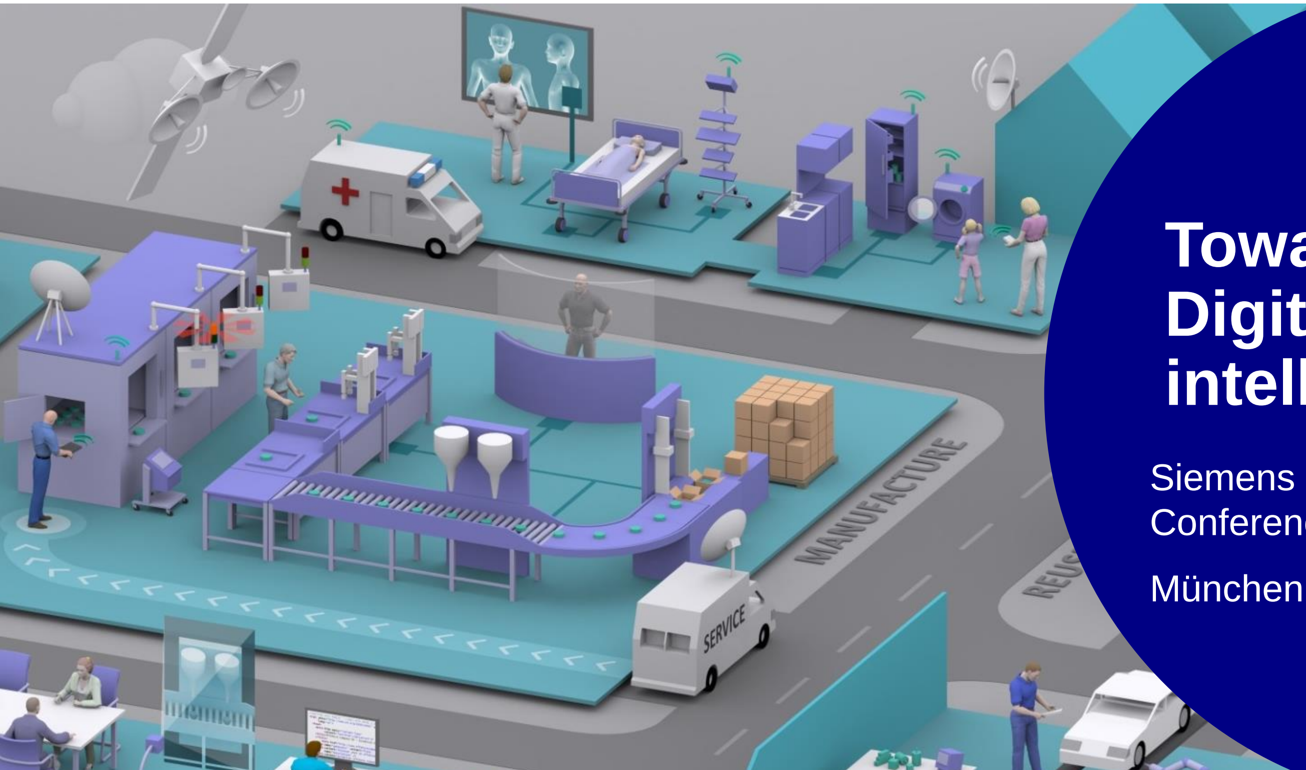
Universität Stuttgart
Industrial Automation and Software Engineering



Towards Digital Twins for intelligent Automation

Siemens Simulation and Digital Twin Conference

München, 19. Nov. 2019

Prof. Dr.-Ing. Dr. h.c. Michael Weyrich

- Head of Institute, Industrial Automation and Software Engineering, Univ. of Stuttgart
- Board member VDI/VDE society for Measurement- and Automation Technology (VDI/VDE GMA)
- Member of the interdisciplinary committee of Digital Transformation of the Association of German Engineers

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New ways of work: Digital Twin and the Internet-of-Things

[2]

The Economist Topics Current edition More

Jul 13th 2017

The Gemini makers

Millions of things will soon have digital twins

From factories to cars to a range of consumer products

"The ***factory of the future*** will be a building stuffed full of robots making robots."

[3]

STAMFORD, Conn., March 13, 2018

Gartner Survey Reveals Nearly Half of Organizations Implementing IoT Are Using or Plan to Use Digital Twin Initiatives in 2018

Analysts to Address the Challenges of Digital Leadership at Upcoming Gartner CIO Leadership Forums and CIO and IT Executive Summits

Gardner Prognosis: „In 2020 about 2/3 of the companies … are going to have a ***Digital Twin in operation****"*

GAIA-X

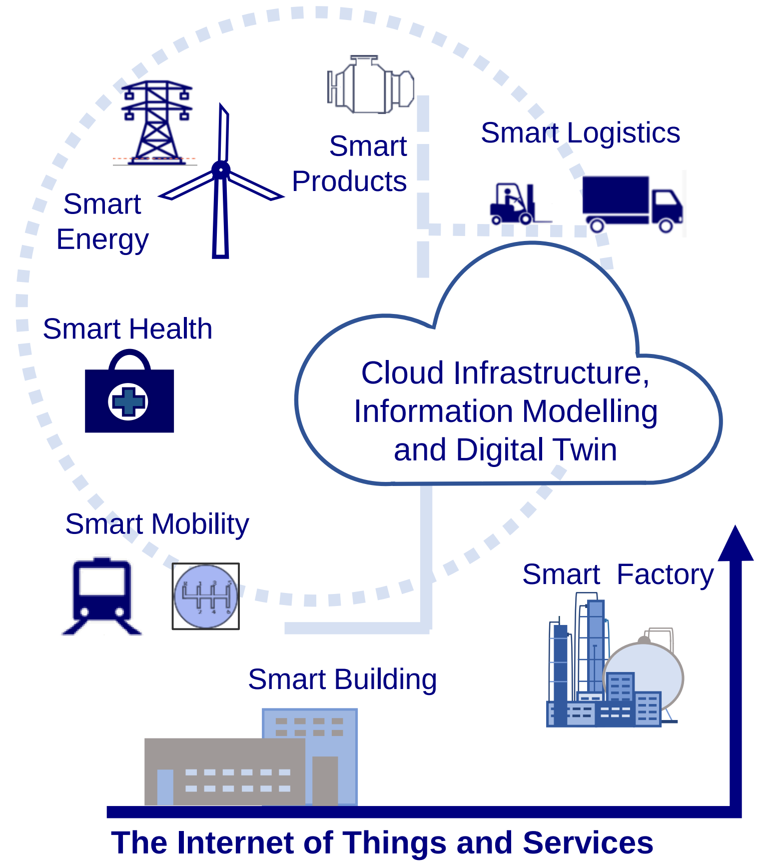
FORTUNE October 30, 2019

Europe Is Starting to Declare Its Cloud Independence

"the ***German plans*** *were formulated … France is also keen"*

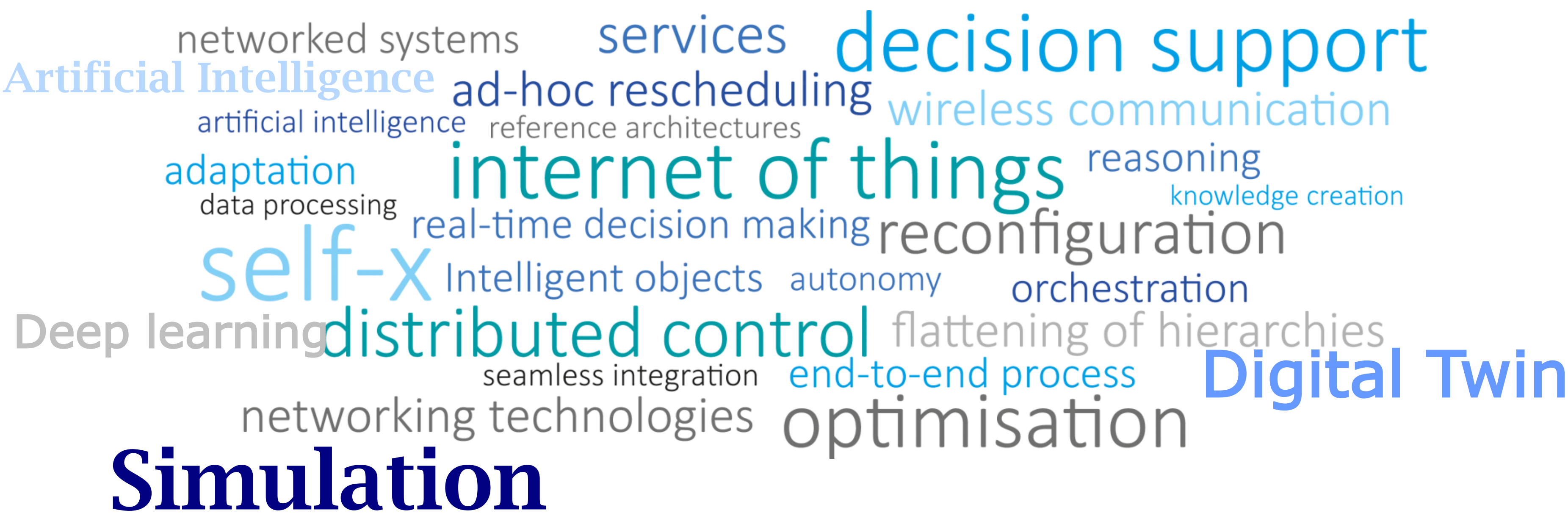
On the way to Industry 4.0 and a connected “everything“ …

- Applications are going to be boosted by information and communication technology.
- Customers, machines, logistics and virtually everything is going to be connected.
- Machines communicate with machines.
- Parts, logistics and machinery are controlling themselves



Digitalisation integrates a variety of different technologies

Networked data, information and artificial intelligence are going to impact all domains from production, mobility, energy to health care.



