FMI TUTORIAL

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Modelon Inc. & INCOSE/NAFEMS SMSWG

INCOSE IW

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Torrance / CA

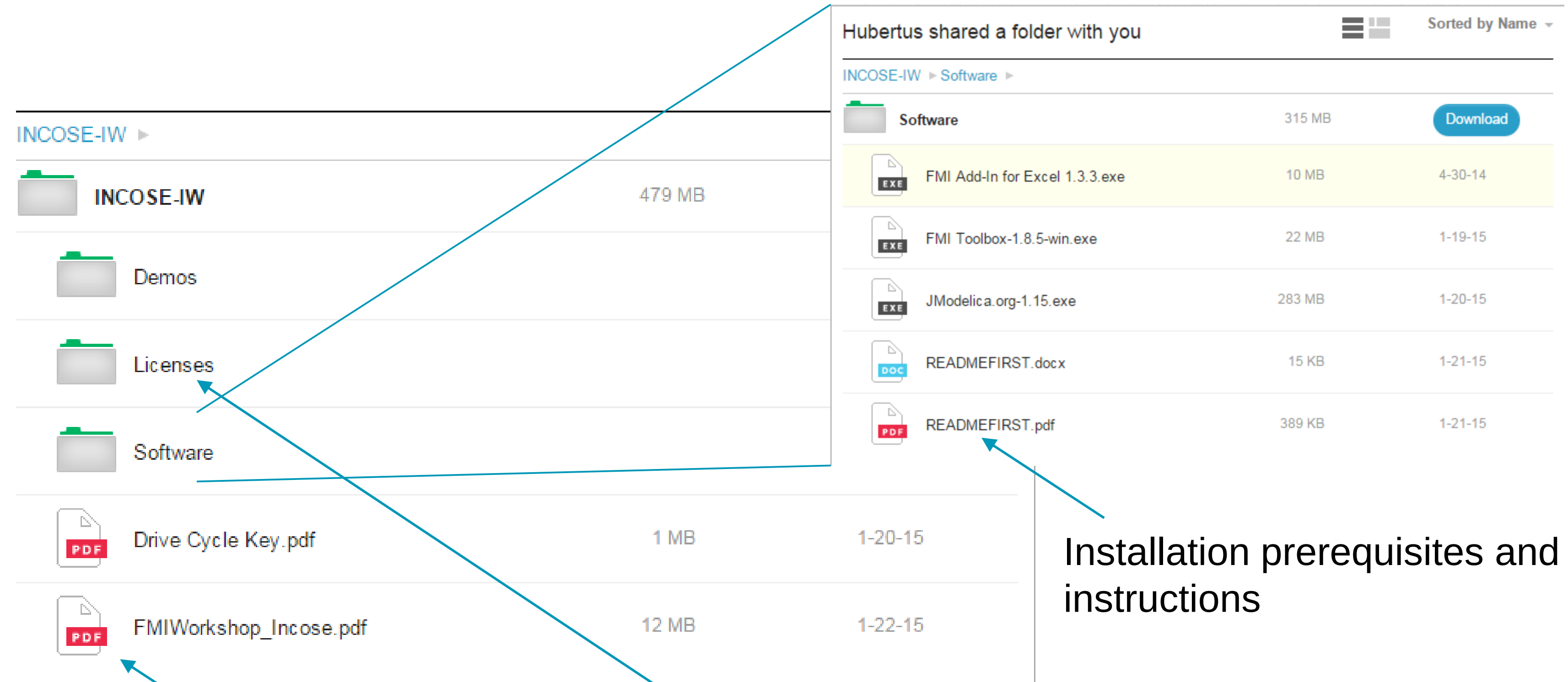
AGENDA

- FMI Overview
- FMI News
- Tutorial Overview
- Hands-on Excercises
  - Presentation of Model (Modelica / Dymola)
  - Hands on: import of FMUs into Excel
- Demo of FMI import in Dymola
- Demo/hands on exercise: FMI import into Python
- Demo/hands on exercise: FMI import into Simulink
- Demo: FMI export from Simulink

