Functional Mock-Up Interface

FMI Applications and Its Role in Digital Twins

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Online Materials:

https://github.com/modelica/fmi-beginners-tutorial-2024/tree/main

Modelica Association

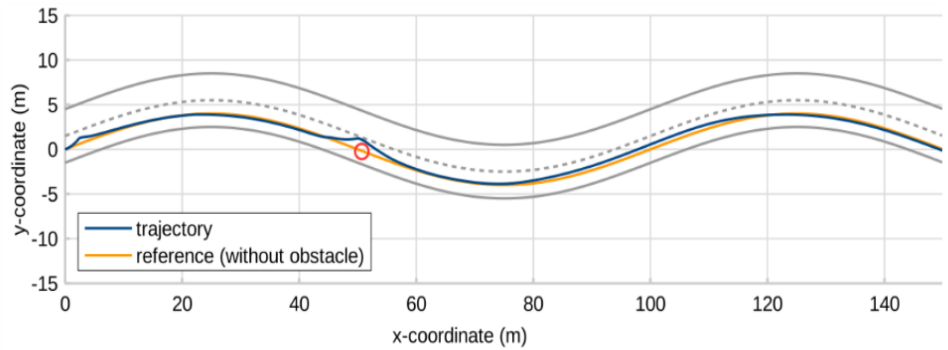
Autonomous Driving Advanced System (SW/HW co-simulation)

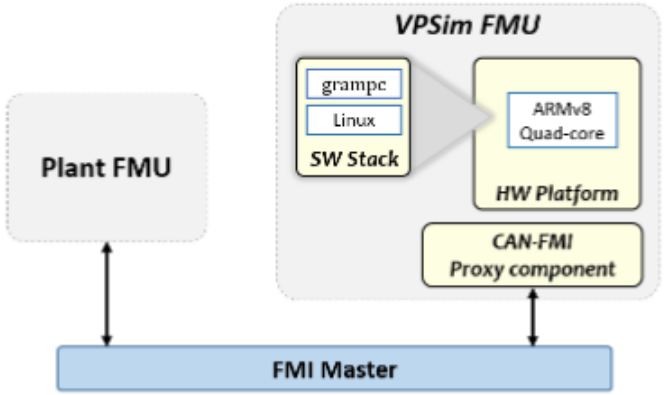
Model Predictive Control simulation on selected Hardware platform

Objective:

Validating the controller and assessing the adequacy of the hardware platform with respect to timing constraints and its performance

- GRAMPC
- VPSim
- Armv8 Quad-core 64-bit
- Simulink





FMI role:
easy validation of deployment of GRAMPC on a simulated architecture

http://www.european-processor-initiative.eu/
H2020, Grant Agreemer No26647

CEA, List, France

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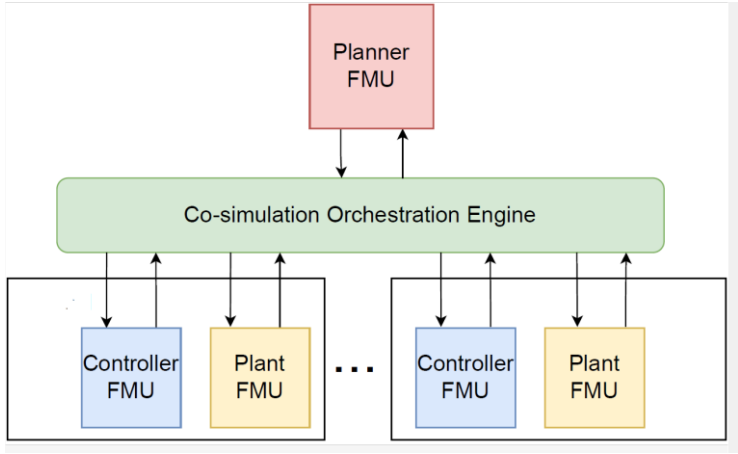
C. Bernardeschi, P. Dini, et al. , Co-simulation of a Model Predictive Control System for Automotive Applications, SEFM 2021 Collocated Workshops, https://link.springer.com/chapter/10.1007/978-3-031-12429-7_15

