



CoFMPy

A Flexible FMI-based Co-Simulation Framework for Digital Twin Applications

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Speaker: Corentin FRIEDRICH (IRT Saint Exupéry, France)

Co-authors: Andrés Lombana, Charlie Schlick, Mouhcine Mendil, Nora Bennani (IRT Saint Exupéry)



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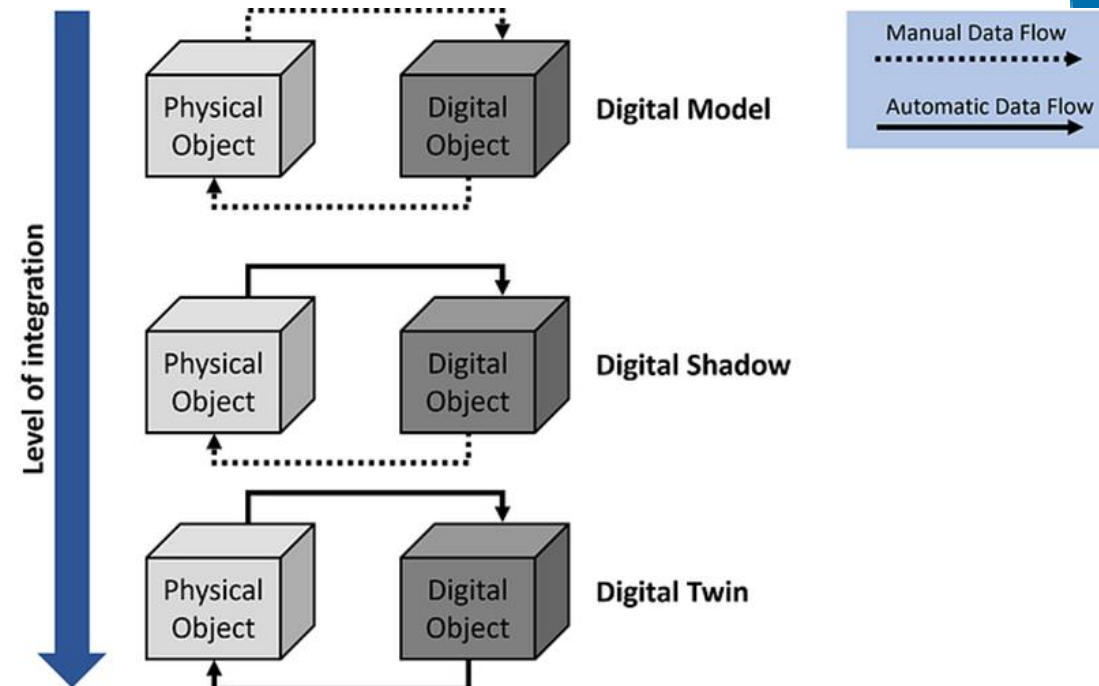
From Simulation to Digital Twin (DT)

Digital models

- Mature simulation tools for predefined offline analysis
- Useful for feasibility studies, early-stage design validation, and controlled experiment
- Lack of adaptability or real-time updates (manual reconfiguration)

Digital twins (shadows)

- Continuous, real-time updates from physical systems
- Can interact and evolve with the physical twin
- Proactive decisions through predictive analytics



