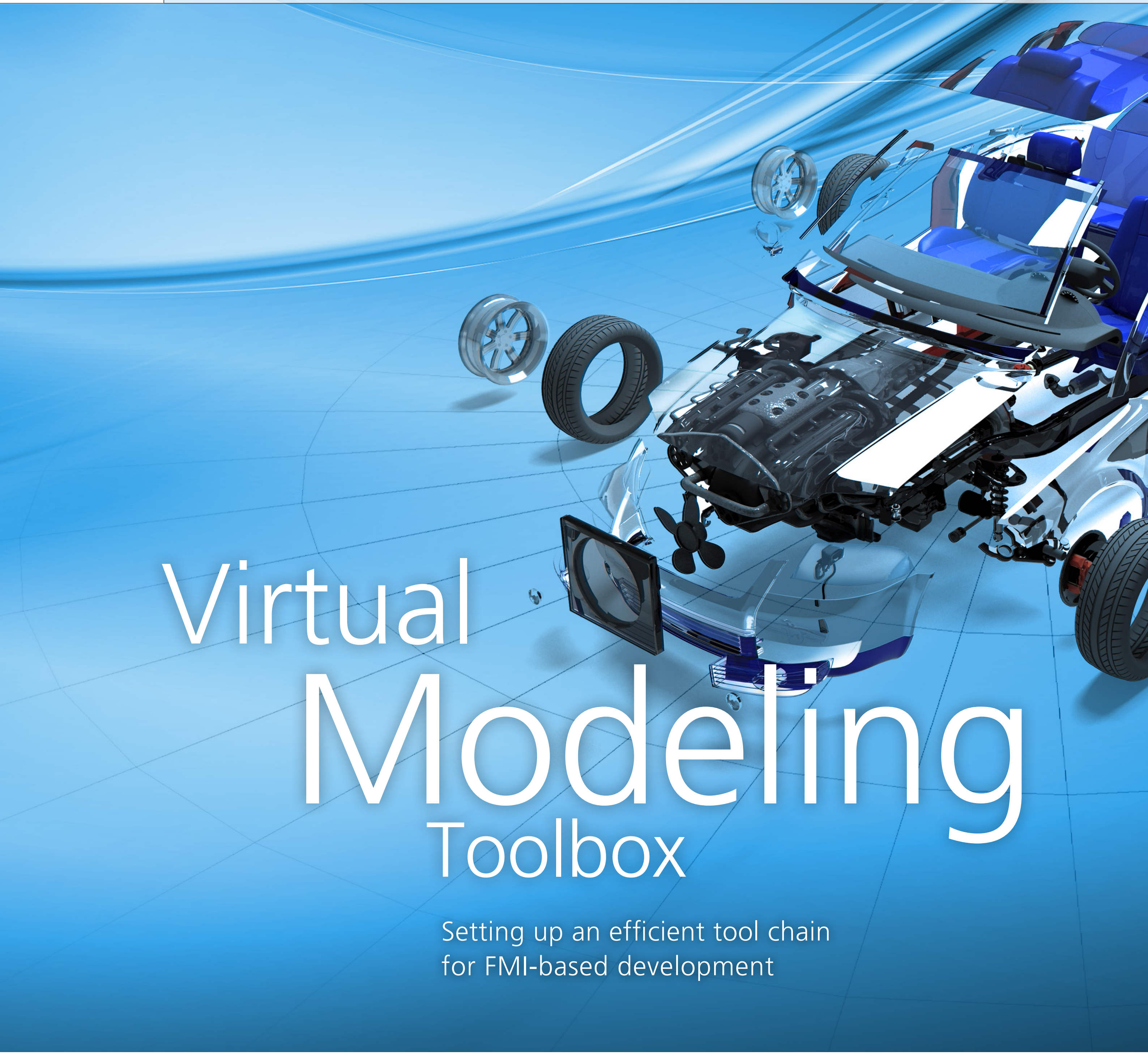

Virtual Modeling Toolbox

Setting up an efficient tool chain for FMI-based development

Functional Mock-up Interface (FMI)