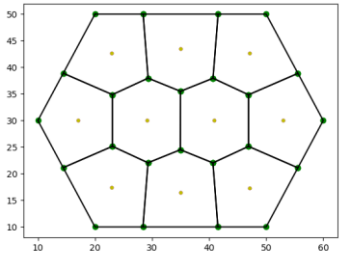
Multi-agent systems: aerial, land vehicles

Multi-UAV system: Planning & Control
Objective:

Controller parameters (attitude and position control) calibration for stability in co-operative systems; optimality of values with respect to time to convergence and energy consumption



- Planning algorithm (logic language, python)
- Controller (C)
- Plant (Modelica)



Voronoi tesselletion

Erle-robotics quadcopter

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FMI role:

Analysis of the relation between the numeric integration step (co-simulation step) and time discretization interval for planning for stability; analysis of optimality of control parameters value

- https://github.com/INTO-CPS-Association/example-linear-quadcopter
- C. Bernardeschi, A. Domenici, et al., Co-simulation and Formal Verification of Co-operative Drone Control With Logic-Based Specifications The Computer Journal, vol. 66, Issue 2, 2023, https://doi.org/10.1093/comjnl/bxab161

Human-centered systems

Integrated Clinical Environment (ICE)

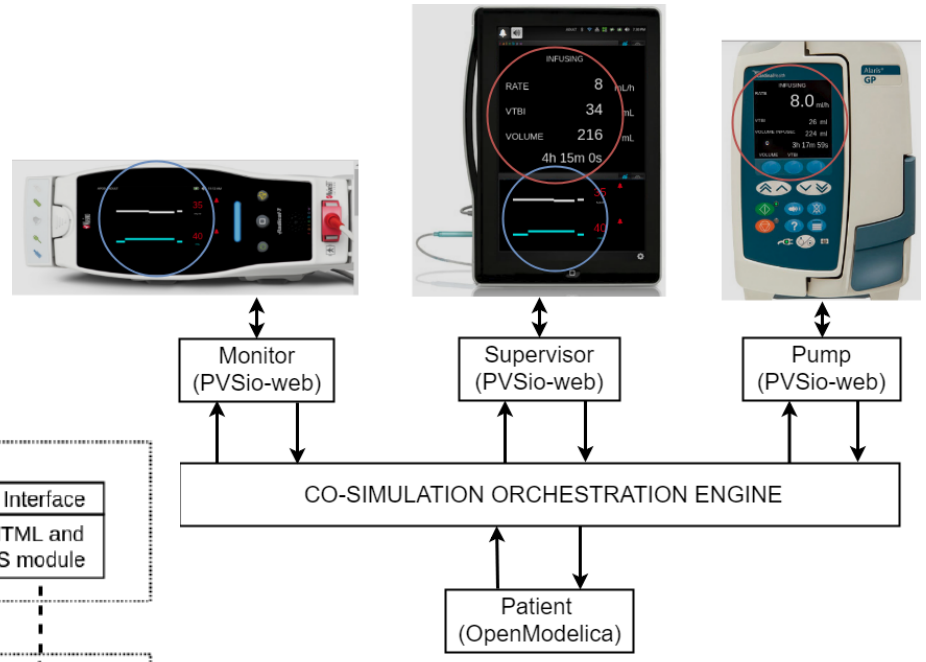
User interaction with the realistic interfaces of the devices
Easy testing and validation of device interaction
from different manufactures (use error)

