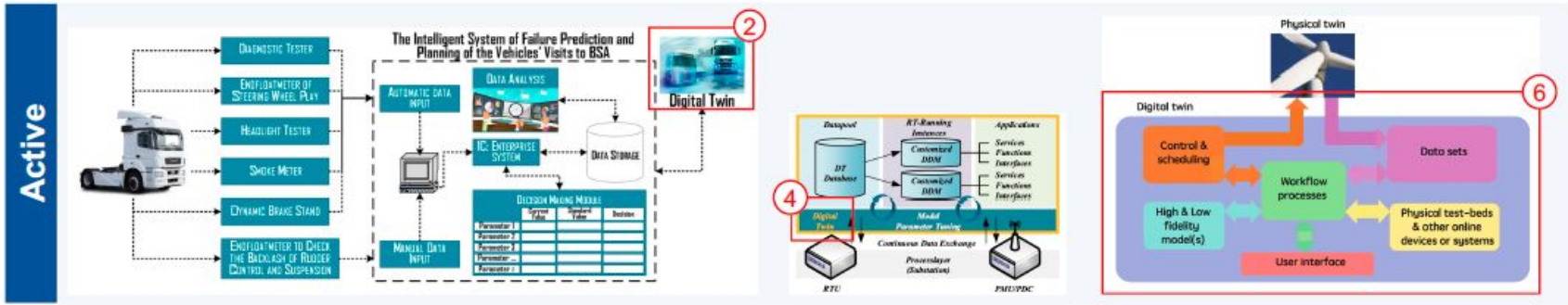


DT: A Characterization Based on Data Flows



Kritzinger, Karner, Traar, Henjes, Sihn: *Digital Twin in manufacturing: A categorical literature review and classification*. IFAC-PapersOnLine, 2018.

Cross-Domain Mapping Study for DTs



Dalibor, Jansen, Rumpe, Schmalzing, Wortmann: *A Cross-Domain Systematic Mapping Study on Software Engineering for Digital Twins*. In: Journal of Systems and Software, 2022.

Cross-Domain Mapping Study for DTs

Who uses Digital Twins?

Mostly manufacturing

- According to the Level 1 classes of the Statistical Classification of Economic Activities in the European Community
- Manufacturing >> rest
- Information includes domain-independent approaches (cf. Azure, AWS, …)
- „A“… Agriculture, Forestry and Fishing

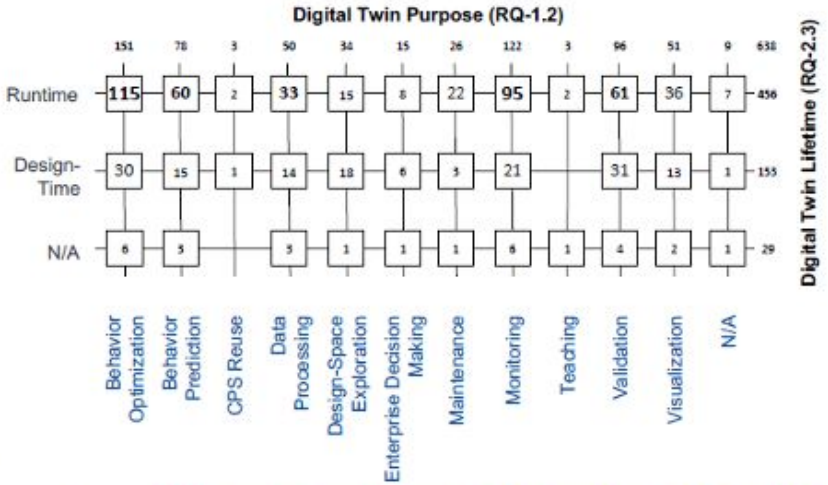
M. Dalibor, N. Jansen, B. Rumpe, D. Schmalzing, L. Wachtmeister, M. Wimmer, A. Wortmann: *A Cross-Domain Systematic Mapping Study on Software Engineering for Digital Twins.* Journal of Systems and Software, 111361, 2022. – Preprint at www.wortmann.ac/preprints

Cross-Domain Mapping Study for DTs

What are Digital Twins used for?

Many purposes are behavioral

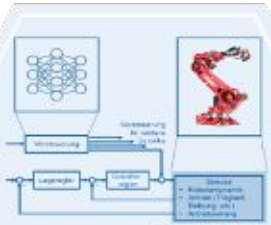
- 356 papers, some w. multiple purposes
- Strong focus on using digital twins at runtime of the twinned system
- Main purposes behavioral
  - Monitor
  - Predict
  - Optimize
  - Validate
- Some counterintuitive findings
  - Design-space exploration at runtime



M. Dalibor, N. Jansen, B. Rumpe, D. Schmalzing, L. Wachtmeister, M. Wimmer, A. Wortmann: *A Cross-Domain Systematic Mapping Study on Software Engineering for Digital Twins.* Journal of Systems and Software, 111361, 2022. – Preprint at www.wortmann.ac/preprints

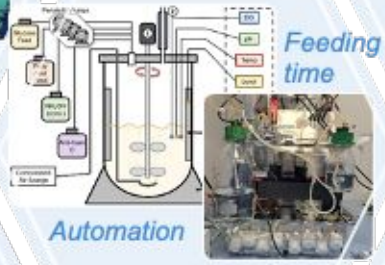
Some Examples of Use Cases

Hospital Transportation



Six-Axis Industrial Robot Arm

Injection Molding



Biomanufacturing

Civil Structures

Wind Turbines

Fischertechnik Factory

Mining Transportation

DT: *"Une Définition de l'AIF"*

COMITÉ TECHNIQUE JUMEAU NUMÉRIQUE

- Collectif d'industriels et d'académiques réunis autour du Jumeau Numérique
- ~1 réunion par mois depuis fin 2020

- Copilotage
  - Olivier SCART Olivier.SCART@3ds.com
  - Ariane PIEL Ariane.PIEL@cea.fr

- Publication :

« Le Jumeau Numérique, levier majeur de la transformation digitale de l'industrie »
Définition, cartographie de cas d'usage, et création de valeur

1

Membre Inria : Pascale Vicat-Blanc

1 Un Jumeau Numérique est un **ensemble organisé de modèles numériques** représentant une **entité du monde réel** pour **répondre à des problématiques et des usages spécifiques.**

2 Le Jumeau Numérique est **mis à jour par rapport au réel,** à une **fréquence** et une **précision** adaptées à ses problématiques et à ses usages.

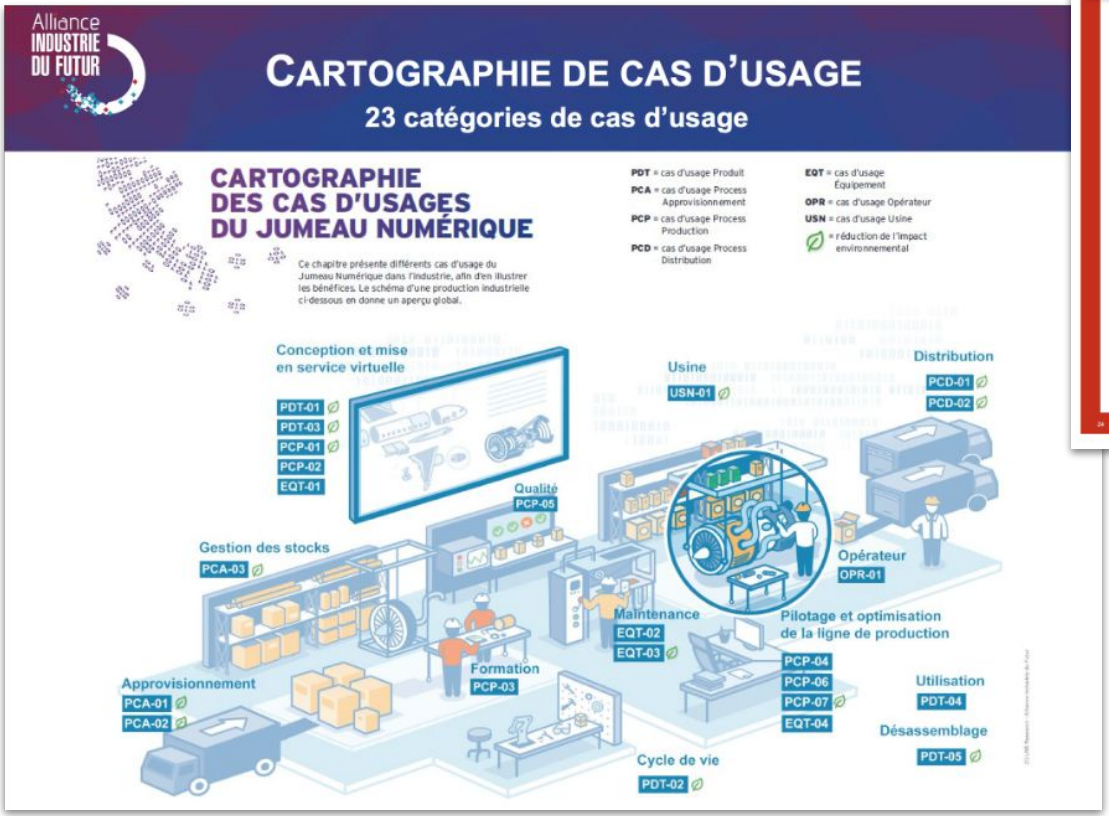
3 Le Jumeau Numérique est doté d'**outils d'exploitation avancés** permettant notamment de :

