TOWARDS AN INTEGRATED TOOL CHAIN FROM PHYSICAL MODELING TO ECU SOFTWARE USING FMI ON AUTOSAR PLATFORMS

MODPROD WORKSHOP

FEBRUARY 7TH-8TH 2017, LINKÖPING

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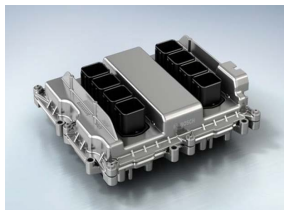
Tool Chain from Physical Modeling to ECU Software
Outline

- Relevance of ECU Software for Bosch
- Motivation of Physical Models on Embedded Targets (ECU)
- Challenges of ECU Software Development
- Solution Approach: Assisted Transformation of Physical Models to ECU Software
- Tool Chain Prototype
- Application Example
- Summary
- Outlook

Tool Chain from Physical Modeling to ECU Software
Relevance of ECU Software for Bosch

- Modern cars have more than 100 ECUs: Electronic Stability Program, Electronic Engine Control,...

- Complexity of software increases, with advanced control functions.
- Specialized hardware: µController with specialized core.



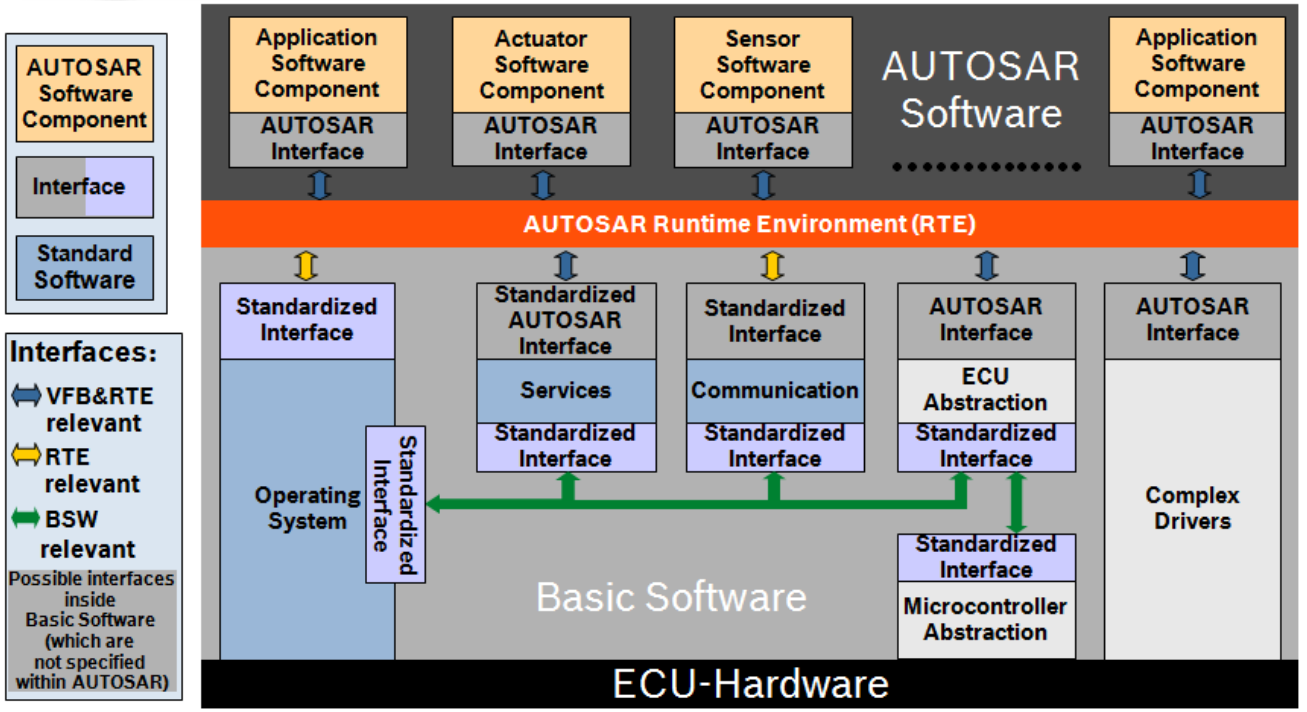
Bosch multi-core ECU

Integrated Tool Chain from Physical Modeling to ECU Software

Introduction: AUTOSAR

- Layer Concept
  - HW Abstraction (BSW)
  - Runtime Environment (RTE)
  - Application Layer (ASW)
- Benefits
  - Standardized interfaces
  - Standardized structure of software modules.
  - Standardized hardware independent sharing of application software.

AUTOSAR



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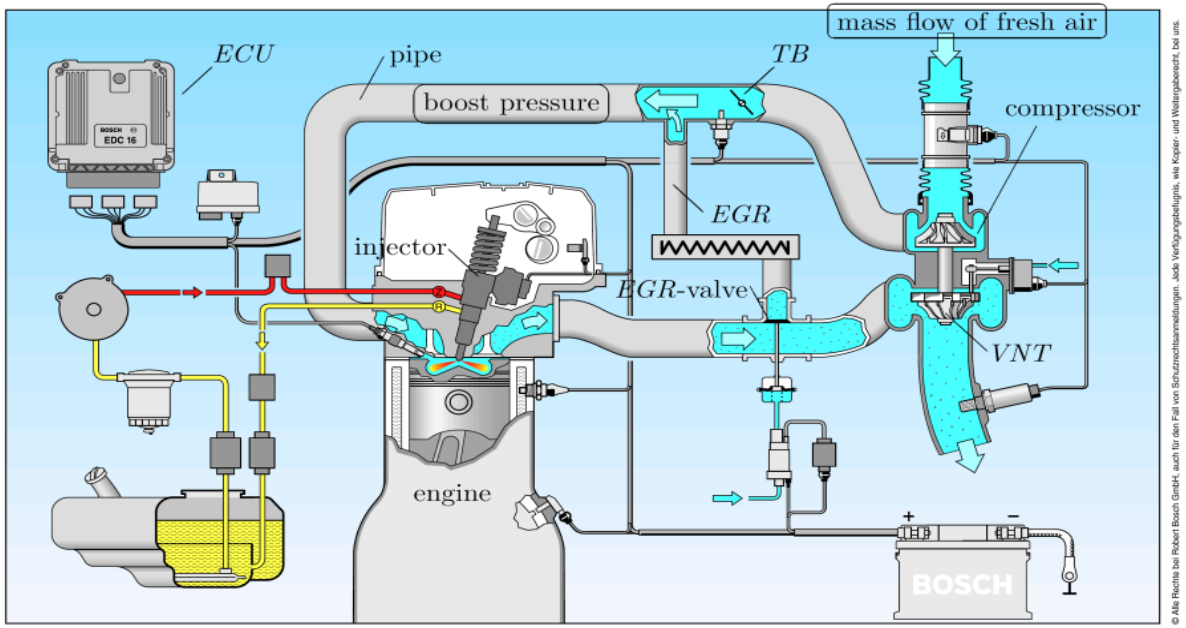
Tool Chain from Physical Modeling to ECU Software
Motivation of Physical Models on Embedded Targets (ECU)

- Online Physics-based Models on ECU, a key technology for:
  - **Virtual Sensors, Observers,**
  - Model-Based Diagnosis,
  - Feed Forward controllers,
  - Model Predictive Control.



Virtual Sensor (Boost Pressure)

Wagner, A., Bleile, T, Lux, S., Fleck, C., “Method for real time capability simulation of an air system model of an internal combustion engine”, US Patent US 8321172 B2, 2008

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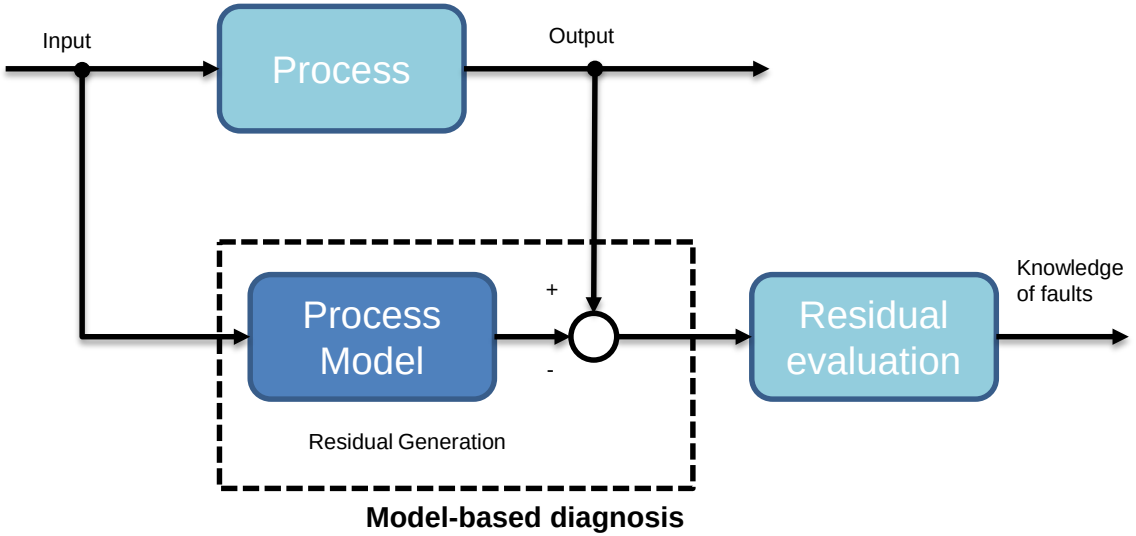

Tool Chain from Physical Modeling to ECU Software
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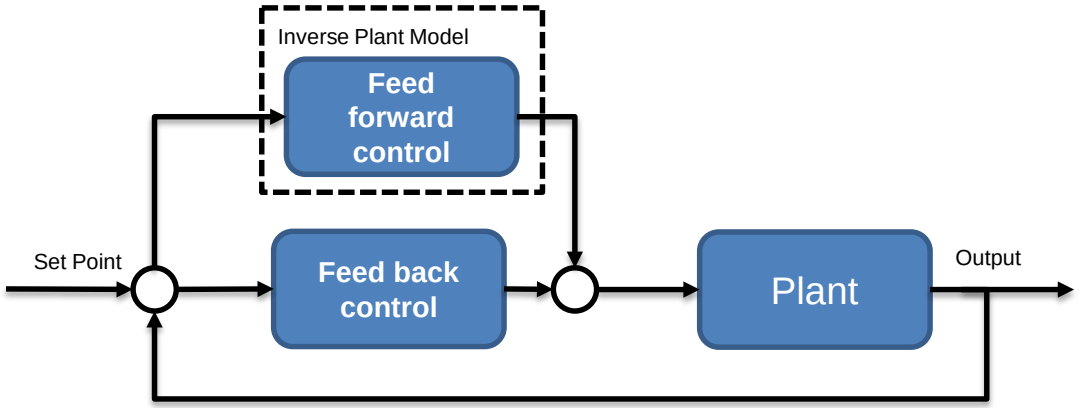