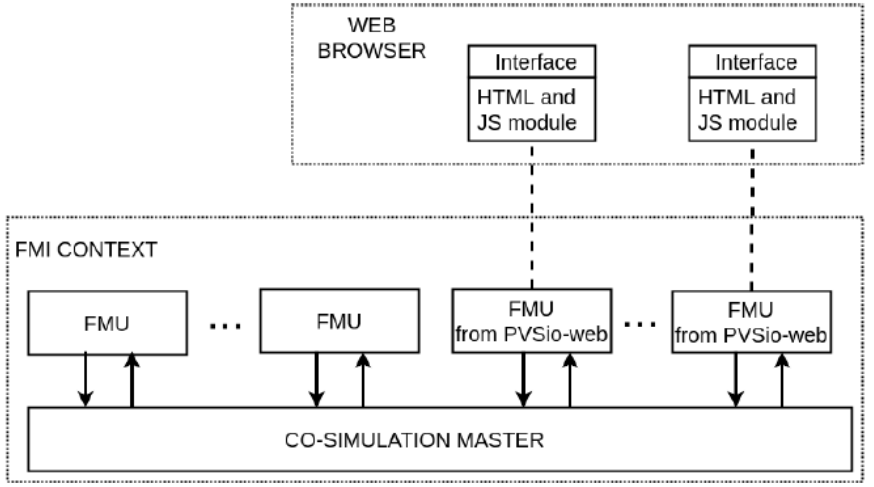
Devices: PVSioweb

Patient: OpenModelica

FMI role:

Validate ICE with respect to patient model. Formal proof of a use-related requirement of a device used in the co-simulation





NASA Langley Research Center

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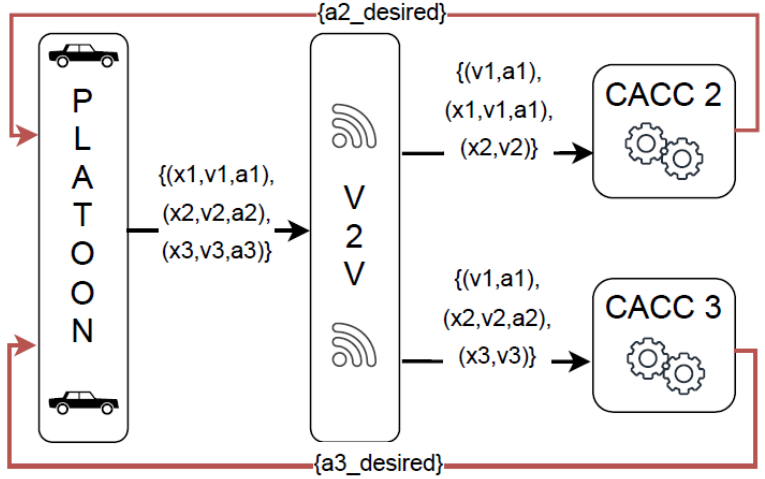
M. Palmieri, C. Bernardeschi, P. Masci. A framework for FMI-based co-simulation of human–machine interfaces, Software and Systems Modeling, vol. 19, Issue 3, 2020, https://dl.acm.org/doi/abs/10.1007/s10270-019-00754-9