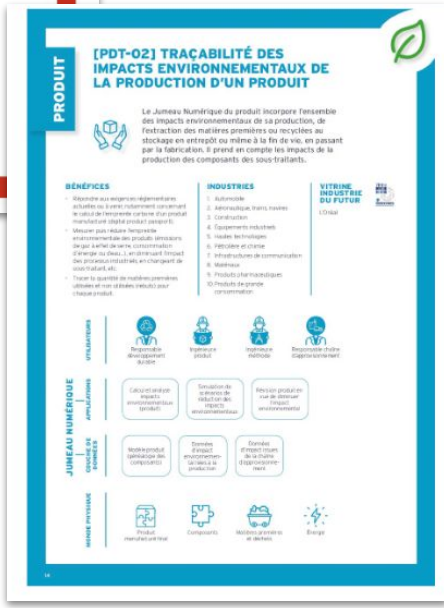
comprendre analyser

prédire optimiser

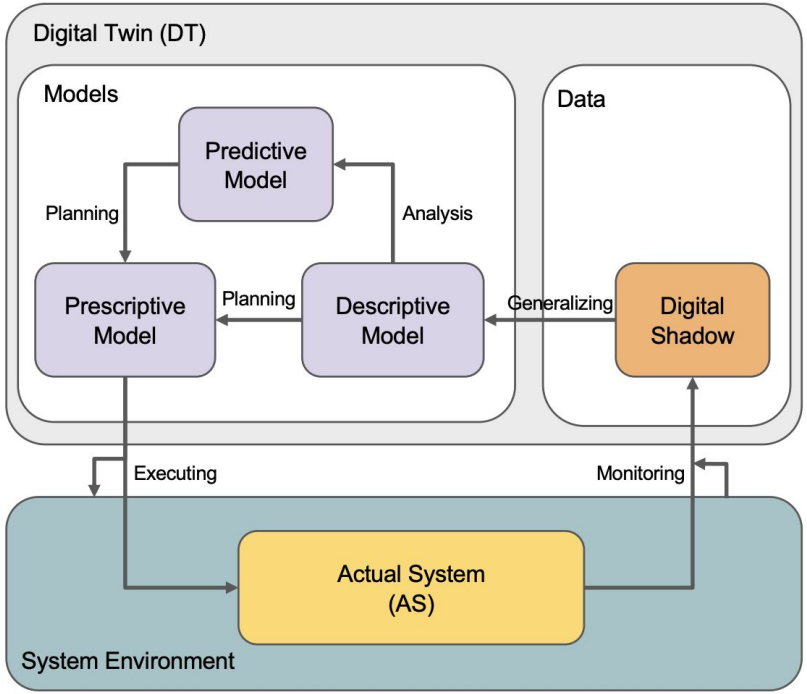
le fonctionnement et le pilotage de l'entité réelle.

DT: *"Cartographie de l'AIF"*



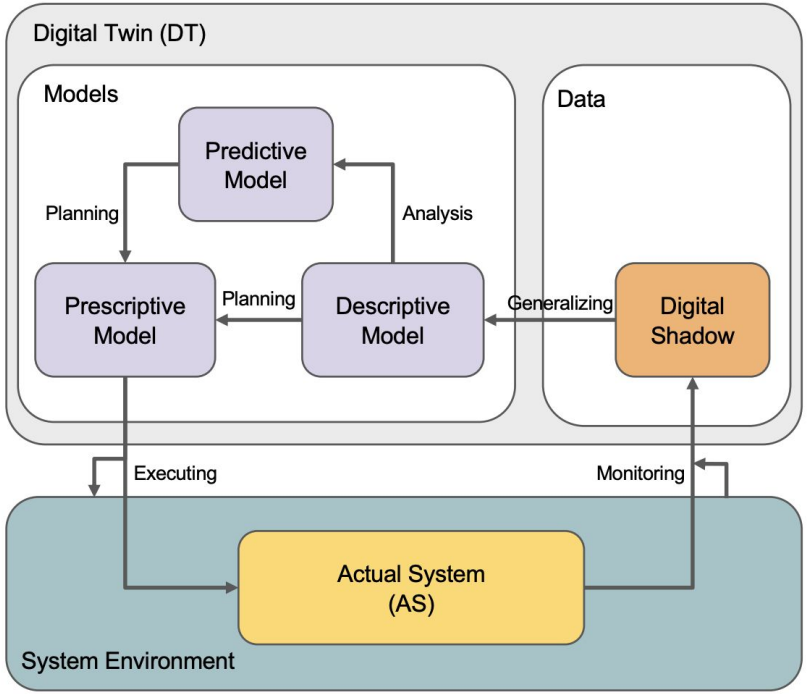


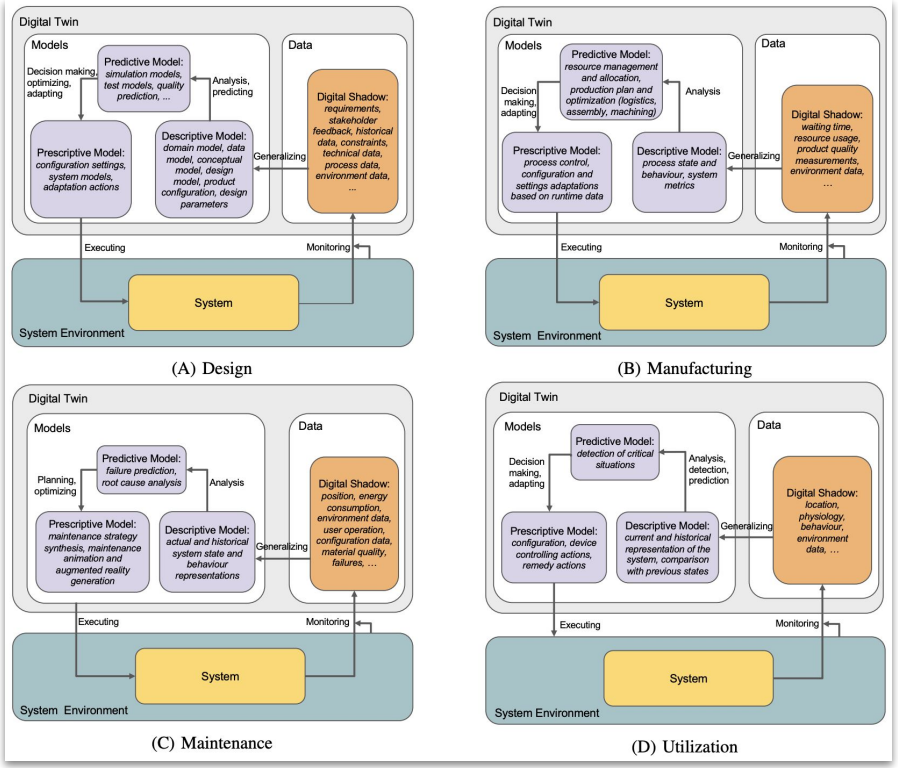
Model-Driven Digital Twin Engineering



Conceptualizing Digital Twins. Romina Eramo, Francis Bordeleau, Benoit Combemale, et al.. IEEE Software, March-April 2022, pp. 39-46, vol. 39.

Model-Driven Digital Twin Engineering

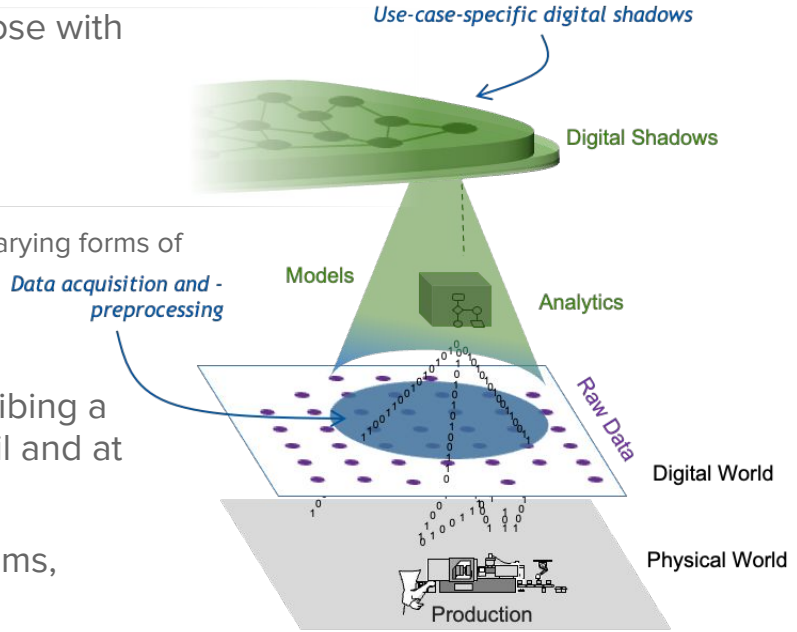




Conceptualizing Digital Twins. Romina Eramo, Francis Bordeleau, Benoit Combemale, et al.. IEEE Software, March-April 2022, pp. 39-46, vol. 39.

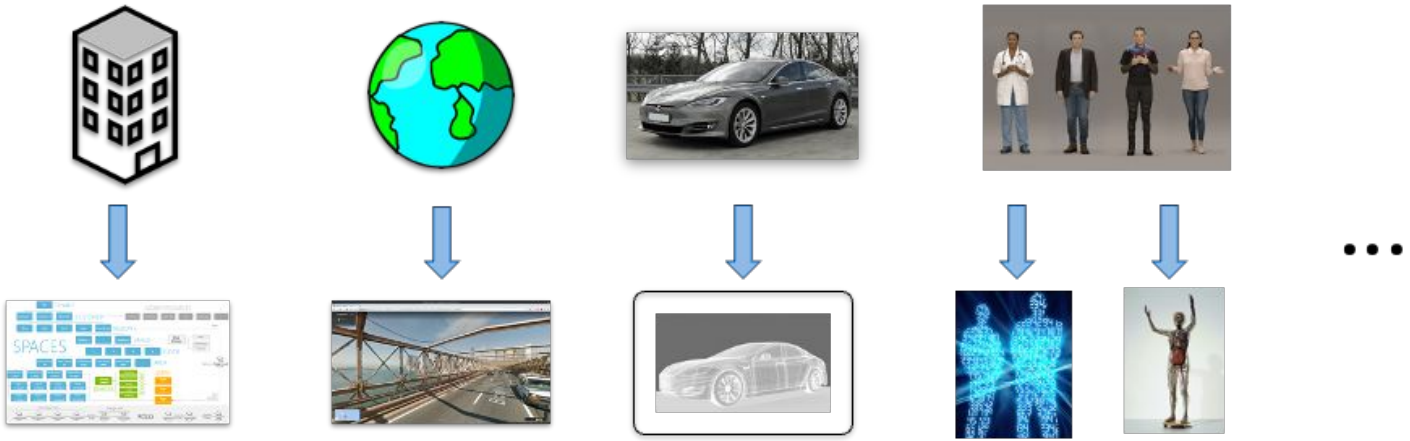
Digital Shadows

- A Digital Shadow is a set of **contextual data** traces and their aggregation and abstraction collected for a specific purpose with respect to an original system.
- A digital shadow is
  - A passive set of data
  - Information source about a system's state and history
  - Shadows are collected, filtered and reduced for their purpose in varying forms of abstractions
  - A purely digital artifact
  - Produced by a (physical) system
- A system can have many **different digital shadows** describing a variety of different aspects of the system in different detail and at different times.
- Shadows may contain information about production systems, production processes, and products