Inverse Feed forward Controllers

Tool Chain from Physical Modeling to ECU Software

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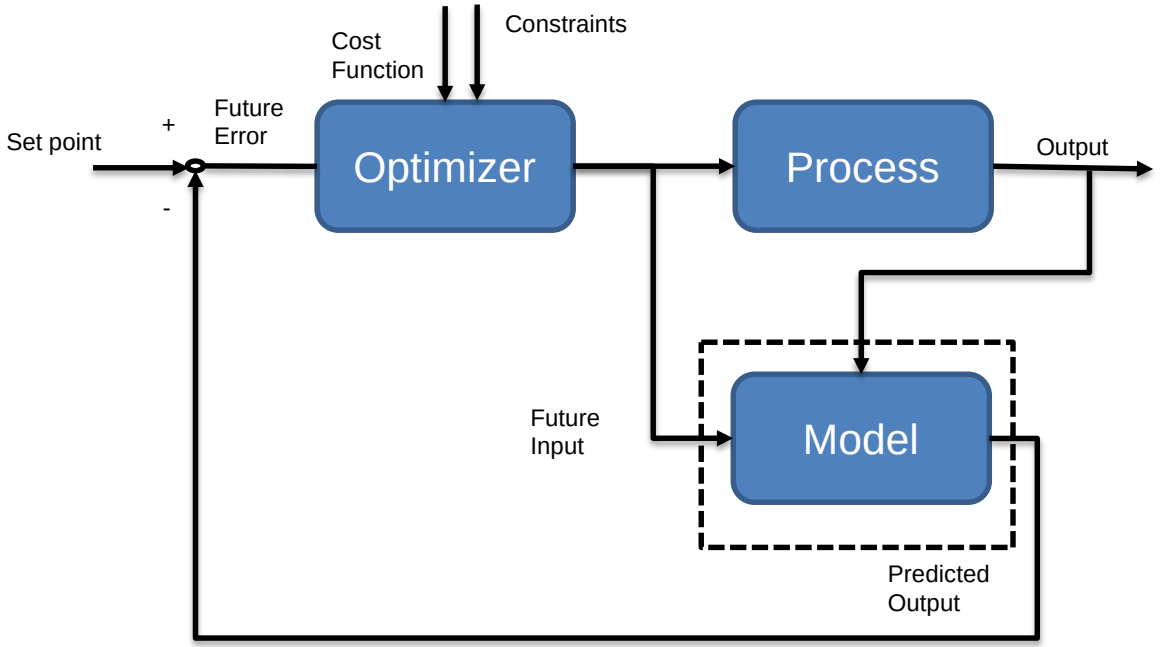

Model Predictive Controller

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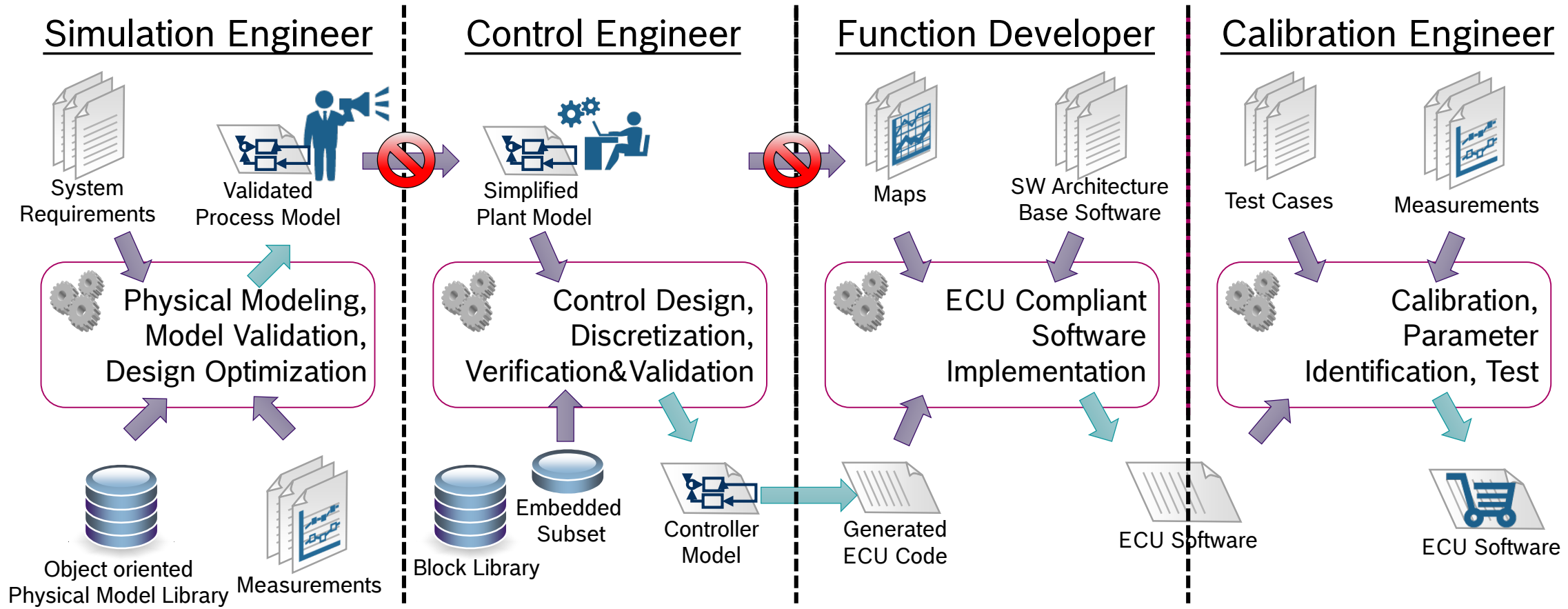
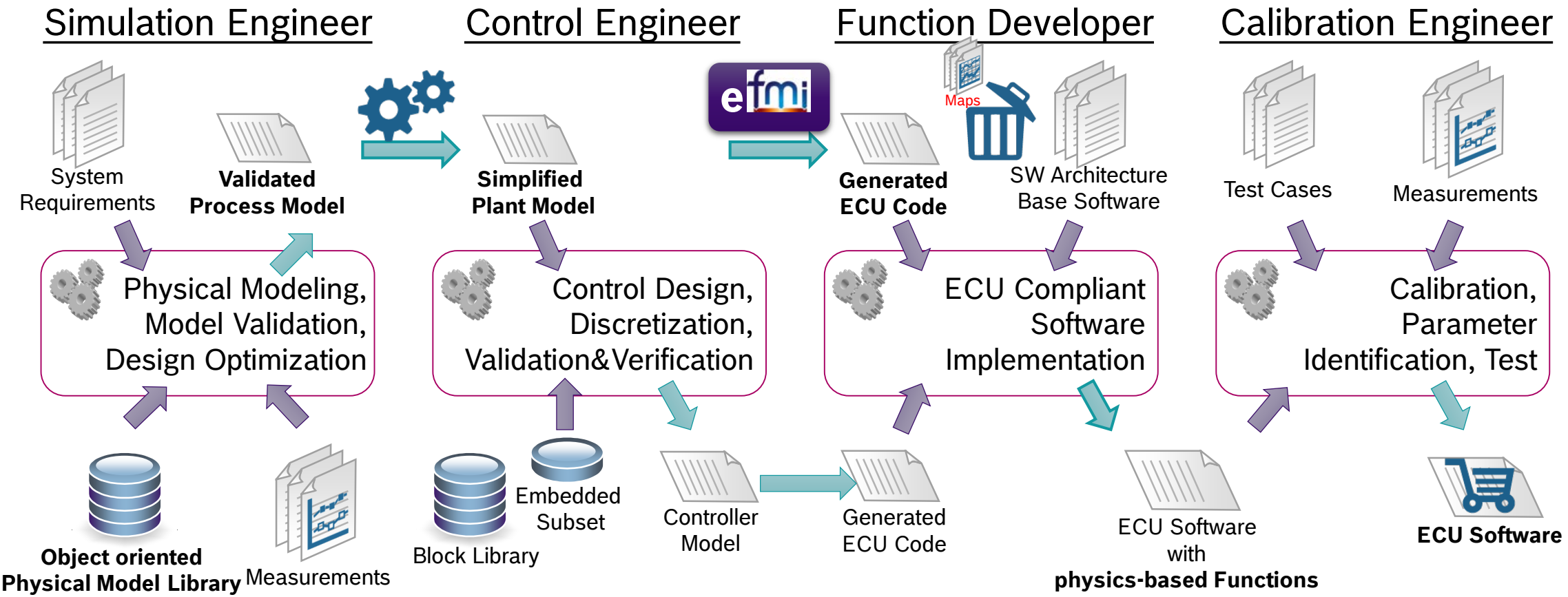
Tool Chain from Physical Modeling to ECU Software

Challenges of ECU Software Development



Tool Chain from Physical Modeling to ECU Software

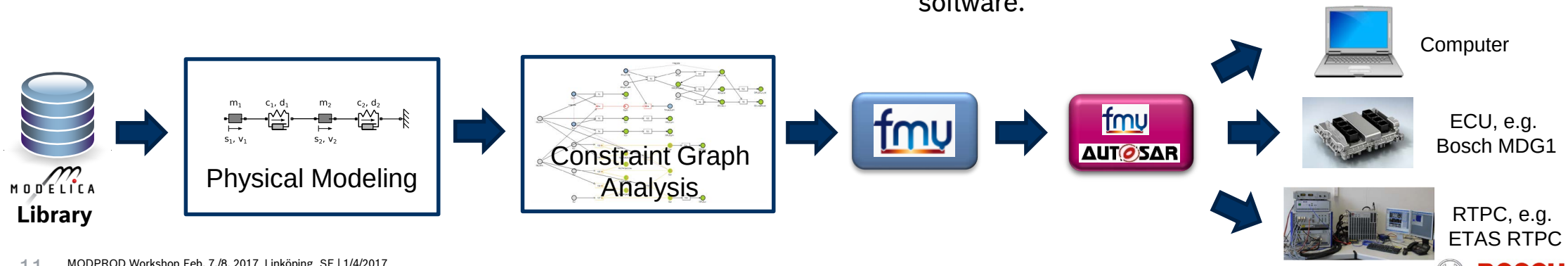
Assisted Transformation of Physical Models to ECU SW



Tool Chain from Physical Modeling to ECU Software
Solution Approach

- Challenge
  - Usage of object-oriented physical modeling
  - Leverage rich multi-domain libraries
  - Make physical models accessible to SW developers
  - Standardized model exchange
  - Generate embedded compliant code
  - Integrate physical models in ECU software architecture
  - Execute physical models on realtime targets
  - Enable cost effective realization.

- Solution Approach
  - Modelica™ language
  - MSL and other commercial libraries
  - Constraint Graph Analysis
  - FMI for model exchange
  - Code generation, MISRA compliance check
  - FMI AUTOSAR wrapper
  - AUTOSAR SW integration and deployment
  - Integrated tool chain from physical models to ECU software.