The Functional Mock-up Interface (FMI) with its variants FMI for Co-Simulation and FMI for Model Exchange is an open standard for the tool-independent exchange and joint simulation of plant models provided by different vendors. Both variants of FMI can be used to exchange models but they differ in their benefits and drawbacks for certain use cases. The main benefit of FMI for Model Exchange is the easier, numerically stable simulation of strongly coupled system parts (e.g., component submodels of a domain), because all the required information an external central solver needs for computing the simulation results is provided. FMI for Model Exchange therefore has a complex interface that requires a higher degree of compatibility and information exchange between the tools and partners in the tool chain. In contrast, the lean interface of FMI for Co-Simulation reduces the number

Long before the first prototypes start their test drives, a vehicle can already be driven and tested virtually. The FMI standard helps the developers of automotive supplier DENSO carry out such virtual test drives with a combination of diverse component models. The basis: simulation platforms by dSPACE.

Today's vehicles are based on complex systems whose further development and integration require knowledge and models from different disciplines and domains. Having a virtual overall system that contains all individual systems is therefore becoming increasingly important in vehicle development. In addition to the technical challenges, the market expects ever shorter innovation cycles. The short time to market poses a particular challenge for the developers: Early tests of individual systems have to be performed in the system network before the hardware and software of all systems is complete and integrated with each other. This applies not only to the actual vehicle components, but also to the environmental conditions and driver behavior. These two factors play an important role for the behavior of the overall system.

Standardized Cooperation

One solution is to simulate the plant models of all components and systems at the overall system level.

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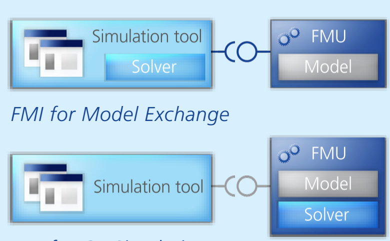
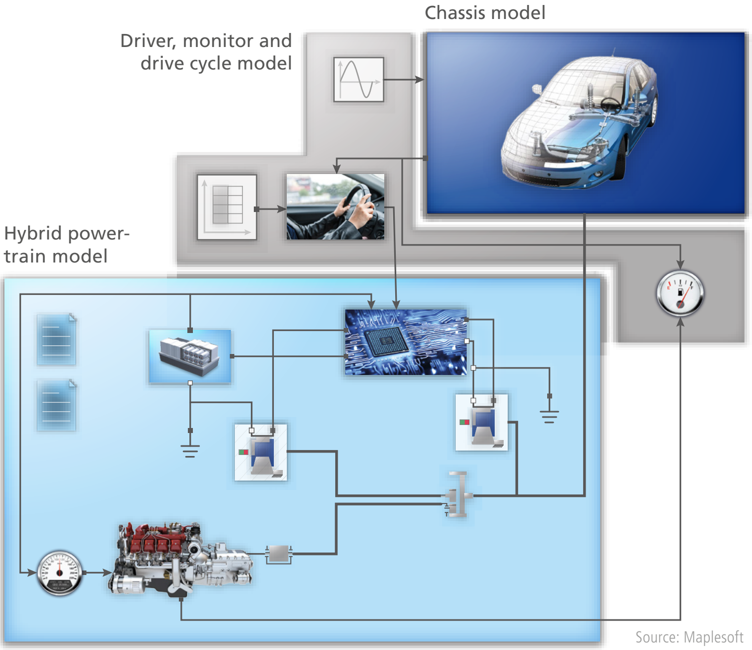
of potential compatibility issues in tool chains that include various types and versions of FMI-supporting tools by systematically separating the Functional Mock-up Unit (FMU) functions (including solver implementations) from the importing tool functions. Thus, co-simulation FMUs can transport verified combinations of solver code and model code, and make it easier to combine models of different physical domains and system dynamics.

www.dspace.com/go/fmi



FMI for Model Exchange

FMI for Co-Simulation



Setup of the commercial simulation model of a power-split HEV. The highlighted areas indicate to which domain models the overall system model is divided.

