

15 Years Functional Mock-up Interface – a Journey from FMI 1.0 to 3.0 and the Road Ahead

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FMI Project Leader
Modelica Association Board Member

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Modelica Association

My personal journey

- Graduated in Mathematics and Physics from Heidelberg University
- Joined Bosch as a simulation engineer for CFD in 2001
- System Simulation at Bosch Research since 2004
- Project Leader for Model-based SW-Functions since 2010

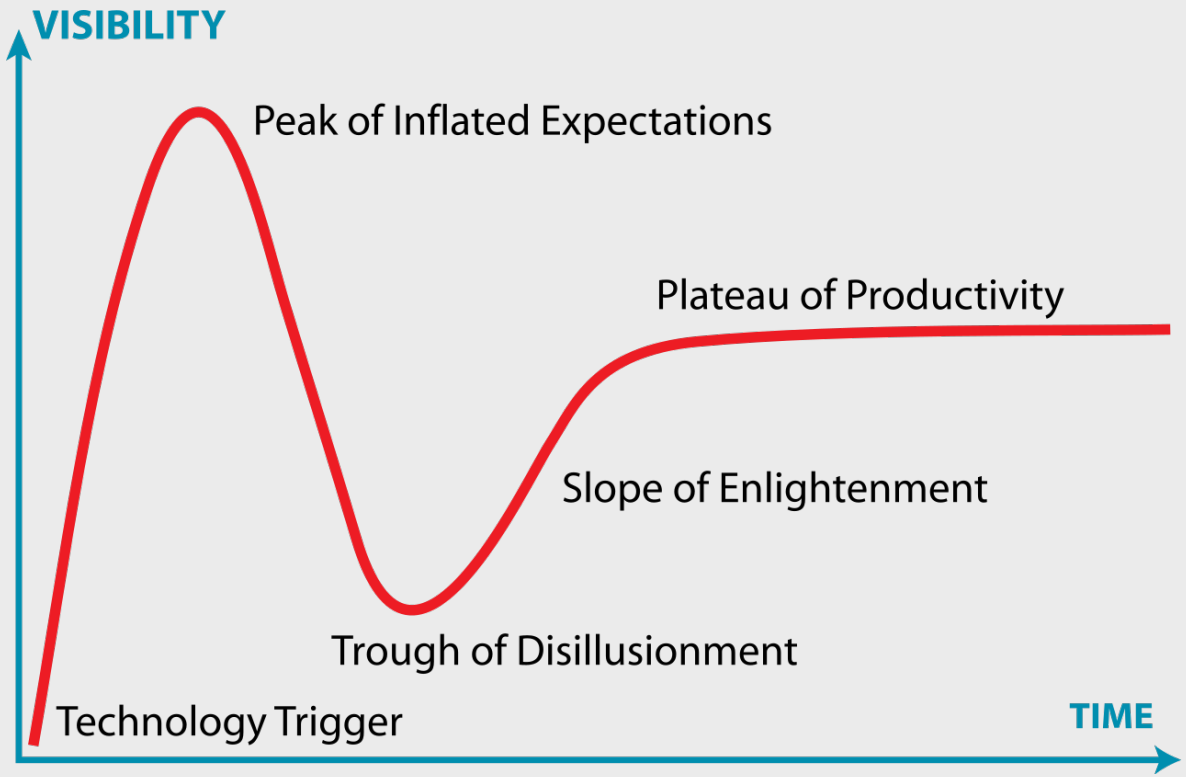


- First got in contact with Modelica in 2007
- Heard about FMI in 2009 …

- Representing Bosch in the FMI Project since 2012
- FMI Project Leader since 2022

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Gartner Hype Cycle – applied to FMI!



fmi Functional Mock-up Interface

The Gartner Hype Cycle is a visual model that shows how the maturity, adoption, and social application of new technologies evolve over time.

source https://en.wikipedia.org/wiki/Gartner_hype_cycle

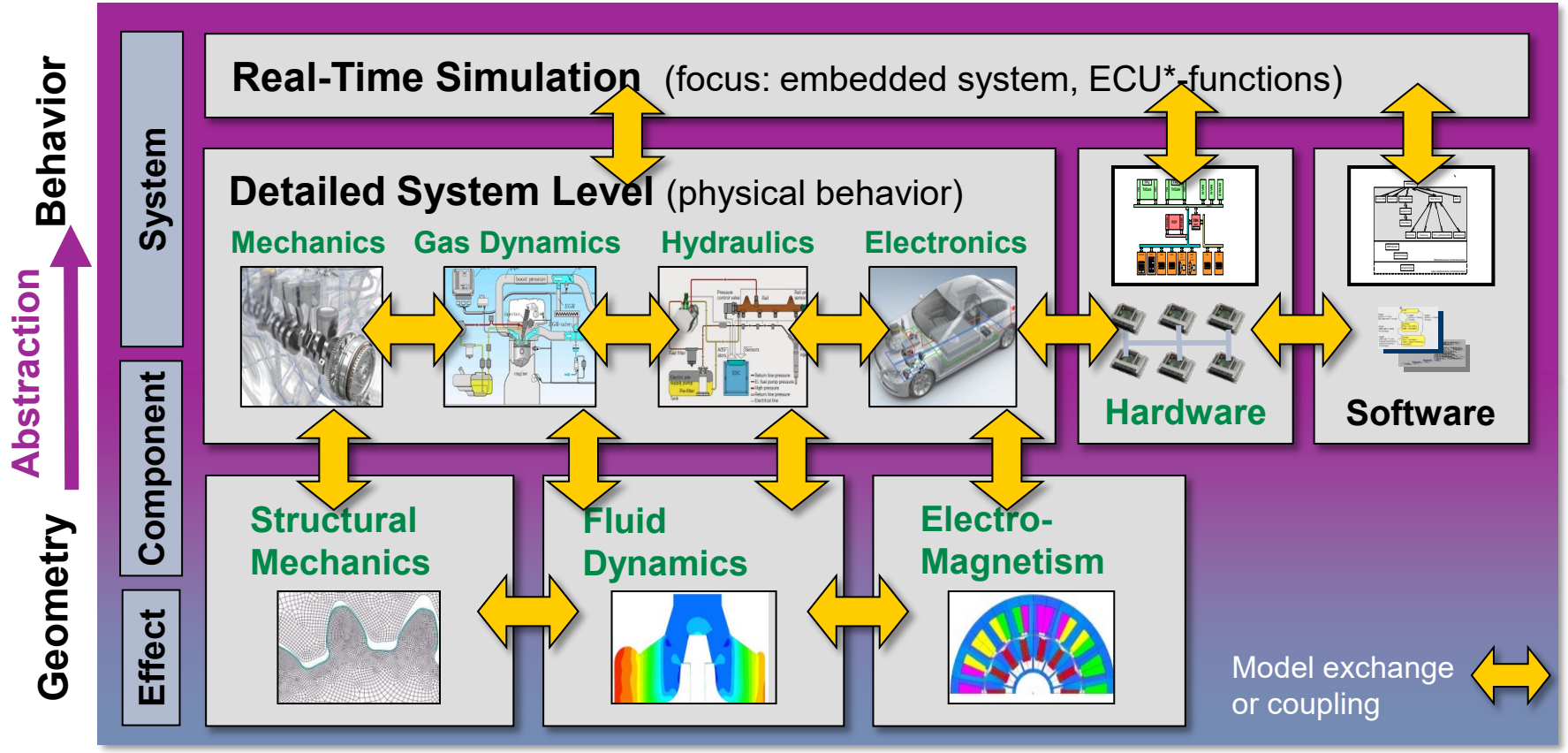
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Prelude – the time before FMI



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What we want for system simulation in a heterogeneous tool environment



Different engineering domains can no longer be treated as isolated.
Vision: Exchanging models shall be “as easy as sharing a YouTube video”.

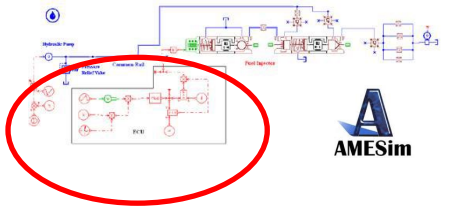
*ECU=Electronic Control Unit

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What we got: Model Exchange and Co-Simulation *before FMI*

Models re-implemented in different simulation tools

- Example: AMESim: Existing Control model
  re-programmed with “red” signal block
- Double work! Error-Prone.



Models all exchanged as Simulink S-functions

- Additional license costs
- One has to adapt to limitations / changes
  of proprietary S-functions



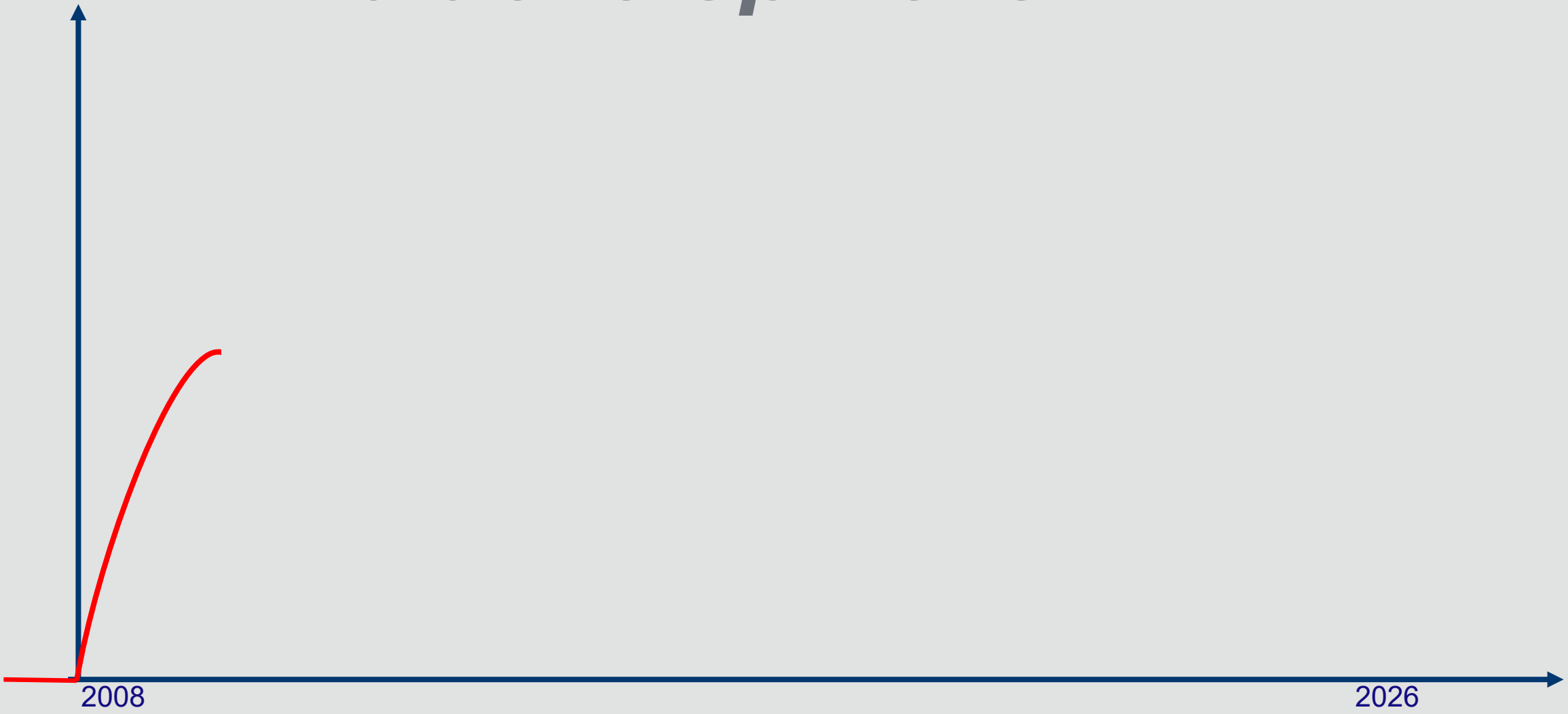
Use special Co-simulation interfaces (“bilateral” or special tools)

- Example: AMESim – Saber coupling with Co-Simulation interface
  Lots of different interfaces to be developed/maintained!