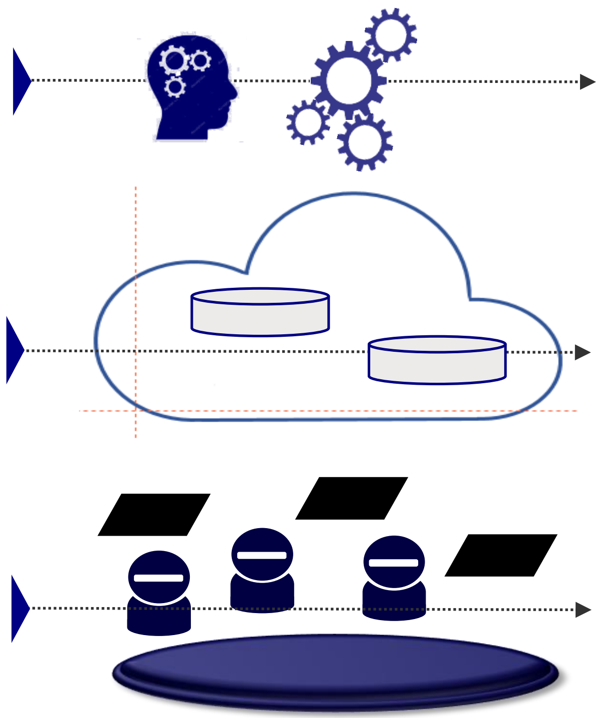
Hypotheses of this Presentation

The future potential of the Digital Twin lies in a data driven approach which enables advanced simulation and leads to an intelligent automation.

AI for Automation

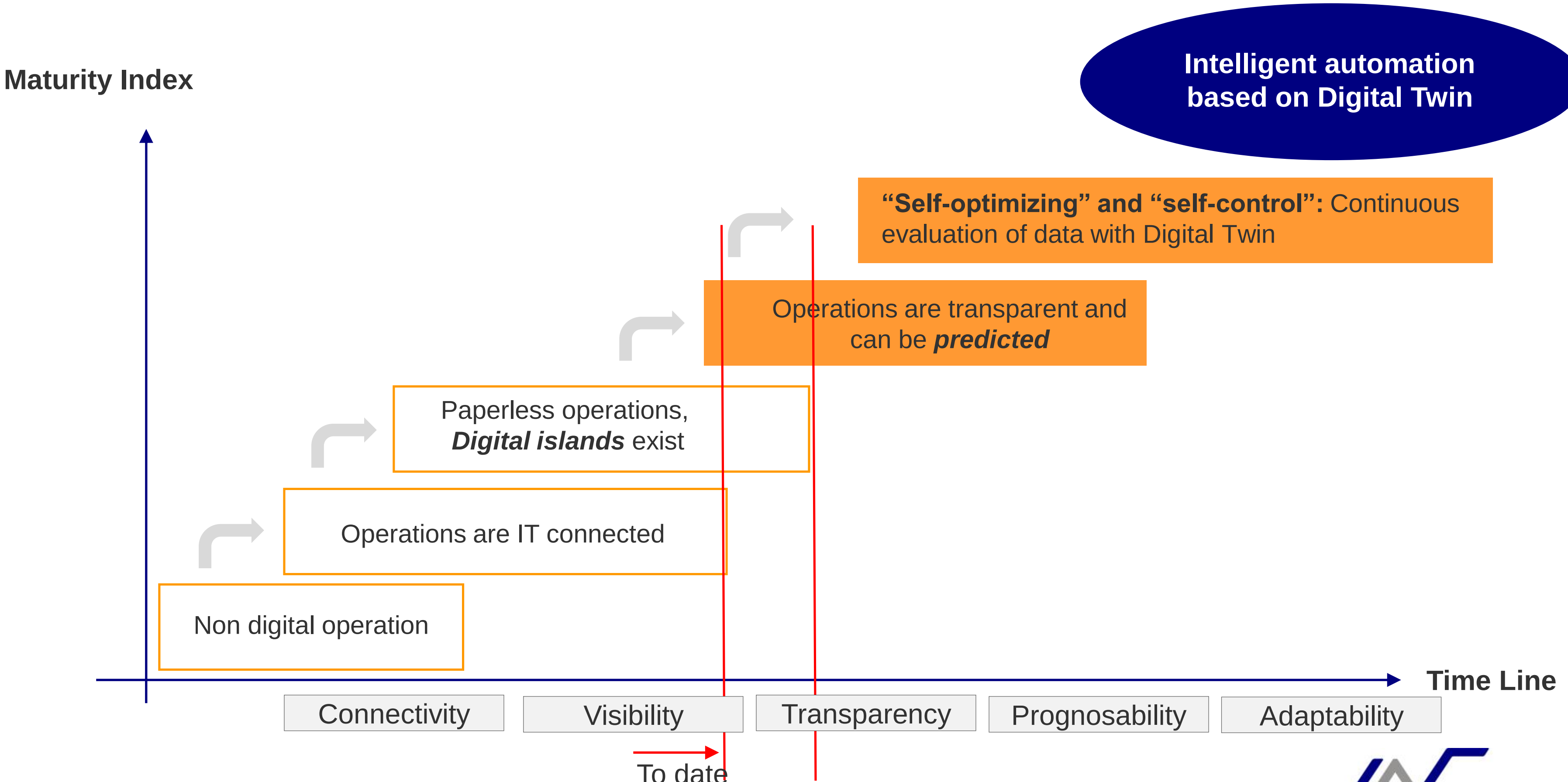
Standardized infrastructure

Apps, bots and simulation platform



- Intelligent automation requires Simulation along with a Digital Twin.
- Cloud solutions are an important step towards standardized platforms for data processing, apps and bots.
- Digital Twin enables new services and assistant functionality for operation.

A Maturity Model for Digitalization leads the Way towards Analytics, AI and the “New Machine Age”

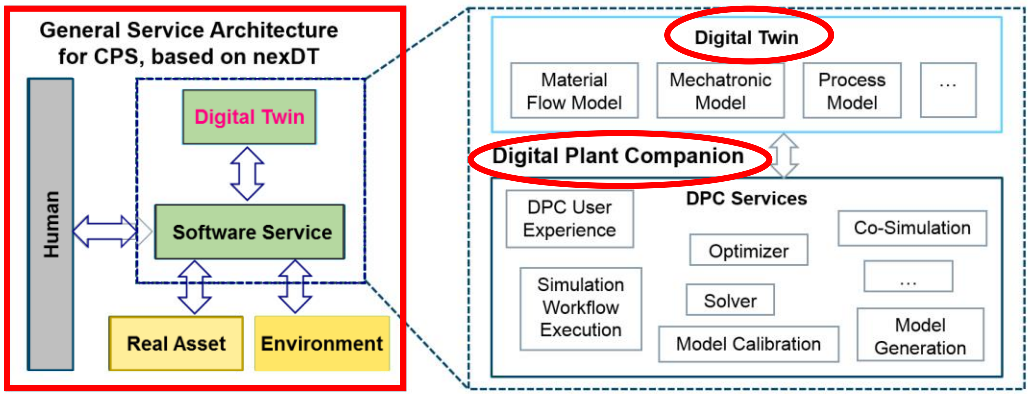


On the way to Cyber physical Systems …

Definition (Source: IFAC mechatronics, Roland Rosen et. al., CT RDA AUC, 09/2019)

Solutions for *Systems of CPS*
Example Digital Plant Companion

SIEMENS
Ingenuity for life



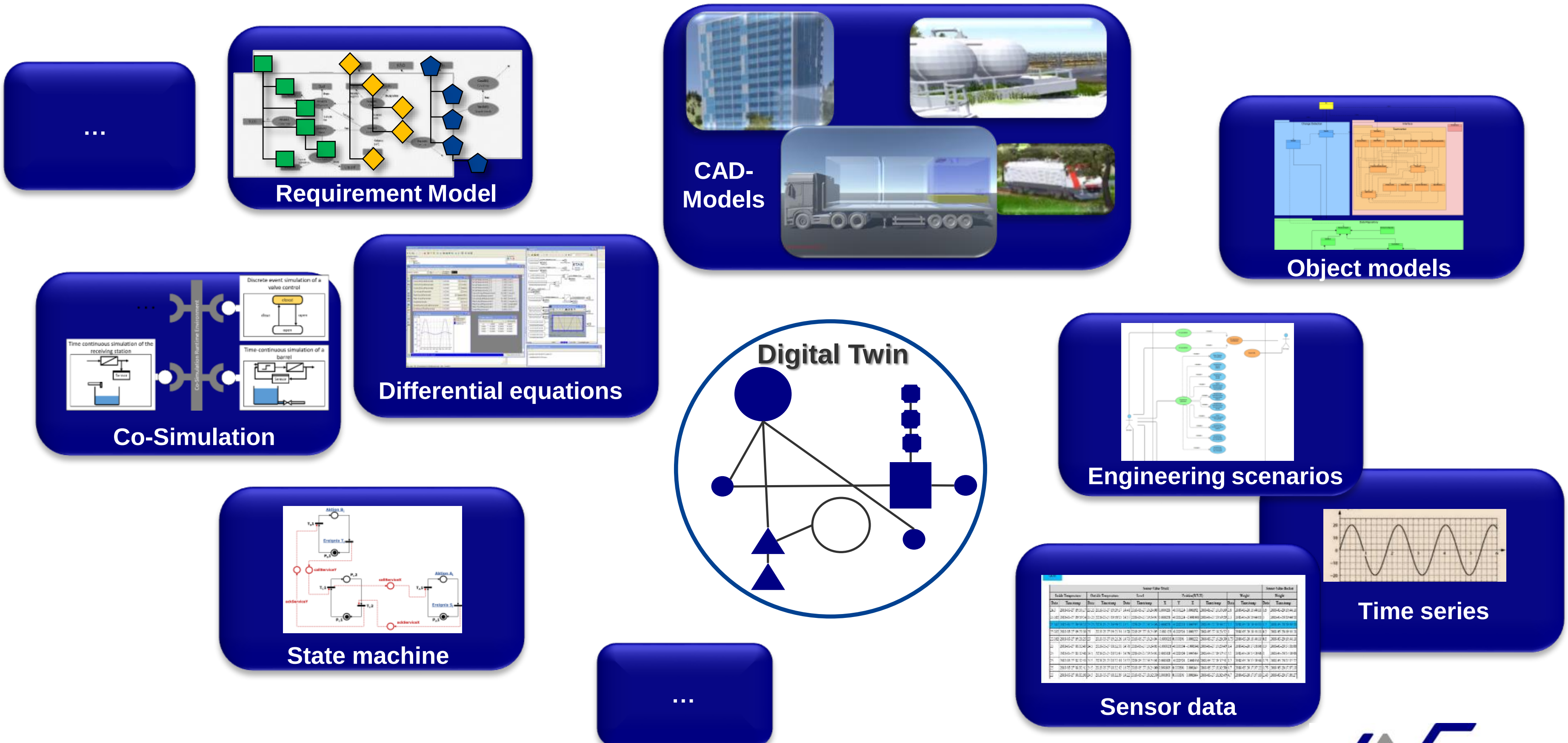
Digital twin as the brain of CPS
- Enabling autonomy as well as supervision and optimization of systems of CPS