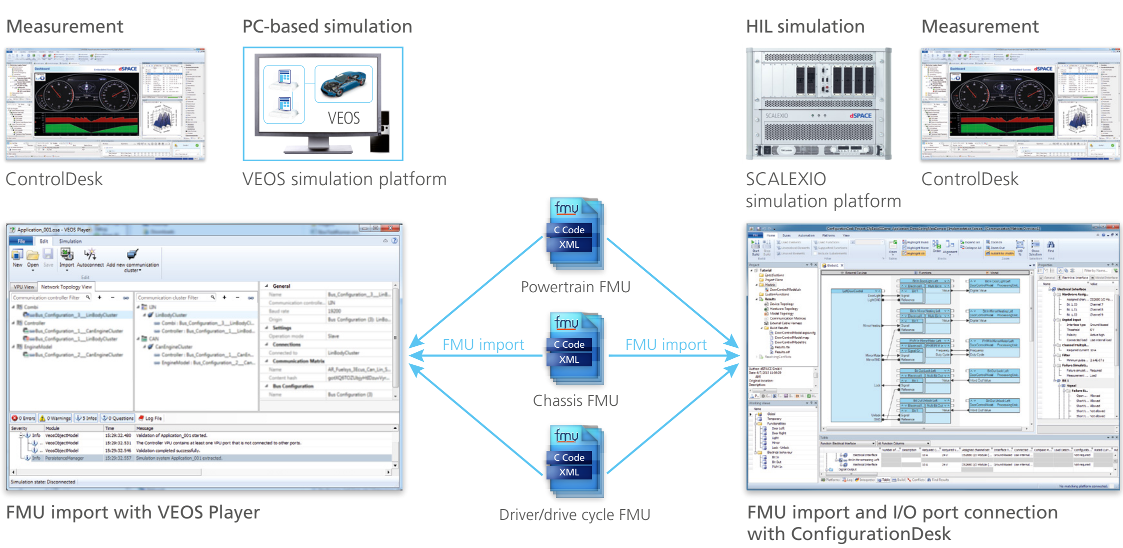
Since the available models usually differ in format and complexity, this requires a standardized intermediate level for easily combining the models. Therefore, the Functional Mock-up Interface (FMI) standard was established. The standard makes it possible to exchange models from different domains with different tools and simulate them together. To enable simulation, the models are prepared as standardized Functional Mock-up Units (FMUs), which contain the model implementation, its metadata, and the implementation of the FMI interface. The standard has two variants: FMI for Co-Simulation and FMI for Model Exchange. Both allow for model exchange but are based on different technological approaches.