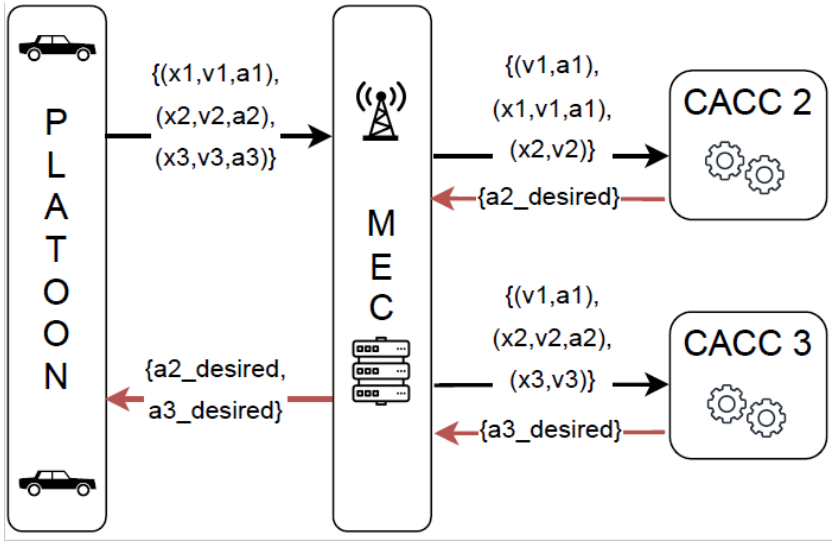
Communications in connected vehicles

Platoon of land vehicles

V2V communication against centralized multi-access edge computing.
Performance with vehicle dynamics and different road surface conditions.
Strategies to drive safely a platoon in critical road conditions.

3-vehicles platoon

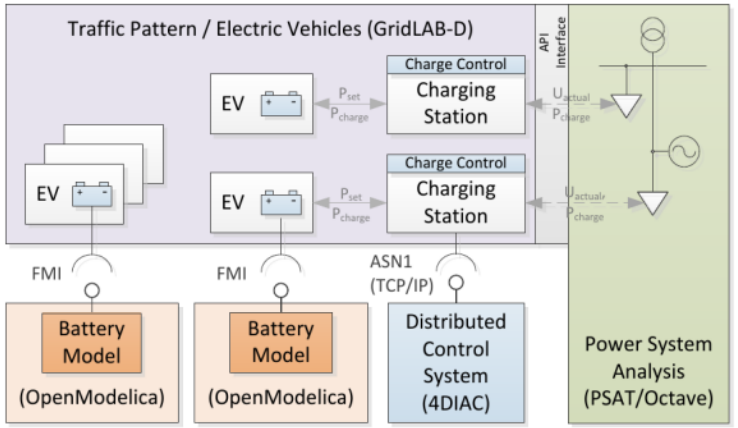




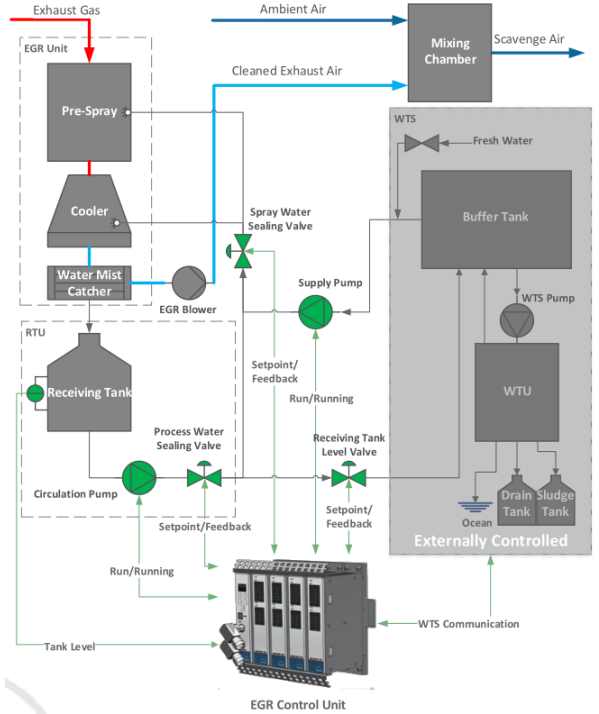
FMI role:
swap from one network architecture to another;
analysis of unsafe conditions

M. Palmieri, C. Quadri, et.al, Co-simulated Digital Twin on the Network Edge: the case of platooning, IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, 2022, doi:10.1109/WoWMoM54355.2022.00096.

