TECHNISCHE UNIVERSITÄT DRESDEN

AirMetro
Research Training Group 2947 at TU Dresden

# T10: Digital Twin

## Cyber-physical consistency of digital twin simulations

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## Motivation

— Complex traffic problems can be analyzed and anticipated using **digital twins**. They facilitate both individual mobility and effective management of traffic flow.

— Advanced Air Mobility (AAM) aircrafts are subject to **multifaceted weather conditions and interactions in urban areas**, resulting in variations from the digital twin's reference data.

— **Inconsistency between model and reality** can have an impact on the cyber-physical system's control and monitoring.

— Continuous consistency is critical and may necessitate **corrections** to the physical state or adjustments to the digital twin.

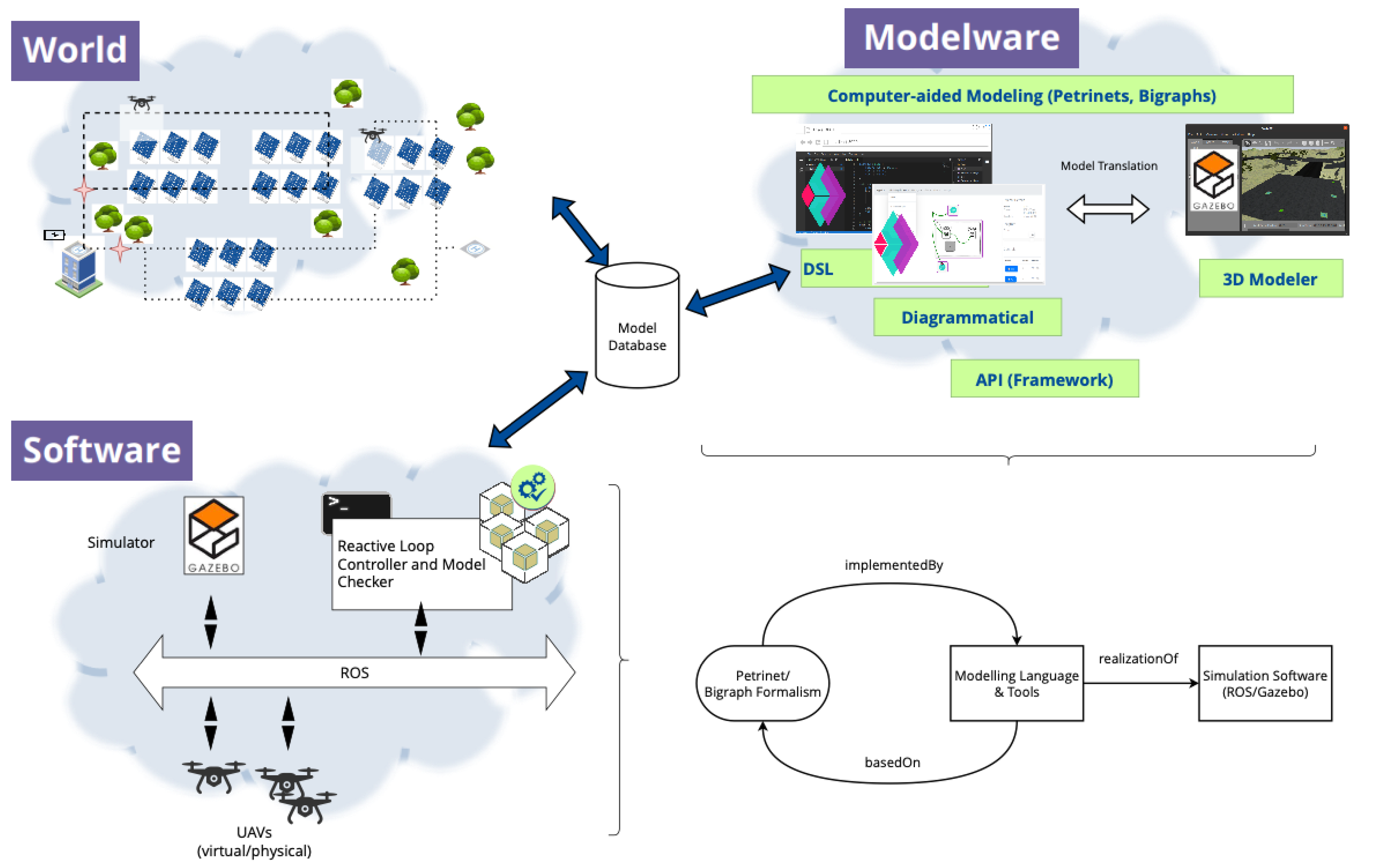


Figure 1: Consistency between the cyber world (digital twin) and the physical world

## Methods

Cyber-physical consistency is achieved through the following measures:

— Formal modeling with behavioural models (hybrid Petri nets, esp. XHPN/Pnlib, Bigraph rewriting) and verification of properties [1], [7]

— Examining cyber-physical consistency for a group of AAM aircrafts with digital twinning (model correction)

— Use of simulations for accurate predictions of 4D flight paths [7]

— Location, navigation, AAM aircrafts, and contexts are hierarchically represented by a multilayered composite model

— Coupling of sensor network elements to the physical world for analysing sensor data and comparison with simulation results

— Adjusting simulation topologies in response to weather changes requires context change in a context-oriented Petri net (CoPN, [2]); if required, this involves triggering movement or status corrections in the master node or modifying the digital counterpart as a slave.

## Results

— Establishing and evaluating the cyber-physical consistency of the digital twin [3]

— Precise modeling of the dynamics of aircrafts and their infrastructure

— Software stack (BTS [4], ROS [5], Gazebo [6]) for formal planning and simulation of AAM flights [7] (same algorithm for analysis and execution via Path Planning by Model Checking)

— Gazebo serves as a 3D mission planning environment (translation of Gazebo world model into bigraph model)

— Collision avoidance checks

— Case study on the topic of **transporting medicine** and **environmental monitoring**

## Networking in the RTG

— Input on the scope and structure of AAM for analysing communication requirements and communication network architecture (T9)

— Using uncertainties such as weather for possible inconsistencies (T6, T7)

— Evaluation of the results obtained from communication network simulations for accident risk modeling (T3)

— Formal foundations from applied category theory, Petri nets, algebraic graph replacement systems and model-oriented programming for the development of autonomous AAM technologies (T1)

— Identification and exploration of new applications and research questions in the field of AAM (T4)

*Literatur:*

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[3] R. Seiger, S. Huber, P. Heisig und U. Aßmann, "Toward a framework for self-adaptive workflows in cyber-physical systems," Softw Syst Model, Jg. 18, Nr. 2, S. 1117–1134, 2019

[4] Dominik Grzelak. A Bigraphical Tool Landscape. 2022. URL: https://www.bigraphs.org/

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[6] N. Koenig and A. Howard, "Design and use paradigms for Gazebo, an open-source multi-robot simulator," 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (IEEE Cat. No.04CH37566), Sendai, Japan, 2004, pp. 2149-2154 vol.3, doi: 10.1109/IROS.2004.1389727.

[7] D. Grzelak, M. Lindner, M. Belov, U. Aßmann, O. Husak, H. Fricke. "A bigraphical framework for UAV inspection scenario modeling and simulation." Submitted to Software and Simulation, Springer, 2023.

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