Source: Kritzinger et al. 2018

Digital Twins Applications

Manufacturing (industry 4.0) 🏭

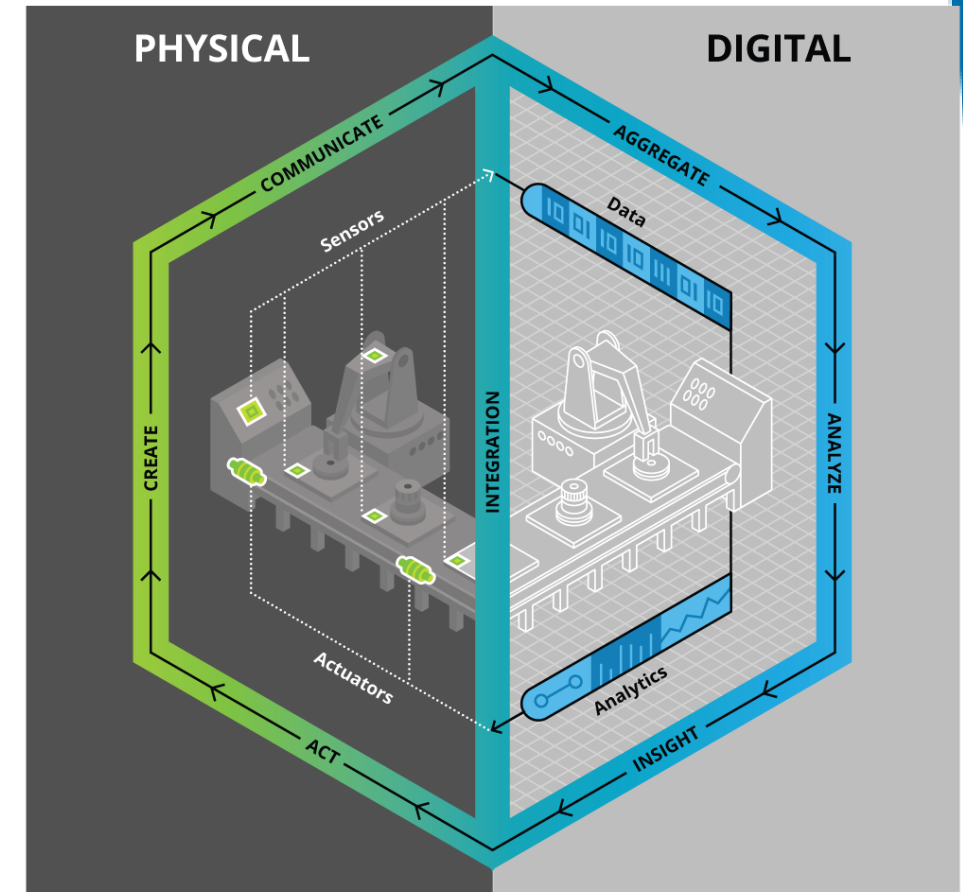
- Monitor production lines
- Enable predictive, condition-based maintenance to reduce downtime

Smart Cities 🏙️

- Manage traffic
- Optimize energy distribution
- Monitor infrastructure health

Aerospace & Defense ✈️

- Simulate performance
- Optimize energy use
- Predict system failures in real time.

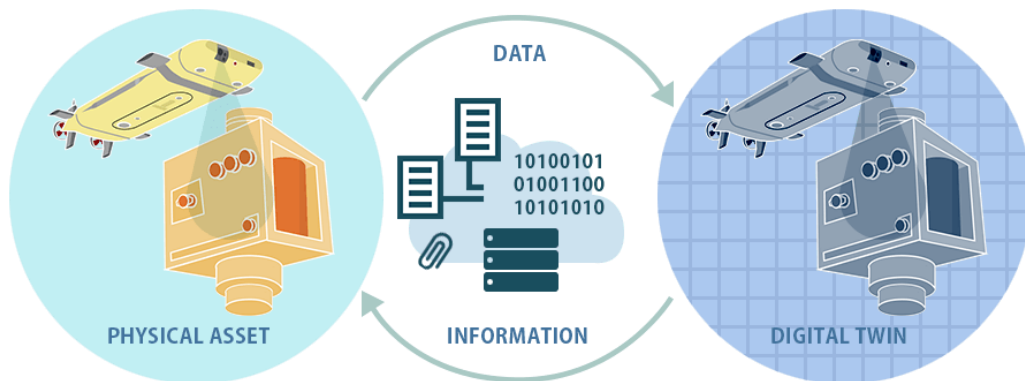


Source: Deloitte University Press.