Digital Shadows

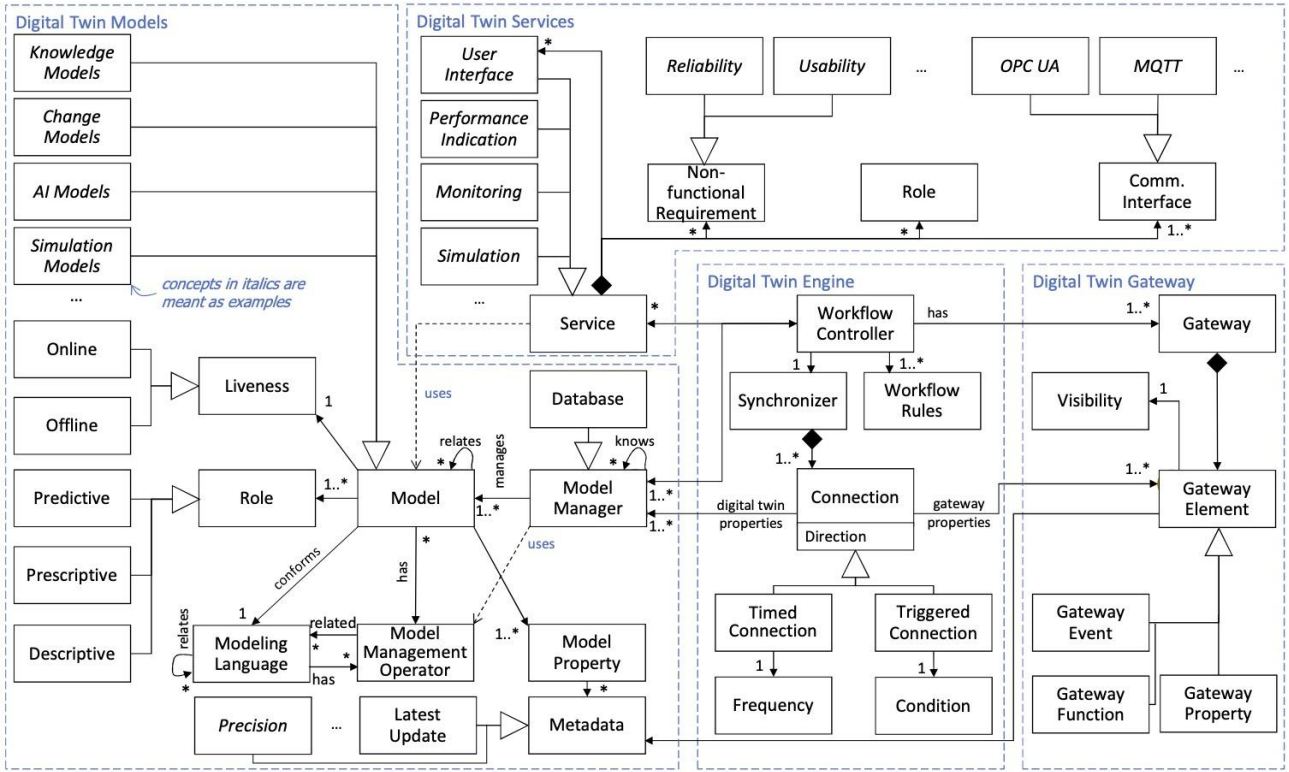
- Different physical entities, very different, purpose specific kinds of data models
  - e.g., BIM, Google Earth, CAD, Conceptual Models



Models usable for a Digital Twin

- **Structural Models**: Representing relevant parts of the system-of-interest
  - The developed system
  - The environment of the developed system
  - Interactions between the developed system and the environment
- **Behavioral Models**: Describe a system's actions
- **Physical Models**: Objects that are identical in the relevant attributes of the real system or similar, e.g., test bench
- **Geometrical Models**: Mathematical description of shapes
  - Procedural: Define shapes implicitly by an algorithm that generates the form
  - Digital Image: Represent shapes as a subset of a fine regular partition of space
- **Mathematical Models**: Expressions or numerical methods to convert input data into outputs with the same functional dependence as the actual system
  - Explain or prescribe system behavior

Towards an unifying conceptual model…

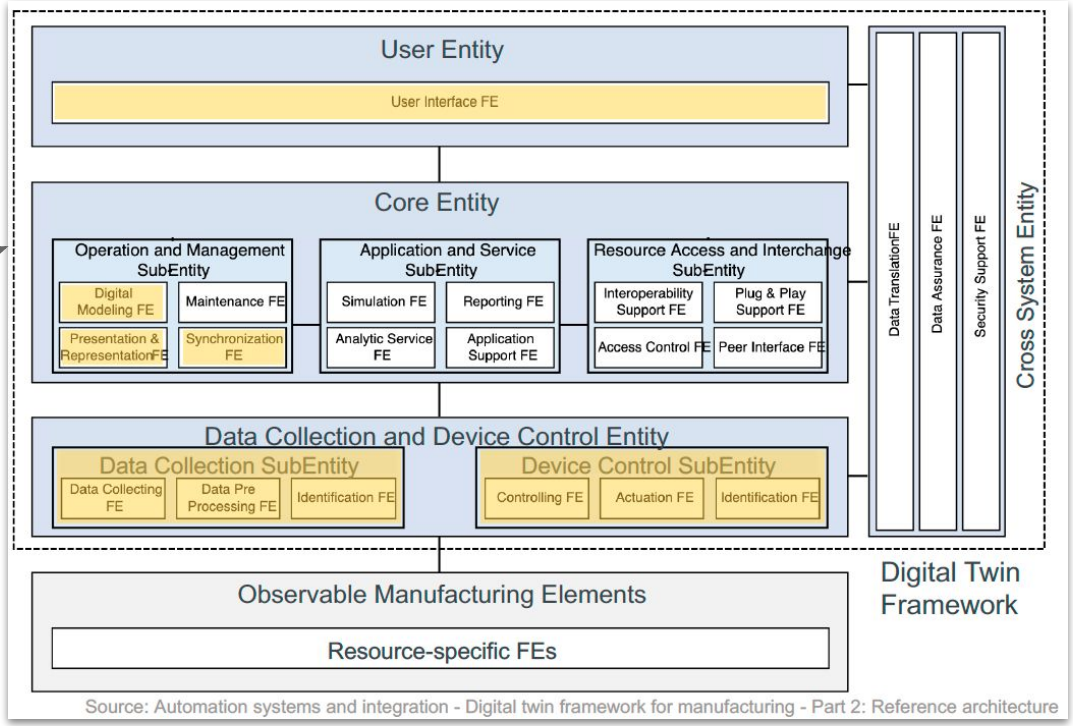


A Conceptual Model for Composable Digital Twins. *WIP.*

DT Framework for Manufacturing (ISO 23247)

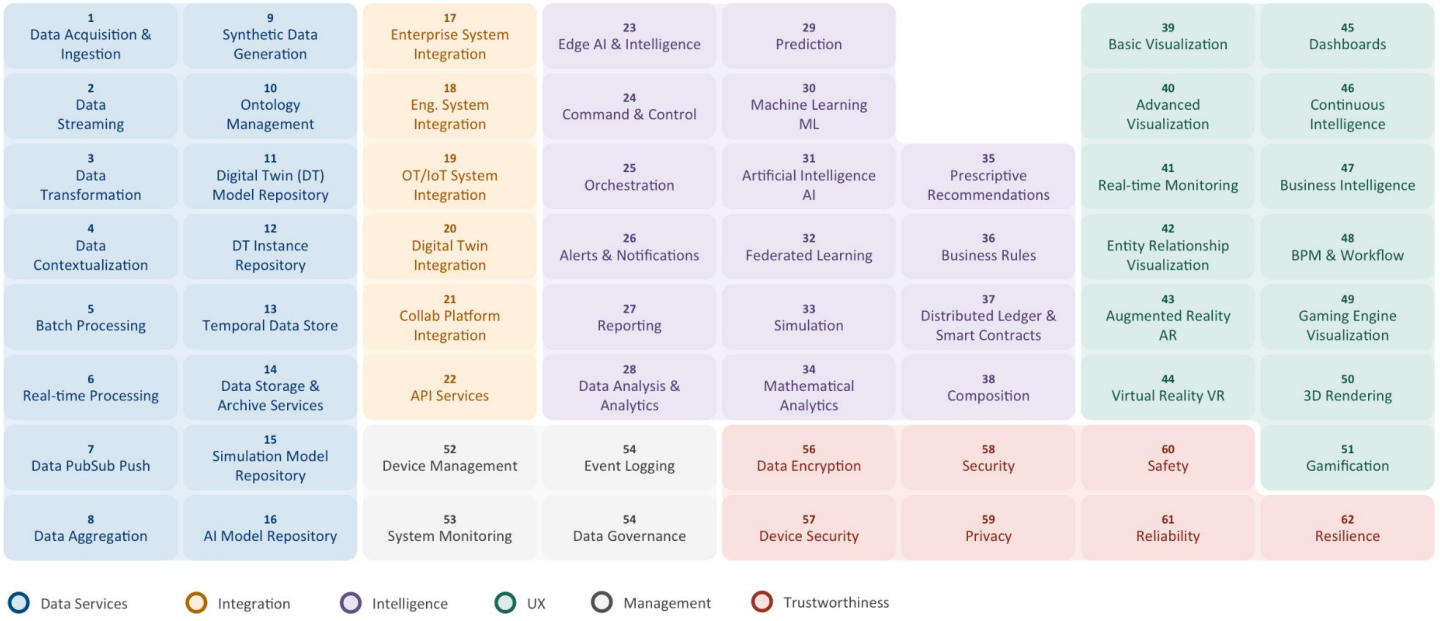
- Published in 2021

- Part 1: Overview & general principles
- Part 2: Reference architecture
- Part 3: Digital representation of manufacturing elements
- Part 4: Information exchange



Source: Automation systems and integration - Digital twin framework for manufacturing - Part 2: Reference architecture

Digital Twin: Capabilities Periodic Table



https://www.digitaltwinconsortium.org/initiatives/capabilities-periodic-table/

Take-away message

“A digital twin is a software system using data, models, and services to purposefully represent and manipulate its original CPS.”