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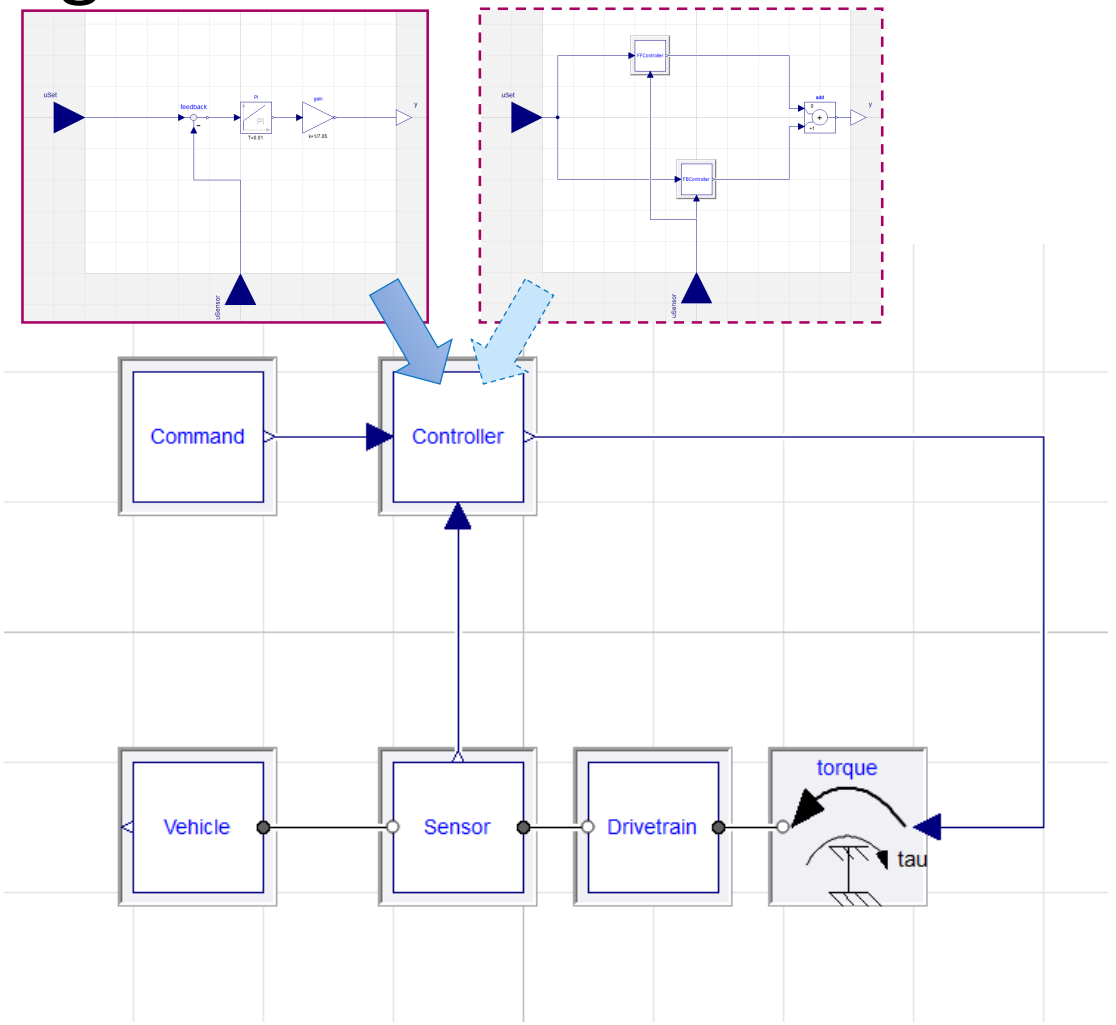
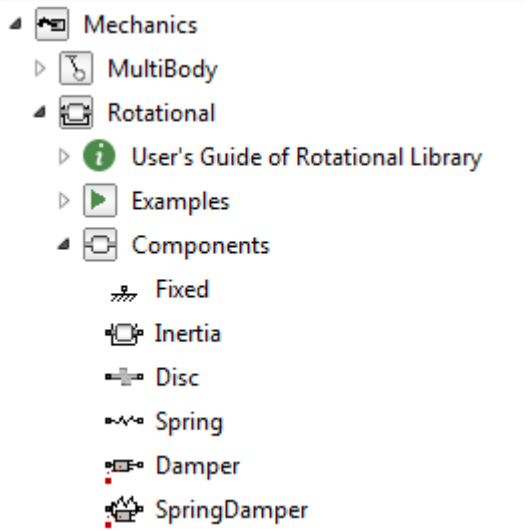
Tool Chain from Physical Modeling to ECU Software
Application Example

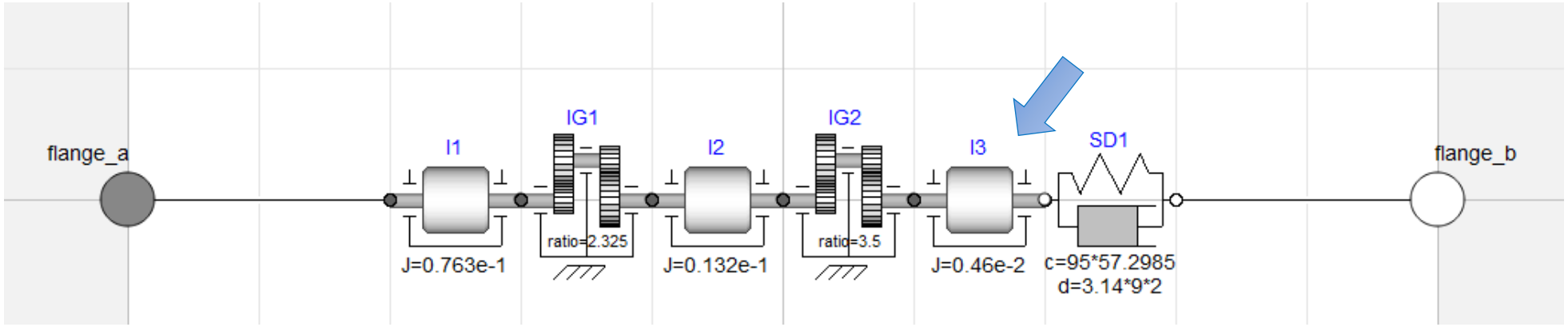
- Object-oriented physical modeling in Modelica™
  - Definition of partial models for the building blocks the control circuit.
  - Definition of a generic control circuit structure using replaceable partial models.
  - Implementation of a variety of concrete models by extending the partial models.
    - PI Feed Back Controller
    - Feed Forward Controller



Tool Chain from Physical Modeling to ECU Software
Application Example

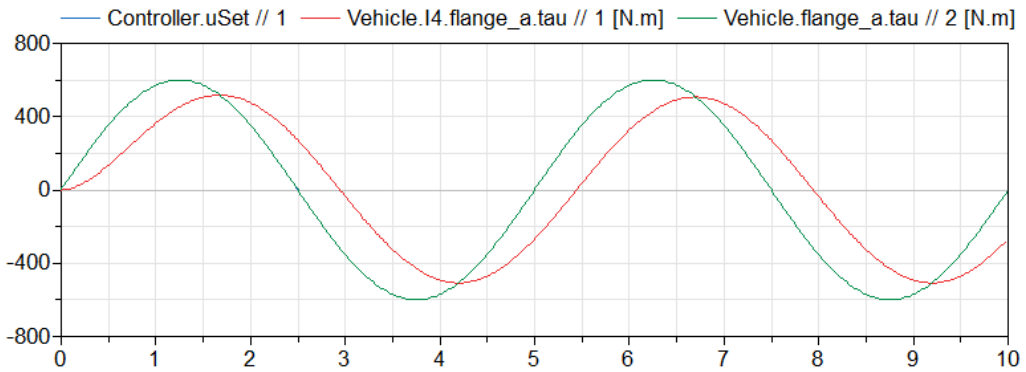
- Object-oriented physical modeling in Modelica™
  - Definition of the physical behavior using acausal physical ports.
  - Reuse of standard components from Modelica libraries.
  - Parameterization using physical units

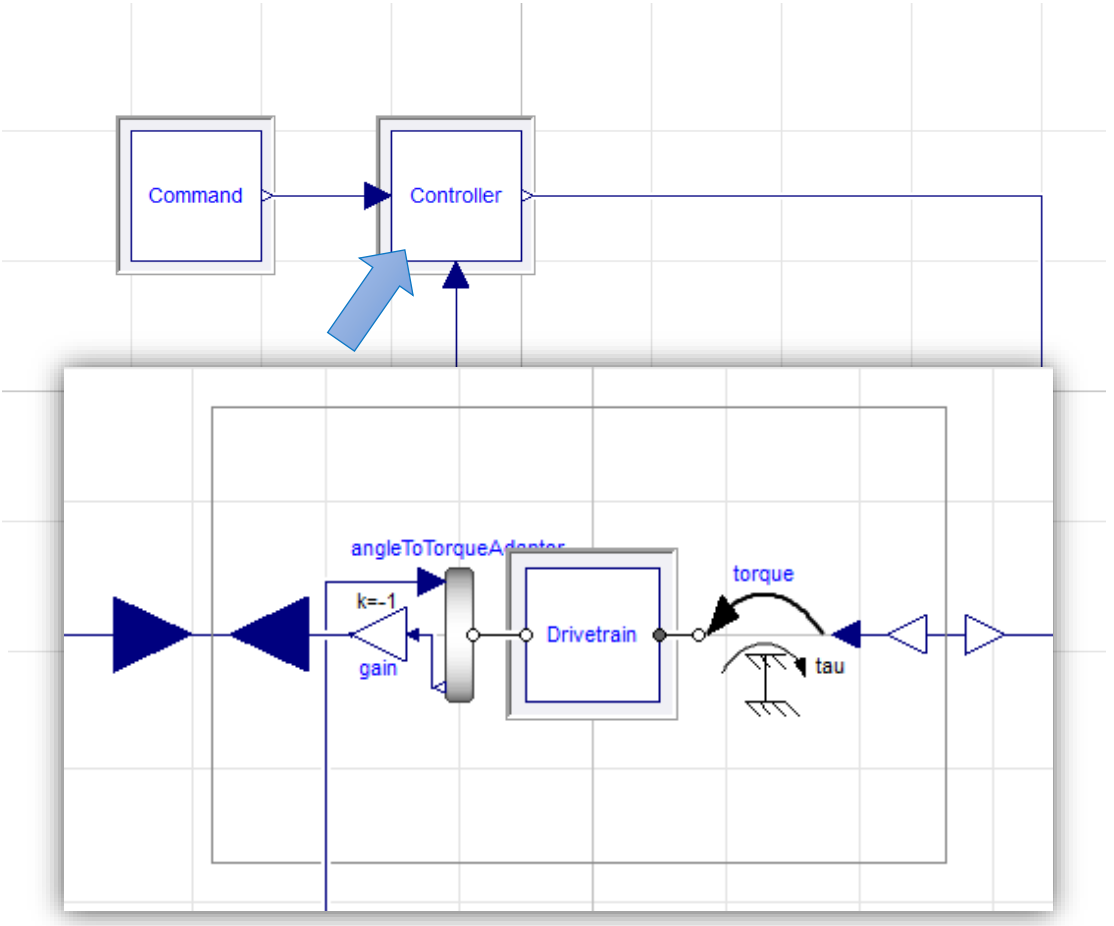




Tool Chain from Physical Modeling to ECU Software
Application Example

- Simulation of the dynamic behavior
  - Straight forward realization of feed forward controller by inverting the physical plant model.
  - Comparison of simulation shows much improved following behavior of FF-Controller vs. PI-Controller.