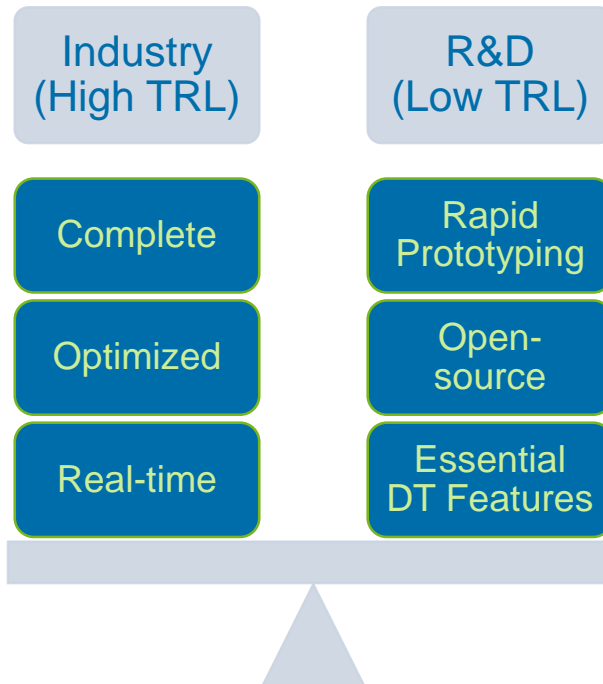
Deloitte University Press | dupress.deloitte.com

Co-simulation Requirements For Digital Twins

- ✓ **Multi-domain integration**
 - Seamless coordination between heterogeneous multidisciplinary systems
- ✓ **Modularity and Interoperability**
 - Modular design to enable flexible model integration and updates
- ✓ **Bidirectional Data Flow**
 - Real-time updates and feedback loops
- ✓ **Scalability**
 - Ability to handle large systems and multiple components