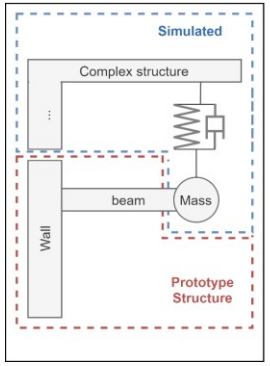
Other applications

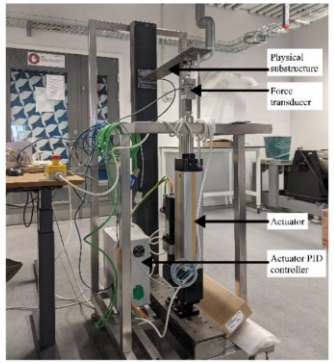


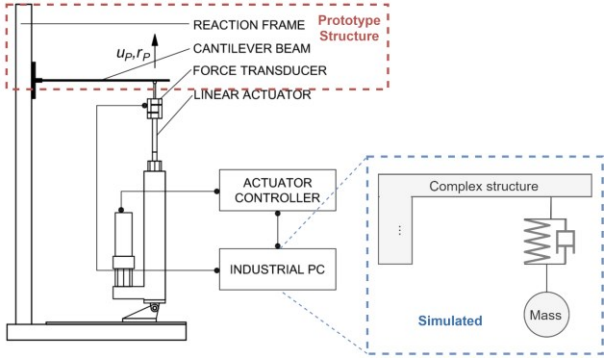
P. Palensky, E. Widl, M. Stifter and A. Elsheikh, "Modeling Intelligent Energy Systems: Co-Simulation Platform for Validating Flexible-Demand EV Charging Management," in IEEE Transactions on Smart Grid, vol. 4, no. 4, pp. 1939-1947, Dec. 2013, doi: 10.1109/TSG.2013.2258050.



Pedersen, N., Lausdahl, et. al (2017). Distributed Co-Simulation of Embedded Control Software with Exhaust Gas Recirculation Water Handling System using INTO-CPS. In 7th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (pp. 73–82).