(borrowed from A. Wortmann)

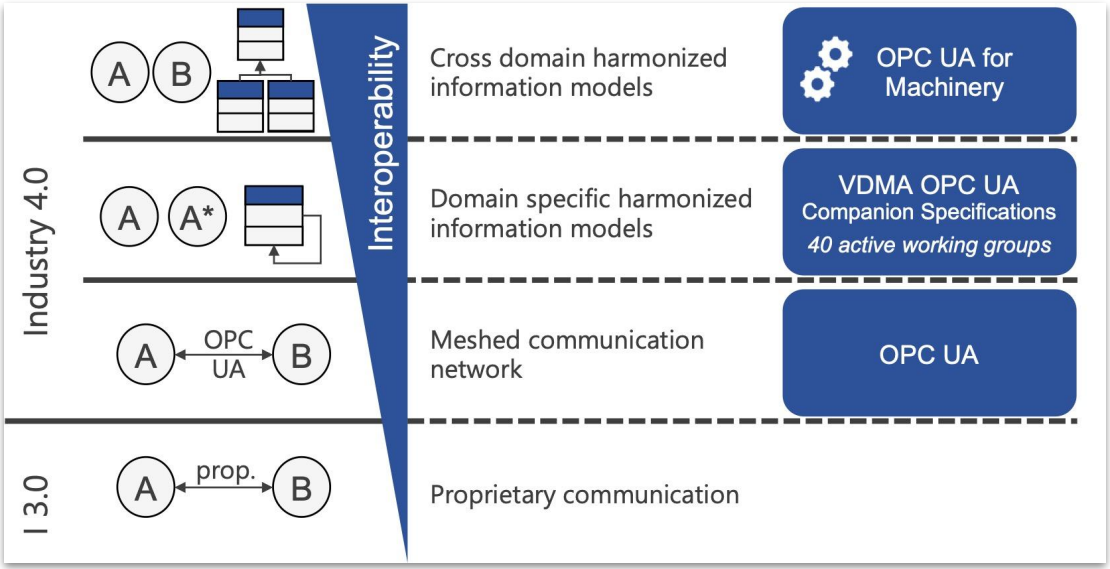
Digital Twins

Technologies for
Engineering Digital Twins

OPC UA

Machine Interaction is the Foundation of Industry 4.0

➔ Open Platform Communications Unified Architecture (OPC UA)

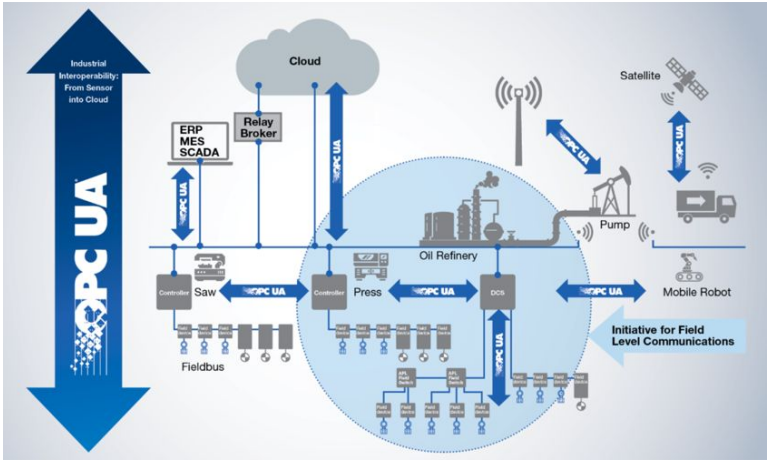


OPC UA

Machine Interaction is the Foundation of Industry 4.0

➔ Tremendous effort for

- System integration
- Connecting services, i.e.,
  - Condition monitoring
  - Optimization
  - Alarming, diagnostics
- Time-consuming and error-prone
- Prevents digital participation / transformation

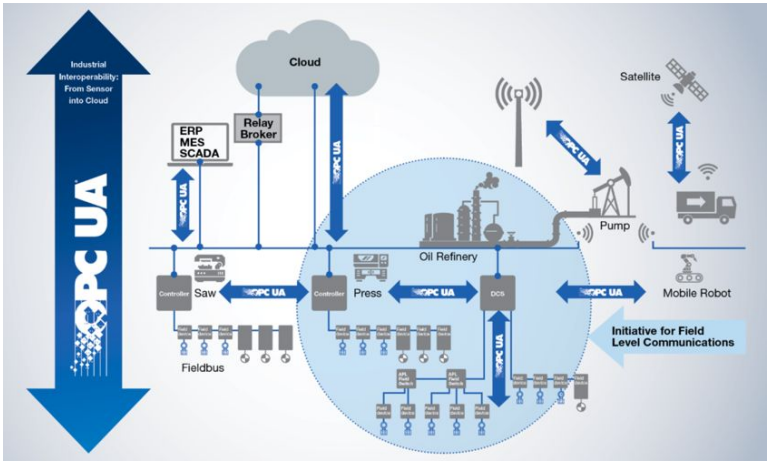


➔ Standardized industry 4.0 communication crucial

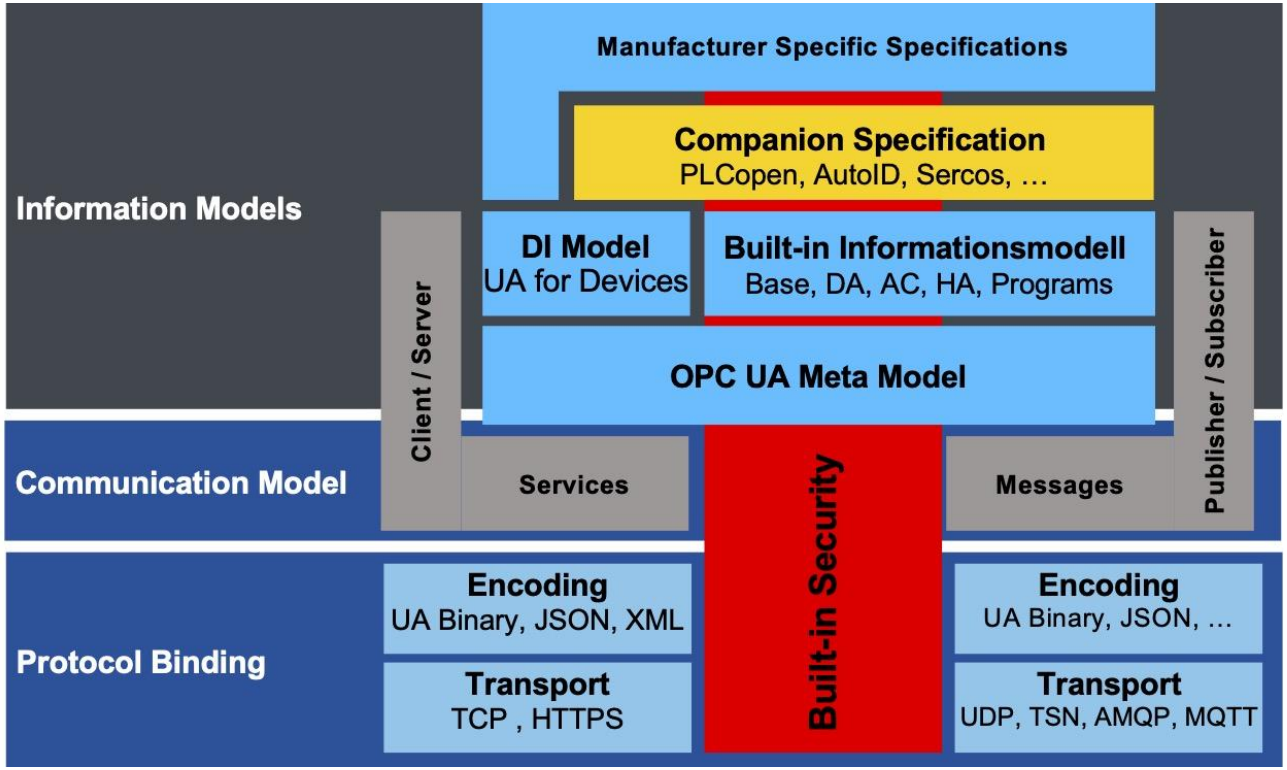
OPC UA

Machine Interaction is the Foundation of Industry 4.0

- ➔ OPC UA solves this problem by defining
  - ◆ A common communication protocol
  - ◆ Common information models
- ➔ OPC UA information models define a common representation of machines of the same category (e.g., mobile robots)
- ➔ Machines from different vendors provide the same data
  - ◆ Simplified system integration
  - ◆ Common approach to connecting services, i.e.:
    - ➝ Condition monitoring ➝ Optimization
    - ➝ Alarming ➝ Diagnosis
- ➔ Saves time and reduces errors

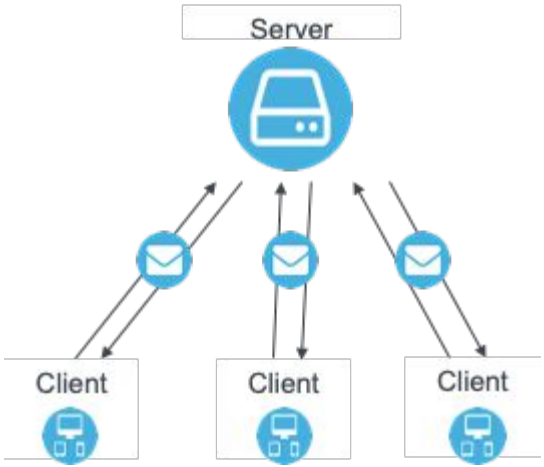


OPC UA



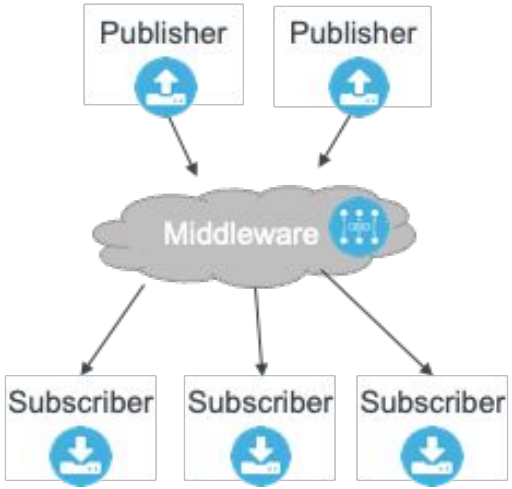
Quelle: Hoppe VDMA Interoperability Day 2018