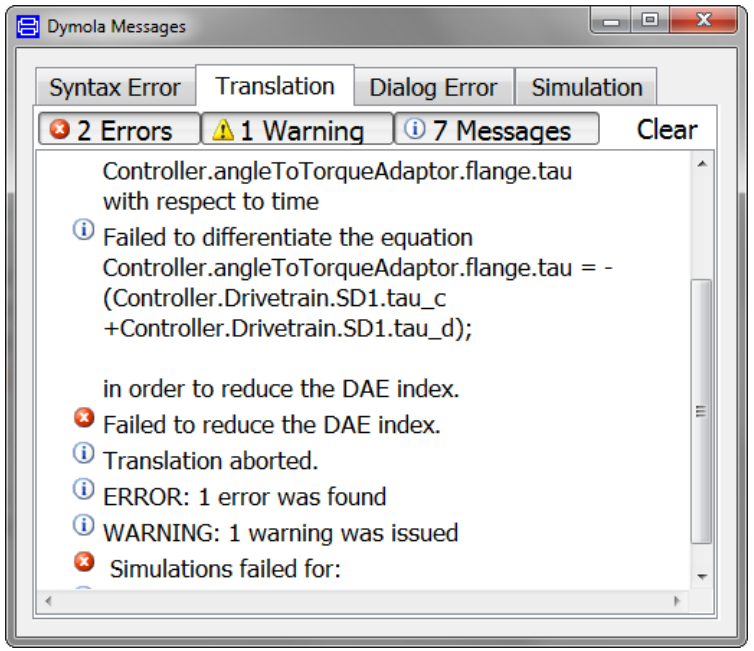


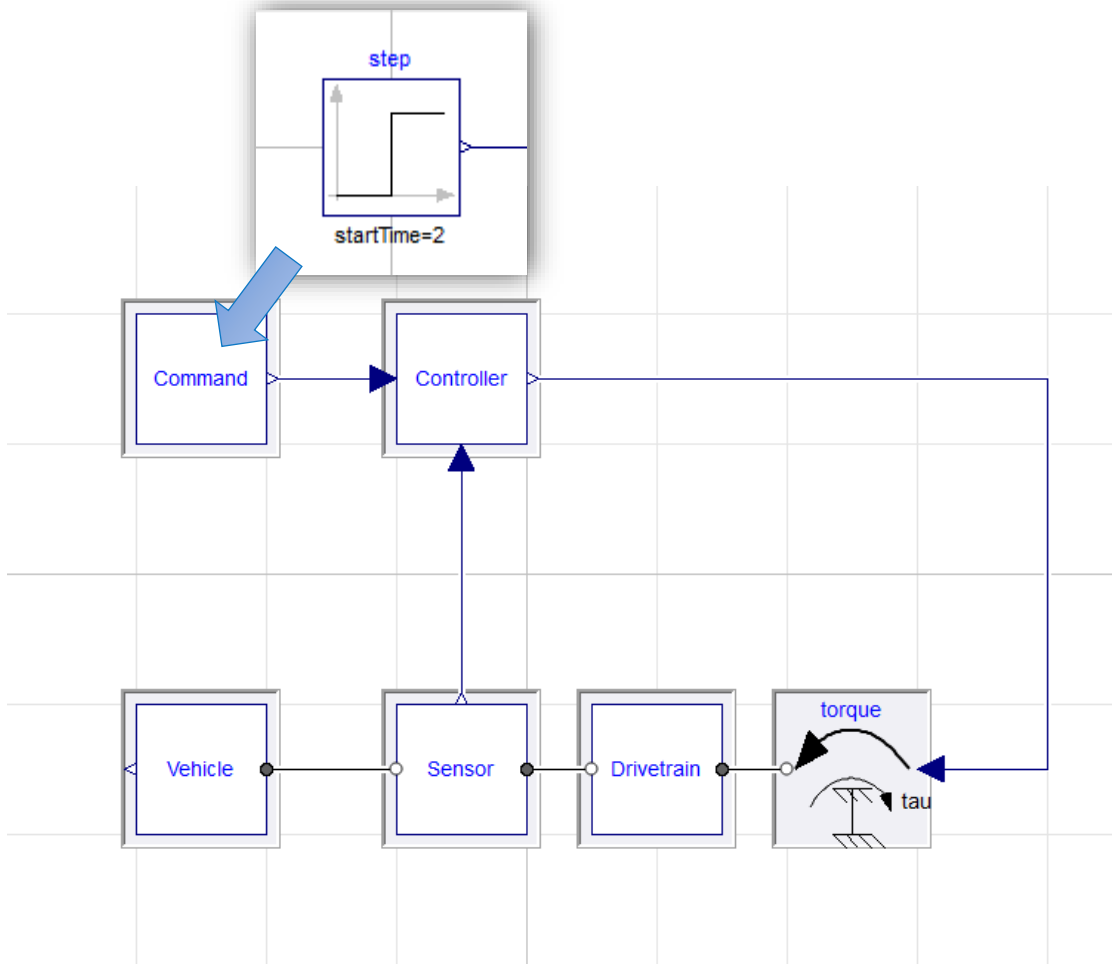


Inverted Plant Model

Tool Chain from Physical Modeling to ECU Software
Application Example

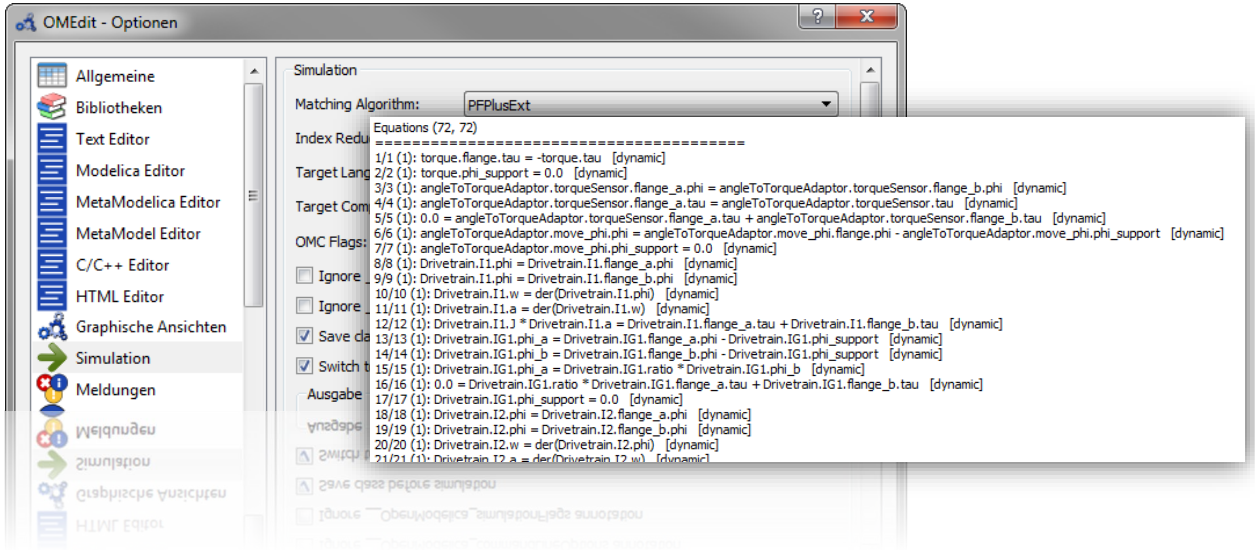
- Simulation of the dynamic behavior
  - But, after applying a Step Command instead of Sine the index reduction fails.
  - The system can neither be compiled nor simulated.