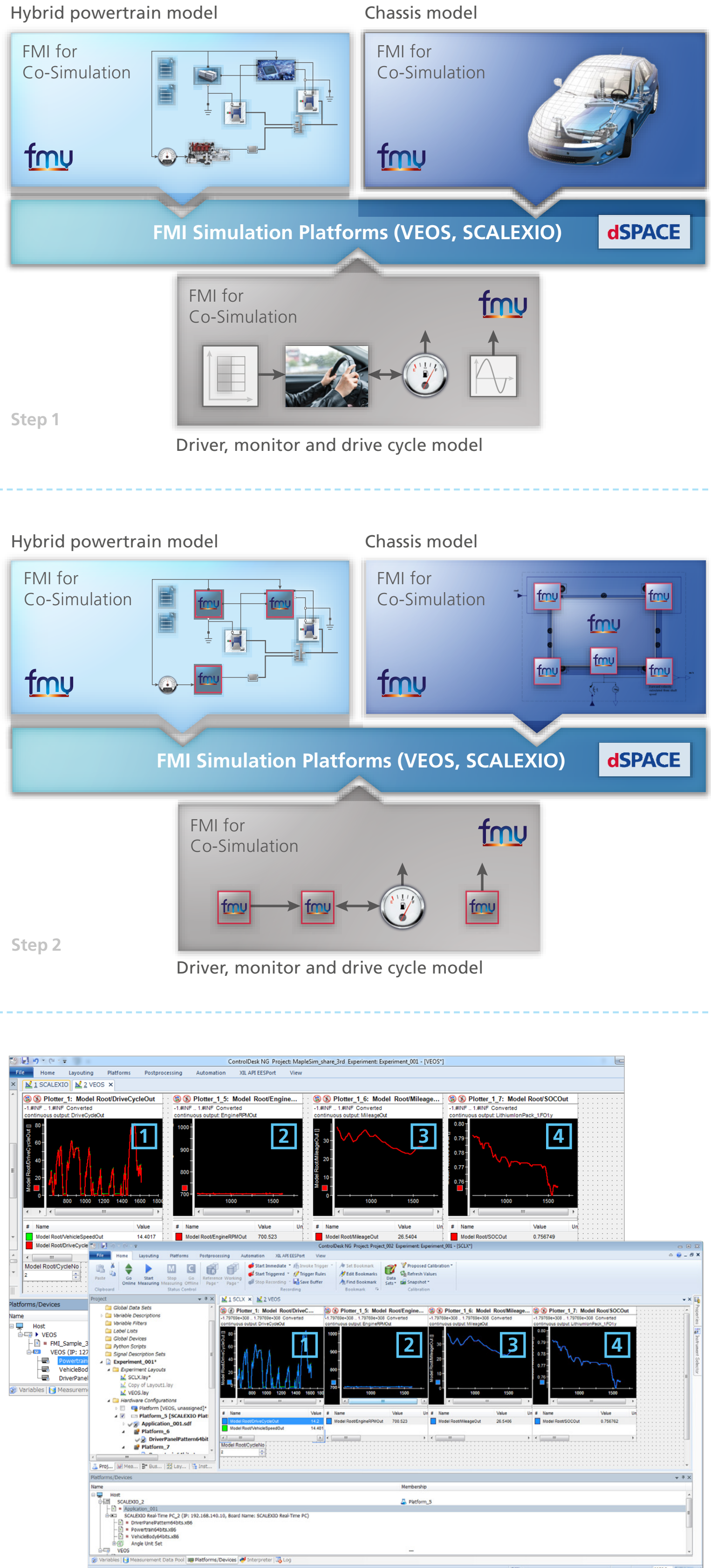
Evaluating FMI with the Installed Tool Chain

DENSO's goal was to analyze the benefits of an FMI-based approach for the development process. Taking into account the tool chain used by DENSO, two main methods were observed:

- In step 1, DENSO analyzed whether a vehicle model that is divided into multiple FMUs can be used for PC-based simulation with VEOS and for hardware-in-the-loop (HIL) simulation with SCALEXIO by reusing project parts, and whether the simulation results of the overall system model can be reproduced in this way. The FMUs were set up according to the FMI for Co-Simulation standard.

The prepared FMUs are integrated on the simulation platforms VEOS (left) and SCALEXIO (right).





Top: The overall system model is divided into domain model FMUs (FMI for Co-Simulation) and executed on the simulation platforms VEOS and SCALEXIO. Center: Some individual component model parts are replaced by FMUs (FMI for Model Exchange) in the domain models. These domain models are exported as FMUs (FMI for Co-Simulation) and executed on the simulation platforms VEOS and SCALEXIO. Bottom: Qualitative overview and comparison of the simulation results obtained with VEOS (red) and SCALEXIO (blue) in dSPACE ControlDesk. In the illustration: (1) Vehicle speed, (2) engine speed, (3) fuel consumption, (4) state of charge.

- For step 2, DENSO plans on first connecting multiple components, i.e., strongly coupled model parts of one vehicle domain that are modeled as FMUs, according to the FMI for Model Exchange standard. The resulting domain model will then be exported as an FMU according to the FMI for Co-Simulation standard. Finally, DENSO will check whether step 1 is possible.

The Evaluation Model

A commercial model of a power-split hybrid vehicle (power-split HEV) from the MapleSim® library was used for the analysis. Using this model makes it possible to check the suitability of the FMI-based workflow for existing overall vehicle models. The following terms are used to describe the model in more detail:

- *Overall system model:* The complete vehicle model consisting of multiple FMUs.
- *Domain model:* Model of a functional unit, e.g., the drivetrain consisting of the combustion engine, electric motor, transmission, etc.
- *Component models:* Models of the components that make up a domain, e.g., the transmission.