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FMI 1.0 development



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The MODELISAR Project 2008-2011

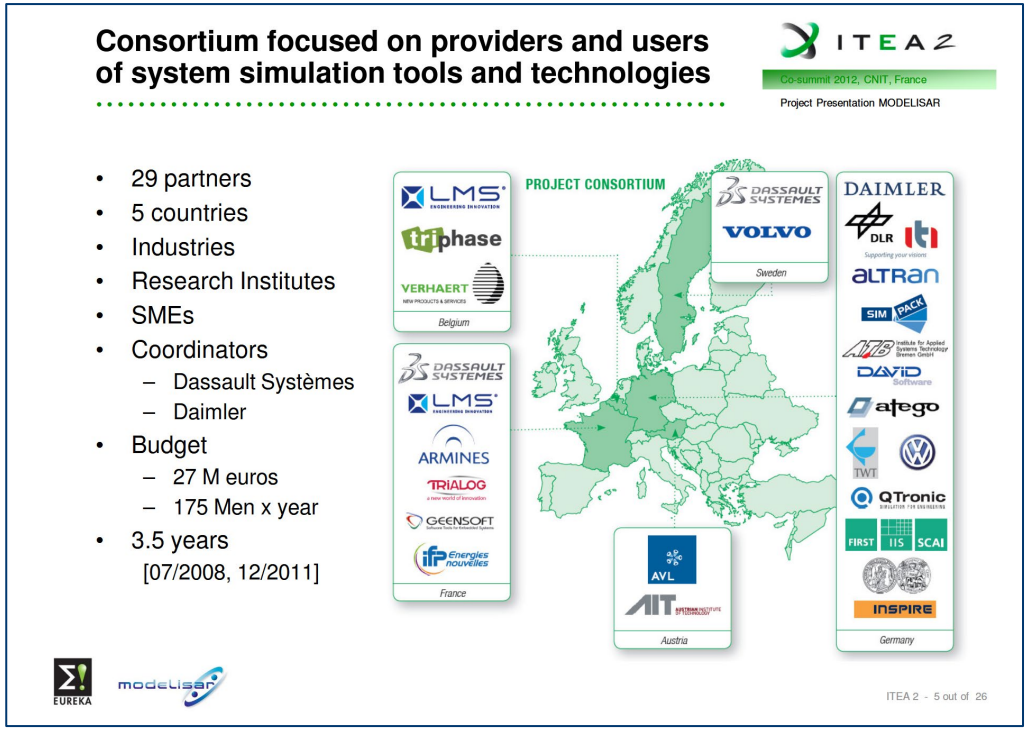


Publicly funded European ITEA project MODELISAR

Initiated by Daimler and Dassault Systems

Project Leader: Patrick Chombard (Dassault Systems)





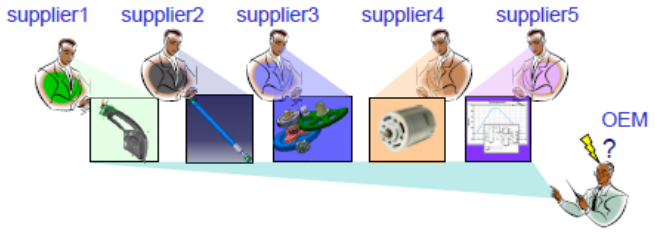
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The motivation for FMI (seen from an OEM perspective)

Functional Mock-up Interface (FMI) - Motivation (1)

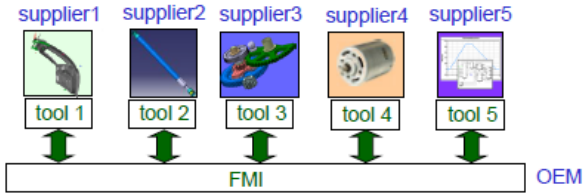
Problems / Needs

- Component development by supplier
- Integration by OEM
- **Many different simulation tools**



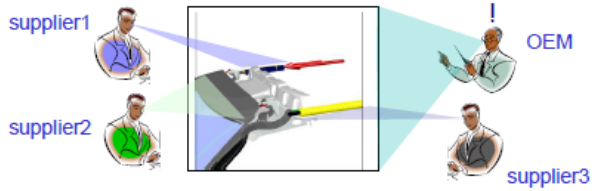
Solution

- Reuse of supplier models by OEM:
  - DLL (**model import**) and/or
  - Tool coupling (**co-simulation**)
- Protection of model IP of supplier



Added Value

- Early validation of design
- Increased process efficiency and quality



slide from Nick Suyam, Daimler (adapted)

modelisar

Modelica 2011: Functional Mockup Interface Slide 2

FMI - Motivation (2)

- No standards available for:
  - Model interface based on C or binaries
  - Co-simulation between simulation tools
- Lots of proprietary interfaces:
  - Simulink: S-function
  - Modelica: external function, external object interface
  - QTronic Silver: Silver-Module API
  - SimulationX: External Model Interface
  - NI LabVIEW: External Model Interface, Simulation Interface Toolkit
  - Simpack: uforce routines
  - ADAMS: user routines
  - …

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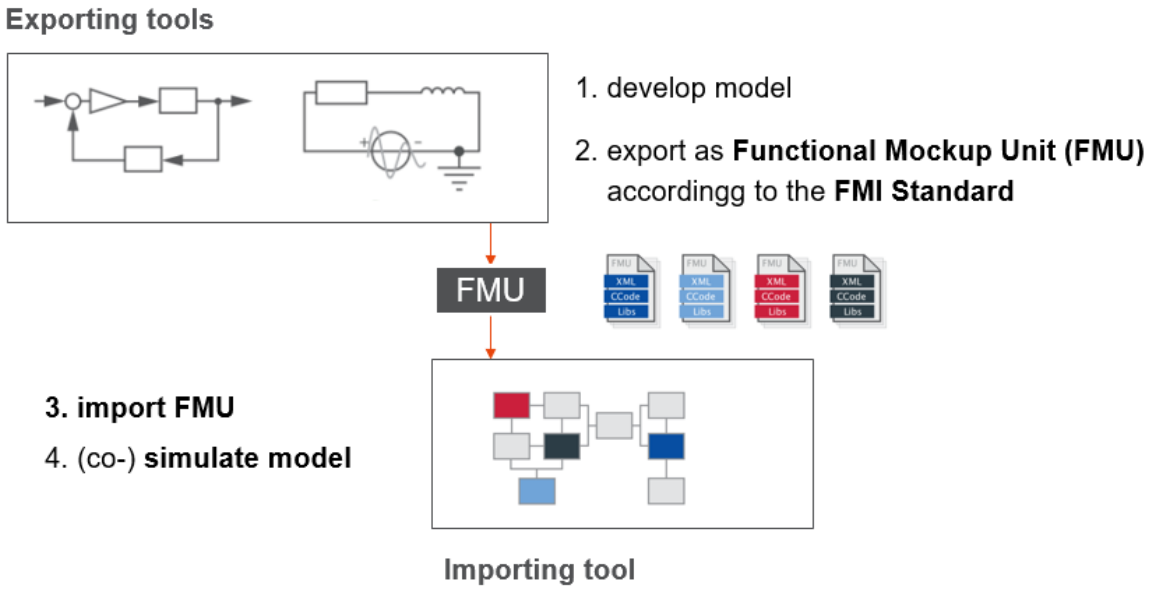
Modelica 2011: Functional Mockup Interface Slide 3

Digital Mock-up (CAD) → Functional Mock-up (Simulation)

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Basic idea of FMI

- Define **a tool-independent**, **free-to-use** standard for exchange and co-simulation of models between different simulation tools
- **Provide models in a containerized form that** allow for the **deployment to different targets**
- **Decouple Know-How**
  - between producers and users of FMUs
  - between different specialized engineers and software programmers
- Massive **Re-use** of modelling investment
- **IP Protection** possible via black-box model exchange

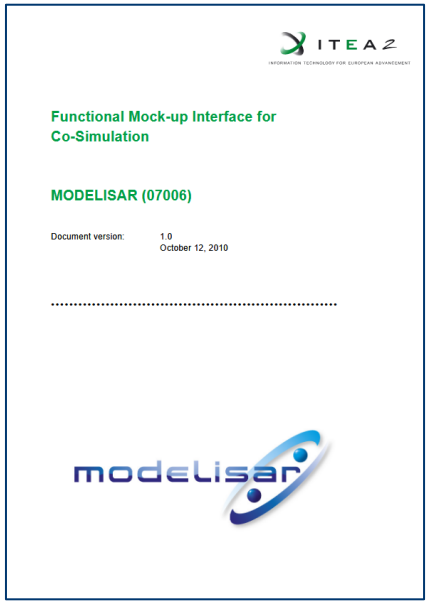


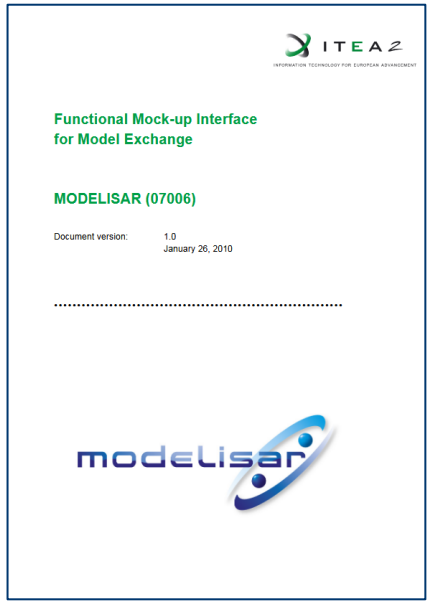
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FMI 1.0

2 separate Standards:

- FMI 1.0 for Model Exchange
- FMI 1.0 for Co-Simulation

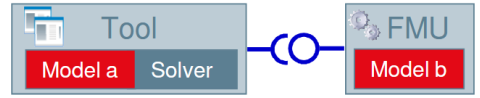




FMI Breakthrough Results

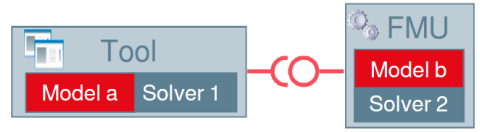
ITEA 2
Co-summit 2012, CNIT, France
Project Presentation MODELISAR

- Enable tool-independent **model exchange** to support collaboration



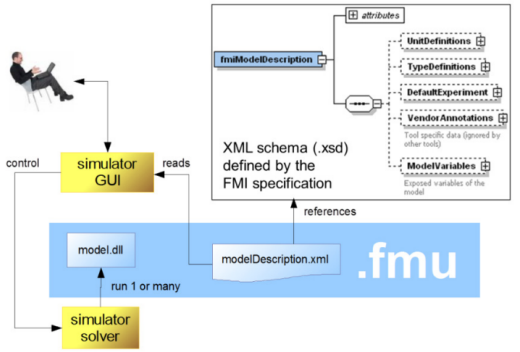
FMI for Model Exchange

- Enable **co-simulation** between heterogeneous tools to support large-scale cross-domain functional mock-ups



FMI for Co-Simulation

- Technical basis:
  - Functional Mock-up Unit (FMU) implemented as zipped file (*.fmu)
  - Separation of
    - description of interface data (XML)
    - functionality (C code or binary)
  - Additional data or functionality includable
  - Multiple targets (i.e. binaries) possible



EUREKA modelisar

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The FMI Standard defines “just an interface”

The FMI Standard defines the “Functional Mock-up Interface” FMI,
an interface between a model and a simulation environment.