Digital *System* Companions in distributed environments
- Integrating data & simulation & cloud technologies

Page 1 September 2019 Corporate Technology

Multiple Models make Digital Twin(s)

A large variety of models exist to cover the multiple aspects of digital twins.



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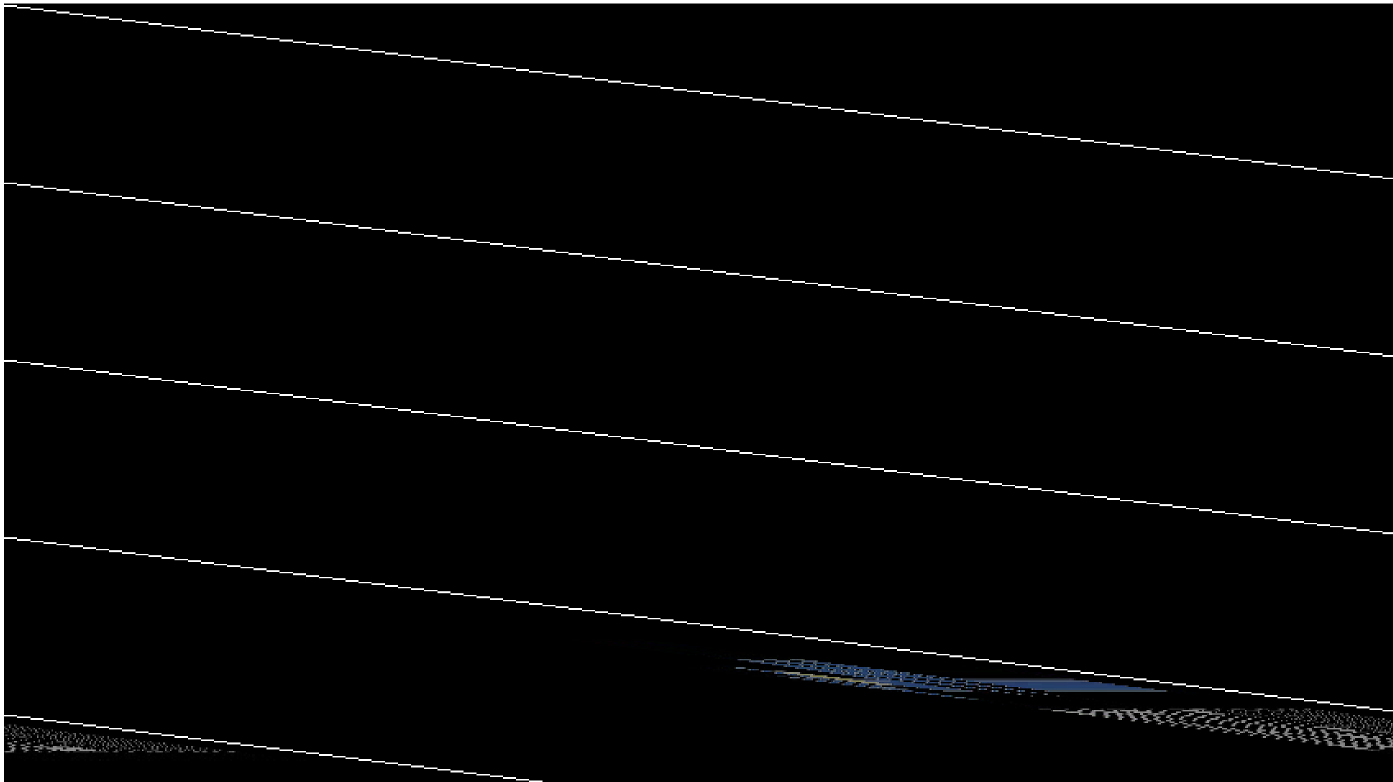
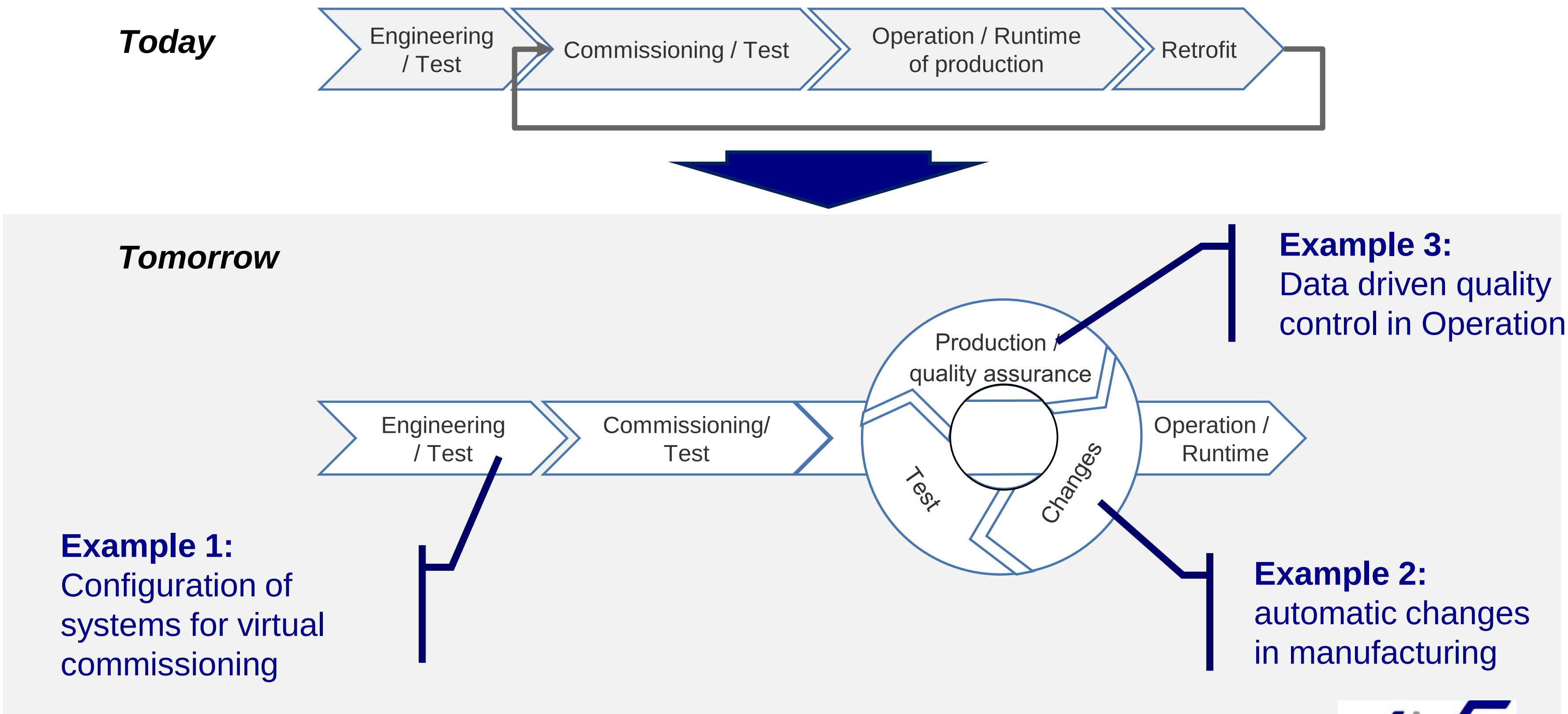
State-of-the-Art: Digital Factory of Daimler

Challenges: Inhomogeneous data and systems complexity



Digital Twin – Design moves to Runtime

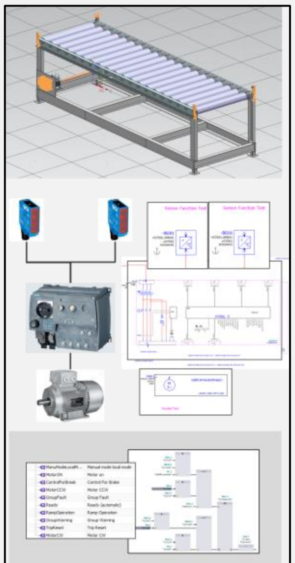
How could the interchange be used between the cyber and physical world?