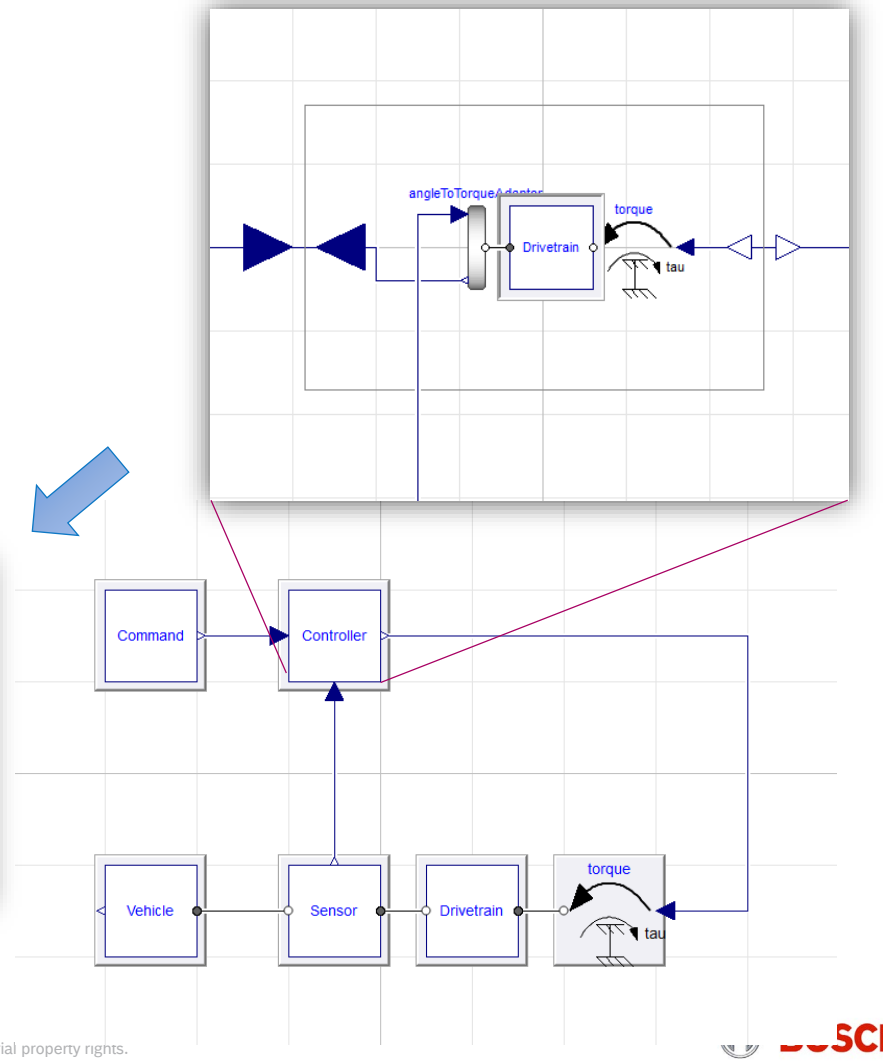




Tool Chain from Physical Modeling to ECU Software
Application Example

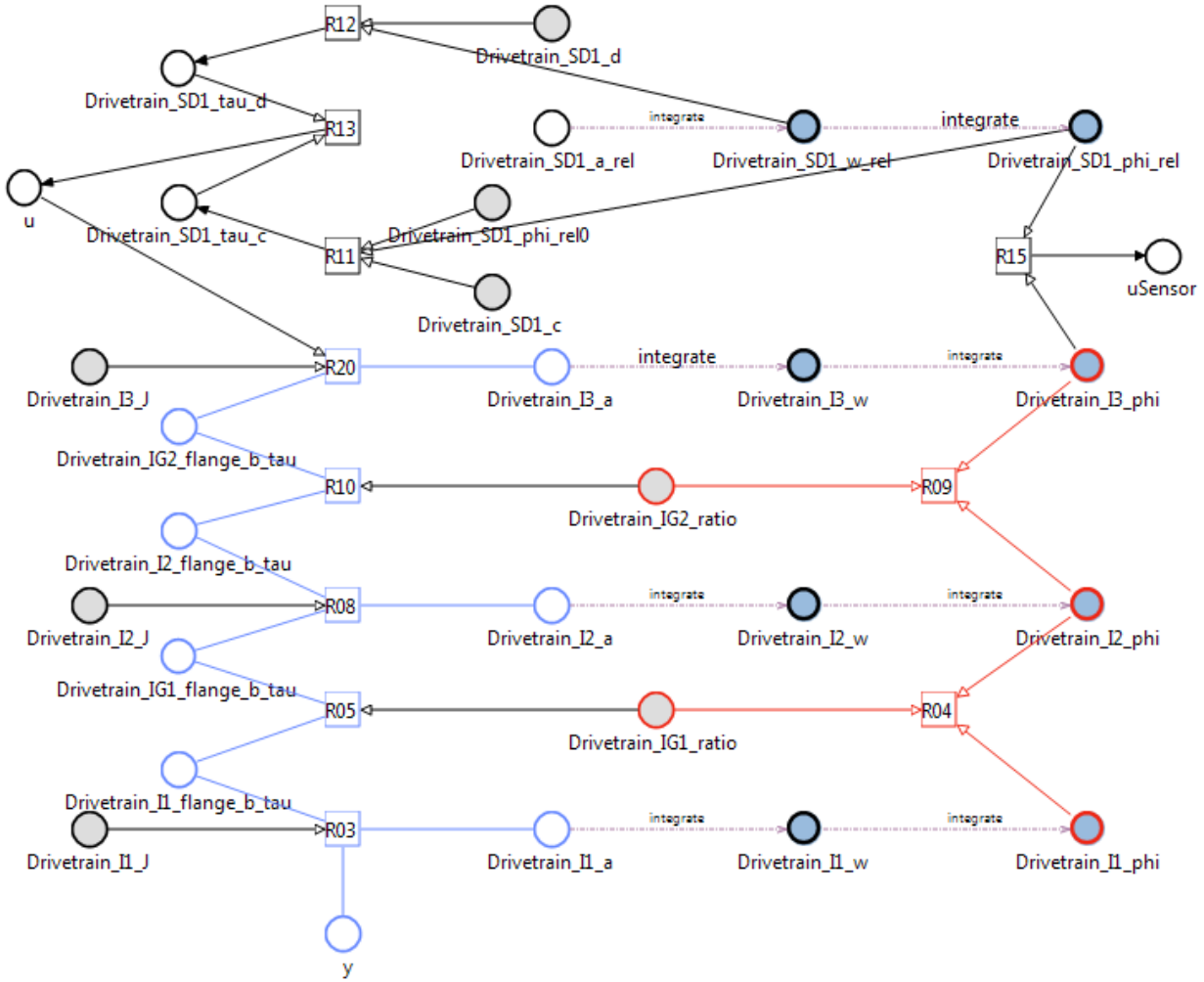
- Transfer of DAE from Modelica™ to ASCET-CONGRA™
  - Dump of the symbolic equations (DAE) of the inverse plant model as txt file from OpenModelica using compiler flag +d=dumdaelow, optdaedump or dumpindxdae.





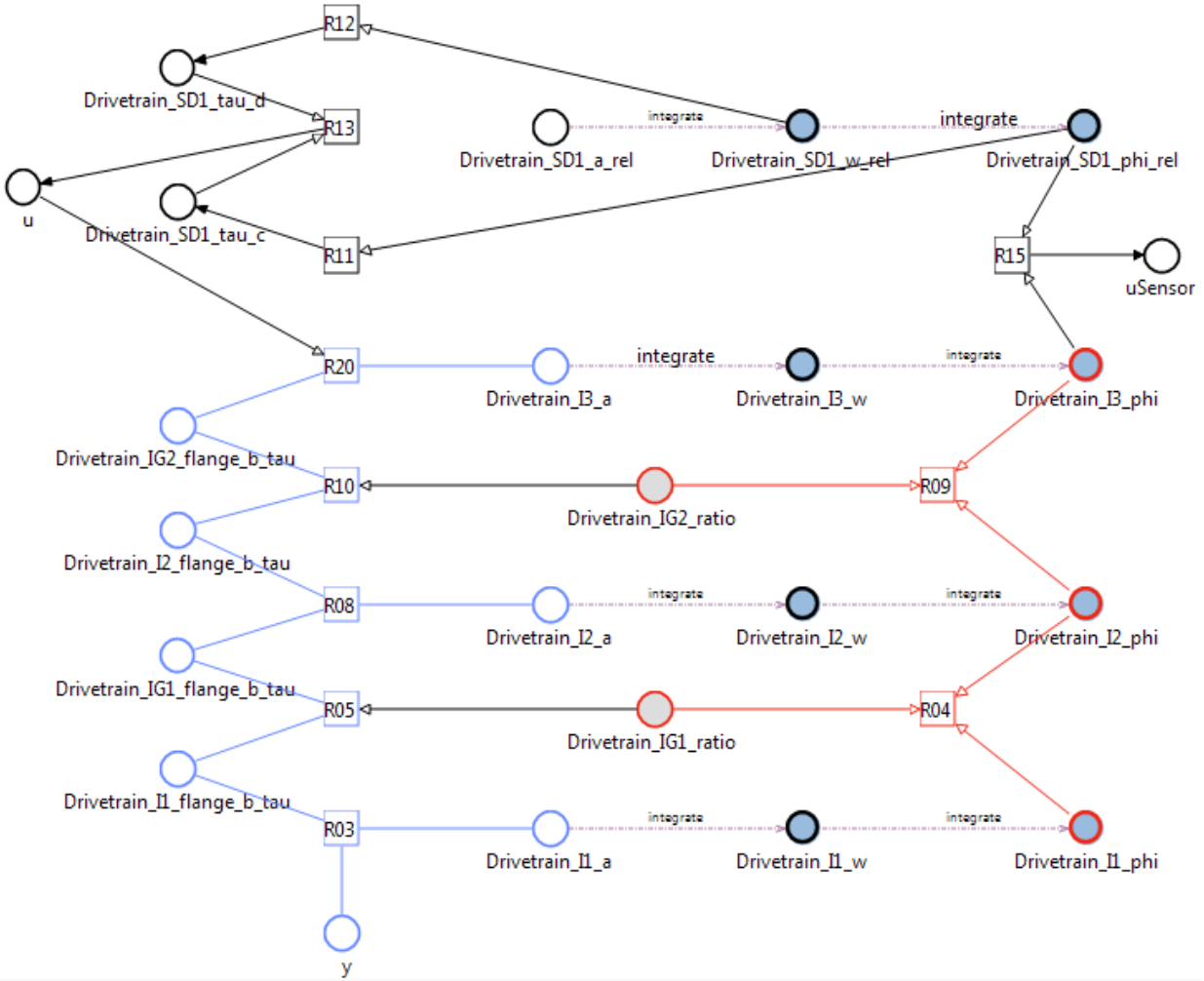
Tool Chain from Physical Modeling to ECU Software
Application Example

- Constraint Graph Analysis in ETAS ASCET-CONGRA™
  - Parse and convert the DAE dump txt file and import into ETAS ASCET-CONGRA.
  - Visualization of the symbolic equations and variables as constraint graph.



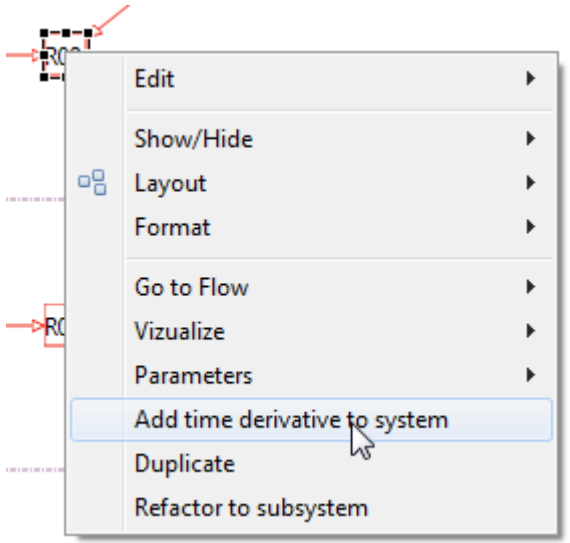
Tool Chain from Physical Modeling to ECU Software
Application Example

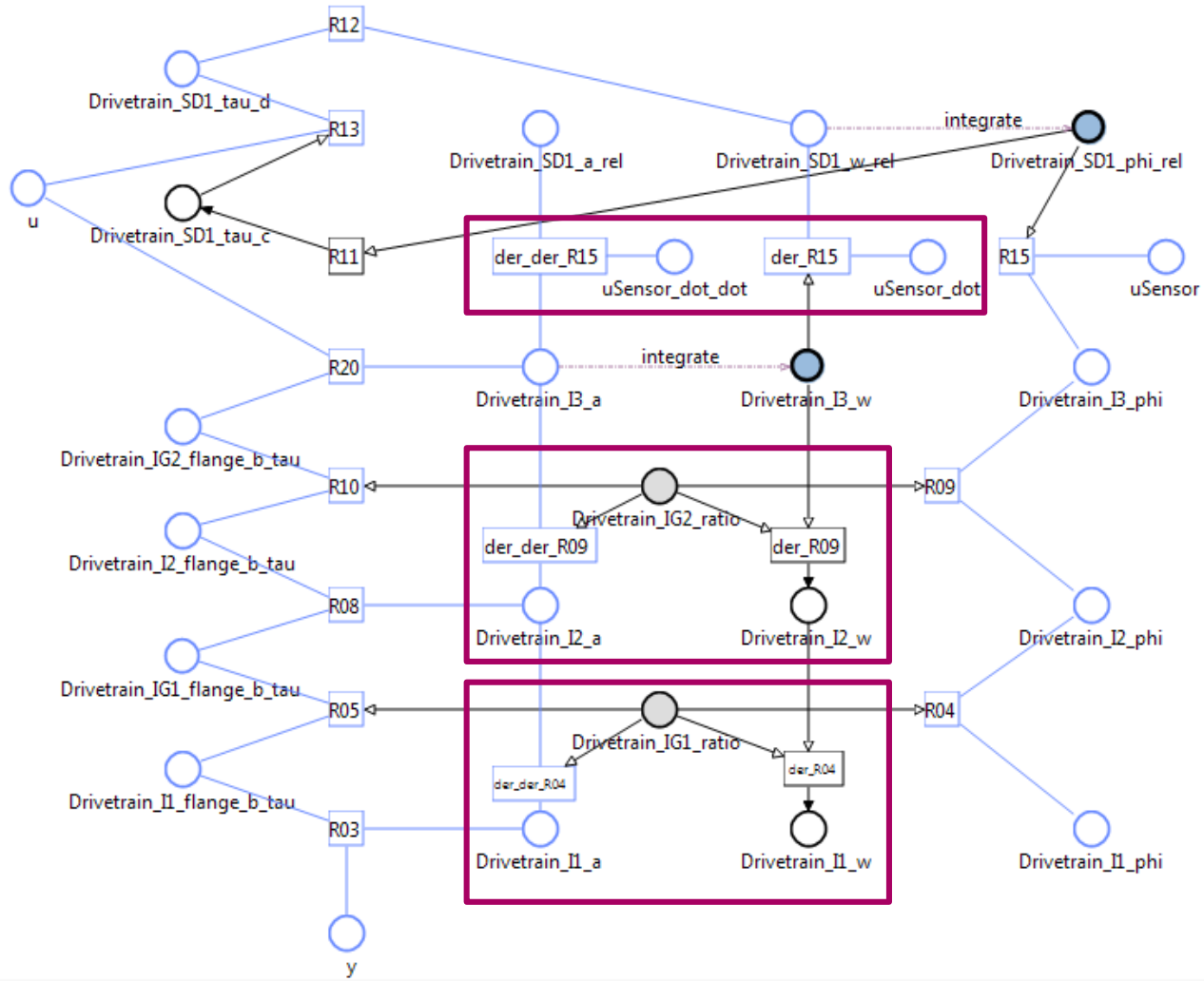
- Constraint Graph Analysis in ETAS ASCET-CONGRA™
  - Hiding some of the parameters makes the relevant structure more visible.
  - By deriving a directed graph “Flow” The over-constraint (red) and under-constraint (blue) substructures become obvious.
  - The higher index problem is apparent due to the fact that the red substructure is determined by the Index0 variables I1_phi, I2_phi, I3_phi, while the blue substructure depends on the index2 variables (I1_a, I2_a, I3_a).