It consists of the definition of

- a **C-API** (application programming interface)
- an **interface description** (modelDescription.xml)
  according to a defined schema
- the **definition of an exchangeable unit**, an
  “FMU” (Functional Mock-up Unit), technically a zip file



The FMI Standard only defines the interface of a single FMU,
not the co-simulation algorithm or solver for multiple FMUs!

The FMI interface does not define how an FMU is implemented or what it contains!

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FMI Project founded – within Modelica Association





- Initial FMI project leaders:
  - Torsten Blochwitz (previously ITI, ESI, now Keysight Technologies)
  - Andreas Junghanns (previously qTronic, Synopsys)

Modelica Association Bylaws were changed to continue FMI development

- From development of Modelica Language and Libraries, to:
- a non-profit, non-governmental organization with the aim of developing and promoting **free and open coordinated standards for system modelling and simulation.**
- Work is done in projects, initial ones:
  - Modelica Language
  - Modelica Libraries
  - Functional Mock-up Interface (FMI)

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FMI got endorsed and promoted heavily by the automotive industry

- New FMI-based initiative of automotive OEMs (started Sep 12)
  - BMW, Daimler and Ford initiate establishment of standard processes for **simulation model exchange between OEMs and suppliers** based on FMI
  - GM, Isuzu and Toyota already support this initiative
  - Accompanying "Smart Systems Engineering" project at ProSTEP iViP started in October

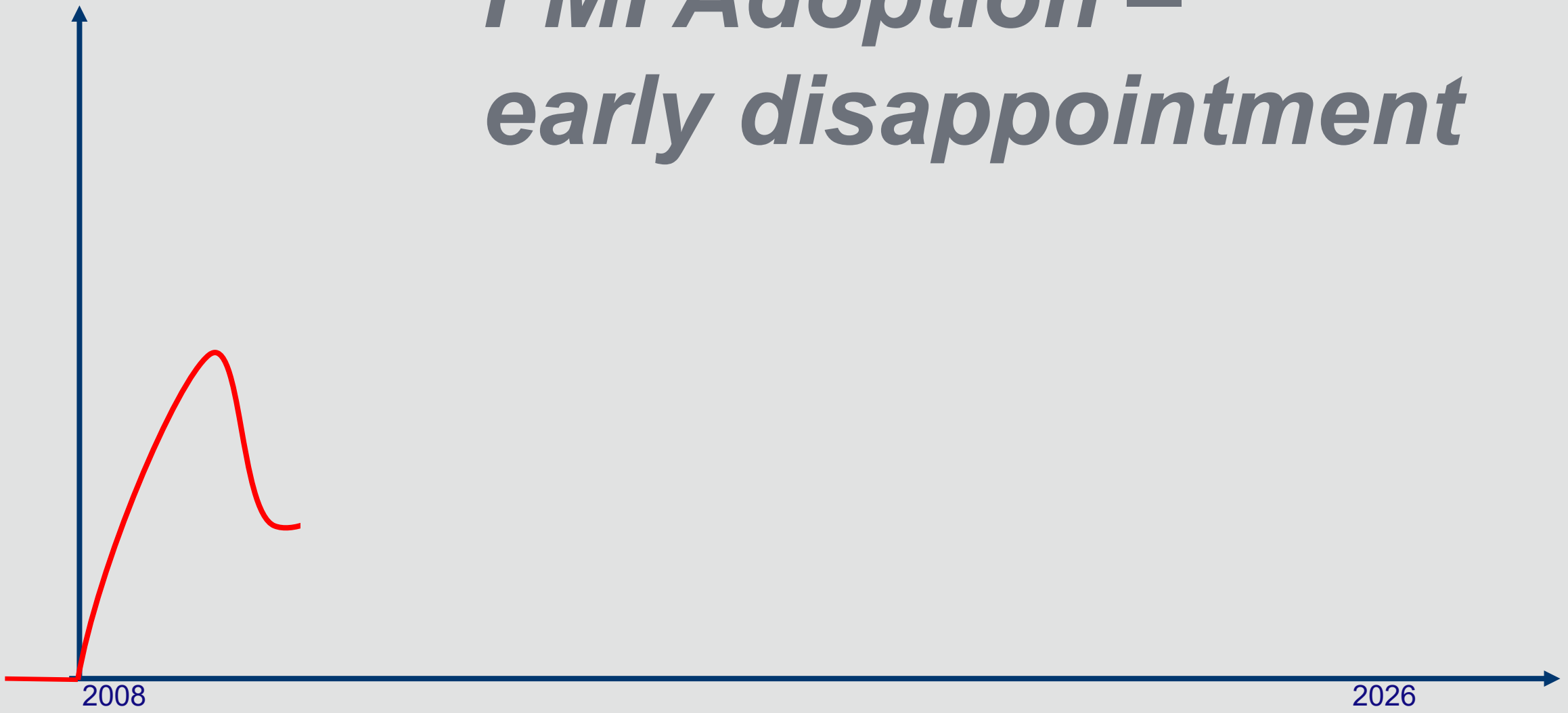
- GAAG Meeting , Munich Oct. 23 2012

Audi	BMW	Chrysler	Daimler
Ford	GM	HKMC	Isuzu
Jaguar Landrover	Mazda	Nissan	PSA
Renault	TMC	Volkswagen	Volvo

GAAG = Global Automotive Advisory Group

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FMI Adoption – early disappointment



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FMI does not work!?!?

ProSTEP iViP: Smart Systems Engineering

Experience with import & export using FMI

18.10.2012

Christian Bertsch
Mechatronic Engineering

Robert Bosch GmbH
Corporate Sector Research and Advance Engineering

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ProSTEP iViP: Smart Systems Engineering

Status 03/2012

Overview Export/Import FMUs

importing Tool / exporting Tool	Tool A	Tool B	Tool C	Tool D + Simulink
Tool A				
Sine generator/ Spring damper	no simulation	errors bevor/during simulation	No simulation	Simulink crashes
MODELICA Model bouncing ball	different result	Error at simulation	Simulation crashes	Simulink crashes
MODELICA Model bouncing ball by Tool vendor A	works	Assertion failed	Simulation crashes	Simulink crashes
C-Code-Model	Error at import	Error at import	Error at import	Simulink crashes
RC circuit	works	Error in event iteration	Error at import	Simulink crashes
Tool B				
Bouncing Ball	Initialization failed	works	works, lib-File has to be moved manually	works
Spring-damper (MSL)	Fatal error: BadXML Format	works	works, initial values not always recognized	works
Injection System	slow and gets stuck	slow with wrong results	slow and gets stuck	slow with wrong results
Tool C				
Bouncing Ball	Failed to initialize	runs, but start value ignored	works	works
Sine from MSL	constant does not have a start value	runs, number of inputs/outputs wrong	works but signal output missing	works
Spring-damper (MSL)	multiple errors at import	runs, but start value ignored	works	works
Thermal model	Fatal error: XML exception	Assert failed: fmiInitialize	works	works

Intern | CR/AEH1 | 12.10.2012 | © Robert Bosch GmbH 2012. Alle Rechte vorbehalten, auch bzgl. jeder Verfügung, Verwertung, Reproduktion, Bearbeitung, Weitergabe sowie für den Fall von Schutzrechtsanmeldungen.

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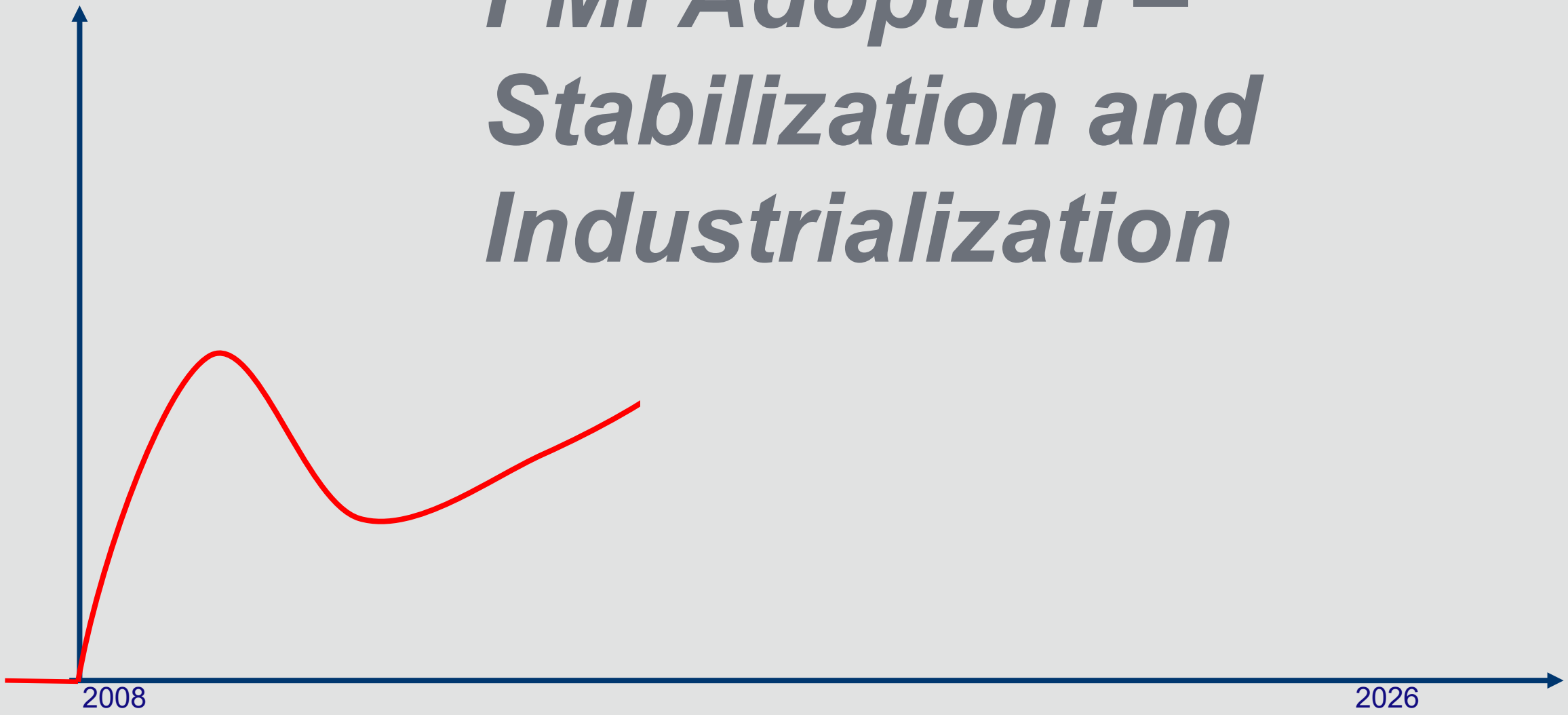
Question for Bosch: Shall we waive the adoption/usage of FMI???

Or get involved? → I travelled to Velizy, France to a joint Modelica /+FMI Design Meeting

… and a little later Bosch joined the FMI Steering Committee.