Protocols and Data Transport



Server - client

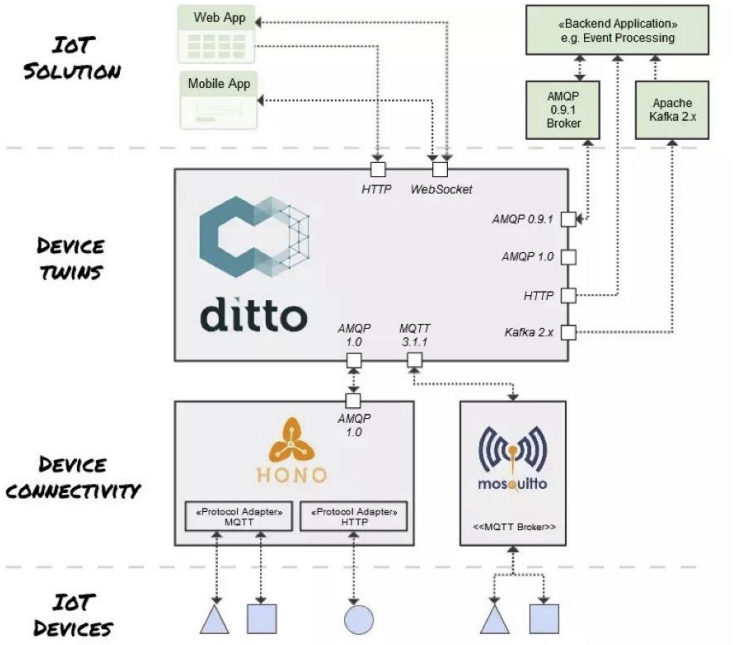
(e.g., HTTP, SNMP)



Publish - subscribe

(e.g., MQTT, AMQP)

Digital Twins in the Eclipse Infrastructure



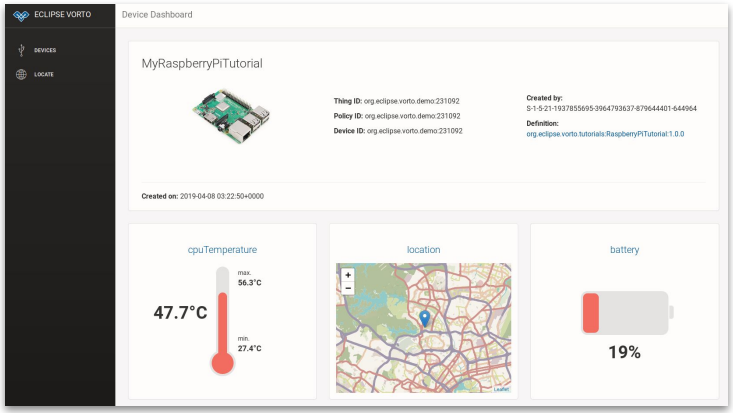
Use Vorto DSL to describe DTs as SW components (ca. function blocks)

Eclipse Vortho DSL Example

```
namespace com.acme
version 2.0.0
displayname "Raspberry Pi"
description "Raspberry Pi with onboard
sensor and GPS module"

using org.eclipse.vorto.Location; 1.0.0
using org.eclipse.vorto.Temperature; 1.0.0

infomodel RaspberryPi{
functionblocks {

   temperature as Temperature
   location as Location

}
```

Digital Twins in the Eclipse Infrastructure

- Modeling language: VortoLang
  - Describe CPS with a digital model
  - Information models compose `functionblocks` into bigger components
  - Function block are reusable implementation parts that can define properties, operations, or events
- Code generators translate models into applications




```
infomodel ECar{
  functionblock {
    battery as Battery
    //…
  }
}
```

```
functionblock Battery {
  status {
    mandatory remainingCapacity
      as Percentage
  }
}
```

```
entity Percentage {
  mandatory value as
    float <MIN 0, MAX 100>
}
```

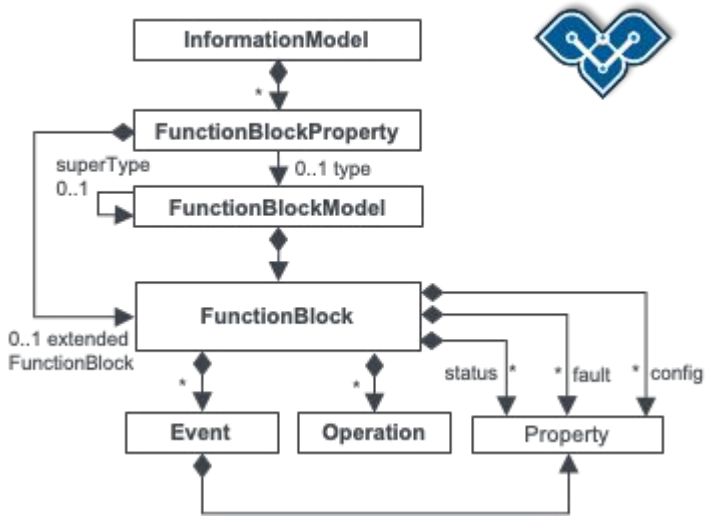
https://github.com/eclipse/vorto/blob/master/docs/tutorials/create_webapp_dashboard.md
https://www.eclipse.org/vorto/

Digital Twins in the Eclipse Infrastructure

Uncovering the metamodel of Eclipse VortoLang

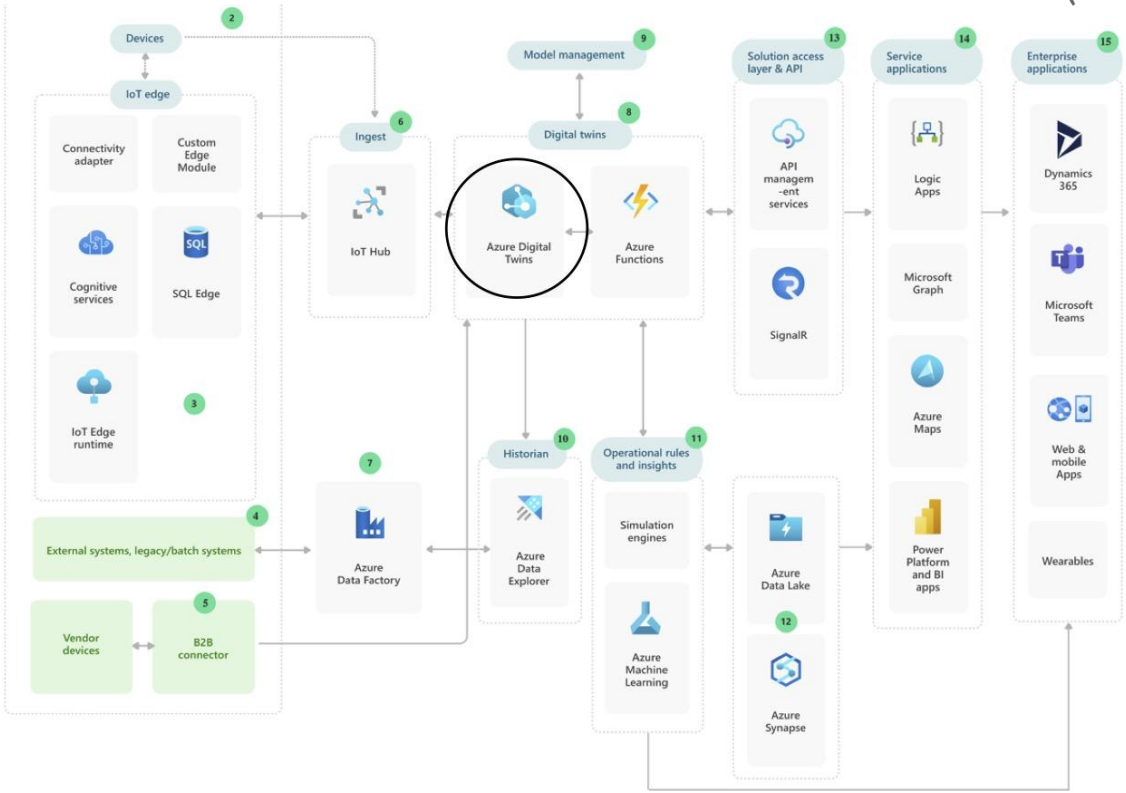
- Based on Ecore metamodel

- Describe asset structure via:
  - InformationModel: aggregates FunctionBlocks
  - FunctionBlock: reusable implementation parts
  - Event: a list of properties with timestamp
  - Operation: interaction with described asset
  - Property: attribute of function block



Digital Twins in Microsoft Azure

Use DTDL to describe interfaces & data structures (ca. UML CD / OPC UA)



Definition: A digital twin is a digital model of real-world things, places, business processes, and people

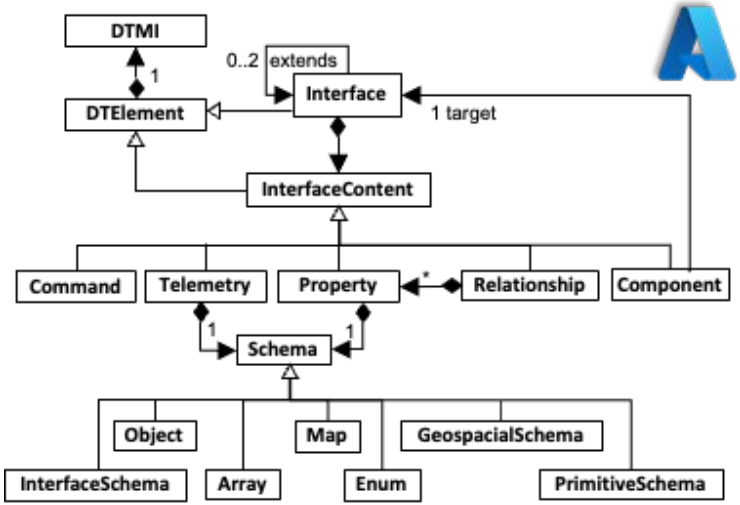
MS DTDL Example

```
{
  "@id": "dtmi:com:example:Building;1",
  "@type": "Interface",
  "displayName": "Building",
  "contents": [
    {
      "@type": "Property",
      "name": "name",
      "schema": "string",
      "writable": true
    },
    {
      "@type": "Relationship",
      "name": "contains",
      "target": "dtmi:com:example:Room;1"
    }],
  "@context": "dtmi:dtdl:context;2"
}
```

Digital Twins in Microsoft Azure

Uncovering the metamodel of Microsoft Azure DTDL

- Extracted metamodel from GitHub
- Structural description via
  - Interface: type of physical asset
  - Command: interaction with devices
  - Telemetry: continuous data streams
  - Property: not frequently changing
  - Relationship: association to interfaces
  - Component: composition of interfaces



[1]https://github.com/Azure/opendigitaltwins-dtdl/blob/master/DTDL/v2/dtdlv2.md

Digital Twins in Microsoft Azure

- Provides JSON-like Digital Twin Definition Language (DTDL) to describe twins by
  - Property
  - Commands
  - Relationships
- Contextualizes raw data and acts as contract to other services
- Querying of data from Azure's cloud and external services to perform analysis and computation on received data
- Visualization