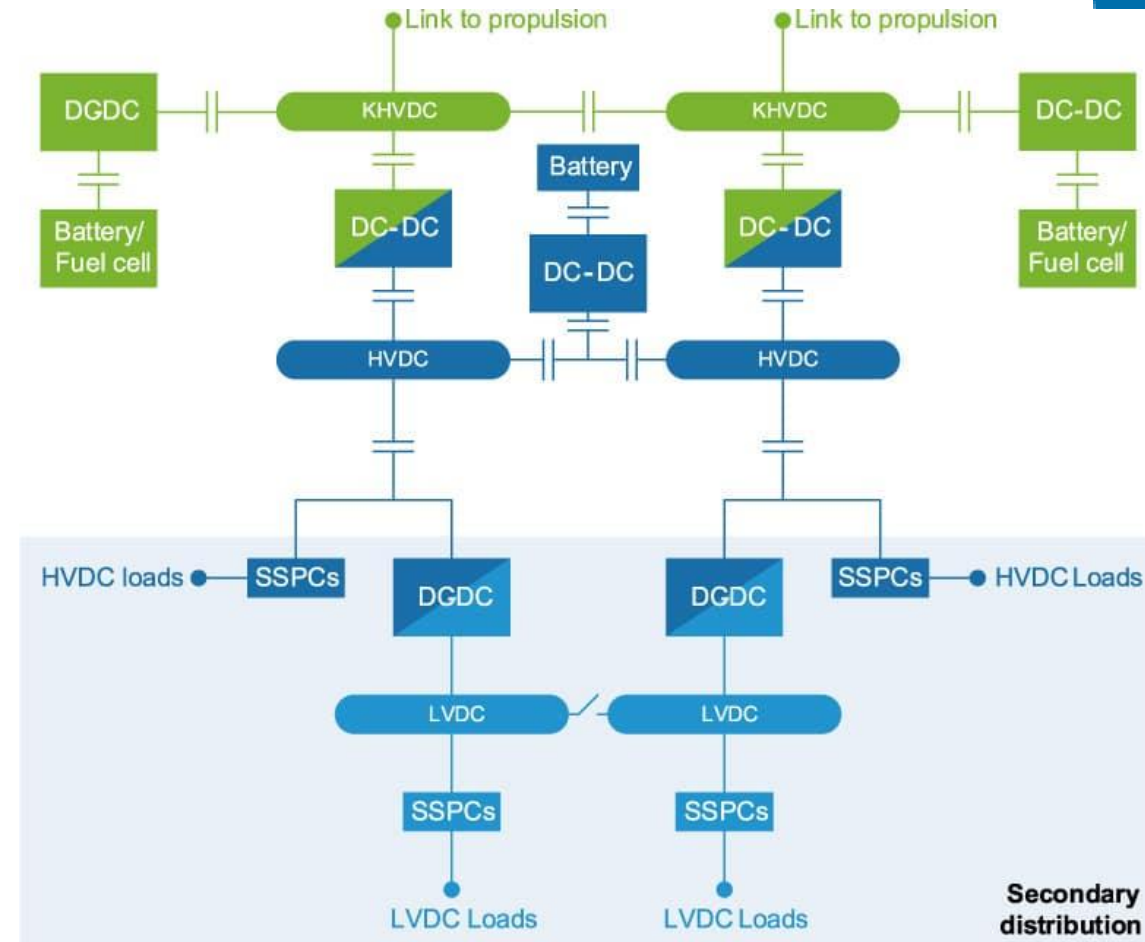


Digital Twin wishlist



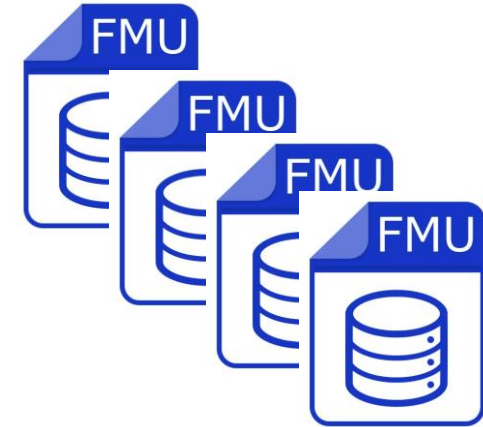
HECATE project

- **HECATE = Hybrid Electric Regional Aircraft Distribution Technologies**
- **Ongoing European project supported by the Clean Aviation Joint Undertaking (CAJU)**
- **One of the challenges – build a Digital Twin:**
 - Primary distribution with very high voltage DC (KHVDC), from 800 to 1500 V
 - Secondary distribution with low and high voltage DC (LVDC and HVDC), from 28 to 540 V
 - DC-DC power converters
 - etc.



HECATE project

- Each partner of the project provides FMU files corresponding to their subsystem simulation (distribution, converters, loads, etc.)



NEED FOR A RAPID PROTOTYPING DT TOOL

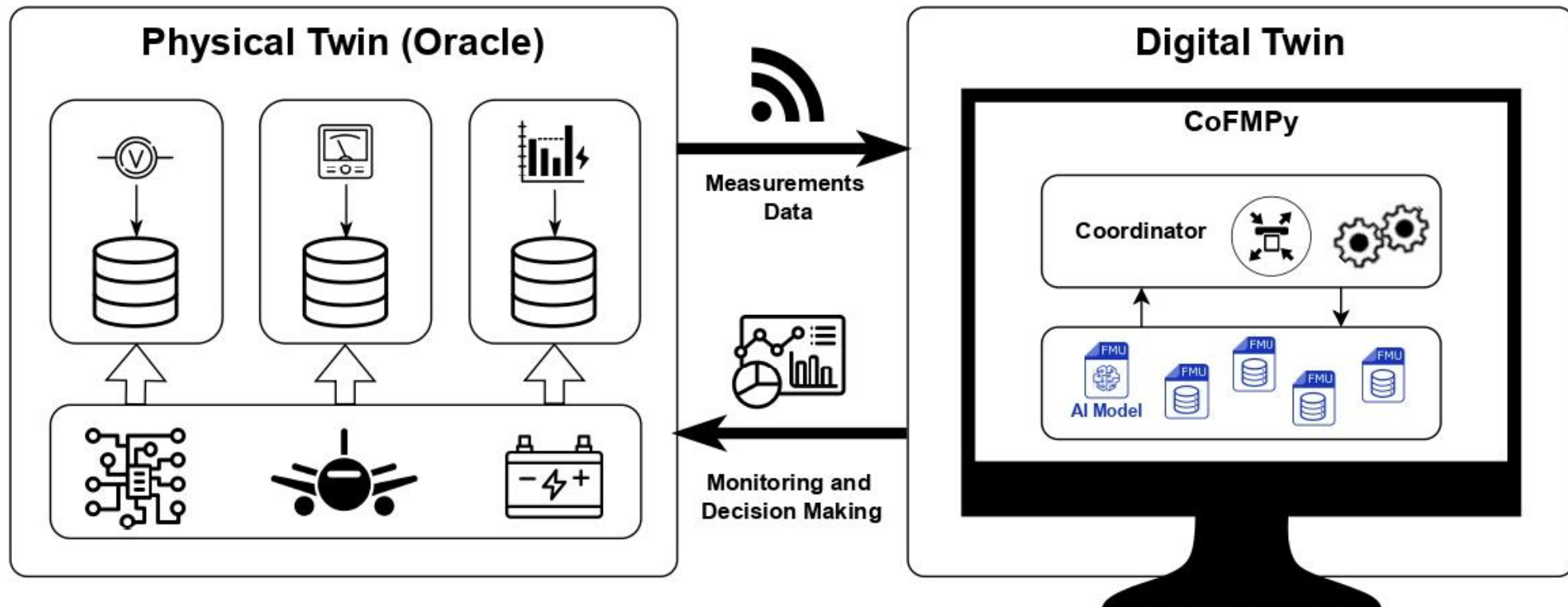
- handling co-simulation from different FMUs with algebraic loops
- supporting inbound and outbound data streams
- storing and visualizing simulation results
- lightweight with flexible, generic and customizable components