DOWNLOAD & INSTALLATION

- Material for hands-on exercises available on USB-sticks and public download
- Public Link: https://app.sugarsync.com/iris/wf/D1068299_77975033_6553767
- Installation instructions under folder Software/READMEFIRST.pdf
- Licenses for FMI Add-in for Excel and FMI Add-in for Matlab/Simulink under Licenses
- All Licenses valid until February 14^{th}
- Open Source option: PyFMI, requires Python 2.7 installation

DOWNLOAD MATERIAL



Installation prerequisites and instructions

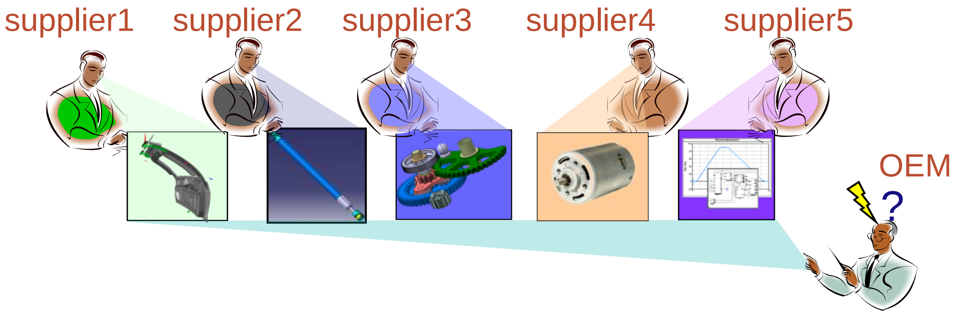
Tutorial instructions

License for Excel- and Matlab FMI tools

1. WHY FMI?

Problem

- Due to **different applications**, **models** of a system often have to be developed using **different programs** (modeling and simulation environments).



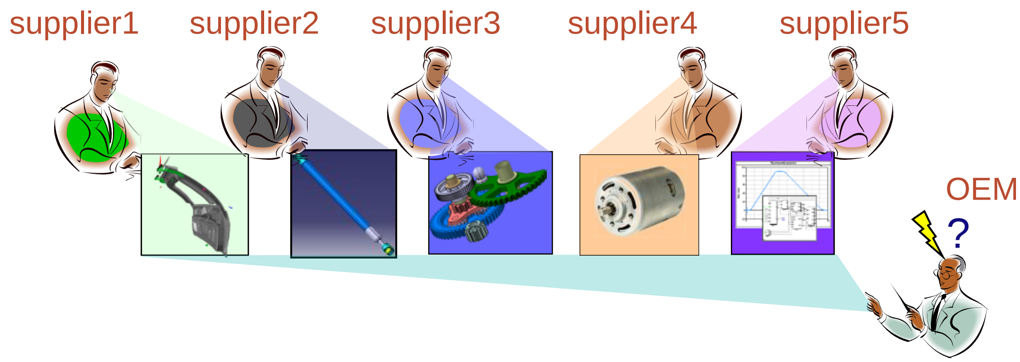
- In order to **simulate** the system, the different programs must somehow interact with each other.

- The system integrator must cope with simulation environments from many suppliers.

- This makes the **model exchange** a necessity. No current standardized interface.

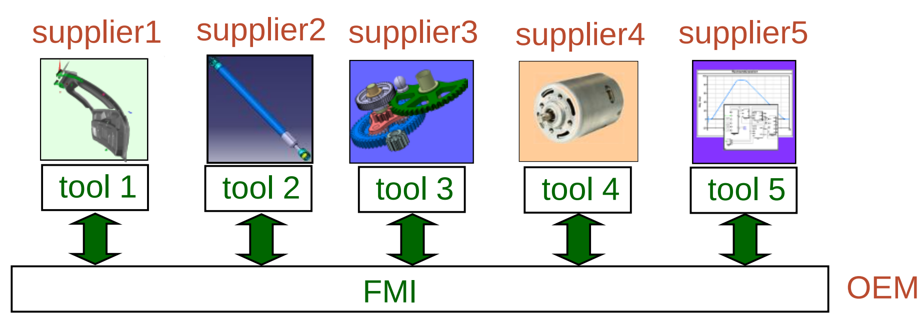
- Even though **Modelica** is tool independent, it cannot be used as such a standardized interface for model exchange.