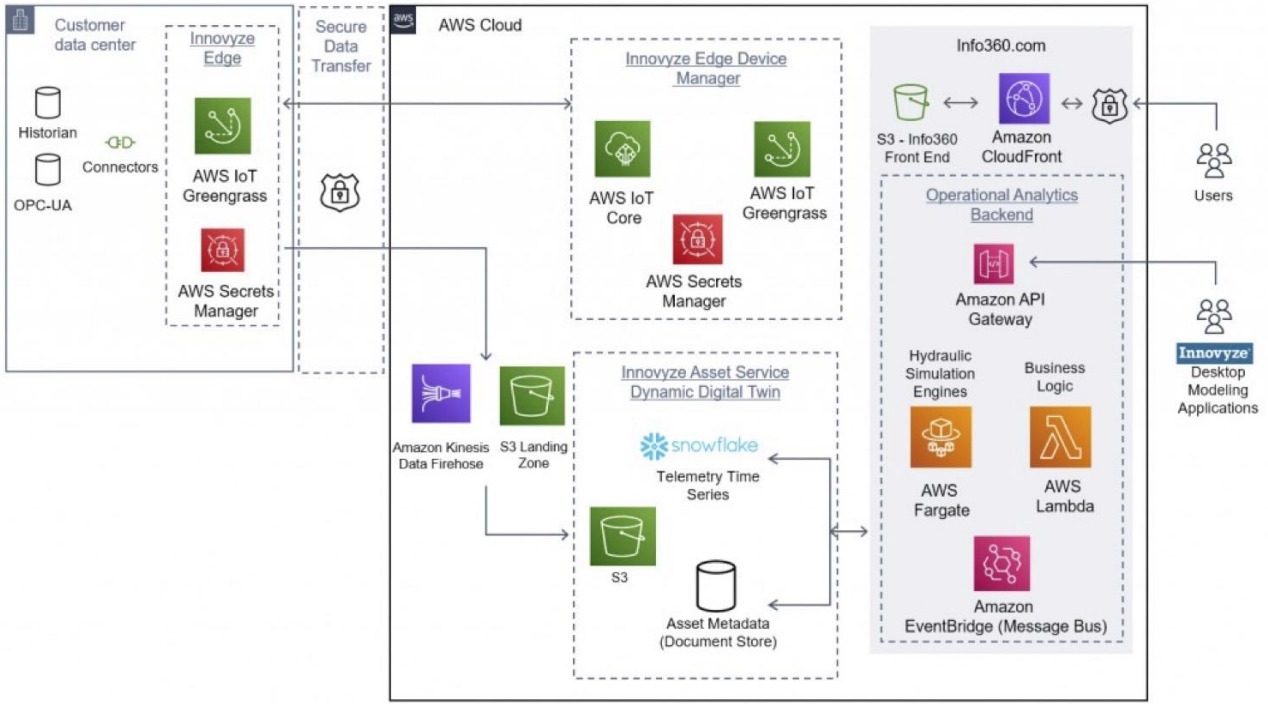
DTDL

```
{
  "@id": "dtmi:com:example:Building;1",
  "@type": "Interface",
  "displayName": "Building",
  "contents": [
    {
      "@type": "Property",
      "name": "name",
      "schema": "string",
      "writable": true
    },
    {
      "@type": "Relationship",
      "name": "contains",
      "target": "dtmi:com:example:Room;1"
    }
  ],
  "@context": "dtmi:dtdl:context;2"
}
```

https://azure.microsoft.com/en-us/services/digital-twins/

Digital Twins in Amazon AWS

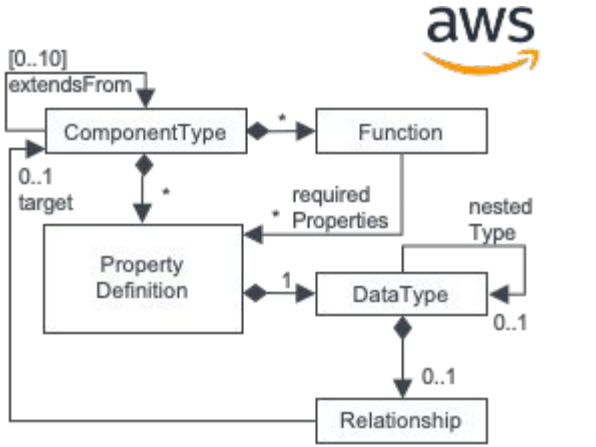
The digital twin is data in an S3 database or document store



Digital Twins in Amazon AWS

Uncovering the metamodel of AWS IoT TwinMaker

- Extracted metamodel from API description
- Model data received from devices
  - ComponentType: defines a type of assets
  - Function: reference a function for interaction
  - PropertyDefinition: Defines properties
  - DataType: type of properties
  - Relationship: associations between types



[3] https://docs.aws.amazon.com/iot-twinmaker/latest/guide/what-is-twinmaker.html

Digital Twins in Amazon AWS

Uncovering the metamodel of AWS IoT TwinMaker

- Definition:
  - A digital twin is a live digital representation
  - Dynamically updated with data to mimic the structure of the system
- IoT TwinMaker is an AWS service
- API to create digital twin models via JSON
- Digital twin consist of components representing structural elements of the digital twin
- Enables querying and visualization

AWS

```
{
  "componentTypeId": "example.alarm",
  "workspaceId": "MyWorkspace",
  "isSingleton": false,
  "propertyDefinitions": {
    "alarm_status": {
      "dataType": {
        "type": "STRING"
        "allowedValues": [
          {"stringValue": "ACTIVE"
          },//...
        ],
      }, //...
    }
  }
}
```

https://docs.aws.amazon.com/iot-twinmaker/latest/guide/twinmaker-component-types-examples.html

Model-Driven Digital Twin Engineering

Approach:

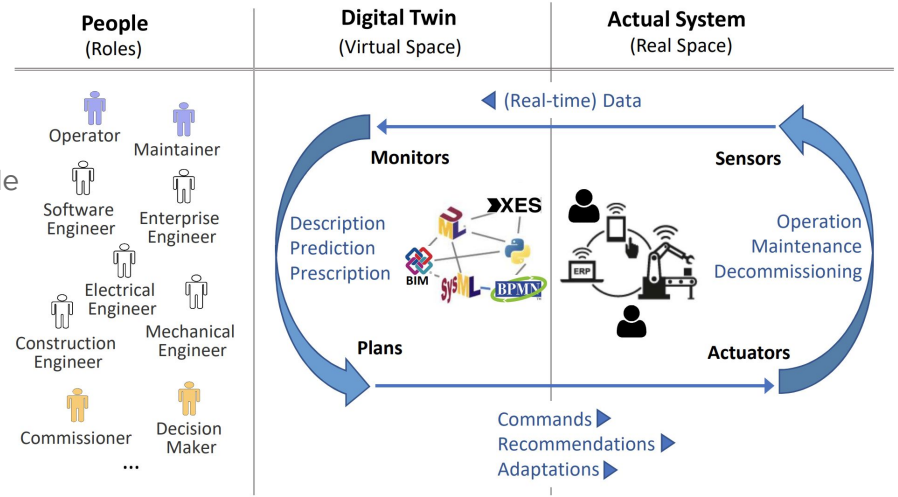
- Modeling continuum across the supply and value chain
- model transformation chain from design models to models@runtime

Opportunities:

- Systematically managing heterogeneous models
- Bi-directional synchronization with the actual system
- Collaborative development throughout the system life-cycle

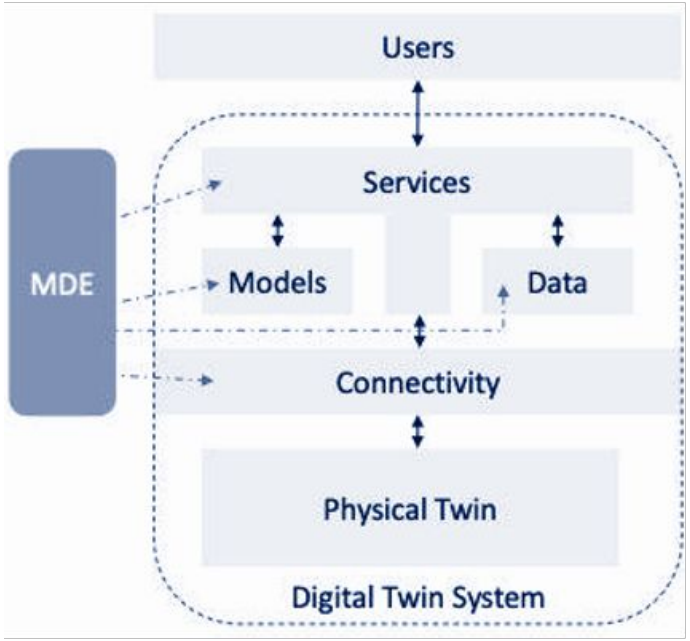
Modeling challenges:

- Modeling Languages for Digital Twins
- Architectural Framework for Digital Twins
- Openness and Sustainability
- Uncertainty
- Design Space Exploration
- Inconsistency Management
- Model evolution and coevolution
- Models AND Data

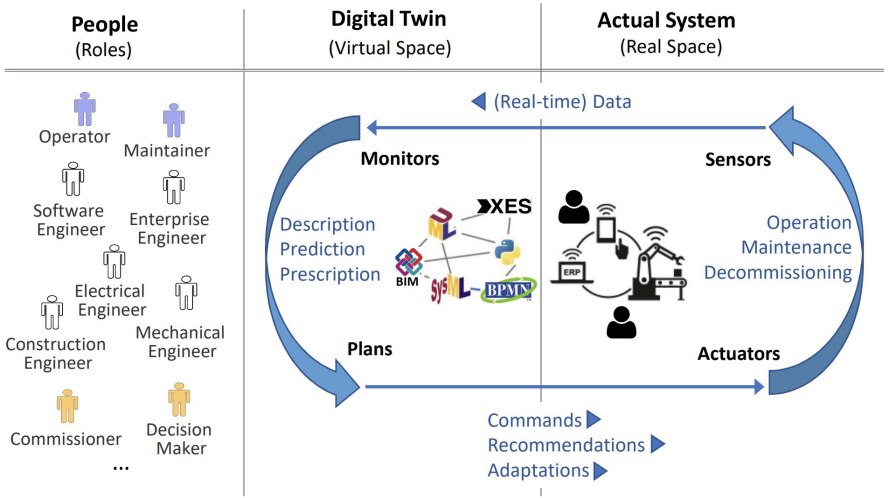


Towards Model-Driven Digital Twin Engineering: Current Opportunities and Future Challenges.
Francis Bordeleau, Benoit Combemale, Romina Eramo, et al.. ICSMM 2020.