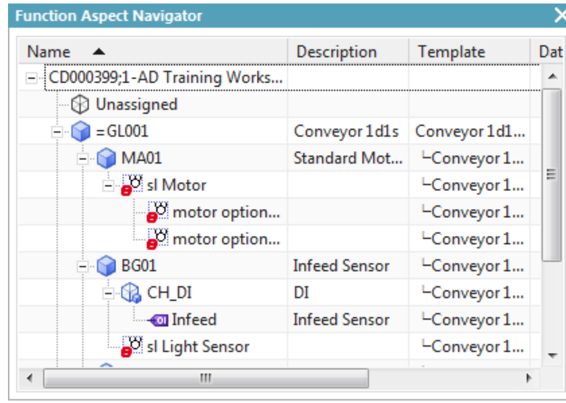


Example 1: Interconnection of multiple Sub-domains / Disciplines

Manufacturing systems are designed using IT-based Engineering systems which support different views of the various mechatronic elements

Components





Station

Whole Line

(Source: Siemens AG-Automation Designer)

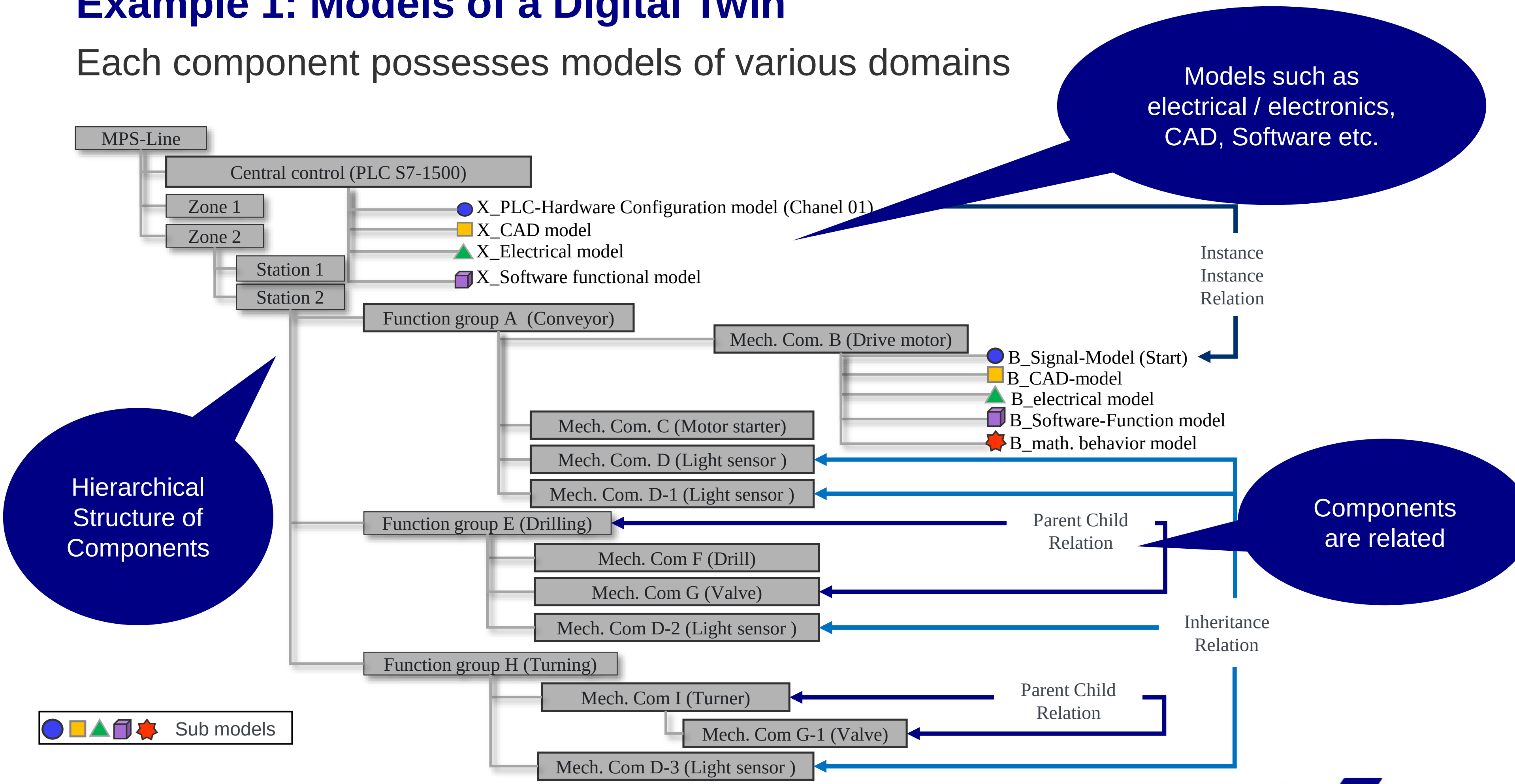
- Discipline mechanical Design
- Discipline Layout of plant
- Discipline Electronics / Electric
- Discipline Software for control

…

> **Challenge:**
> How to synchronize the multiple legacies of the Engineering systems?

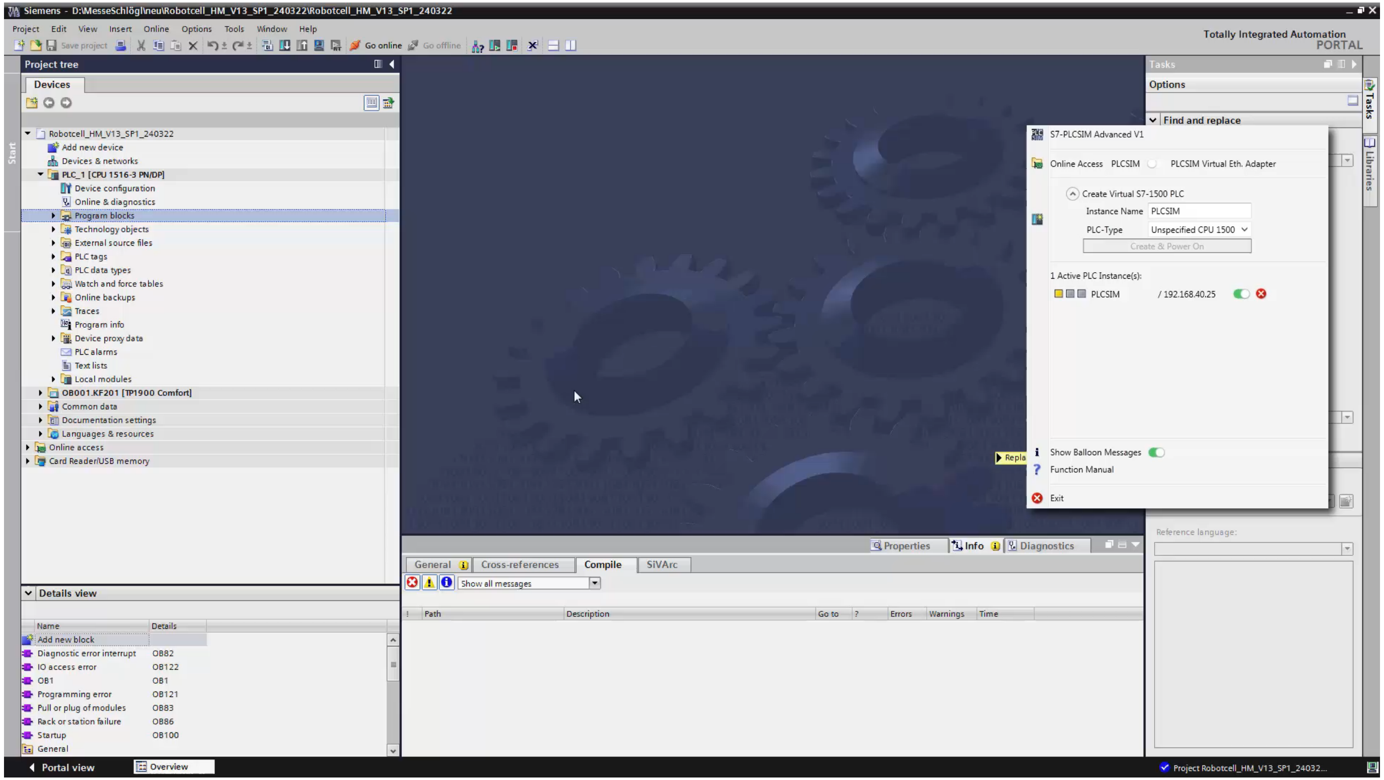
Example 1: Models of a Digital Twin

Each component possesses models of various domains



Example 1: Digital Twin for Virtual Commissioning

Assistant systems to interconnect multiple engineering models



Example 2: Digital Twin with Automatic changes in Operation

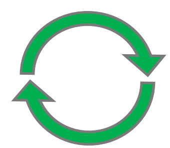
During Operation maintenance, monitoring and optimization is required