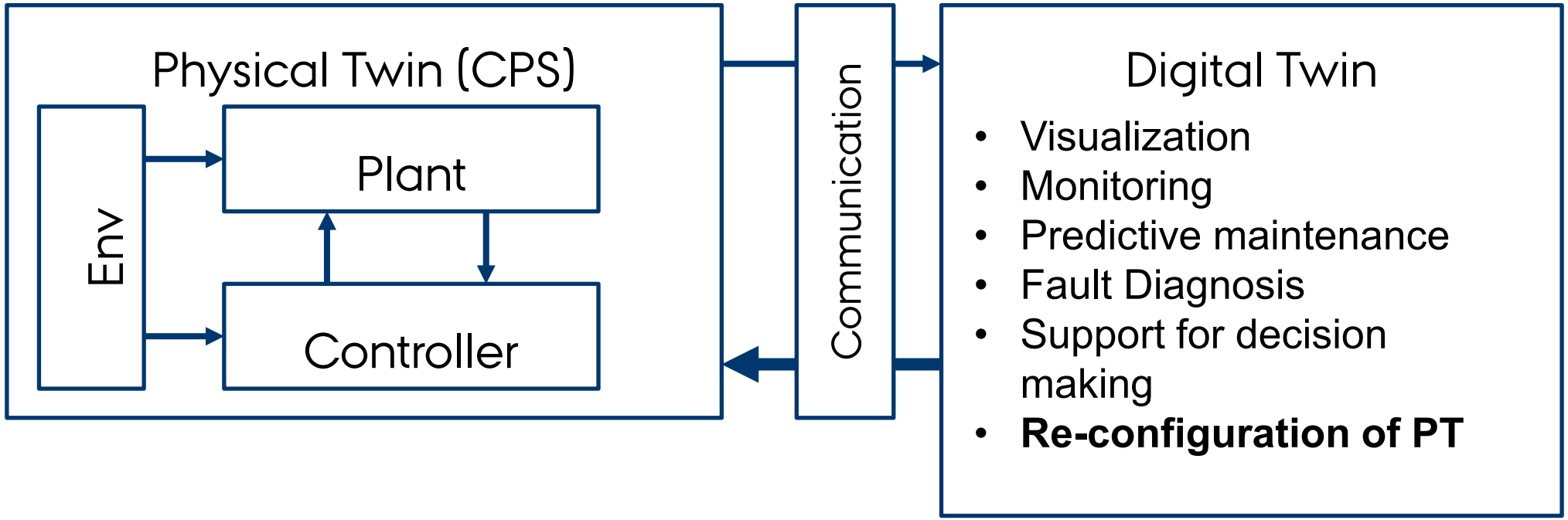




Gomes, Cláudio, Giuseppe Abbiati, and Peter Gorm Larsen. “Seismic Hybrid Testing Using FMI-Based Co-Simulation.” In Proceedings of the 14th International Modelica Conference. online: Linköping University Electronic Press, Linköpings Universitet, 2021. https://doi.org/10.3384/ecp21181287.

FMI & Digital Twins

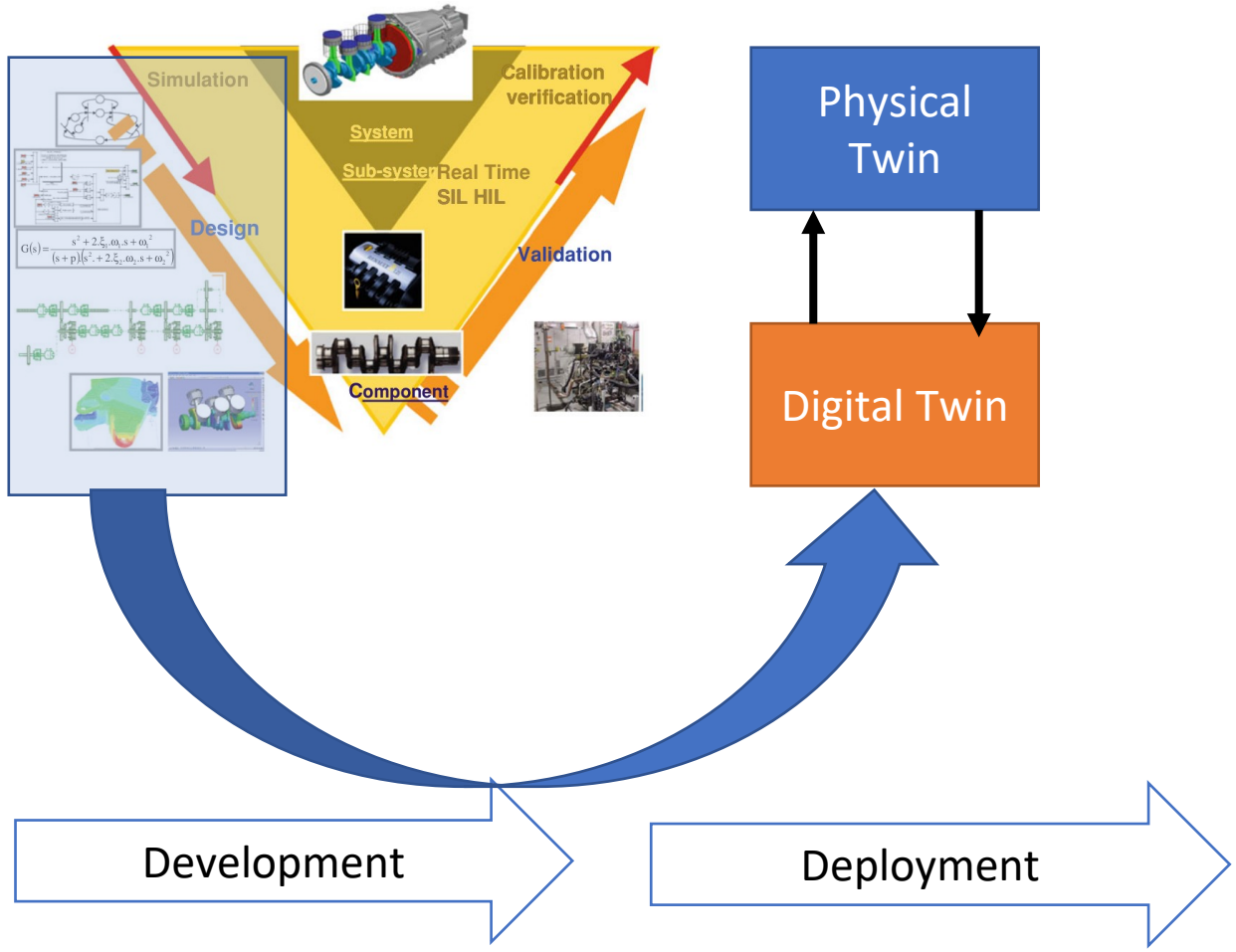
Digital Twin Definition in this Tutorial