Model-Driven Digital Twin Engineering

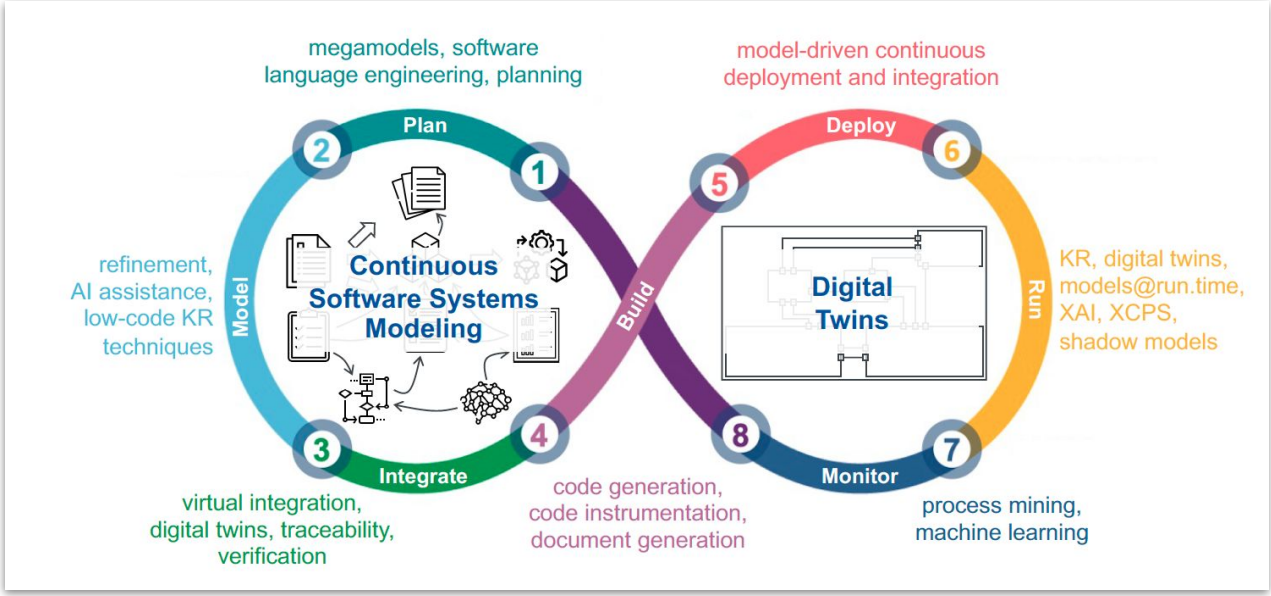


Model-Driven Engineering of Digital Twins.
Dagstuhl Seminar #22362, 2022.
https://www.dagstuhl.de/22362



Towards Model-Driven Digital Twin Engineering: Current Opportunities and Future Challenges.
Francis Bordeleau, Benoit Combemale, Romina Eramo, et al.. ICSMM 2020.

Model-Based DevOps for CPS (MBDO)



Université de Rennes

RWTH AACHEN UNIVERSITY

Universität Stuttgart

AGENCE NATIONALE DE LA RECHERCHE ANR DFG Deutsche Forschungsgemeinschaft

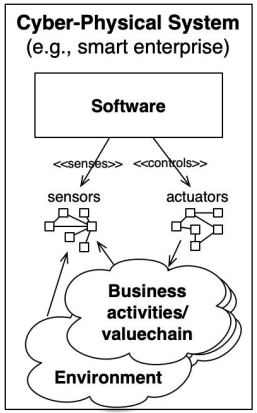
Digital Twins

Some examples @ DiverSE

OneWay: The Case Of Avionics Program Development Plan

Digital Enterprise:

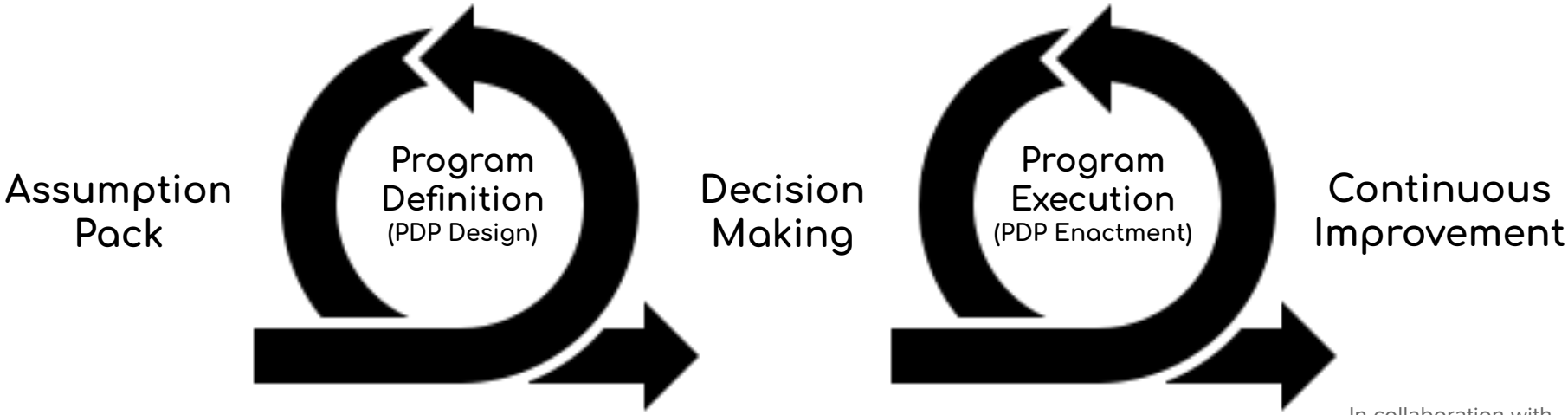
- Enterprise are complex socio-technical systems
- Digitalization of most of the business activities
- Opportunities to offer a digital (model-based) continuum
- Digital enterprises as Cyber-Physical Systems



OneWay: The Case Of Avionics Program Development Plan

Model-based approach

from PDP instantiation, to PDP exploration, optimization and digital twin

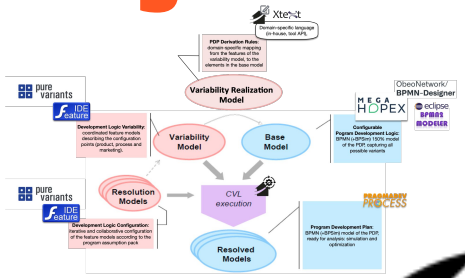


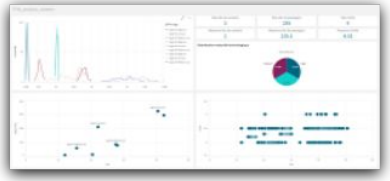
In collaboration with

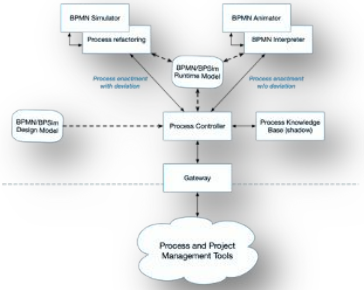
CIMPA PLM Services a Sopra Steria company

AIRBUS

OneWay: The Case Of Avionics Program Development Plan







Assumption Pack

Program Definition (PDP Design)

Decision Making

Program Execution (PDP Enactment)

Continuous Improvement

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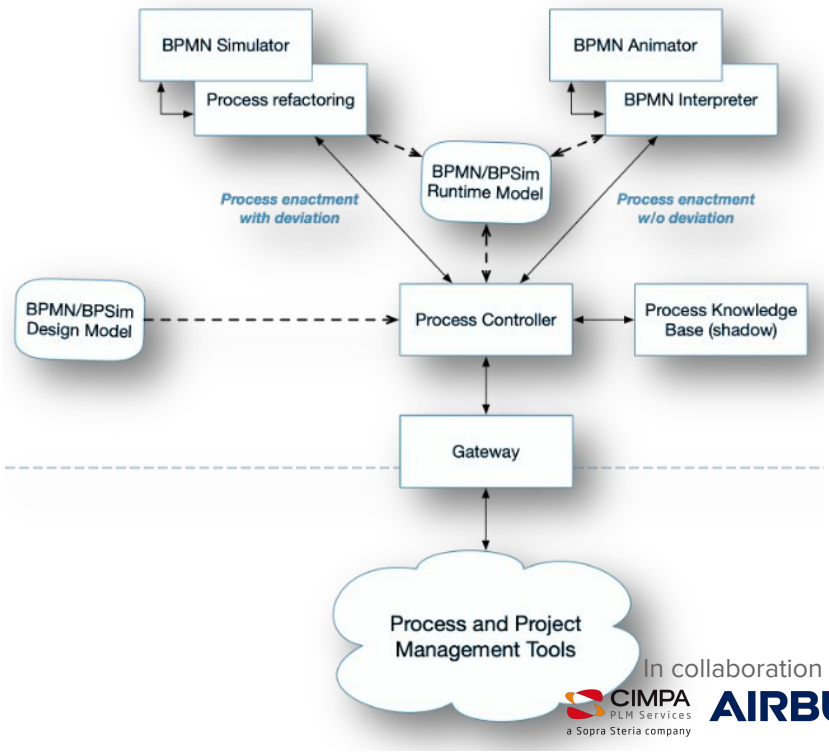
AIRBUS

OneWay: The Case Of Avionics Program Development Plan

- Monitoring via process enactment with the interpreter
- Capitalization through the shadow
- Refactoring (automatic optimization or manual refactoring) of the prescriptive part of the model (i.e. the future)
- Impact analysis with the simulator

Perspectives:

- Deviation management
- Automatic optimization
- Process Knowledge Base Optimization
- Cockpit definition