CoFMPy

Python open-source library – Rapid prototyping – FMI-based co-simulation

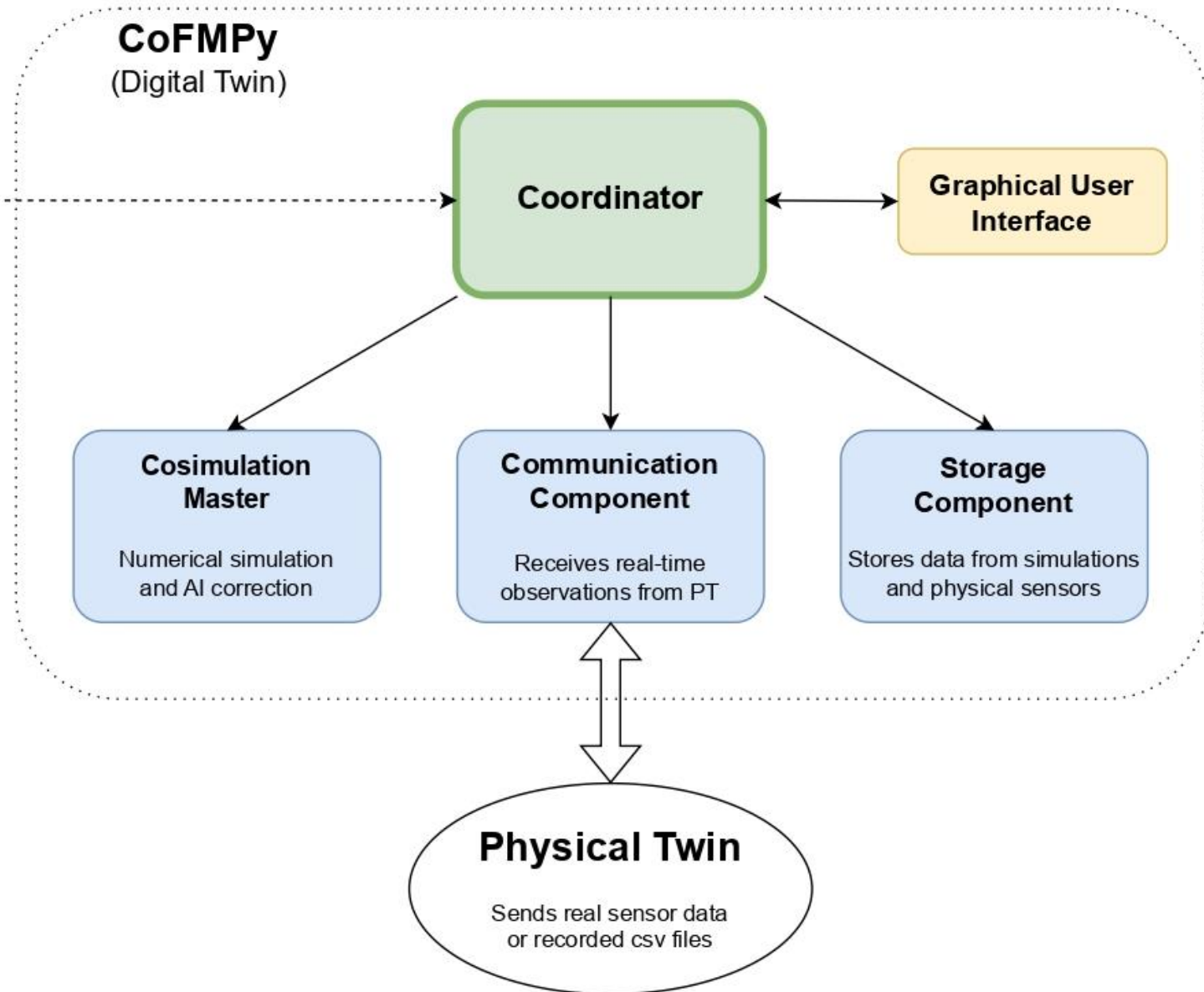
Lightweight – Customizable



CoFMPy structure

- **Coordinator:** The core unit that supervises the other components and control the interactions between them.
- **Co-simulation Management:** A Master algorithm ensures accurate, synchronized simulations and resolves discrepancies between digital and physical twins.
- **Data Communication:** Bidirectional data exchange keeps the digital twin aligned with the physical twin.
- **Data Storage:** A repository stores historical data, simulation outputs, and logs.
- **User Interface:** A GUI visualizes real-time data, simulation results, and the FMU coupling graph.

Config files
(cosimulation master,
data stream, etc.)



CoFMPy in practice

- Easy to use: JSON configuration file with FMUs and connections
- Two modes:
 - User interface
 - Python API (high or low-level)
- FMU execution based on FMPy
- Create your own components:
master algorithm, inbound/outbound data streams, etc.
- Online documentation

The screenshot displays the CoFMPy user interface, which is divided into several sections:

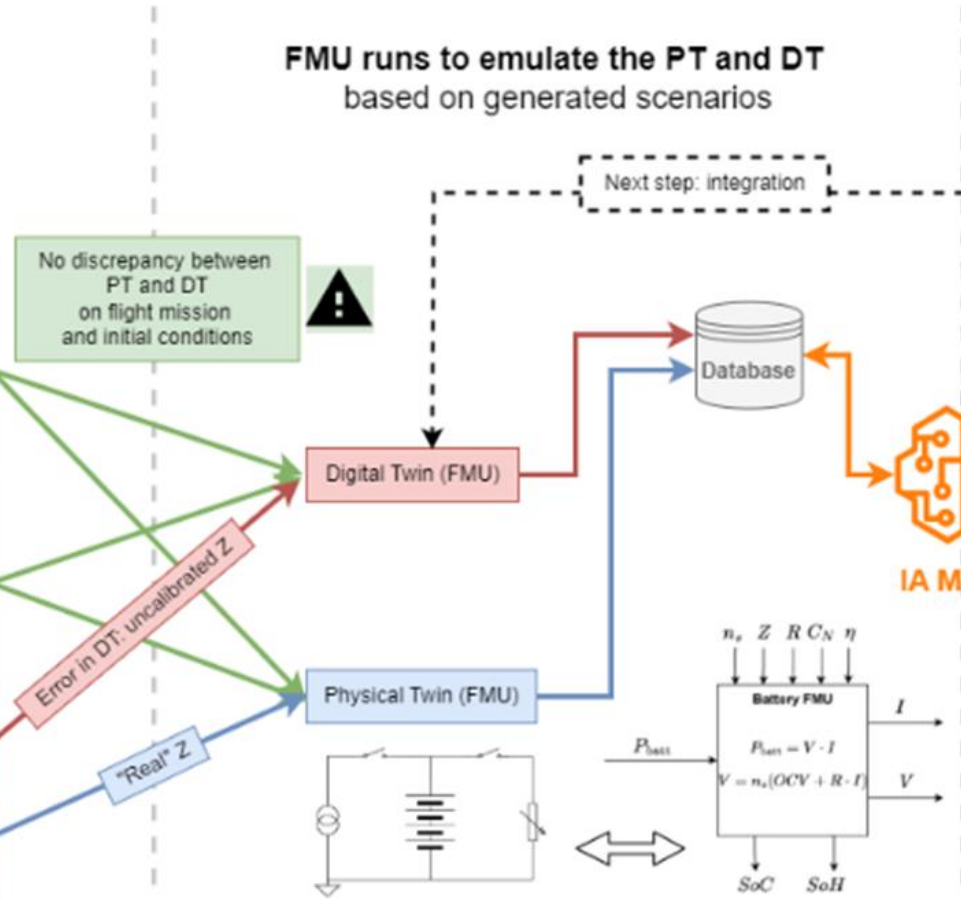