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FMI Adoption – Stabilization and Industrialization



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Industrialization of FMI

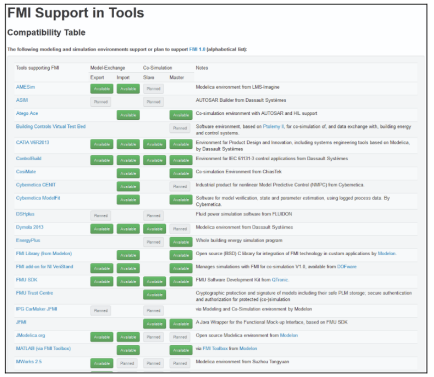
Initiatives to improve maturity of FMI

- **FMU Compliance Checker** developed
  - Open source implementation by Modelon under contract of MA
  - Checks compliance of XML model description
  - Simulates single FMUs for Model Exchange and Co-Simulation
- **FMU Cross Check**
- **Public Error Tracking System** https://trac.fmi-standard.org/
- First draft of **Reference FMUs**

The Functional Mockup Interface
- seen from an industrial perspective

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DOI 10.3384/ECP1409627
Proceedings of the 10th International ModelicaConference
March 10-12, 2014, Lund, Sweden



Improving Interoperability of FMI-supporting Tools
with Reference FMUs

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[3]QTronic GmbH, Germany, Andreas.Junghanns@QTronic.de

DOI 10.3384/ecp17132533
Proceedings of the 12th International Modelica Conference
May 15-17, 2017, Prague, Czech Republic

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Logo, and trademark, CCLA

- First FMI logo



- Trademarks in Europe and the US





- Corporate Contributor's License Agreement providing a legal framework and IP regulations

CCLA

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FMI 2.0 development



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Versioning of FMI

FMI uses semantic versioning:

Major releases

- not backwards or forward compatible changes

e.g. **„FMI 2.0.4“**

Minor releases

- Can introduce new features
- Backwards compatible
  „FMI 2.0 FMUs will be valid FMI 2.1 FMUs“

Bugfix/Maintenance releases

- No new features, only bugfixes and clarifications possible
- Backwards and forward compatibility

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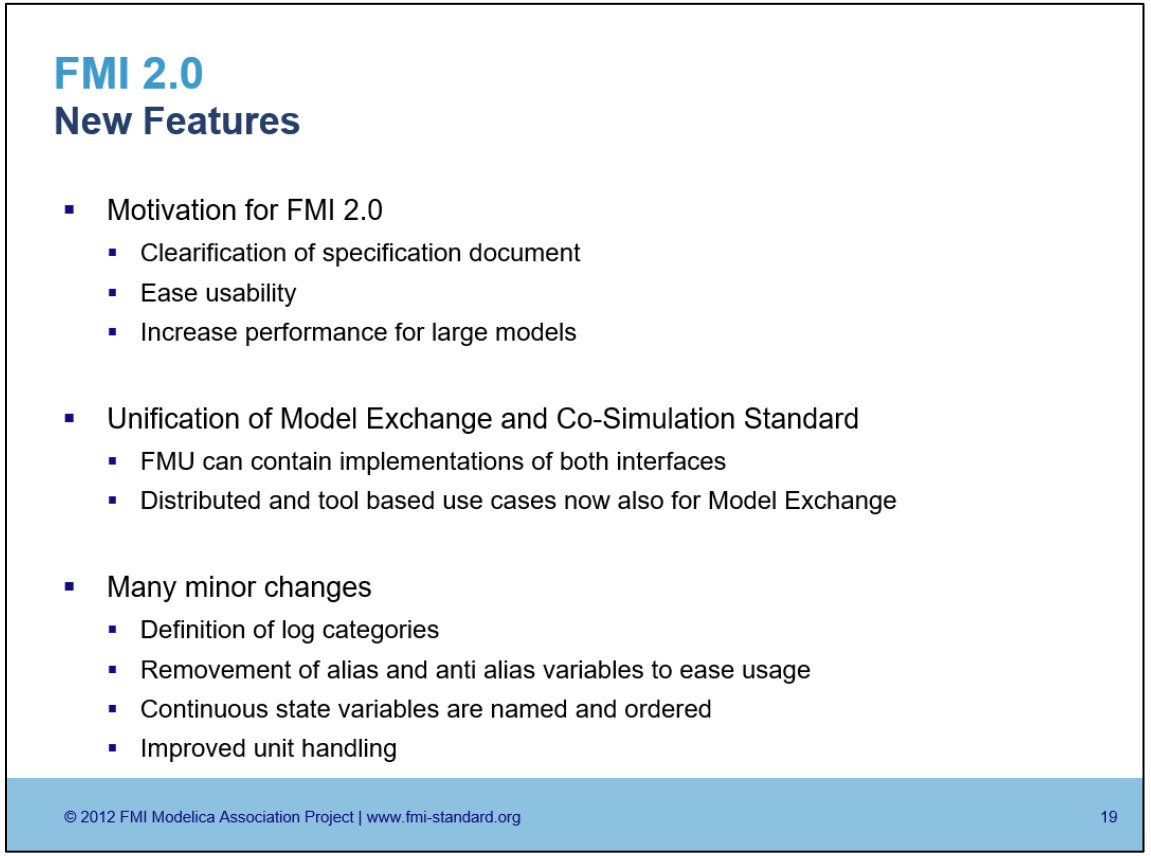
FMI 2.0 – released in 2014

Learning from FMI 1.0 usage and shortcomings.

Unification of FMI 1.0 ME + CS standards

Technical improvements:

- Better Classification of interface variables
- Save and Restore FMU State
- Improved dependency information
- Partial (directional) derivatives
- ….



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Facing reality - FMI is great – but not magic!

Managing expectations – educating users





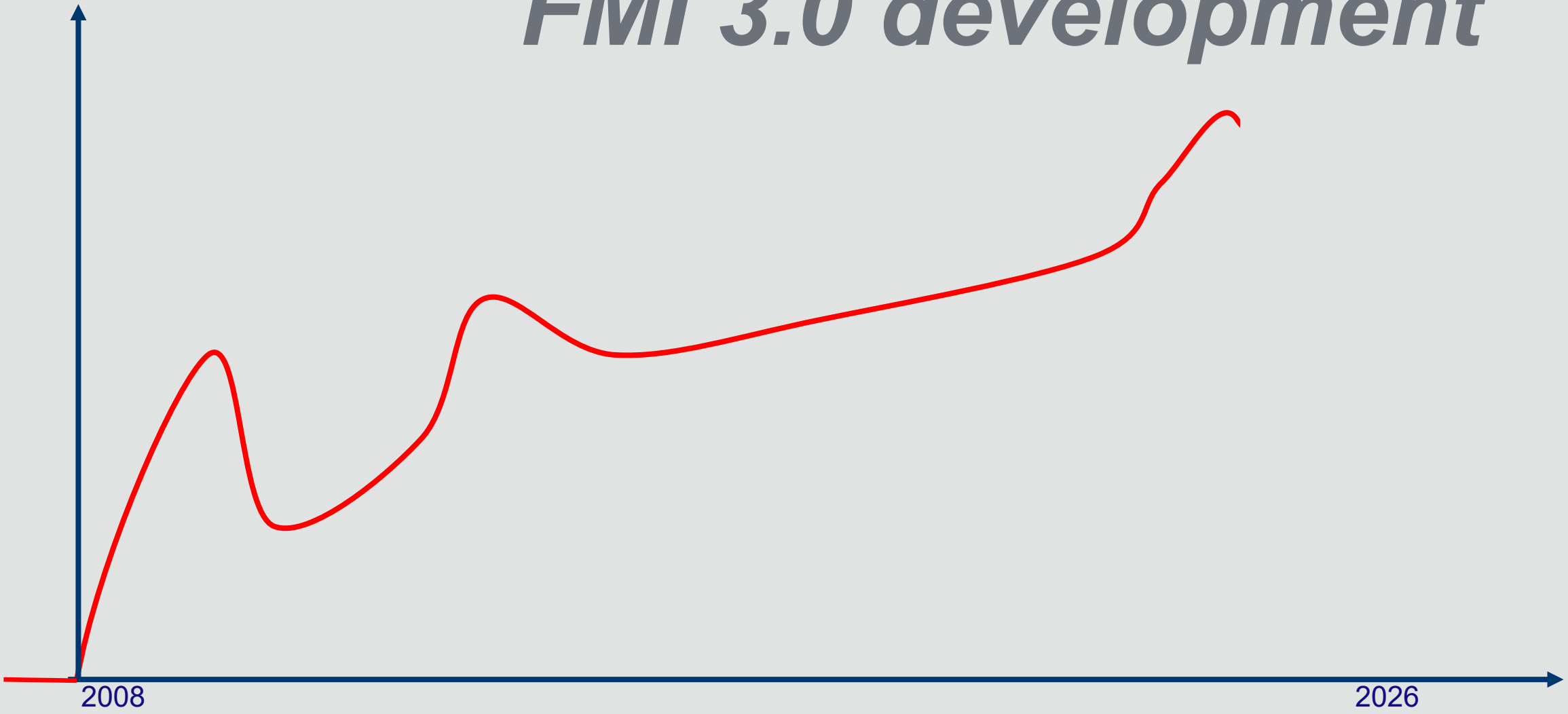


FMI solves many problems, but still **it is "only an interface"**.

You still must cut your overall system at the right place, master the numerics, set up a suitable (co-)simulation, educate people how to use it, …

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FMI 3.0 development



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FMI 3 development by the FMI Design Group 2015-2022

- **No funding - Voluntary contributions** by FMI Project Member companies/organizations
- **Development process was defined**
  - For larger changes: separate documents “FMI Change Proposals”
- Regular bi-weekly **web meetings**
- **Working groups** to define “FMI Change Proposals” (FCPs)
  - Additional working group meetings
  - 2-3 in-person meetings/year for 2-3 days

First the FMI project worked on a **version 2.1** of the standard, but when we saw, **that too many compromises** would be necessary, **we decided to go for a 3.0 release**…

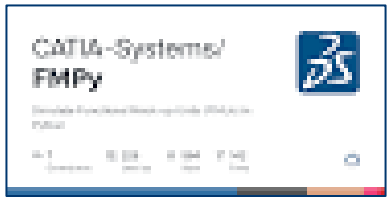
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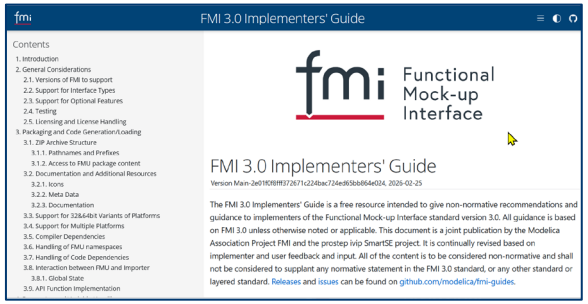
Supporting infrastructure for FMI 3.0 development

Development on Github

- For smaller: via GitHub Pull Request
- Automatic Document creation with AcsiiDoc GitHub Actions

- **Internal test implementation and cross check**
- fmpy and fmusim as **validation and prototyping tools**
- **Reference FMUs**
- **FMI 3.0 Implementers' guide**
- Provision of **compatibility information** and example FMUs on FMI tools page.
- a lot of **experience with FMI 1.0 and FMI 2.0 implementation**





→ Much better conditions for a **stable standard and implementations** than in the past!