Physical Manufacturing

- Active data acquisition

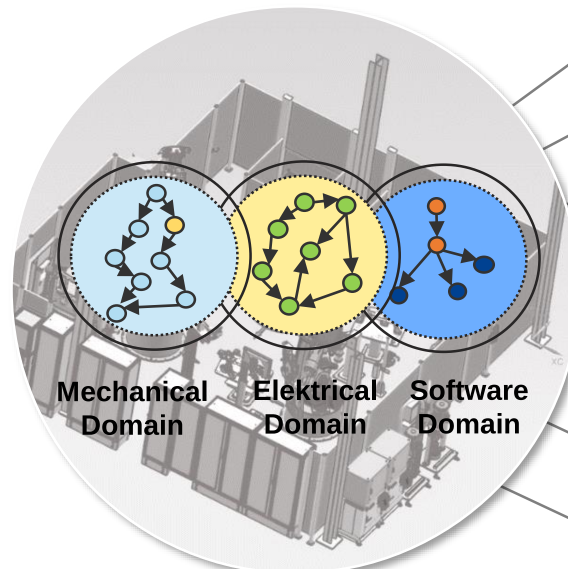
(Source: https://media.daimler.com)

Synchronisation



Digital Twin

- Modelling and Analysis



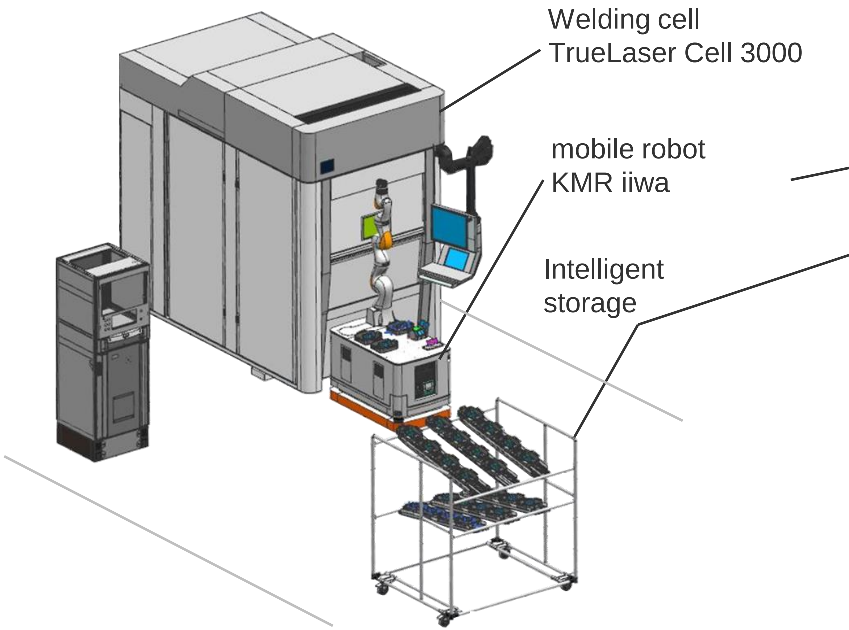
Simulation

- Prognosis

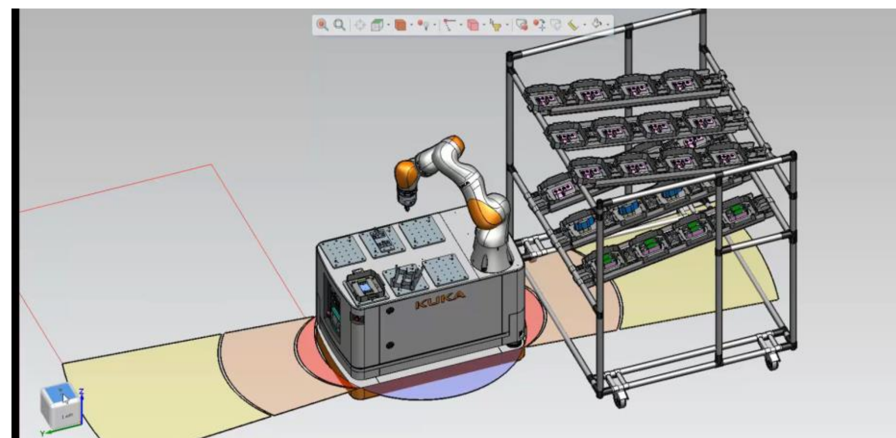
- Robot simulation
- Ergonomic simulation
- virtual commissioning
- Process driven cell simulation
- Digital Mock-Up
- Virtual Reality/ Mixed Reality
- Energy-Simulation

Example 2: Digital Twin for a flexible manufacturing cell

The flexible manufacturing cell can be reconfigured based on a What-If-Simulation based on a digital twin synchronized with the physical system.



ARENA2036 - “Active Research Environment for the Next Generation of Automobiles”



Example 3: Data driven quality control in Massive Forming

Process data entail information and can be analyzed to improve process quality of machinery which can not be sufficiently modelled.

Press Process Challenges:

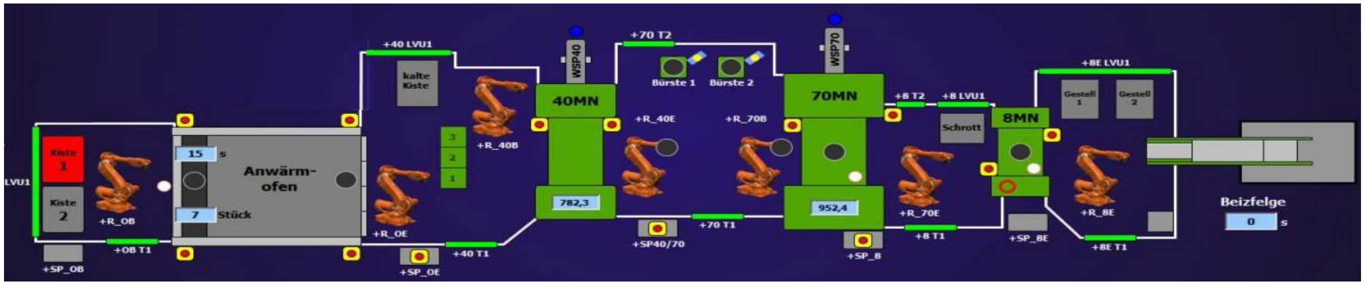
- Capture of data and extraction of unknown patterns
- Analysis and generation of action proposals

Project: BMWi EMuDig-Projekt

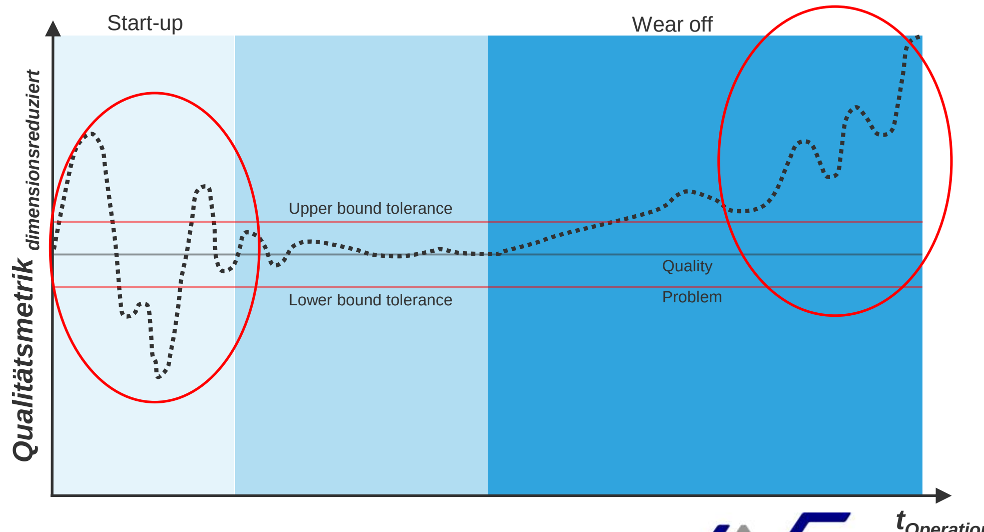
- Track and Trace of workpieces throughout a phased chain of production
- Bar code can be read despite 1250 °C and forming

Example 3: Data is monitored in Operation

Anomaly detection such as sudden events and creeping wear



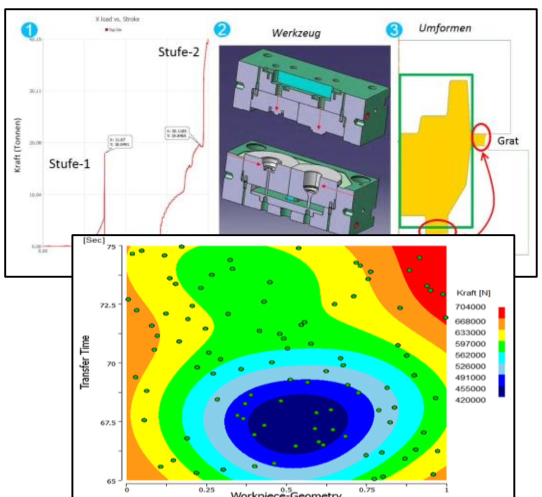
- **Wheel rim production** with Otto Fuchs KG
- **Available data**
  - Size: 2 TB
  - Data space: 86 Sensors
  - Duration: 4 month recording
- Extraction of process data from controls
- Approach: machine learning (LSTM networks)