Tool Chain from Physical Modeling to ECU Software
Application Example

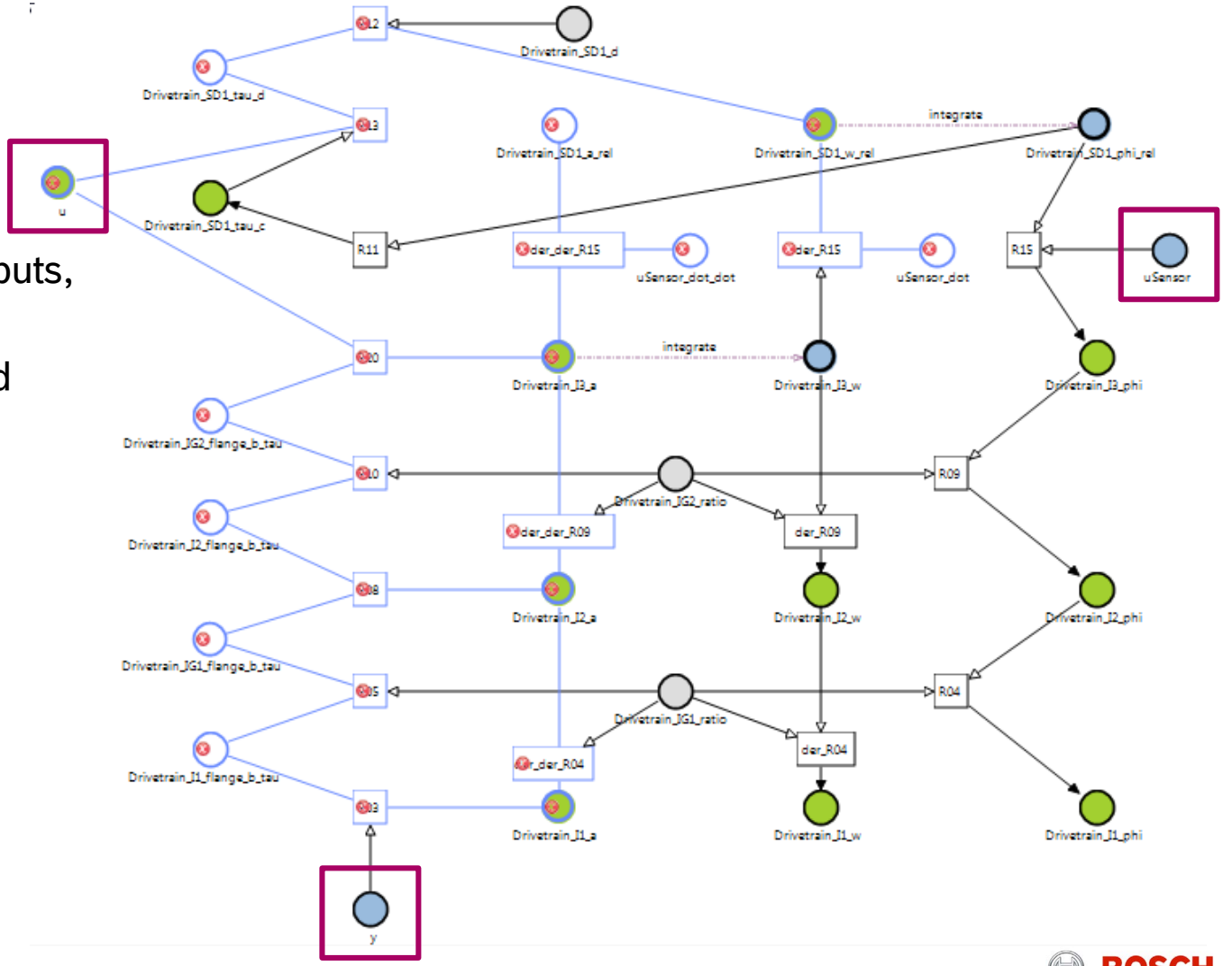
- Constraint Graph Analysis in ETAS ASCET-CONGRA™
  - The index is reduced by adding the time derivatives of the over-constraint relations R09 and R04.





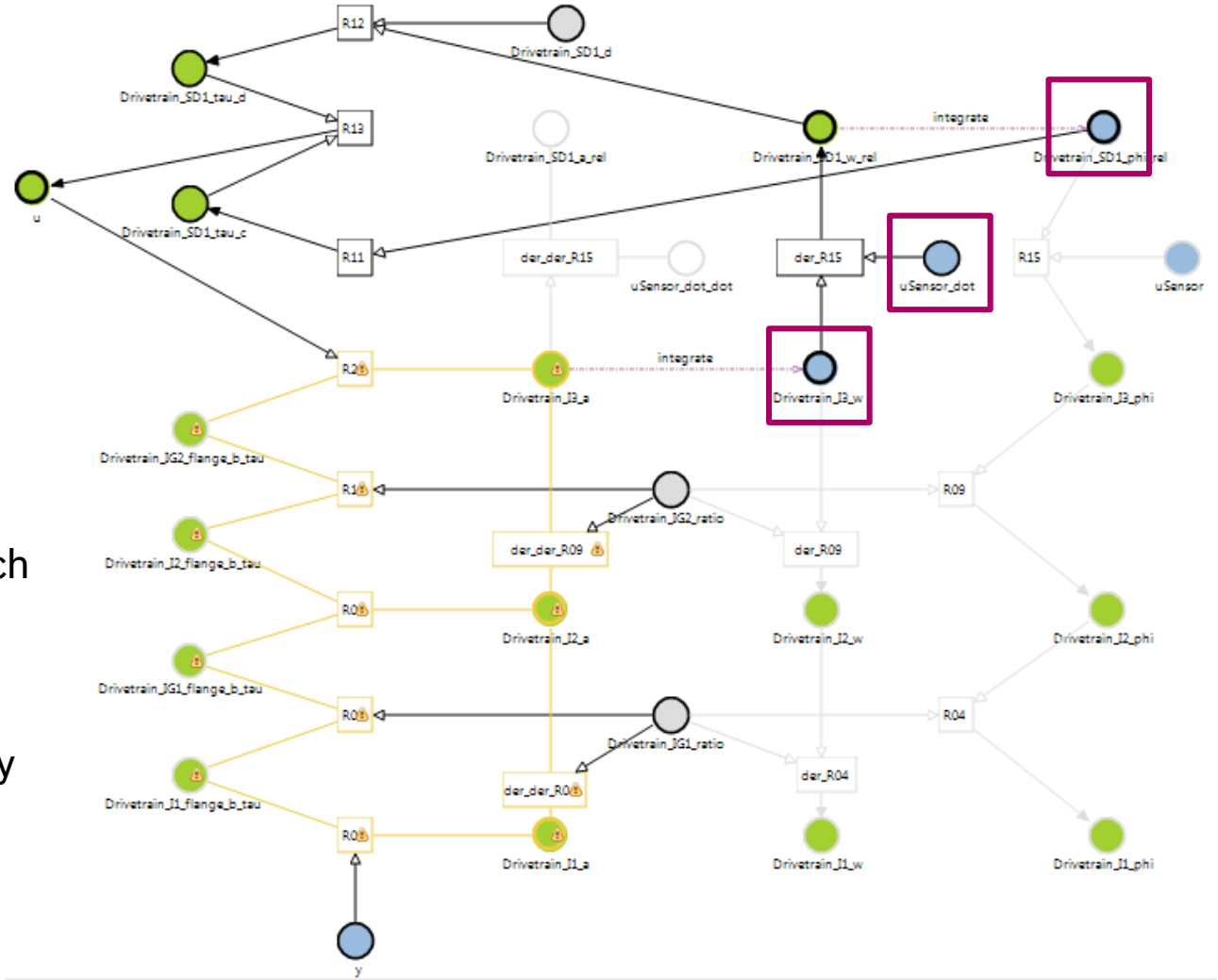
Tool Chain from Physical Modeling to ECU Software
Application Example

- Constraint Graph Analysis in ETAS ASCET-CONGRA™
  - After defining the known inputs and outputs, states can be selected explicitly.
  - The directed graph displays the reached and not reached branches.
  - States can be added until the required output can be calculated.