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In-person FMI Design Meetings

2-3 times/year

Mostly representatives by tool vendors



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Motivation for FMI 3.0:

New use-cases and requests:

- Virtual Electronic Control Units (**vECUs**):
  - better support needed!
- **Advanced Co-Simulation**
  - improved co-simulation methods are needed to improve performance and accuracy
- **Multi-FMU simulations** are getting more common
  - **Events** necessary in complex control systems
  - Events must be synchronized across FMUs
- New **ML, AI, optimization** applications
  - More derivative computations are required

Main Improvements:

Performance Accuracy

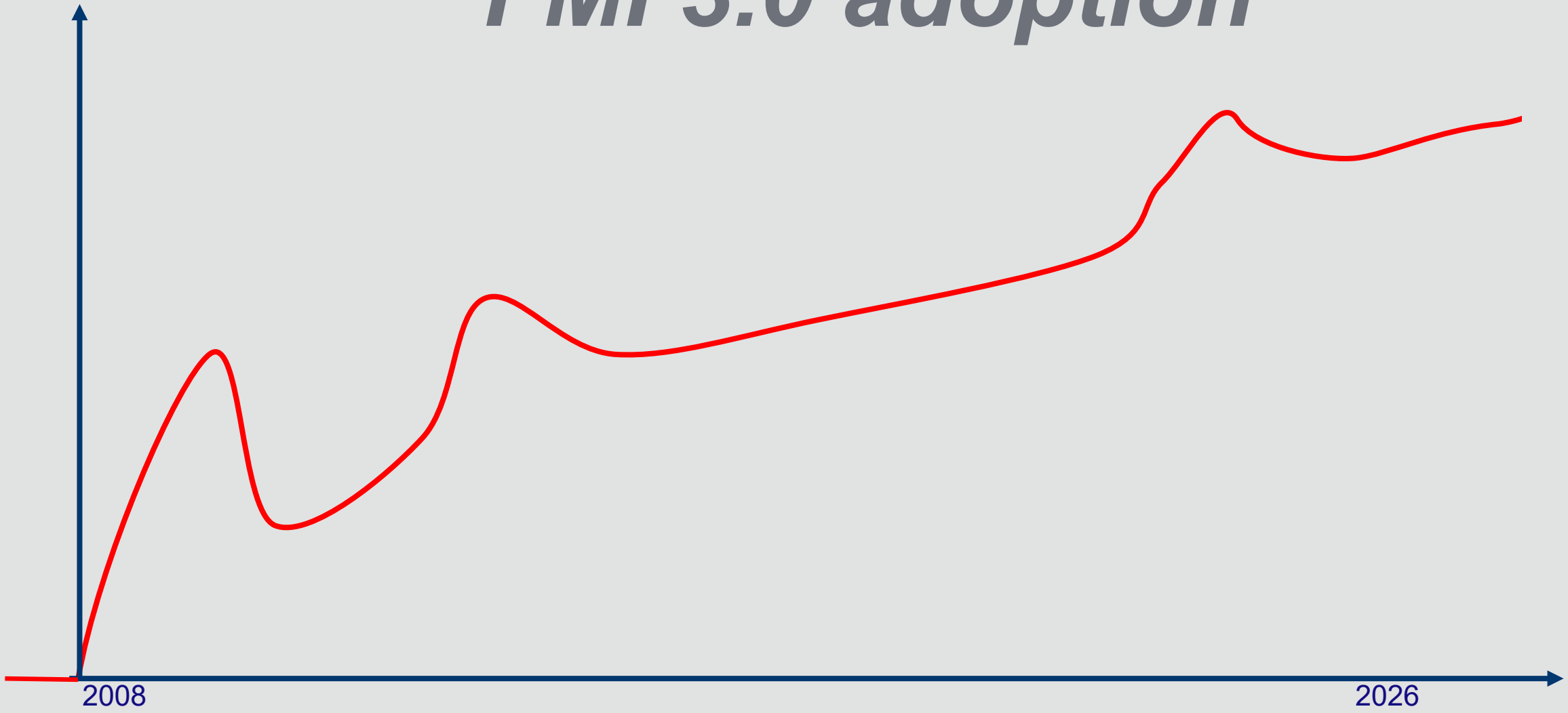
- Event mode for Co-Simulation
- Intermediate variable update
- Clocks
- New variable types
- Array variables

New Applications

- Terminals and icon
- FMI for Scheduled Execution (SE)
- Adjoint derivatives
- **Preparation for Layered Standards**

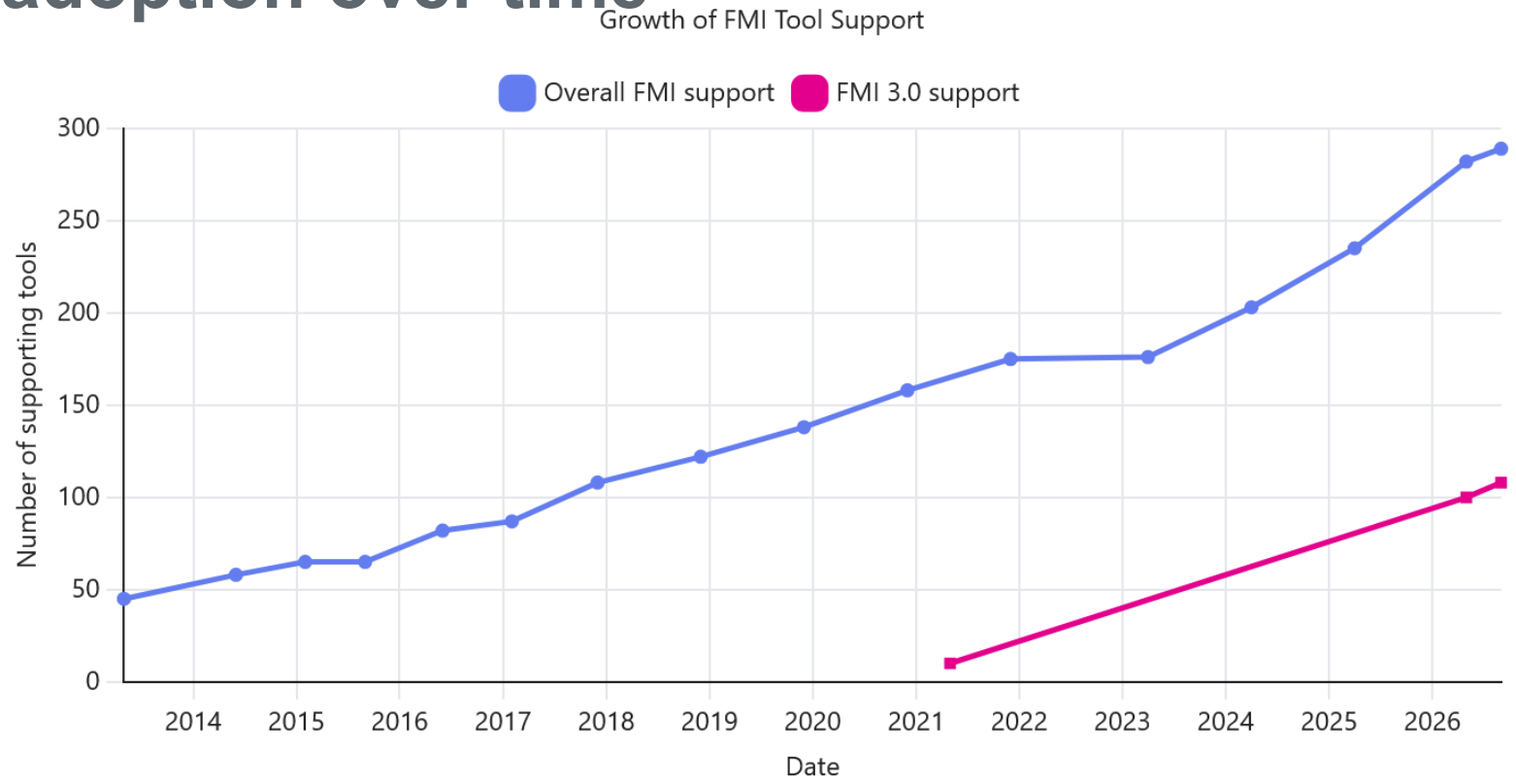
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FMI 3.0 adoption



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FMI adoption over time



FMI is the de-facto industry standard for tool independent model exchange and co-simulation.

FMI 3.0 is becoming the new normal!

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Who uses FMI? Employers of the Members of the FMI LinkedIn Group (2024)

Who uses FMI? For a free standard it is hard to get the full picture. But looking at the employers of the members of the FMI LinkedIn Group, we at least get an indication – which is quite impressive:

Aerospace: Airbus, Ascendance Flight Technologies, Blue Origin, Boeing, BULATSA, Collins, Dassault Aviation, LIEBHERR Aerospace, Leonardo, Lockheed Martin, NASA, Norasi, Northrop Grumman, Pratt & Whitney, Rogoz, Saab, TASECS

Automotive OEMs: AMG, Aston Martin, Audi, Bugatti Rimac, Cummins, Dana, Ferrari, Ford, GM, Honda, Hyundai, Jaguar Land Rover, Mahindra Racing, MAN, Maserati, Mercedes-Benz, Navistar, Porsche, Scania, Stellantis, Tata, Tesla, Toyota, Uber, Volvo Cars, Volvo Cars, Volvo Trucks, Volvo Autonomous Solutions, Volta Trucks

Automotive Suppliers: AGCO Power, alvier, Borg Warner, Bosch, CARIAD, Continental, Cyngn, DENSO, Elektrobit, FPT Industrial, Garrett, Grayson Thermal Systems, Harman, Hyundai MOBIS, Knorr Bremse, Kreisel Electric, Recharge, Schaeffler, SEG Automotive, Traila, Tula Technology, Valeo, Vitesco Technologies, ZF Group

Offroad, Agriculture, Construction, Mining, Railroad: AGROINTELLI, Alstom, Claas, John Deere, Knorr Bremse, KRYTON, LIEBHERR, Putzmeister, Sandvik, Tolsa, Wabtec Corporation, Yara

Energy, Heating, CCS: BDR Thermea Group, AEP Energy, BLAUD Energy, Bosch Home Comfort, Carrier, BSZ.Netz, Daikin, Danfoss, EDF, e.on Energy Research Center, EPRA Energy, GE-Hitachi Nuclear Energy International, GE Power, Indoorclima, KWS Energy Knowledge, Origen, promeos, MAPNA, National Grid ESO, NOV, Principle Power, Rolls-Royce Power Systems, Shell, Siemens Energy, Siemens Gamesa, SOURCE Global, Sunny Shark, SUNO, Swiss Rotors, TEİAŞ, Trane Technologies, Vestas, Viessmann, Wärtsilä Energy

Healthcare: Arcabel Solutions, Philips, Quanta Dialysis Technologies, Siemens Healthineers

Automation & Robotics: ABB Robotics, Balluff, Bucher Emhart Glass., Delta Electronics, Festo, Johnson Controls, Keba, R&D Test Systems, Rexroth, Rockwell Automation, Stanley Robotics

Mechanical + Electrical + Consumer Products: Alfa Laval, BSH, ABB, Bosch, Bosch Rexroth, Briggs & Stratton, Electroingnium, FCK Ingenieria, Groz-Beckert, Heliox, Krones, LG, MANITOU Group, Mitsubishi, Miele, Poclain Hydraulics, Samsung, Schindler Aufzüge, SFO, SICK, Siemens, Sonceboz, Swegon, Tenet Technetronics, Toshiba, Whirlpool

Maritime and Offshore: DNV, IAPS, Naval Group, Rolls-Royce Power Systems, seaplace, Stiesdal Offshore Technologies, SeeByte, SMD, TECHNO PRO

Engineering Companies: AETOS, ALTEN, Akkodis, Applied Intuition, Arup, ASAP, BeonD, Blueke, BrownSim, Brunel, CapGemini Engineering, Cloudare Technologies, cogniBIT, CORYS, DPS, EDAG Group, Edvance, :em, energyflexibility.org, Envinn, EKS InTec , Eradity, FEV, GEED Simulations, Hinduja Tech, IAV, ITK Engineering, L&T Technology Services, LADUGA, MegaRide, Page Southerland Page, Paninian, Persival, Phimeca, Pitch Perfect Engineering, Powersys, Pratt Miller, R&D Test Systems, Sarayu systems solutions, shonDynamics, Sigma Industry, Silver Atena, SVS FEM, Syngineers, Tata Elxsi, Tietoevry, Technica Engineering, Tecnicas Reunidas, Teoresi Group, Universal Technical Systems, Vestervang Engineering, viattech, Vintecc, Vitech, Windgrid, 8tronix