1. WHAT IS IT ALL ABOUT?



Solution

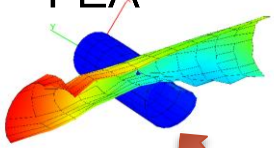
- As a universal solution to this problem the **Functional Mockup Interface (FMI)** was developed by MODELISAR, and is now maintained by the Modelica Association



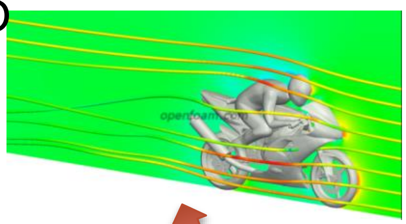
ANOTHER USE CASE

- Combine different modeling formalisms into coherent simulation
  - Physical models, 1D-3D
  - Controls

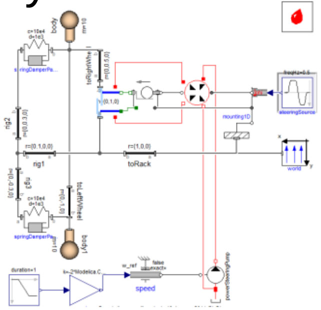
FEA



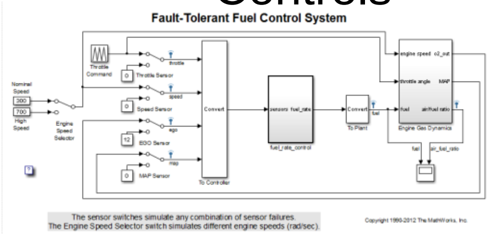
CFD



Modelica /
1-D Systems Simulation



Block Diagrams
Controls



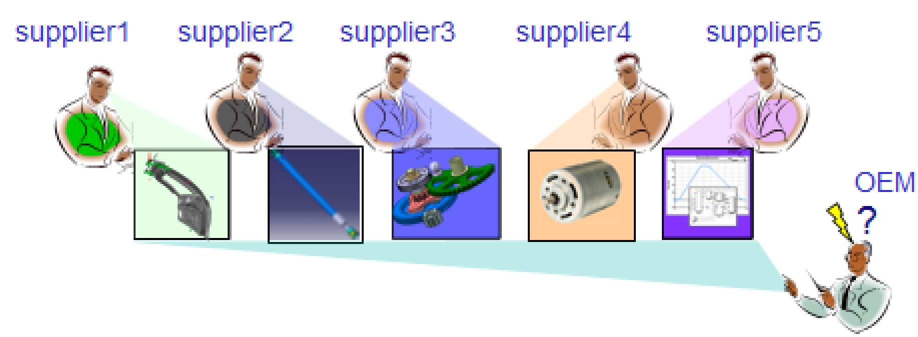
FMI-based System Simulation

FUNCTIONAL MOCKUP INTERFACE (FMI)

- Tool independent standard to support both model exchange and co-simulation of dynamic models
- Original development of standard part of EU-funded MODELISAR project led and initiated by Daimler
- First version FMI 1.0 published in 2010
- FMI currently supported by over 60 tools (see www.fmi-standard.org for most up to date list)
- Active development as Modelica Association project
- FMI 2.0 just released and brings additional functionality to FMI standard