- Configuration:** This section allows users to set various parameters for the simulation. It includes options for initialization approach (set to 'None'), cosimulation algorithm (set to 'Jacobi'), cosimulation timestep (set to 1.00), end time (set to 677), and data exchange timestep (set to 1). There are also file upload sections for JSON configuration files and CSV/Stream uploads.
- Coupling Graph:** This section shows a diagram of the FMU connections. It features three FMU nodes (FMU1, FMU2, FMU3) connected by lines, representing the data flow between them. A legend on the right identifies the nodes.
- Results Control:** This section provides system information and allows users to select outputs to plot. It includes dropdown menus for selecting outputs for each FMU (FMU1, FMU2, FMU3) and a 'Vout' output selected for FMU1.
- Cosimulation Results:** This section displays a line graph showing the results of the cosimulation. The Y-axis represents the output value (0 to 200) and the X-axis represents time (0 to 60u). The graph shows a blue line representing 'FMU1:Vout (V)' and a red line representing 'Physical Twin data'. Both lines show a similar oscillatory pattern.
- Measurements:** This section displays another line graph showing the results of the measurements. The Y-axis represents the output value (0 to 200) and the X-axis represents time (0 to 60u). The graph shows a blue line representing 'FMU1:Vout (V)' and a red line representing 'Physical Twin data'. Both lines show a similar oscillatory pattern.