Tool Vendors: Altair, Ansys, Ape.AI, AVL, BeamNG, CADFEM, cosin scientific software, Chiastek, Dassault Systèmes, dffrnt.ai, DIgSILENT, DMagis, dSPACE, ds.tools, eGolem, ESI, ESSS, ETAS, eXXcellent solutions, Flite Software, Foretellix, Gamma Technologies, Geminus.AI, Global Crown Technology, IVH, JuliaHub, LTX, Maplesoft, MathCore, Modelon, MetaCompliance, MSC Software, National Instruments, OPAL-RT Germany, OPENSPDMOptimation, Orthogonal Technology, Semantum Oy, PragmaDev, Siemens Digital Industry Software, Simercator, splight-ai, Synopsys, The MathWorks, TLK Energy, TLK Thermo, TraceTronic, Vector, VIAS3D, VI-Grade, Wolfram, XRG Simulation,

IT+Semiconductors+ Telecom: Akeski IT Solutions, Aras Corporation, Amazon, Apple, Akeski IT Solutions, Aras Corporation, ASML, Atruvia, AWS, Axis Communications, DY Information Technology, Eazy Way Rides, Edwards Vacuum, Embitel Technologies, Equinix, Fernride, Infineon, Jio, Live Aware Labs, Manzo & Vetere, Microsoft, MoaSoft, Mozilla, Si-Vision, Tata Elxsi, Wedia, WiserBrand, 84codes

Research Institutes: AEE Intec, AIT, ASD Lab, Battelle Memorial Institute, CATARC, DLR, EPRI, Fondazione Bruno Kessler, Forschungszentrum Jülich, Fraunhofer IPK/IKS, Indian Institute of Technology, IDAEA-CSIC, IFP Energies Nouvelles, INRIA, IRT AESE - Saint Exupéry, ISAE-SUPAERO, LBNL, NOBATEK/INEF4, RSE, Ricerca sul Sistema Energetico, Shanghai Institute of Applied Physics, SINTEF, Southwest Research Institute, SuperGrid Institute, Swedish National Road and Transport Research Institute (VTI), Virtual Vehicle

Universities: RWTH Aachen, Aalborg University, Aarhus University, Université Amar Telidji de Laghouat, Universiteit van Amsterdam, Augsburg University, Australian National University, HTW Berlin, Brno University of Technology, Universität Clausthal, Clemson University, University of Colorado Boulder, Comillas Pontifical University, Université de Technologie de Compiègne (UTC), University of La Coruna, DTU, Eindhoven University of Technology, Universiteit Gent, Georgia Tech, TU Hamburg, Universidade Federal de Juiz de Fora, IT-Universitetet i København, KU Leuven, Lund University, North Carolina State University, Universidad Politécnica de Madrid, Universidad de Málaga, The University of Manchester, Hochschule München, Ludwig-Maximilians-Universität München, TU München, University of Naples, Università degli Studi di Napoli Federico II , NTNU, University of Oran, University of Pisa, Punjab Engineering College, Instituto Superior de Engenharia do Porto, Charles University Prague, University of Queensland, Rensselaer Polytechnic Institute, RWTH, University of Salerno, Universidad de Sevilla, University of South-Eastern Norway, Stuttgart University, Texas A&M University , Università Trieste, University of Trento, Universidad de Valladolid, TU Wien, University of Wisconsin-Madison, Universidad de Zaragoza

Institutions and Associations: European Commission, IDTA, INCOSE,

Other: Carrefour, Citi Private Bank, DeliverMe.City, Fressnapf International Business Services, SIA - Startup Investor Accelerator

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FMI adopted by new communities & standardization organizations

- Inter-operabel and crossed referenced with ASAM standards
- International Digital Twin Association (IDTA)
  endorsing FMI for sub-models in “Asset Administration Shell”
- FMI included in the reference model and process of ISO 21175-1
- Lotar Standard uses FMI for long-term archiving of system simulation models
- ProSTEP endorses FMI for system simulation and provides implementation support
- JAMBE endorses FMI and provides implementation guide.

…..

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Current & future developments



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The Modelica Association today

Modelica Association

MA Projects:

- A project to develop, standardize, and promote Modelica, a language to model and simulate multi-domain cyber physical systems in a convenient way. Modelica Language
- A project to develop, maintain, and promote the open source Modelica libraries and model components in many domains based on standardized interface definitions. Modelica Libraries
- A free standard that defines a container and interface to exchange dynamic simulation models using a combination of XML files, binaries, and C code. fmi-standard.org
- A tool independent standard to define complete systems of one or more FMUs including its parameterization that can be transferred between simulation tools. ssp-standard.org
- A platform and communication medium independent standard to integrate models and real-time systems into simulation environments. dcp-standard.org
- A standard to seamlessly integrate physics design models of systems with their electronic controls development. efmi-standard.org

- NEW: Coordination project between Modelica Association projects:
  Goal: develop overarching harmonized specifications

© 2026 Modelica Association Project FMI | fmi-standard.org

The Modelica Association FMI Project

The development of the FMI Standard is organised as the Modelica Association Project *Functional Mock-up Interface* under the roof of the Modelica Association

Project Leader and Deputy:
Christian Bertsch (BOSCH) and Torsten Sommer (Dassault Systèmes)



- **Members of the Steering Committee:**
  AVL List, BOSCH, Dassault Systèmes, dSPACE, ESI Group, Maplesoft, Modelon, PMSF, Siemens PLM, Synopsys

- **Further Contributing Members:**
  Aarhus University, ABB, Altair, Akkodis, AMEPERE, Ansys, Augsburg University, Beckhoff, Boeing, Danfoss, DLR, EKS INTEC, ETAS, Fraunhofer IEM, IAV, ITK Engineering, iVH, JuliaComputing, LTX, MachineWare, Renault, Saab Group, Virtual Vehicle Research, Wolfram MathCore AB, TLK Thermo, tracetronic, TU Dresden *and all Steering Committee Members*

- **Advisory Committee:** ***(open to join – please contact me! – next 10.11.2026)***
  AIRBUS, blue automation, Claytex, COMSOL, DNV, Fraunhofer (IIS/EAS First, SCAI), GM Motorsports, KEB Automation, LBL, NVIDIA, Knorr-Bremse Rail Vehicle Systems, MathWorks, Open Modelica Consortium, Samares Engineering, SINTEF Nordvest, University of Halle, Volkswagen, Volvo Autonomous Solutions, VTI, *and all Contributing and Steering Committee Members*

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System Structure and Parameterization (SSP)



Project Leader: Pierre Mai (PMSF), Deputy: Robert Hällqvist (Saab)

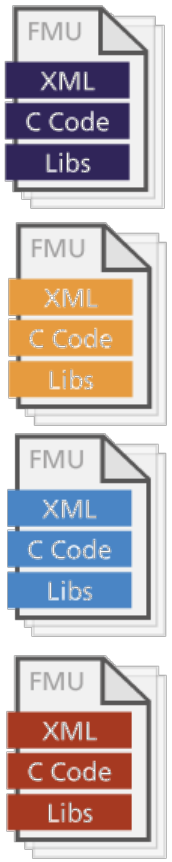
- free standard that defines a tool-independent format for the description, packaging and exchange of system structures and their parameterization.
- Currently supported by 17+ tools Releases

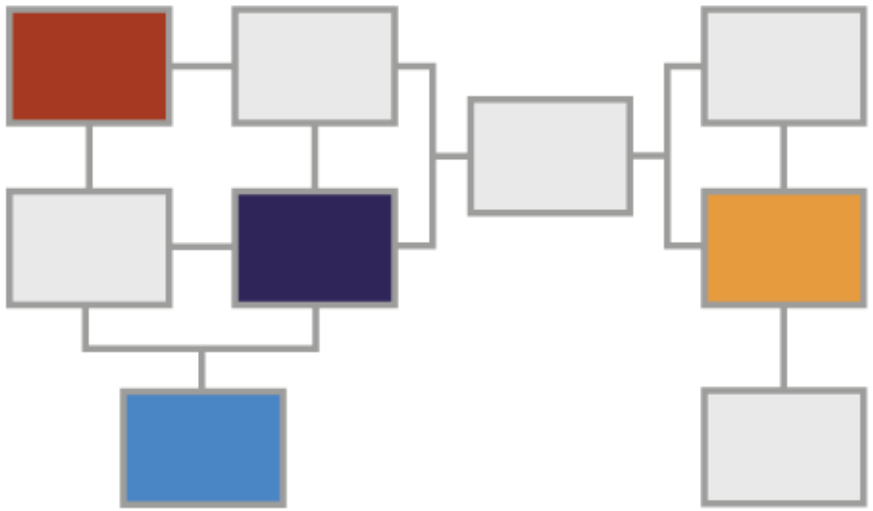
It can be used to define

- The **connection of FMUs** (SSD file)
- **Parameter sets** (SSV Files)

And with Layered Standards

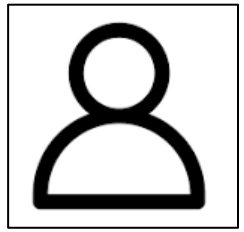
- **Traceability** and Simulation credibility information
- ..





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eFMI – FMI for embedded systems

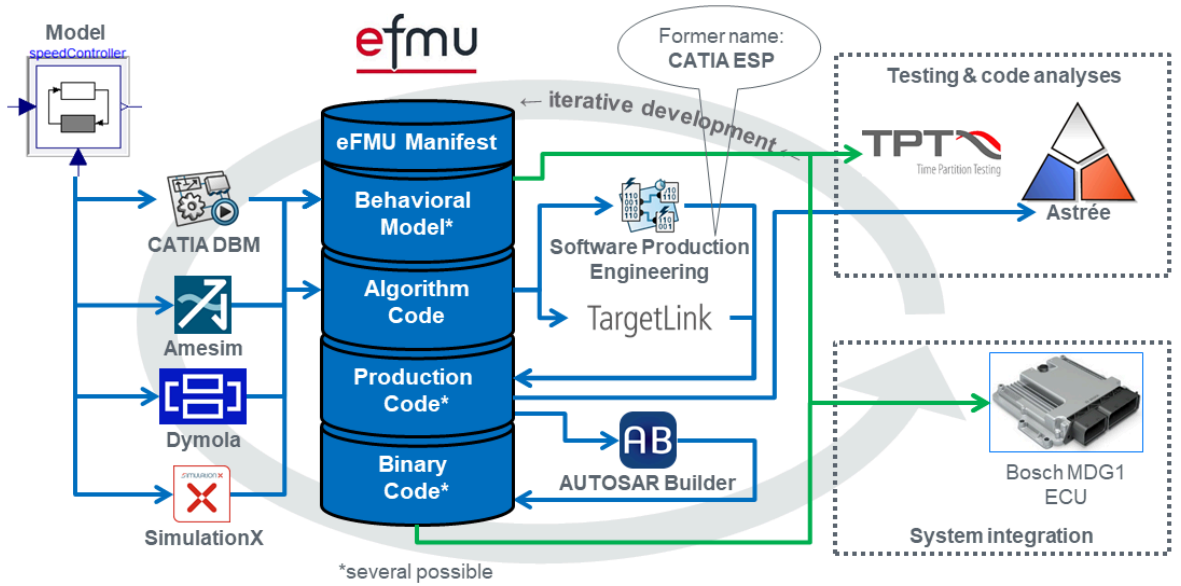




Project Leader: Christoff Bürger (Dassault System) Deputy: Daeoh Kang

eFMI was developed in the publicly funded project
EMPYHSIS led by Oliver Lenord (Bosch)





Currently in beta stage: v1.0.0-beta.1

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Current development in the FMI project

- Tool vendors are **still implementing FMI 3.0 features**

- **FMI 3.0.3 with clarifications** and smaller bugfixes to be expected this year