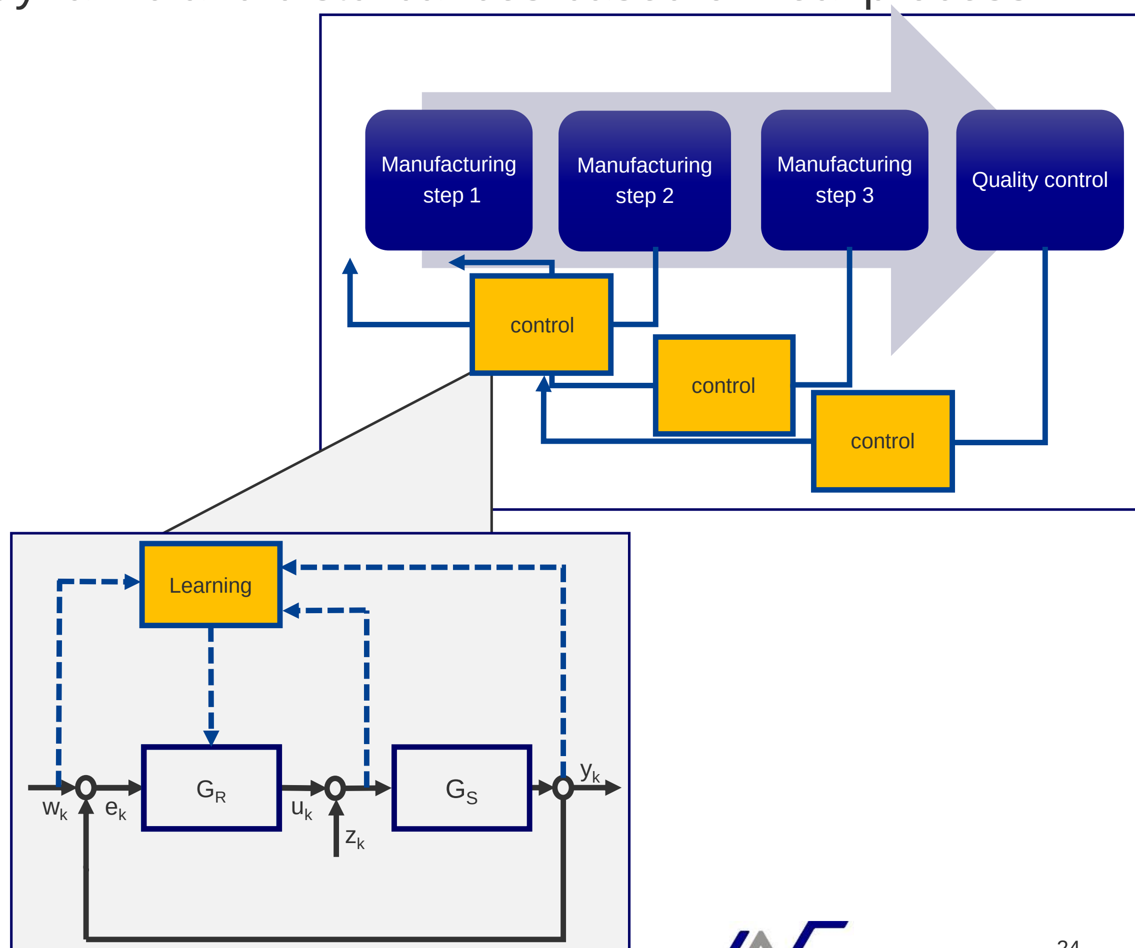


Example 3: Self-learning of System Components

The System learns about the dynamic and disturbances based on real process data.

A learning approach is utilized in order to optimize the cascaded quality controller based on Backpropagation Through Time and LSTM networks.





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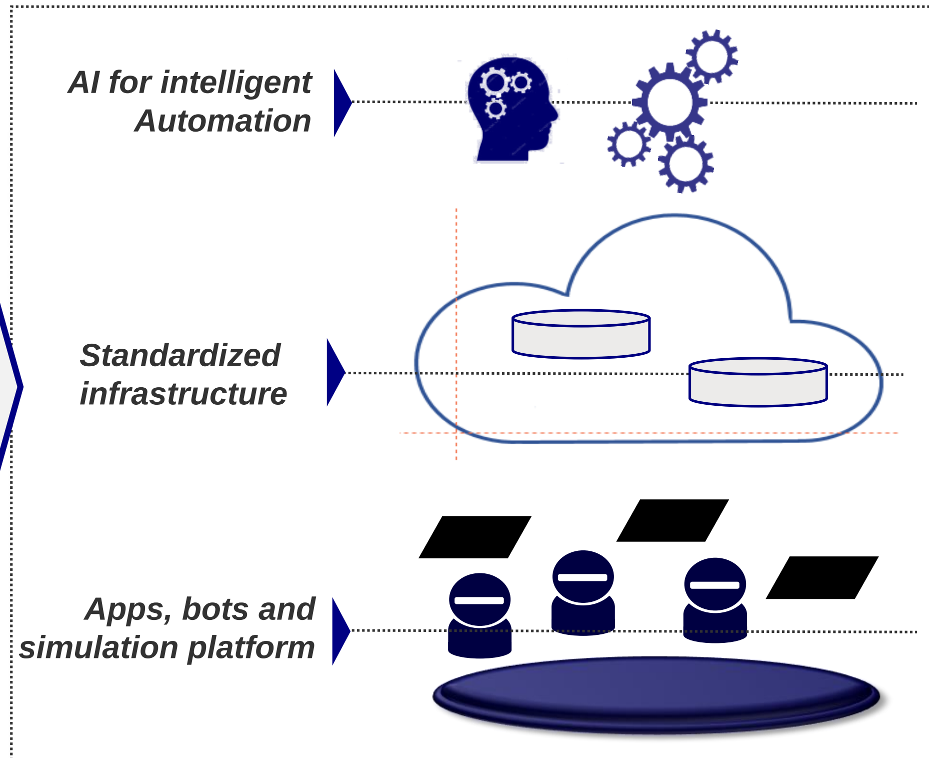
On-going Reseach: Preliminary Conclusion

Multiple approaches for data collection, Information processing and simulation based on multiple “best of class” technologies.

Presently a lot of research on Digital Twin focus on the ***various application*** in the domains



What are the open research questions?

Research Questions

Various Aspects are relevant but two appear dominant

How to obtain standards which ***integrates data and simulation***?

How to make a Digital twin a real "***brain of CPS***" enabling intelligent automation or even autonomy?

Applications need to be with respect to:

- ***Different location*** (special distributed / decentral) and
- Tools from ***different vendors***
- ***Dynamics***, i.e. changing participants

- Intelligent automation and Autonomy of decision making needs to be ***enabled by reinforcement learning which requires simulation***

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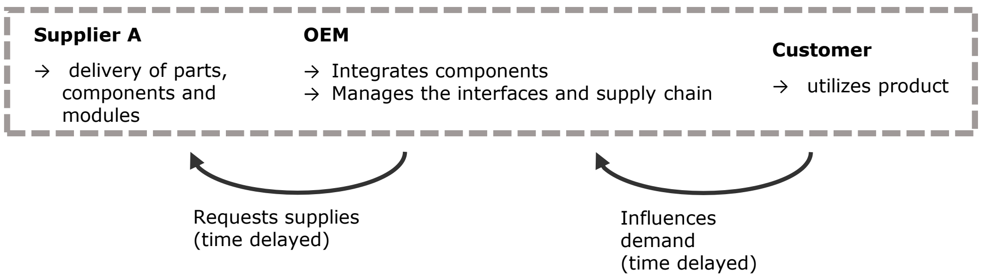
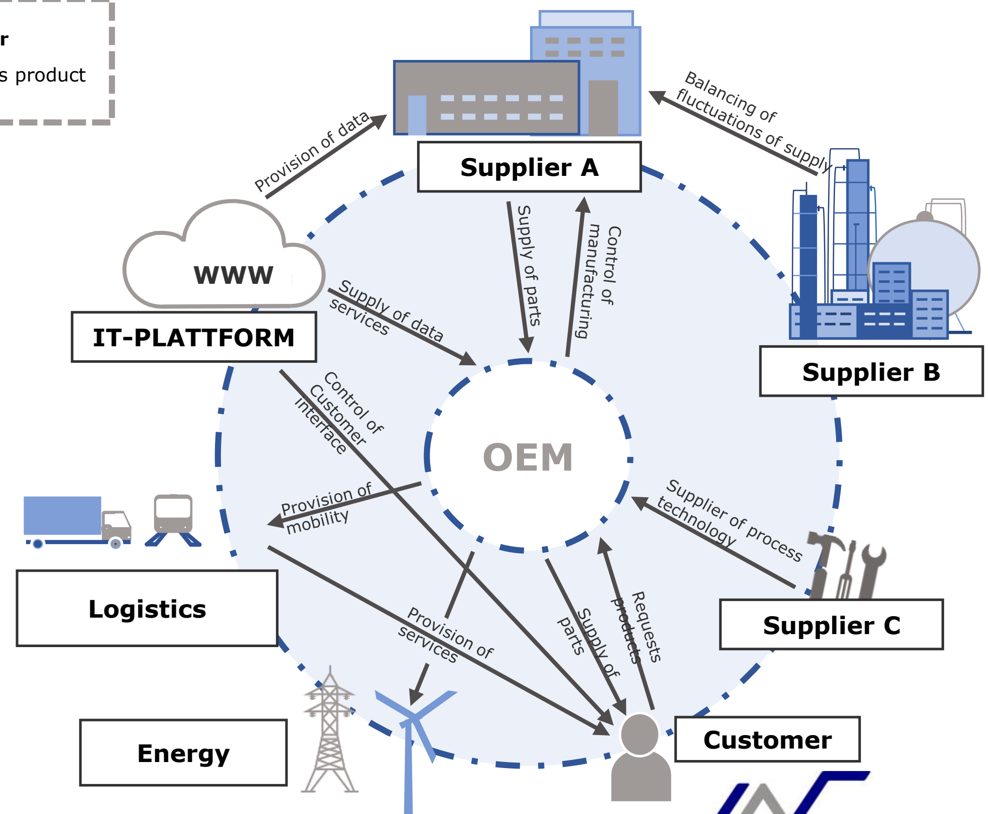
Co-Simulation and Control of complex Value Networks