Application: AI-powered DT for battery systems in hybrid aircraft

POC: battery health monitoring with AI correction model

Design of experiment:
 - Latin Hypercube Sampling
 - Scenario Diversity

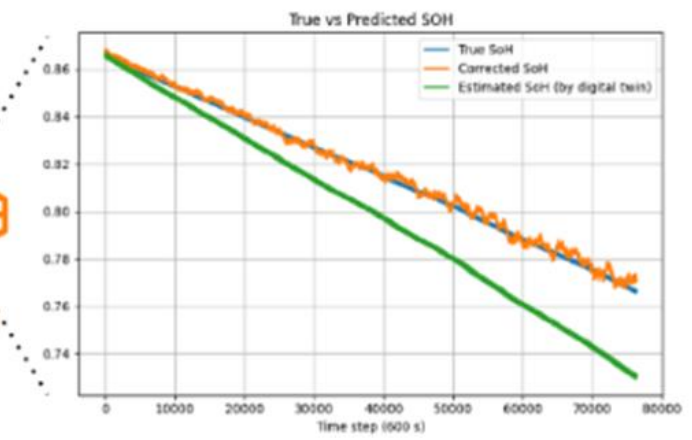
	Power demand profile + Gaussian noise Segment length profile + Uniform offset	
	Initial battery capacity Initial State of Health value	$C_{init} = \dots \text{ Ah}$ $SoH_{init} = \dots \%$
	Cycle aging coefficient	Z_{aim} Z_{phy}



AI correction Model:
 Discrepancy between prediction and measurement:

- Uncalibrated aging model in DT $Z_{sim} \neq Z_{phy}$

Correction of estimated SoH



Results: average estimation error divided by 10 with interpretable model !

Key takeaways

- **Need for rapid DT prototyping** of FMU-based co-simulation
- **We developed CoFMPy**, an open-source library written in Python with elementary DT features.
- Easy to use, one JSON configuration file, GUI or Python API, flexible and customizable.
- Applied on **battery health monitoring with AI correction**.

Thank you!

Contact points for any question:

Speaker

- Corentin FRIEDRICH (IRT Saint Exupéry)
- Email: corentin.friedrich@irt-saintexupery.com

Coordinator

- Ignacio Castro Álvarez (CAI)
- Email: ignacio.castro@collins.com

[https://hecate-project.eu/
contact@hecate-project.eu](https://hecate-project.eu/contact@hecate-project.eu)



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