- **Current development mainly in Layered Standards** that use FMI (3.0) features, but do not modify the core standard

Layered Standards

- **Possible FMI 3.x extensions**
  - E.g. for efficiency improvements for communication dominant simulations



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Efficiency working group

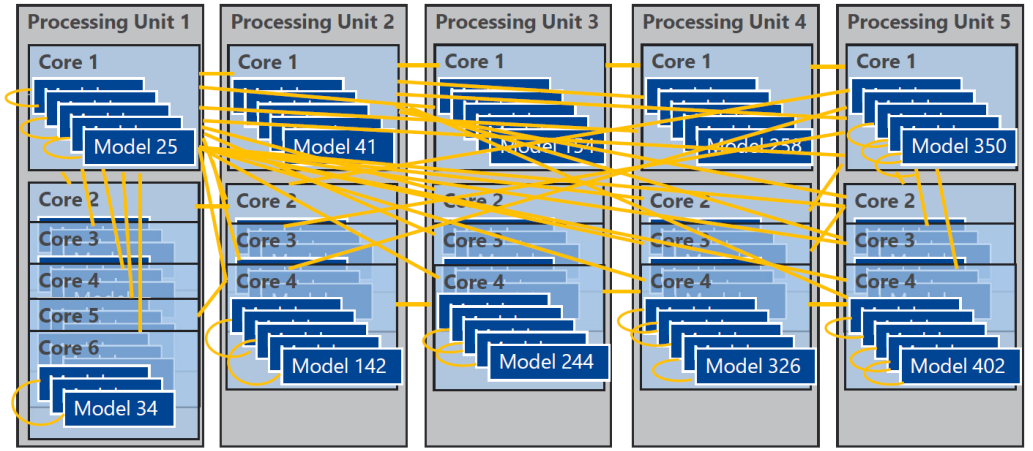
- Working group led by Irina Zacharias (dSPACE)
- Goal: **improve efficiency for communication intensive simulations**

- Idea: Avoid calling fmi3GetXXX() and fmi3SetXXX() functions for large structures

- Possible Solution: direct memory access instead of get/set copy operation
- Possibly also for GPU support.

- Currently: investigation of use cases

- **Do you face efficiency topics caused by communication overhead? Tell us!**



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Layered Standards

- Layered standards **extend the FMI standard** for **new application domains.**
- They can be defined by **different organizations**
- **Layered Standards in development by the FMI Project:**



Layered Standards

Layered Standards define extensions of the FMI Standard and can be released by any organization.
The following Layered Standards are maintained by the FMI Project.

FMI-LS-XCP — FMI Layered Standard for XCP 1.0.0

FMI-LS-BUS — FMI Layered Standard for Network Communication 1.0.0 1.3.0-beta.1

FMI-LS-STRUCT — FMI Layered Standard for Structured Data 1.0.0-rc.1

FMI-LS-REF — FMI Layered Standard References 1.0.0-beta.1

FMI-LS-DAE — FMI Layered Standard for DAE (Differential Algebraic Equations) 1.0.0-alpha.1

FMI-LS-WASM — FMI Layered Standard for WebAssembly

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FMI-LS-BUS: Layered Standard Network Communication



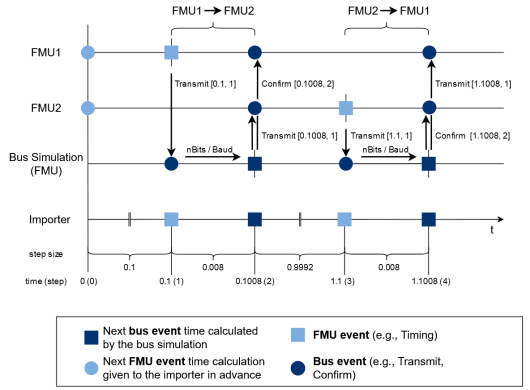
Working Group led by Benedikt Menne (dSPACE)

1.0.0 1.3.0-beta.1

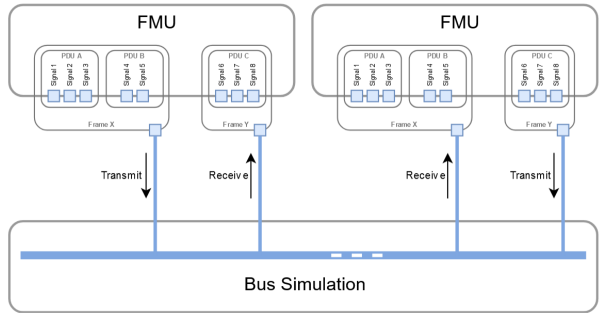
Simulation of automotive systems requires **network communication between vECU.**

Idea:

- **Use FMI 3.0 core standard features** to specify a common bus interface, using **Co-Simulation**, **Binary Variables**, **Clocks** and **Terminals**
- Support **automotive network protocols** and others from **different industries** (CAN, LIN, FlexRay, Ethernet, …)



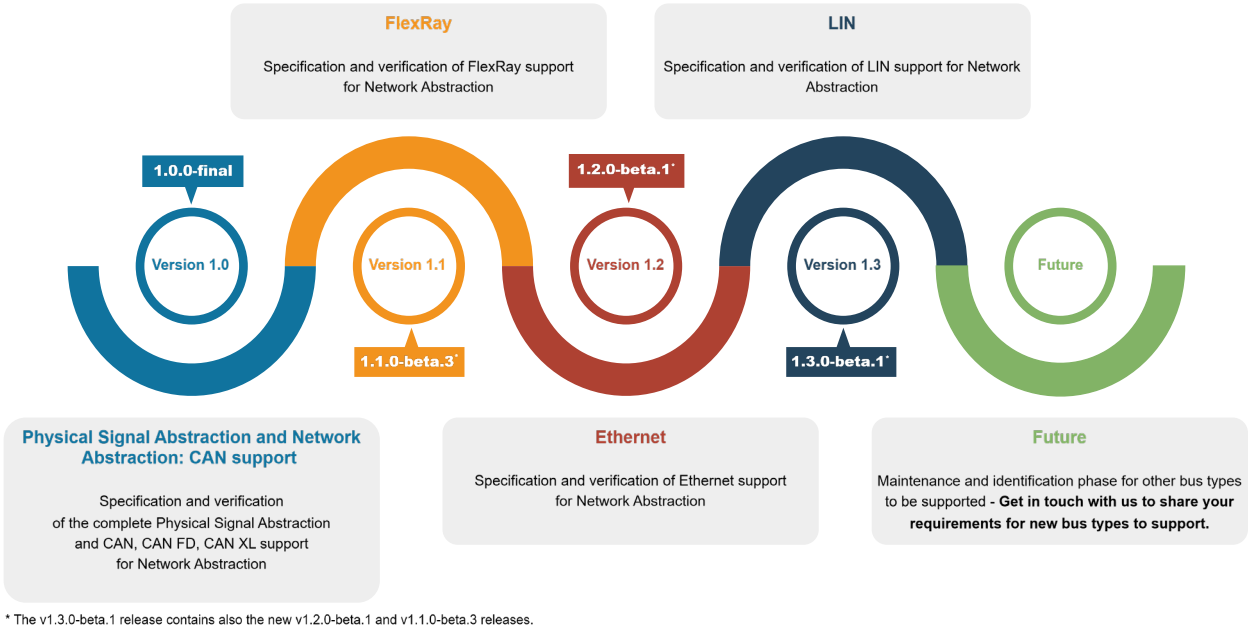
- **Two variants:**
  - **Physical abstraction layer ("high cut"):** Simply transport physical signal values between virtual ECUs by using unit-based and clocked variables
  - **Network abstraction ("low cut"):** Detailed emulation of a specified bus system to realize virtualized bus driver implementations, including feedback from the physical drivers about transmission status or network node states



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FMI Layered Standard for Network communication (FMI-LS-BUS)

- Working Group led by Benedikt Menne (dSPACE)
- Already supported in 11 tools!



* The v1.3.0-beta.1 release contains also the new v1.2.0-beta.1 and v1.1.0-beta.3 releases.

Tool	Type	Features	Remarks
Akkodis PROVEtech:RE	Importer	DC BSF IBS HC LC: CAN	Available since PROVEtech:RE 2026
Altair Twin Activate	Importer	DC BSF HC LC: CAN LC: FlexRay** LC: Ethernet** LC: LIN**	Fmi3-Terminals are not supported
AVL Model.CONNECT™	Importer	DC BSF HC LC: CAN LC: FlexRay** LC: Ethernet** LC: LIN**	-
dSPACE SystemDesk	Exporter	LC: CAN LC: FlexRay** LC: Ethernet** LC: LIN**	Available since RLS 2024-B
dSPACE VEOS	Importer	IBS LC: CAN LC: FlexRay** LC: Ethernet** LC: LIN**	Available since RLS 2024-B
FMU Manipulation Toolbox	Importer	DC BSF HC LC: CAN	Open-source software. Available since version 1.9.2
MachineWare VCML Virtual Platform	Exporter	LC: CAN	-
Synopsys Silver	Importer	IBS LC: CAN	-
tracetronic ecu.test	Importer	IBS LC: CAN	Available since ecu.test 2025.3
Vector SIL Kit FMU Importer	Importer	IBS LC: CAN LC: Ethernet**	Open-source software
Vector vVIRTUALtarget	Exporter	LC: CAN LC: Ethernet**	

https://github.com/modelica/fmi-ls-bus

FMI-LS-BUS Web event 15.12.2026 please contact me if you want to join!

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FMI LS-STRUCT: Layered Standard for Variable Structuring

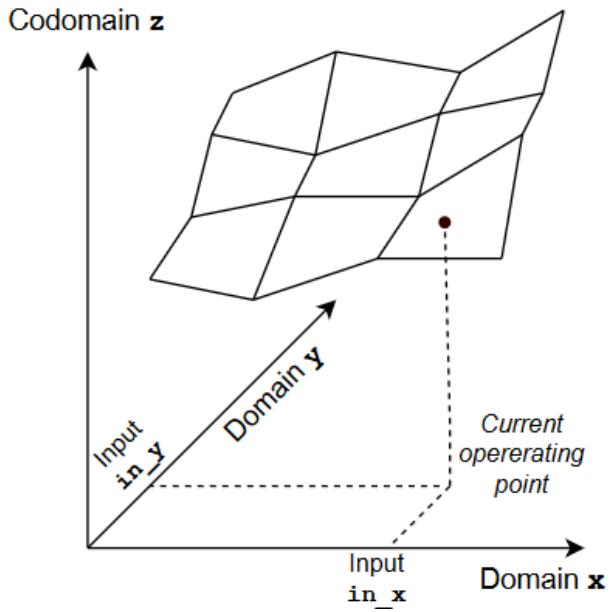


Working Group led by Klaus Schuch, AVL

1.0.0-rc.1

Current scope:

- **Maps sampled on rectilinear grids**
  using FMI 3.0 arrays by adding meta-data to define
  - Domains
  - Codomain
  - Optionally: Variables referencing current operating point, …
  - Support for Modelica Standard Library CombiTables
  - Compatible with ASAM-MCD2 MAPs, CURVEs, …
- Maps sampled on an irregular grid (“Point Cloud”)
- Using “FMI 3.0 Terminals” for grouping



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FMI Layered Standard References (FMI-LS-REF)



- Working group led by Pierre Mai (PMSF IT Consulting)

1.0.0-beta.1

- Based on FMI 2.0 and FMI 3.0, this layered standard defines how to **provide additional related files inside an FMU** with role information.

Table 4. Role Values.