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> "We successfully implemented the model of a hybrid vehicle, which consists of multiple Functional Mock-up Units, on the simulation platform dSPACE SCALEXIO and simulated it in real time."
>
> *Fumiyasu Shirai, DENSO*

The power-split HEV model consists of the component models of an engine, a transmission, a throttle valve, a simple controller, a motor-generator, a battery, an inverter, the wheels, a differential transmission, and the chassis.

Preparing the FMUs

In the first step, the overall system model was divided into three domain models that were prepared as FMUs according to the FMI for Co-Simulation standard. The division into the hybrid system, chassis, and driver/drive cycle models was made to be able to assign each FMU to one dedicated processor core on a quad-core SCALEXIO Processing Unit. The fourth core is used for communication with the host PC.

Implementing and Evaluating the FMUs

The prepared domain FMUs were used first on the PC-based simulation platform VEOS and then, with identical parameterization, on the SCALEXIO HIL simulator. The aim was to check the correct function and the performance of the FMUs on both platforms.
All tests indicated a strong correlation between PC-based and HIL simulation, and they matched the simulation results of the overall system model in MapleSim. The complex, dynamic model can therefore be executed in real time, and the powerful SCALEXIO processor platform has even more reserves for more complex models, I/O, and bus simulation.

Seamless, Efficient Development

The dSPACE tool chain not only ensures continuous simulation and parameter access on both simulation platforms for the used FMUs. It can also be seamlessly used with other tools for HIL testing and virtual validation. This means that developers can reuse the real-time-capable FMUs as well as the associated tests and experiments with tools like dSPACE ControlDesk and AutomationDesk as well as the XIL API standard. This completes the FMI concept of easy, direct model reuse for both virtual validation and HIL testing, allowing for an efficient and seamless development process.

Using FMI More Broadly

DENSO will successively integrate the

> "The PC-based simulation platform dSPACE VEOS lets us frontload complex, FMI-based simulations to earlier phases of the development process."
>
> *Nobuya Miwa, DENSO*

FMI Models for SCALEXIO Multicore Processors

Real-time-capable Functional Mock-up Units (FMUs) of a wide variety of modeling tools can be integrated directly in SCALEXIO-based HIL projects. The FMUs can be integrated with further FMUs and other supported model formats to an overall model. To achieve the best possible computation performance, the FMUs can be assigned to specific SCALEXIO processor cores. With dSPACE Release 2017-B, SCALEXIO also supports the execution of multiple FMUs on one SCALEXIO processor core. By providing consistent support for the FMI standard with SCALEXIO, dSPACE offers an open system for integrating models from different sources.

> "The seamless dSPACE tool chain makes our FMI-based development process more efficient."
>
> *Satoshi Koike, DENSO*

insights of its experience with the power-split HEV model in the development of the simulation models. This will make it easy to exchange models in vehicle development projects that involve multiple parties. DENSO's aim is to prepare the existing component models of the vehicle under development as FMUs according to the FMI for Model Exchange standard and combine them to a domain FMU according to FMI for Co-Simulation. This approach makes it possible to combine the benefits of both variants of the FMI standard and thus set up a flexible, real-time-capable and numerically stable overall system model. ■

Satoshi Koike, Nobuya Miwa,
Fumiyasu Shirai,
DENSO CORPORATION

At a Glance

The Task

- Evaluating an FMI-based development approach.
- Using submodels from potentially different sources to simulate a complete automotive system.

The Challenge

- Implementing the FMI-based workflow on the installed tool chain.
- Ensuring an efficient development process.

The Solution

- Integrating FMUs on the simulation platforms VEOS (MIL/SIL-based) and SCALEXIO (HIL-based).
- The seamless and open tool chain from dSPACE enables the efficient reuse of the project data.

FMI/FMU: Functional Mock-up Interface/Unit
MIL/SIL/HIL: Model-/software-/hardware-in-the-loop

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