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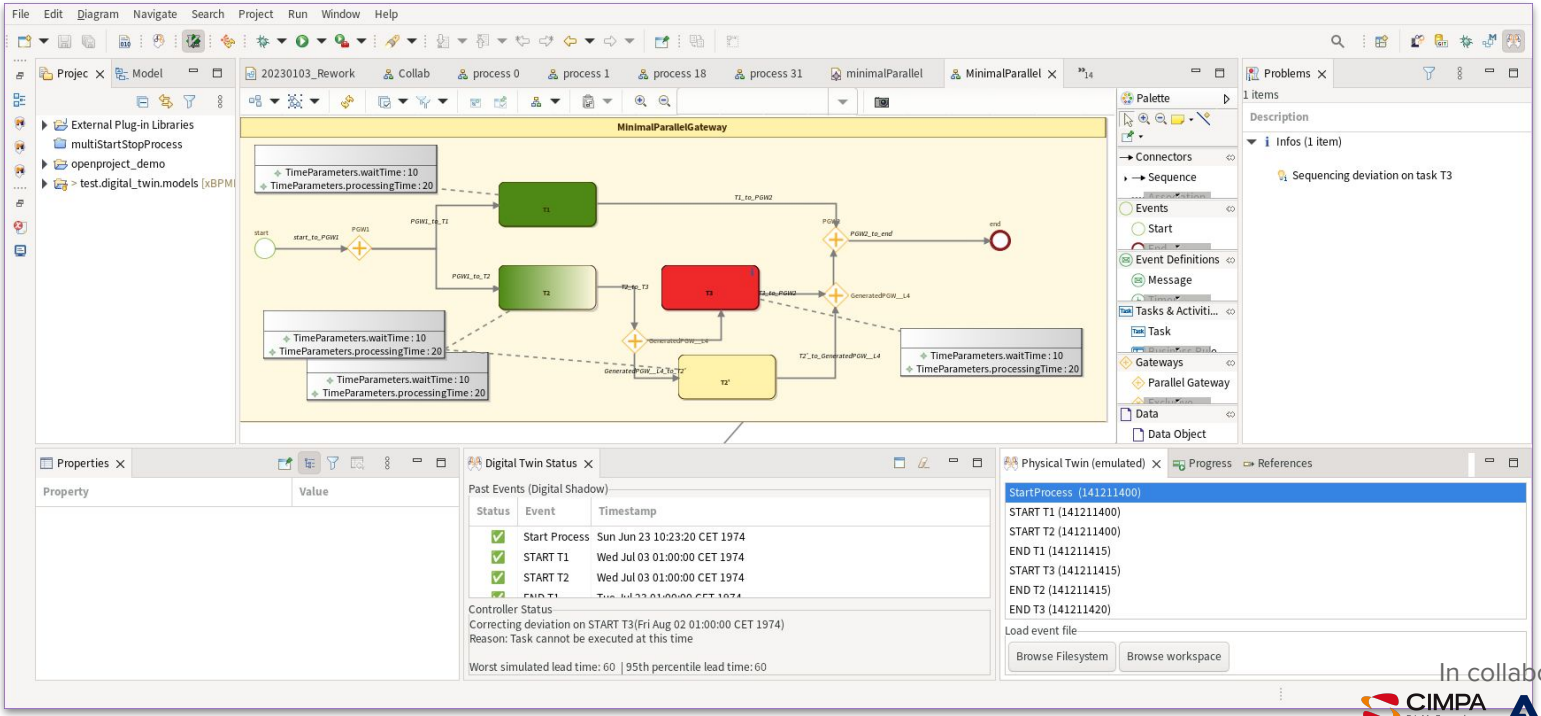
OneWay: The Case Of Avionics Program Development Plan



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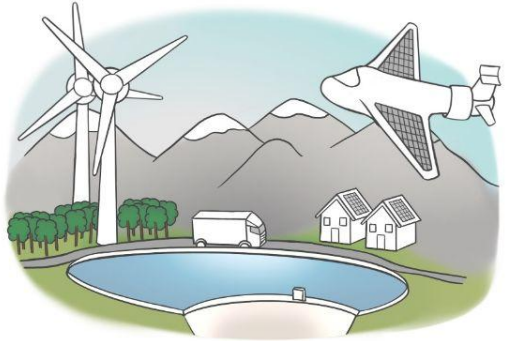
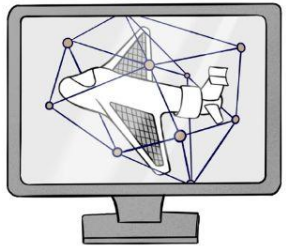
AIRBUS

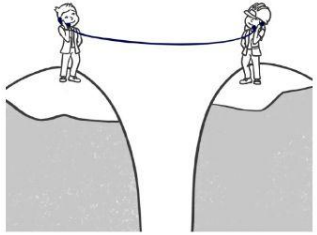
Nowadays products are gaining in **complexity**, operated in **various environments** with increasing interactions and **multiple** use cases.



Our multi-field adaptive modeling technology offers you an **innovative digital representation** of your product



Comprehensive view from design to maintenance



Efficient collaboration between expertise fields

Efforts focused in the right place

Our digital twin solution is made of **open-source** modules **compatible** with your existing tools.

Quicker and smarter design

Reduced operating costs

Assessed maintenance costs

Developed by a **highly skilled team** led by :

Dr. Guy DE SPIEGELEER, CEO
guy.de-spiegeleer@twiinit.com
Aerospace design, system engineering

Eng. Adrien DELSALLE, CTO
adrien.delsalle@twiinit.com
Computer science & modeling

Scientifics advisors from Inria

Prof. Benoit COMBEMALE
CSA
Systems eng., Open Source Software

Prof. Olivier BARAIS
CTA
Web dev., DevOps

twiinIT
Collaborative Design Software

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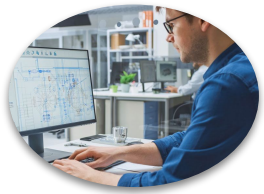
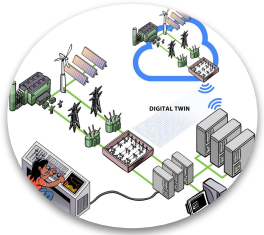
Digital Twins

Looking Ahead?

(some) Open challenges

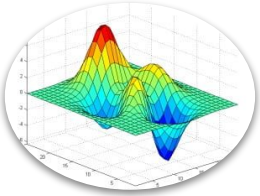


- software engineering, MBSE
- collaborative modeling
- interoperability and composability



- Distributed systems
- Cloud-,Edge-computing, HPC
- Internet of Things

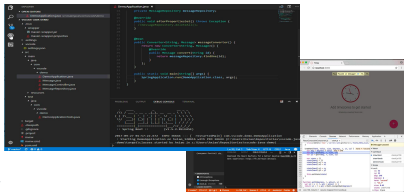
- great opportunities for saving resources, balanced with massive resource consumption
- humain value-driven systems engineering



- numerical analysis
- multi-physics simulation

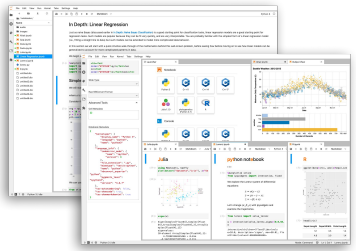
- predictive modeling
- resilience engineering
- explainable AI

Virtual Lab

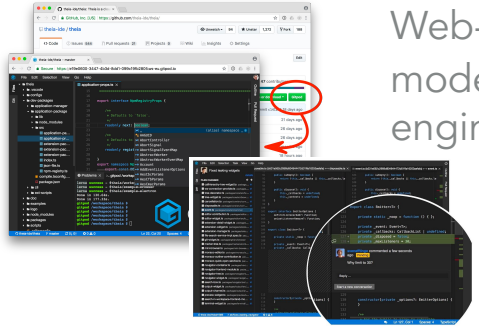


Lightweight, modular, customizable, distributed and self-adaptable scientific and engineering platforms…

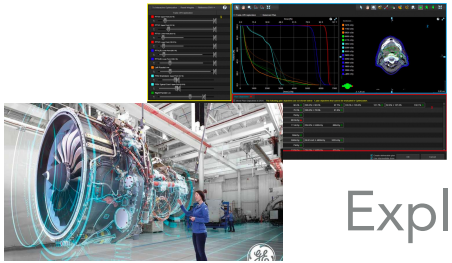
Socio-technical coordination



Polyglot, literate
modeling and programming



Web-based, Collaborative modeling, modeling flow, social engineering



Exploratory and live programming, digital twin

EDT.COMMUNITY

https://edt.community

ENGINEERING DIGITAL TWINS – ONLINE SEMINAR SERIES

SHARING KNOWLEDGE

Providing a platform to share experiences, challenges, and novel research

BUILDING A COMMUNITY

Bringing together people from academia and industry to discuss the applications and engineering of digital twins

ESTABLISHING RESEARCH GOALS

Building a common understanding and vocabulary and defining research agendas for the future

STEERING COMMITTEE

ORGANISING COMMITTEE

ModDit Workshop Series

https://gemoc.org/events

MDE OF DIGITAL TWINS – Workshop @ MODELS

3rd International Workshop on Model-Driven Engineering of Digital Twins

ModDiT'23

co-located with MODELS 2023

About | Program | Call | Dates | Committees

About the Workshop

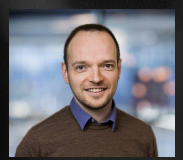
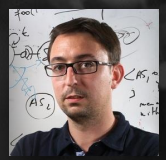
Digital twin (DT) is a concept that is gaining growing attention in many disciplines to support engineering, monitoring, controlling, and optimizing cyber- physical systems (CPSs) and beyond. It refers to the ability to clone an actual system into a virtual counterpart, that reflects all the important properties and characteristics of the original system within a specific application context. While the benefits of DT have been demonstrated in many contexts, their development, maintenance, and evolution, yield major challenges. Part of these needs to be addressed from a Model-Driven Engineering (MDE) perspective. MoDDiT'23 aims at bringing together researchers and practitioners on DTs to shape the future of systematically designing, engineering, evolving, maintaining, and evaluating DTs across different disciplines.

Topics

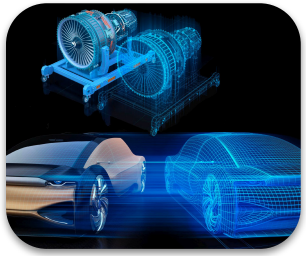
Topics of interest include, but are not restricted to:

- Modelling concepts and languages, methods, and tools for developing digital twins
- Digital twins for DevOps
- Quality assurance for and evaluation of digital twins
- Deployment and operation of digital twins
- Model consistency, management, and evolution of engineering models
- Architectural patterns for digital twins
- Digital twins for continual learning and continuous improvement
- Combining models and data in digital twins
- Digital twins for dynamic (re)configuration and optimization
- Case studies, experience reports, comparisons

ORGANISING COMMITTEE


En résumé…



Jumeaux numériques

- Point de vue donnée / modèle et architectural
- Continuum entre la conception, l'opérationnalisation, l'évolution, la maintenance…

Jumeaux numériques à DiverSE

- centrée humain
- connecté, résiliente et souveraine
- responsable

Encore des verrous scientifiques

- Ingénierie des jumeaux numériques
  - composabilité et complémentarité des modèles
  - interopérabilité et composabilité des jumeaux numériques
  - environnement numérique continu (conception ∞ operations)
- Gateways pour systèmes physiques (IoT, Cloud/Edge, HPC, etc.)
- …