Role
document
requirement
specification
model
parameter
system
testcase
experiment

```xml
<?xml version="1.0" encoding="UTF-8"?>
<fmiReferences
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:noNamespaceSchemaLocation="../../schema/fmi3LayeredStandardReferenceManifest.xsd"
    xmlns:fmi-ls="http://fmi-standard.org/fmi-ls-manifest"
    fmi-ls:fmi-ls-name="org.fmi-standard.fmi-ls-ref"
    fmi-ls:fmi-ls-version="1.0.0-alpha.1"
    fmi-ls:fmi-ls-description="Layered Standard providing information on related files included
in an FMU.">

    <Related type="text/modelica" source="modelica/mymodel.mo" role="model" description="Modelica
Model Source"/>
    <Related type="application/x-ssp-parameter-set" source="baseline-params.ssv" role="parameter"
description="Baseline Model Parameters"/>
    <Related type="application/x-ssp-parameter-set" source="midend-params.ssv" role="parameter"
description="Midend Model Parameters"/>
    <Related type="application/x-ssp-parameter-set" source="highend-params.ssv" role="parameter"
description="Highend Model Parameters"/>
    <Related type="application/x-ssp-parameter-set" source="dynamic-params.ssv" role="parameter"
description="Dynamic Model Parameters"/>
    <Related type="application/x-ma-ls-experiments" source="smoke-tests.exp" role="experiment"
description="Smoke Tests of FMU"/>
</fmiReferences>
```

- E.g.
  - SSV Parameter files
  - (Modelica, …) Source files
  - Experiment File (according to MA-HS-Experiments, see MAP Coord)

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FMI Layered Standard for DAE support (FMI-LS-DAE)

1.0.0-alpha.1





- Working group led by
  - Joel Andersson (FMIOPT; CasADi developer) and
  - Andreas Heuermann (Sant Anna Research Institute, OSMC)
- Support for **differential algebraic equations** in FMI
- Idea: **Expose residuals on the interface** and solve nonlinear equations externally!

- Development in the open on GitHub: https://github.com/modelica/fmi-ls-dae
- Use case collection, including
  - **Optimization**
  - DAE-mode use case (e.g. in OpenModelica)
  - ODEs with invariants
  - Multibody equations of motion (e.g. Simpack)
  - Steady state simulation
  - …

Semi-Explicit DAE

The *semi-explicit DAE* representation

$$\begin{aligned}\dot{x}(t) &= f(x(t), y(t), t)\\ 0 &= g^1(x(t), y(t), t)\\ 0 &= g^2(x(t), y(t), t)\\ 0 &= g^3(x(t), y(t), t)\\ &\vdots\end{aligned}$$

with g^1 solvable for y, $det\left(\frac{\partial}{\partial y} g^1\right) \neq 0$ and $\left\{\frac{d}{dt} g_i^k\right\} \subseteq \{g_i^{k-1}\},\ k > 1.$

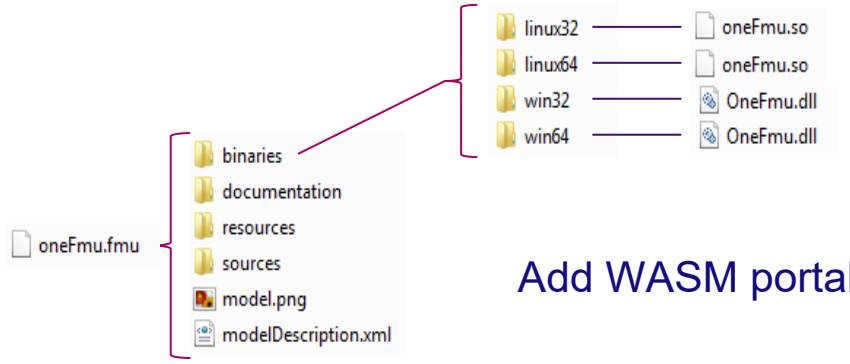
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FMI-LS-WASM: Working group for Web-Assembly FMUs

- New working group formed

- Motivation:
  - Sandboxing addressing cybersecurity concerns
  - Increased portability
  - Cloud/Browser-based simulation

  - Prototype already exists!
    https://github.com/modelica/fmi-ls-wasm



Add WASM portable binary!

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Modelica Association Coordination Project



Project Leader: Hubertus Tummescheit
(Model Based Innovations LLC)

- development, standardization and promotion of the Modelica Association Standards
- align with the MA vision of **coordinated** and **interoperable** standards.
- **by harmonizing the standards**, or by
- **creating layered, modular standards** that improve the main standards' interoperability.
- **promote interoperability with standards from other standardization organizations**, such as, for example, the OMG (Object Management Group).

Ongoing work: (Modelica Association Harmonized Specifications)

- **MA-HS-CSV**: a unified CSV format for time series and similar data (GitHub) 1.0.0-beta.1
- **MA-HS-Experiments:** unified Experiments specification (GitHub)
- **Standardization of Mapping SysML 2.0 and SSP**

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New players adopting FMI - e.g. NVIDIA

LinkedIn

NVIDIA



Adam Moravanszky • 1st
Senior Director, Simulation Technology at NVIDIA
2mo • Edited •

We are excited to announce the release of ovfmi v0.1 as part of the new Omniverse Labs repository on GitHub:

https://lnkd.in/eU7ddy8d

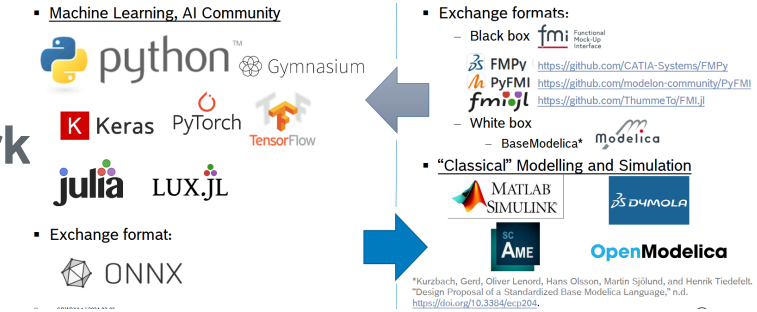
ovfmi 0.1 is a Python code sample that integrates FMI and SSP co-simulation models into OpenUSD scenes using a new USD schema, first introduced by SoftServe and NVIDIA at GTC last year. This integration allows a USD stage to capture both the appearance and behavior of a digital twin, regardless of the simulation model being used.



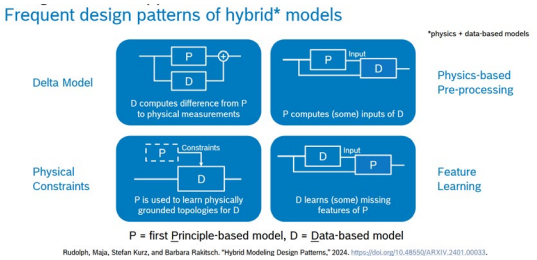
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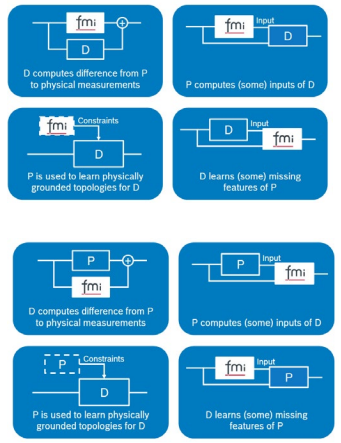
FMI and Machine Learning

- FMI can be used to **exchange models between "classical simulation tools" and machine learning framework**
  - Using simulation models in reinforcement learning (RL)
  - Deploying Neural Networks



- Creating **hybrid physics-based/machine learning models**





- FMI 3.0 supports **directional / adjoint partial derivatives**:
  - Efficient training of black box (machine learning …) models is possible with FMI!

Forward Sensitivity Analysis:
- compute the directional derivatives: $\mathbf{v}_{sensitivity} = \mathbf{J} \cdot \mathbf{v}_{seed}$
- `fmi2GetDirectionalDerivatives(V)`
  `fmi3GetDirectionalDerivatives(V)`

Backward Sensitivity Analysis:
- calculate the adjoint derivatives: $\mathbf{v}^{\mathbf{T}}_{sensitivity} = \mathbf{v}^{\mathbf{T}}_{seed} \cdot \mathbf{J}$
- `fmi3GetAdjointDerivatives(V)*`

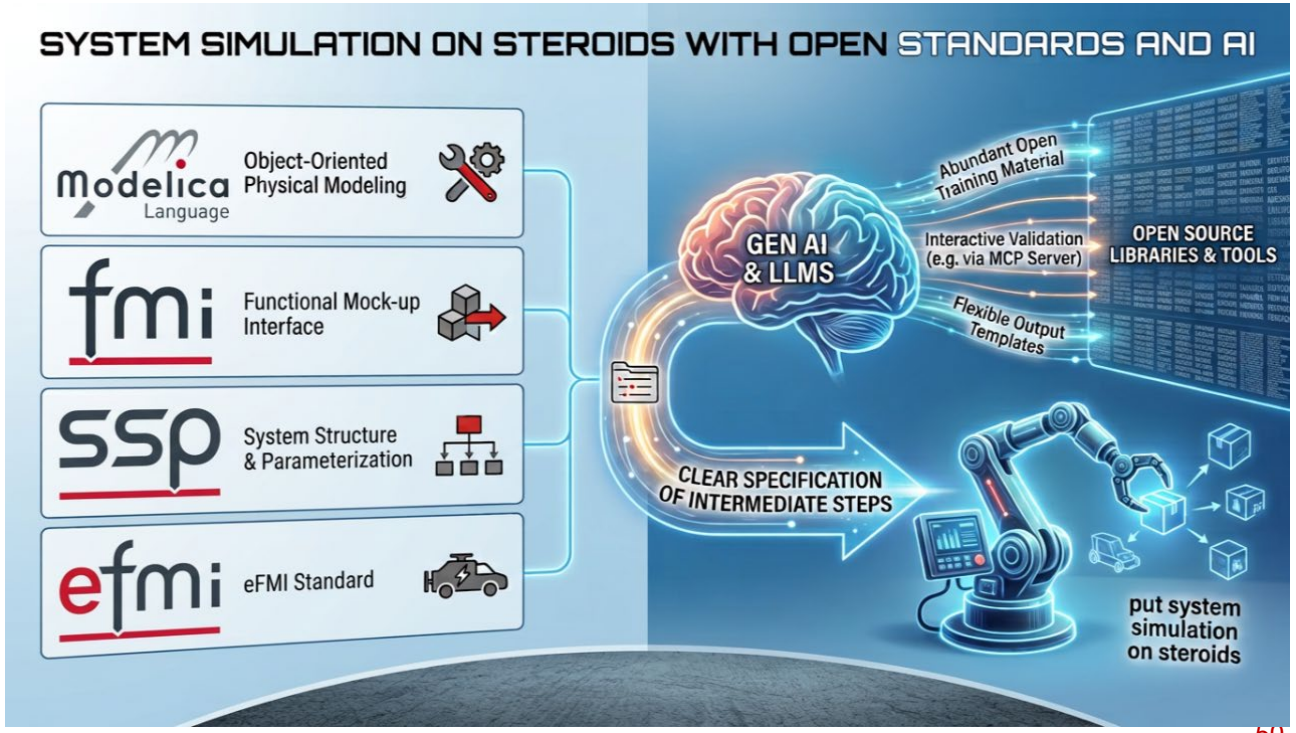
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FMI and AI

Our open standards (**Modelica, FMI, SSP, eFMI, DCP**) are proving to be the ultimate enablers for LLMs and AI agents:

Here is **why open standards and GenAI are a match very well**:

- 🎯 **Clear Intermediate Steps**
- 📚 **Abundant Open Training Material**
- ⚙️ **Autonomous Model Generation**
- 🔄 **Interactive Validation**
- 🔀 **The Power of Cross-Specification Transformation**



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Great to see the broad usage and fast growth of FMI usage in Asia and especially China!

Let’s collaborate and exchange even more!



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