Value networks can be co-simulated and be transparently controlled

Supply Chain



Value Network



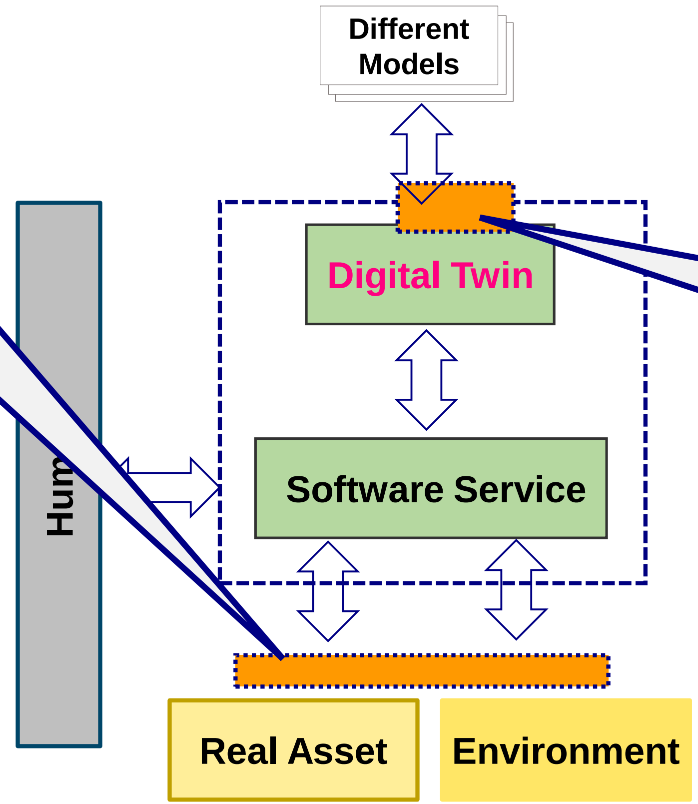
… from „static supply chains“ to „self-organising“ networks …

What Standards exist for distributed systems with Digital Twins?

Activities are presently at least on to levels for Digital Twins and Physical Assets.

1. Data acquisition interface:

Value-add:
Information exchange with the real world

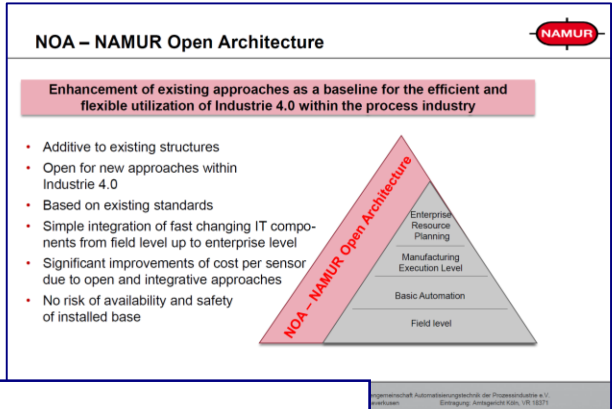


2. Model exchange and Synchronisation:

Value add: exchange data and synchronization with different models

Multiple Standards for Factory Automation are emerging

Interoperable control architectures are the basis for information exchange

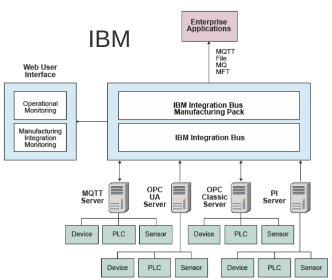


Open Process Automation™

proof-of-concept: ExxonMobil worked with Lockheed Martin to develop a base design and established a systems integration laboratory

Integration Bus Manufacturing

IBM



BMWi Project „FabOS – An Operating Systems for Factories“

FABOS

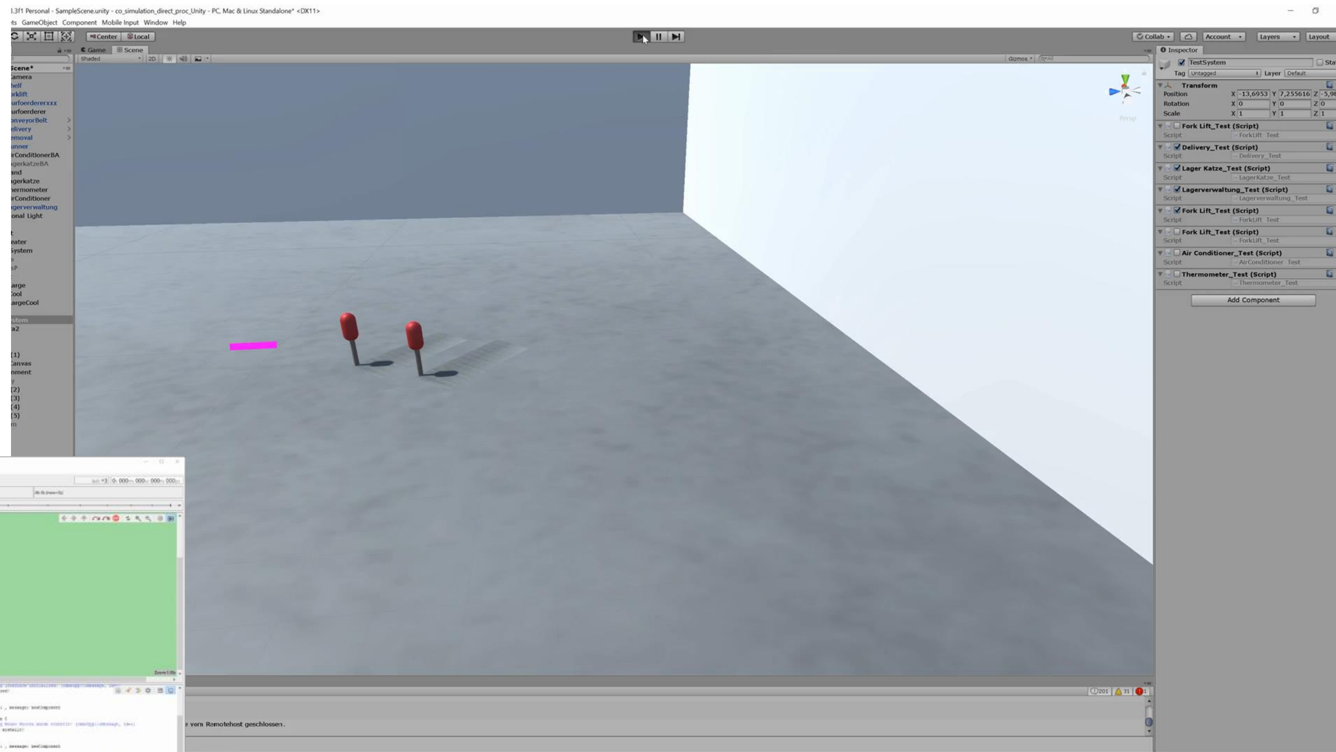
... other activities …

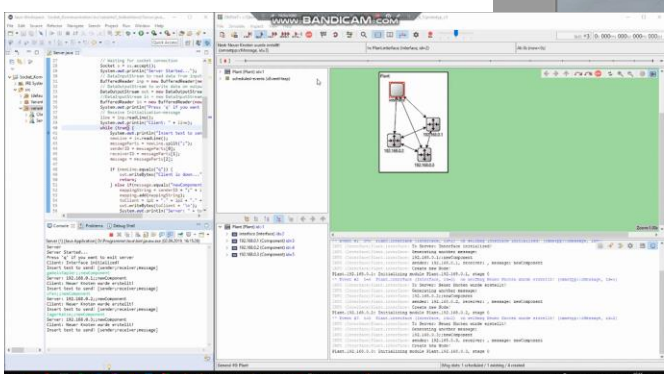
IAS Research: Software-Agents for Co-Simulation in intra Logistics

A „Plug-and-Simulate“ Framework for co-simulation during runtime is under research, in which simulation can be added during runtime.

Verknüpfte Simulationen:

- Unity (3D Visualisation)
- MATLAB Simulink (autonomy fork lifter)
- AnyLogic (autonomy forklift and distribution system)
- OMNet++ (Connectivity)





IAS-Research: Co-Simulation Framework

Smooth “plug-in” despite heterogeneous interfaces: Agents encapsulate simulation tools and enable them to be integrated into a Co-Simulation.