Problems / Needs

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



FMU: a model with standard interface

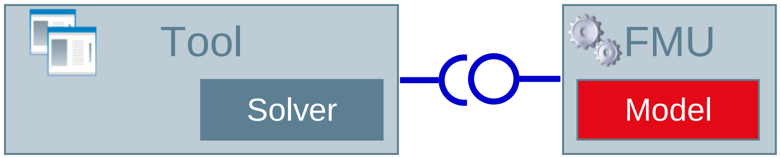
- A component which implements the FMI standard is called *Functional Mockup Unit (FMU)*
- Separation of
  - Description of interface data (XML file)
  - Functionality (C code or binary)
- A FMU is a zipped file (*.fmu) containing the XML description file and the implementation in source or binary form
- Additional data and functionality can be included
- Information & Interface specification: www.fmi-standard.org

Modelon

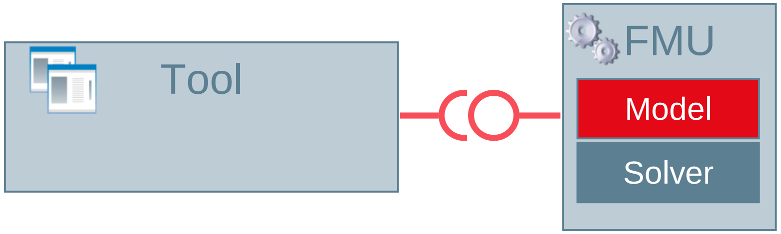
From the official FMI presentation (adapted)

FMI FLAVORS

- The Functional Mock-up Interface (**FMI**) is a **tool independent standard** for
  - **Model Exchange (ME)**