Opportunities of FMI in DTs

Leverage design time models at deployment time.

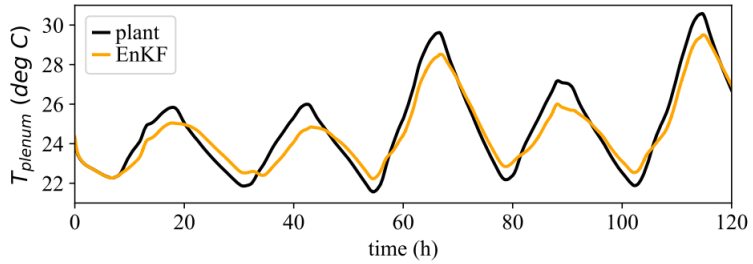
Deploy models without design time tooling.



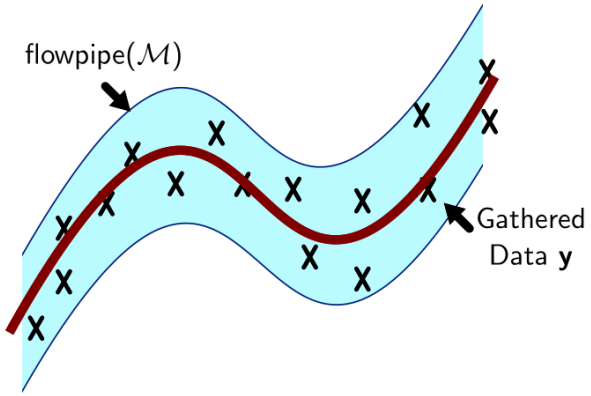
Role of FMI in Digital Twinning

Digital Twin

- Visualization
- Monitoring
- Predictive maintenance
- Fault Diagnosis
- Support for decision making
- Re-configuration



Models



Laughman, Christopher, and Scott A Bortoff. "Nonlinear State Estimation with FMI: Tutorial and Applications," 23–25, 2020.

Legaard, Christian Møldrup, Cláudio Gomes, Peter Gorm Larsen, and Frederik F. Foldager. "Rapid Prototyping of Self-Adaptive-Systems Using Python Functional Mockup Units." In *Proceedings of the 2020 Summer Simulation Conference*, 1–12. SummerSim '20. Virtual Event. https://doi.org/10.5555/3427510.3427532.

Bogomolov, Sergiy, Cláudio Gomes, Carlos Isasa, Sadegh Soudjani, Paulius Stankaitis, and Thomas Wright. "Reachability Analysis of FMI Models Using Data-Driven Dynamic Sensitivity." *SIMULATION*, Special Issue: Engineering of Dependable Digital Twins, 2023, accepted.

Wrap up

Resources

- FMI Webpage
  - FMI tools list
  - FMU validation
  - Publications

- Reference FMUs
  - A set of hand-coded FMUs for development, testing and debugging of FMI.

- In case of questions we recommend to use StackOverflow with tag „fmi“
- You are welcome to join the (unofficial) FMI LinkedIn Group

Thank you!

Any questions or comments?

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