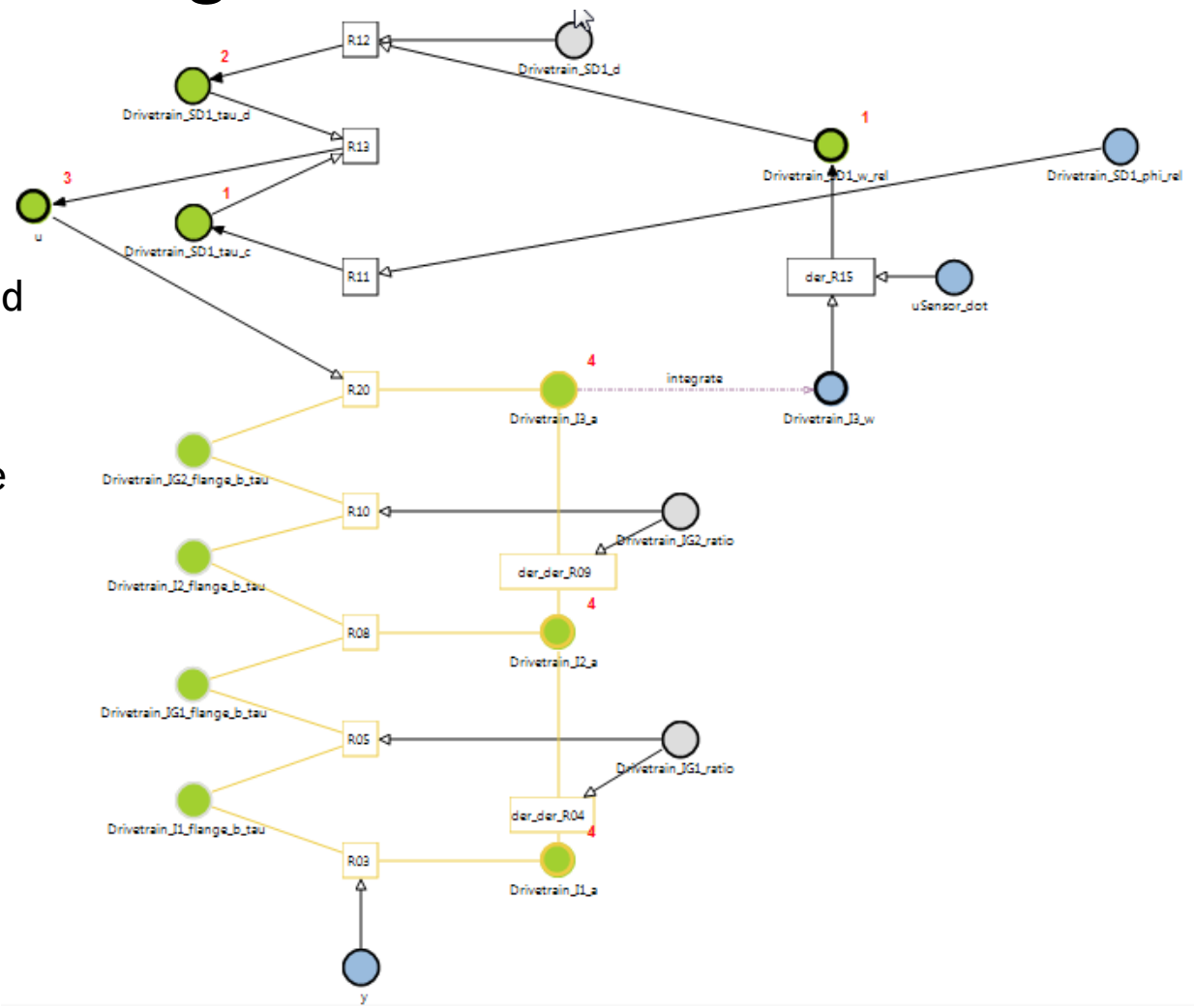
Tool Chain from Physical Modeling to ECU Software
Application Example

- Constraint Graph Analysis in ETAS ASCET-CONGRA™
  - Finally it can be shown that with:
    - **y** and **uSensor_dot** as input and
    - only two states **I3_w**, **SD_phi_rel** the
    - required output **u** can be calculated.
  - It remains an algebraic loop (orange), which can be passed to the symbolic engine to see whether this loop can be analytically solved or will have to be broken at one or multiple edges to be solved iteratively or by using a delay.



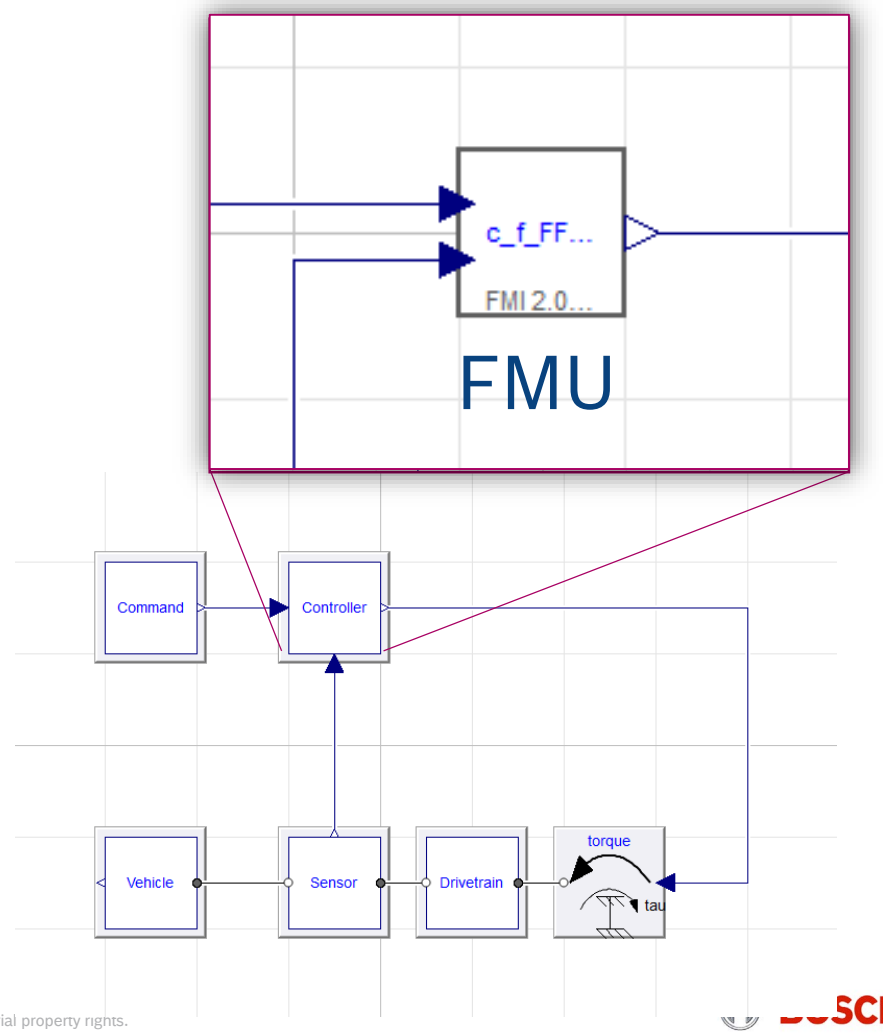
Tool Chain from Physical Modeling to ECU Software
Application Example

- Constraint Graph Analysis in ETAS ASCET-CONGRA™
  - In this case the algebraic loop can be solved analytically.
  - The computation sequence is determined.
  - The corresponding FMU is generated in the background.



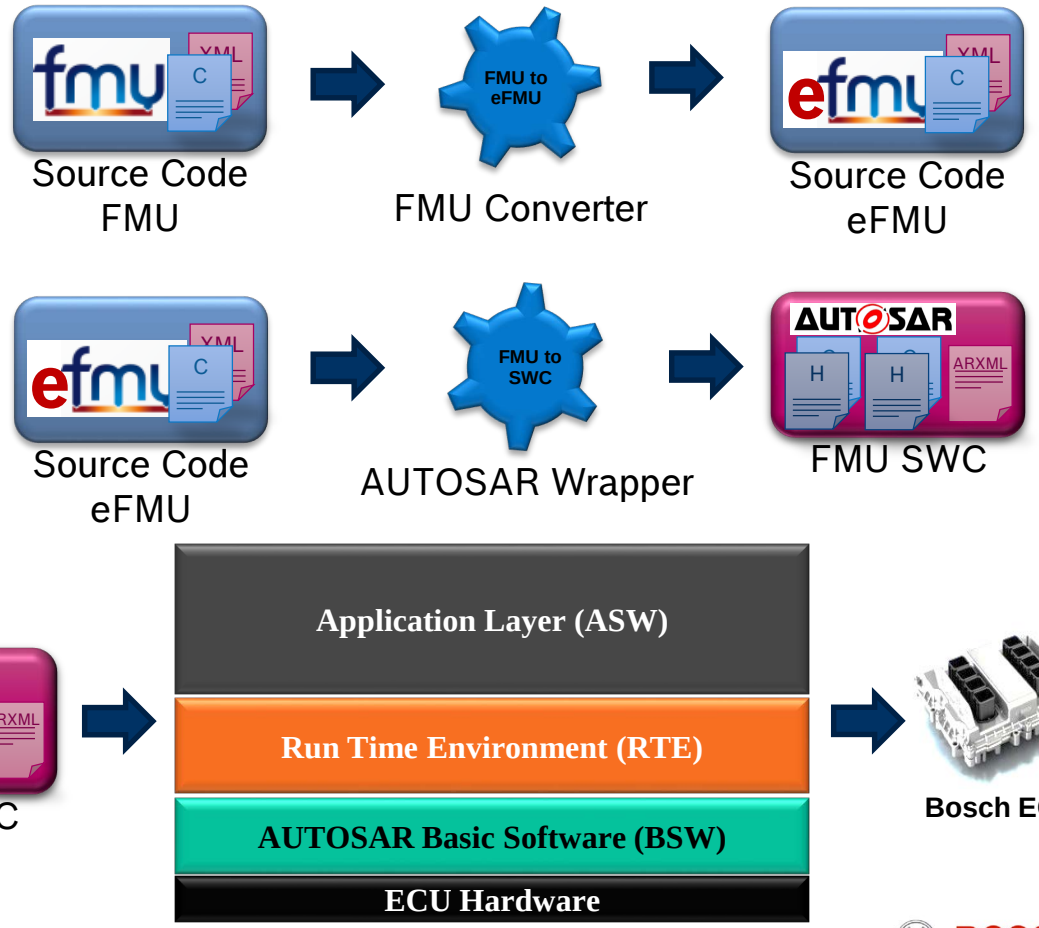
Tool Chain from Physical Modeling to ECU Software
Application Example

- MiL Simulation of FF-Controller
  - Import of the FMU into the system simulation.
  - Replacing the original controller block with the FMU.
  - Verification of the results.



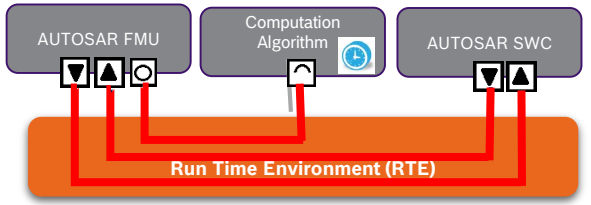
Tool Chain from Physical Modeling to ECU Software
Application Example

- FMU2eFMU Semi-automated Prototype
  - Use only ECU compliant types.
  - Replace ECU non-compliant code.
- eFMU2AUTOSAR Prototype
  - Generate AUTOSAR model description (ARXML).
  - Generate AUTOSAR function calls.
- Integrate FMU-SWC in AUTOSAR ASW

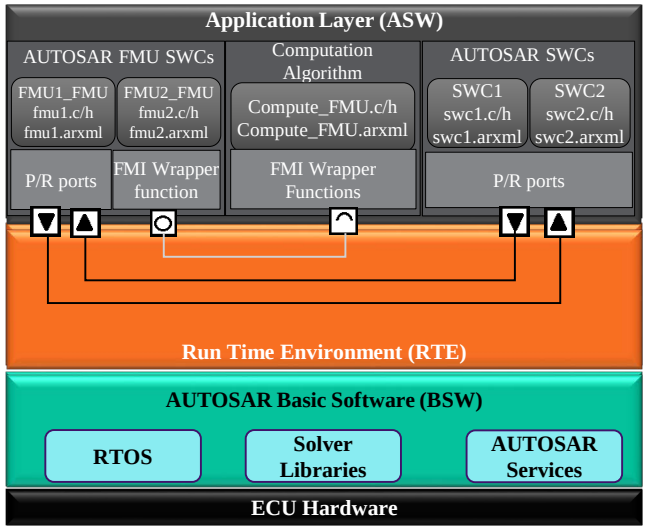


Tool Chain from Physical Modeling to ECU Software
Integration of FMU in AUTOSAR

- Architecture
  - FMUs as AUTOSAR SW-Cs in ASW.
  - Interface and service communication over Ports.
  - Solver library in BSW.
  - Computation algorithm executes FMUs using the events provided by Real-Time OS.