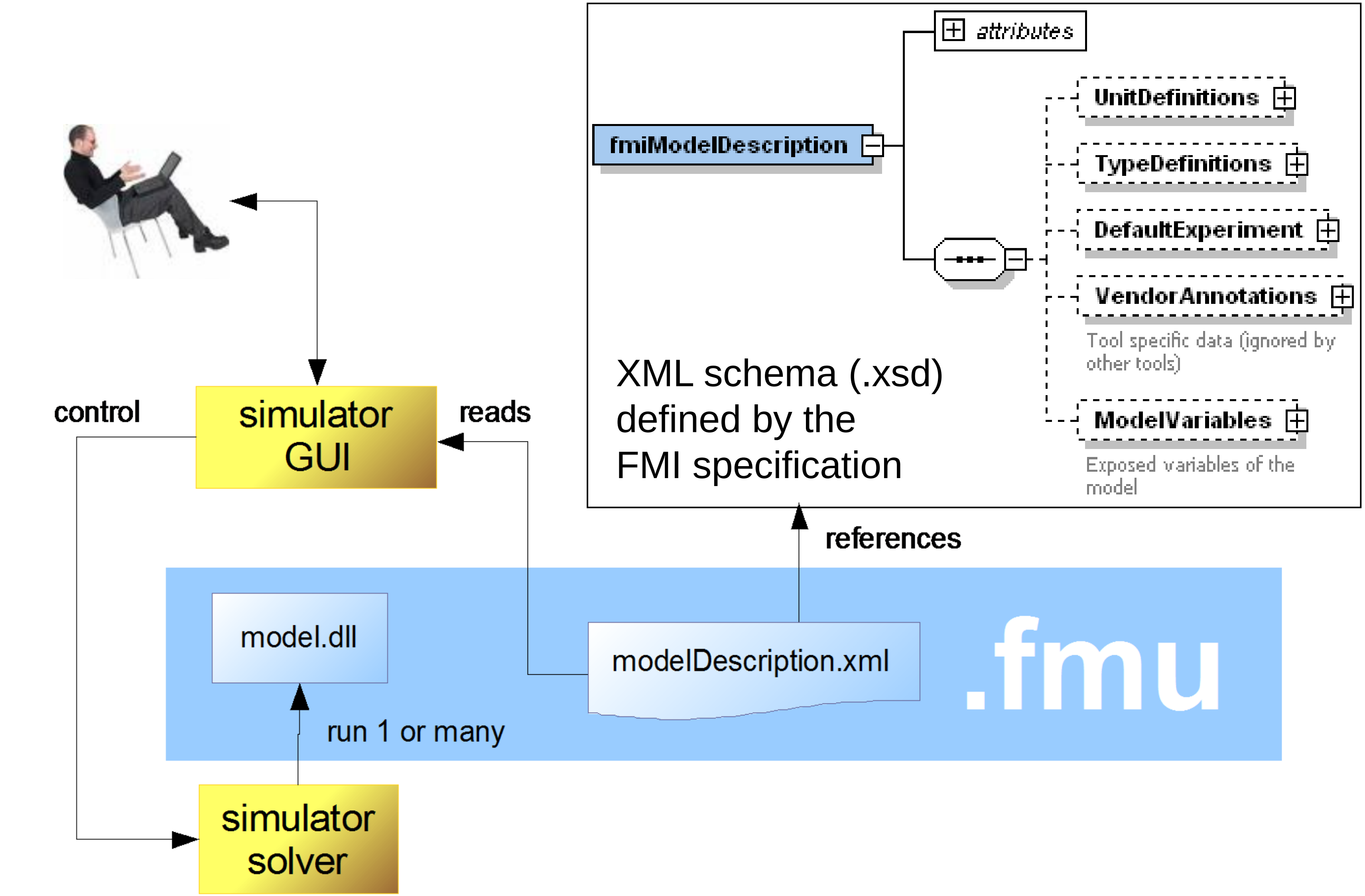


  - Co-Simulation (CS)



- The FMI defines an interface to be implemented by an executable called Functional Mock-up Unit (**FMU**)

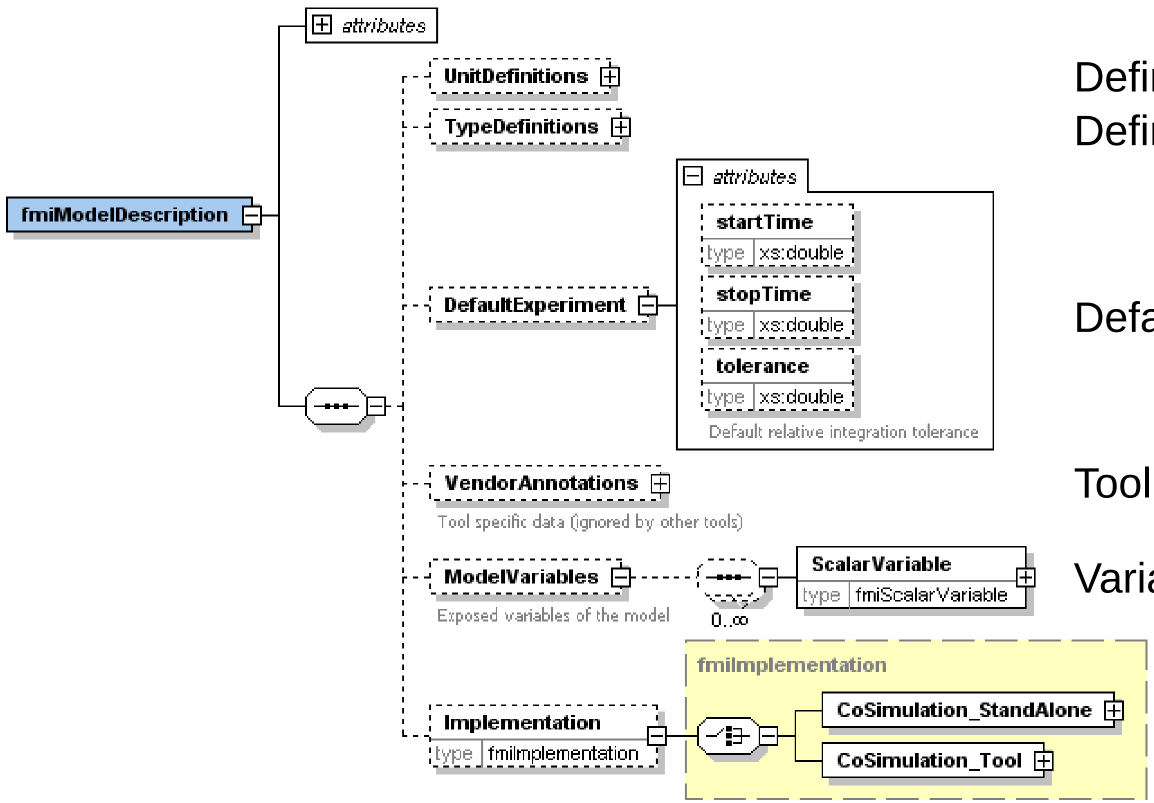
FMU=Model w/ Standard Interface



From the official FMI presentation (adapted)