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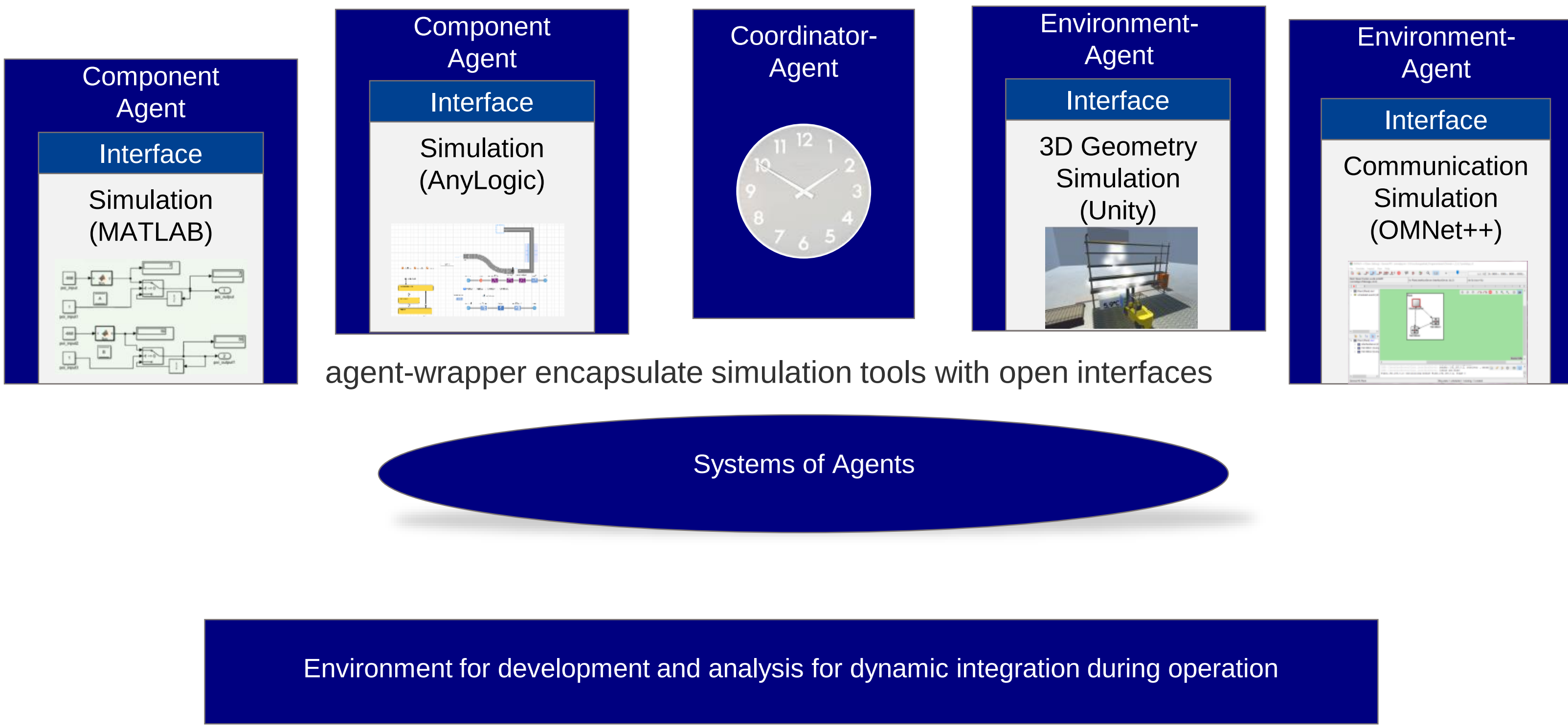

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A Scenario for Research on Complex Value Networks …

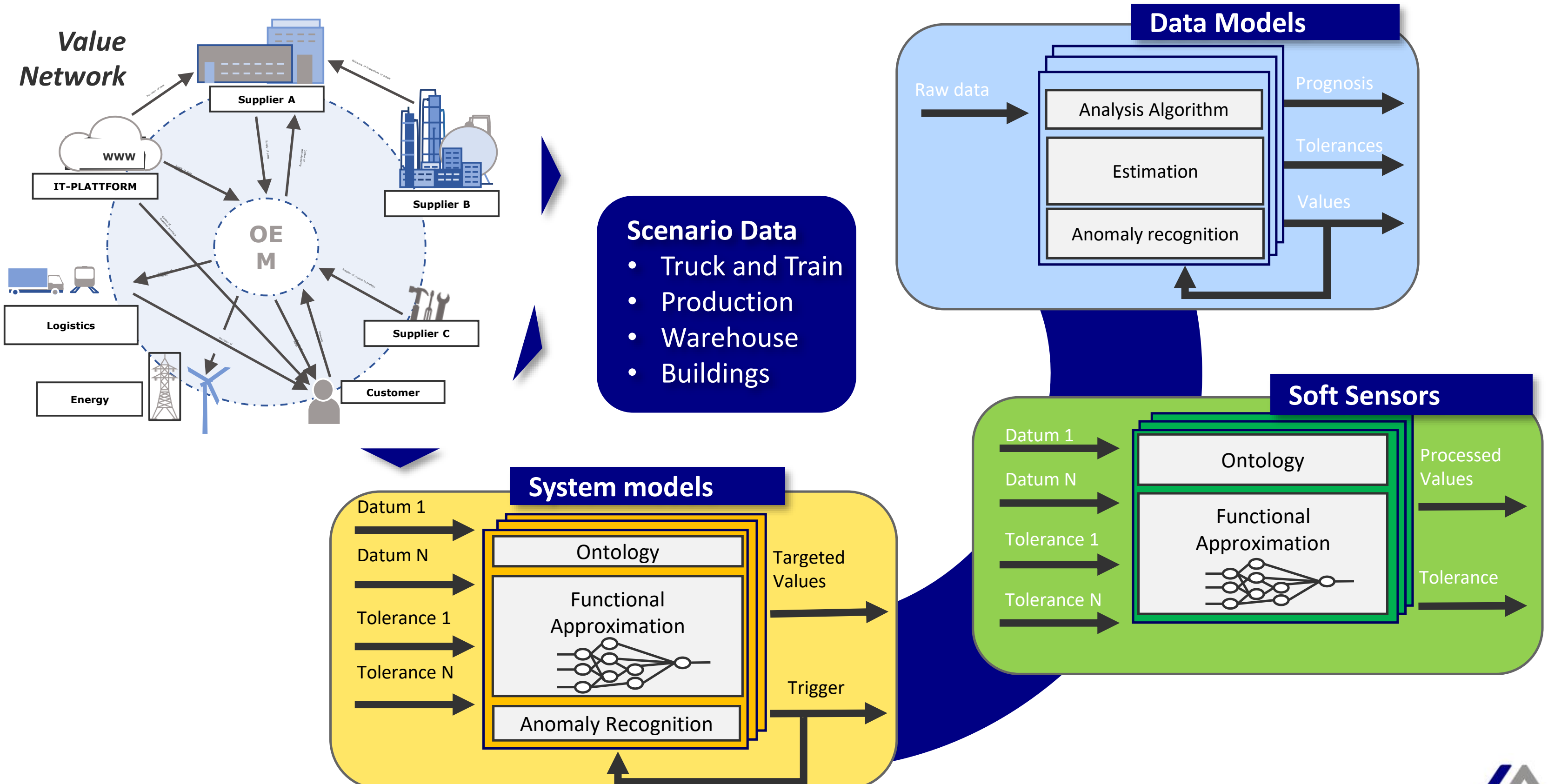
Intelligent Digital Twin: Transparency, Prediction, Self-optimizing and Self-control

Co-simulation of Value Network consists of:

- Smart Logistics (Trucks, Trains)
- Smart Factory
- Intelligent Warehouse
- Intelligent Building

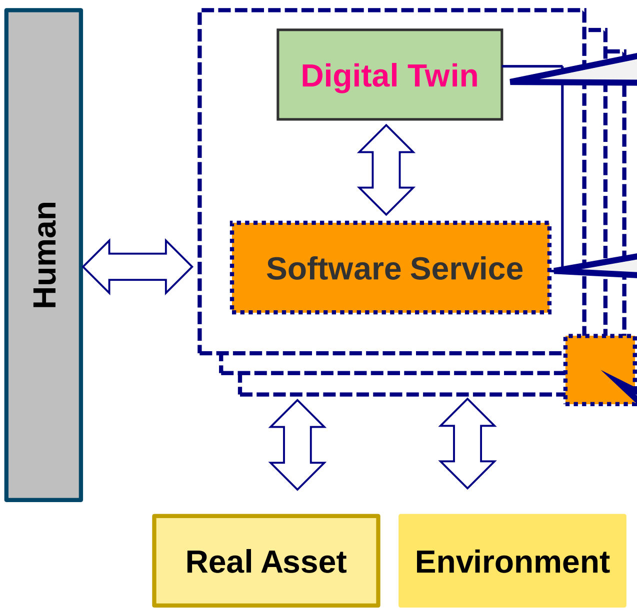
Overview of the Digital Twin for the Scenario

The information model consist of data from physical systems, ontologies, soft sensors and functional system models



The Scenario aims to demonstrates the value-add of co-simulation in complex “real world” operation

Digital Twin and Companion



Functionality

- ***Management, identification and analysis***
- ***Deployment of*** *(dynamic)* ***Co-Simulation***
- ***Digital Twin to Digital Twin Interfaces***

Value-add

Transparency and Prediction

Prognosis of future scenarios and “Self-x”

Potential transfer learning

Contents

Future Vision of the Digital Twin

Models should be able to manage the multiple model dimensions, recognize changing boundary conditions and synchronize with real data from operations.

- Simulation, models and data can be put in different perspectives
- Model dimensions can reduced or expanded
- Models synchronize themselves with other models and real-world data

©:https://www.independent.co.uk/arts-entertainment/art/news/inception-inspired-coffee-table-bends-reality-and-a-city-in-your-own-home-a6800956.html

A Management of Digital Twins and Co-Simulation creates the basis for „self-learning“ approaches

Towards intelligent Systems

Multi-agent reinforcement learning requires a (co-simulation) to be trained and adapted

Real Life: dynamic rules, infinite states with complex assessment

https://de.wikipedia.org/wiki/V%C3%B6lkerschlacht_bei_Leipzig#/media/Datei:MoshkovVI_SrazhLeypcigomGRM.jpg

Mastering Strategy Games:
For more complex situation assessment e.g. in Starcraft II

https://www.deepmind.com/blog/article/AlphaStar-Grandmaster-level-in-StarCraft-II-using-multi-agent-reinforcement-learning

Mastering Chess:
Static reals and a fairly simple assessment of situations

https://www.youtube.com/watch?v=NJarxpYyoFI