Composition of AUTOSAR FMU SWCs



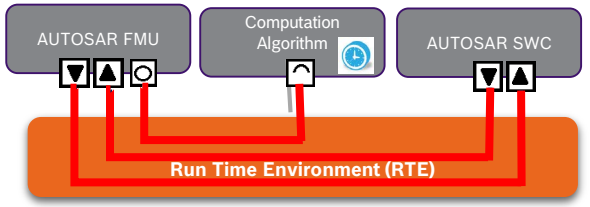
FMUs as AUTOSAR SWCs in AUTOSAR architecture

Jonathan Neudorfer, Siva Sankar Armugham, Mathews Peter, Naresh Mandipalli, Isidro Corral, Christian Bertsch, Karthikeyan Ramachandran *FMI for Physics-based Models on AUTOSAR Platforms*, SIAT Conference January 18-21, 2017, Pune, India, 17SIAT-0566/2017-26-0358

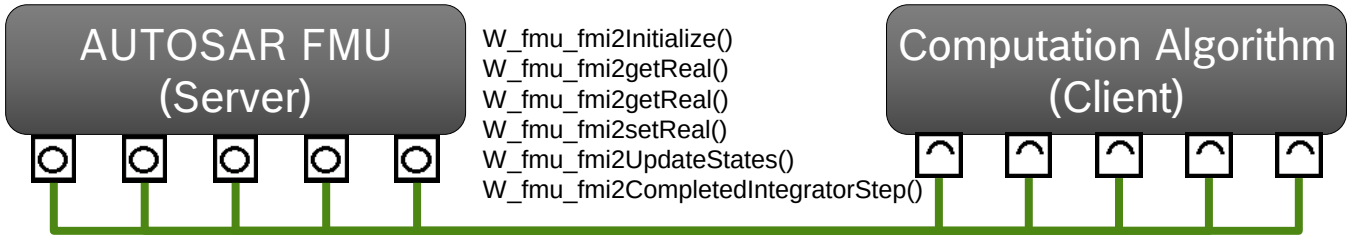
Tool Chain from Physical Modeling to ECU Software
Prototype Integration of FMU in AUTOSAR

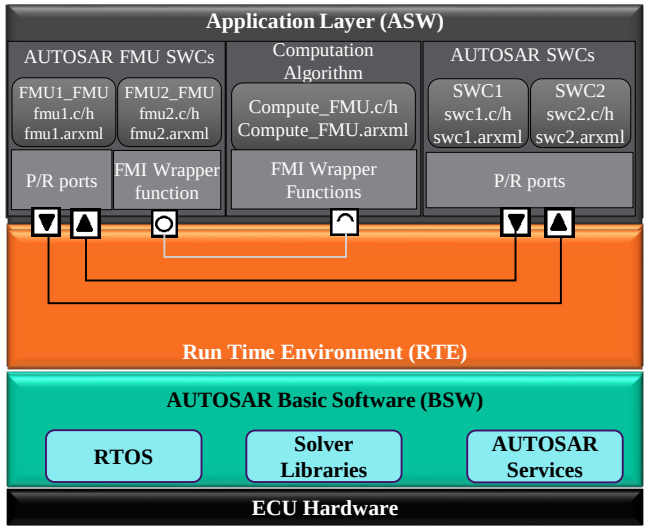
- Interface mapping of FMI to AUTOSAR.
- FMI interface functions are called via wrapper function using AUTOSAR client server communication.
- Data Exchange over RTE. AUTOSAR RTE read/write routines with FMI get/setReal functions

FMI	AUTOSAR
Input	Required Port
Output	Provider Port
Parameter	(Calibration) parameter



Composition of AUTOSAR FMU SWCs





FMUs as AUTOSAR SWCs in AUTOSAR architecture

Tool Chain from Physical Modeling to ECU Software
Summary

State of the Art

- Plant modeling and control design is powerful in object oriented physical M&S tools for offline simulation.
- No code generators for ECU → Code of offline simulation cannot easily be used on ECU.

Solution Approach

- Enable function developers to analyze physical models in software related fashion.
- Use FMI standard of physical model on all targets.
- Use FMI standard with AUTOSAR for embedded targets

Benefits

- Reduce complexity of ECU software using physical models.
- Reduce development effort for advanced ECU functions.

fmi FUNCTIONAL MOCK-UP INTERFACE

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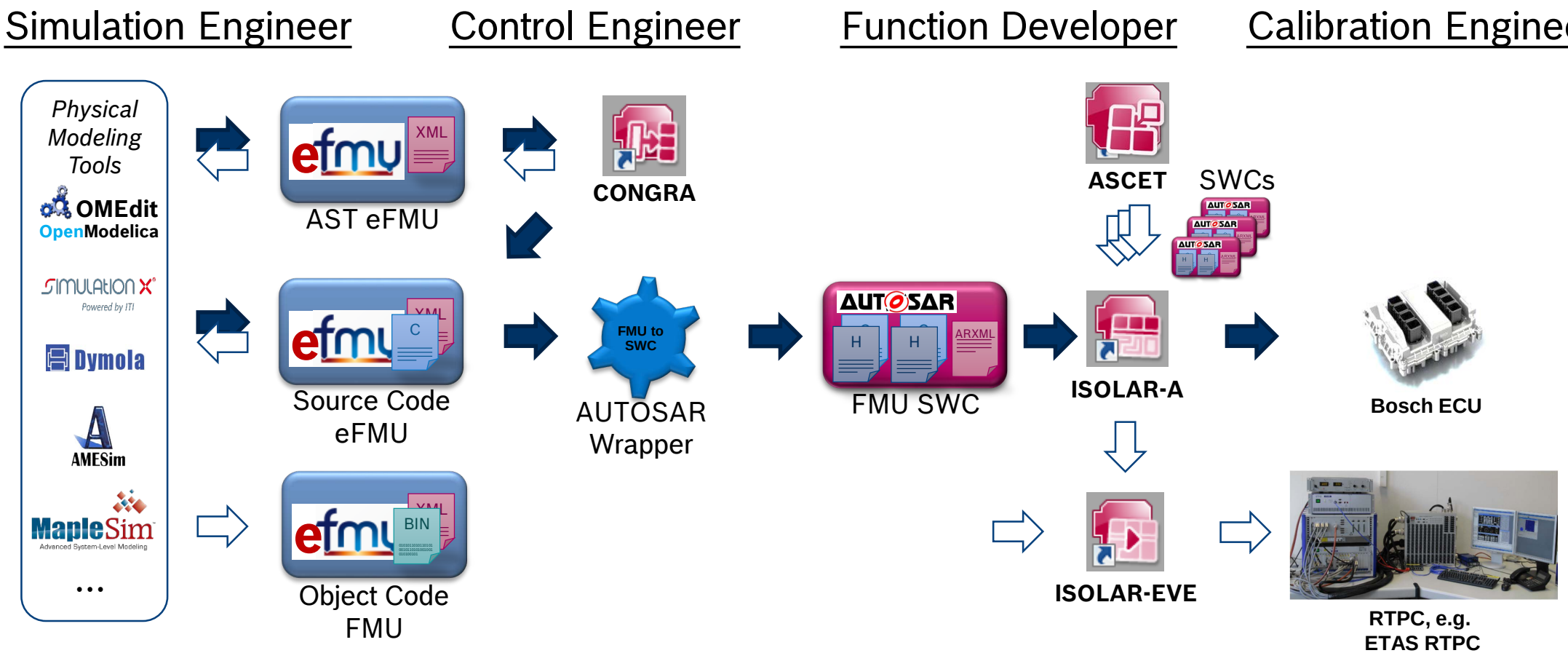
Tool Chain from Physical Modeling to ECU Software

Outlook: Future Tool Chain based on eFMI → PFP EMPHYSIS



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Thanks to all contributors.

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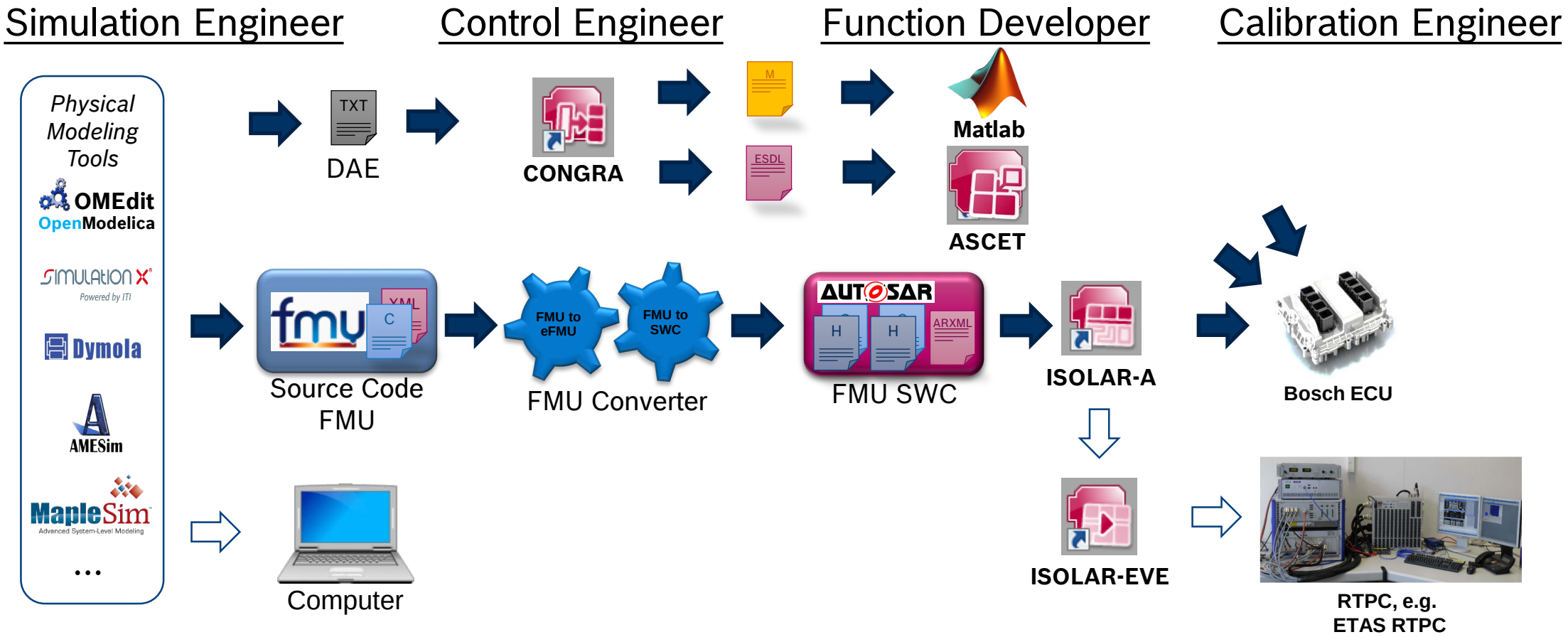
Tool Chain from Physical Modeling to ECU Software
Alternative Workflow



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