FMI XML Schema

- **Information** not needed during execution is stored in one **xml-file**:
  - Complex data structures give still simple interface.
  - Reduced overhead in terms of memory.



Definition of display units

Definition of type defaults

Default stop time, tol. etc.

Tool specific data

Variable names and attributes

From the official FMI presentation (adapted)

C-interface

- Two C-header files:
  - **Platform dependent definitions** (basic types):

```
/* Platform (combination of machine, compiler, operating system) */
#define fmiModelTypesPlatform "standard32"

/* Type definitions of variables passed as arguments */
   typedef void*        fmiComponent;
   typedef unsigned int fmiValueReference;
   typedef double       fmiReal    ;
   typedef int          fmiInteger;
   typedef char         fmiBoolean;
   typedef const char*  fmiString ;

/* Values for fmiBoolean  */
#define fmiTrue  1
#define fmiFalse 0

/* Undefined value for fmiValueReference (largest unsigned int value) */
#define fmiUndefinedValueReference (fmiValueReference)(-1)
```

  - **C-functions:**
    - 18 core functions
    - 6 utility functions
    - no macros
    - C-function name: <ModelIdentifier>_<name>, e.g. Drive_fmiSetTime"

From the official FMI presentation (adapted)

C-interface

- Instantiation:

```
fmiComponent fmiInstantiateXXX(fmiString instanceName, ...)
```

- `fmiComponent` is a parameter of the other interface functions
  - Opaque `void*` for the importing tool
  - Used by FMU to hold any necessary information.
- Functions for initialization, termination, destruction
- Support of real, integer, boolean, and string inputs, outputs, parameters
- `Set` and `Get` functions for each type:

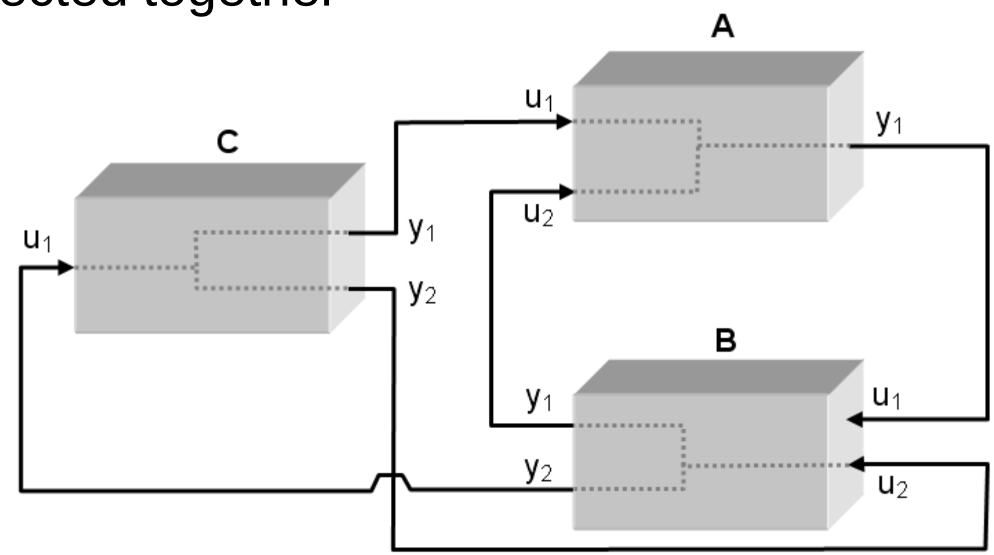
```
fmiStatus fmiSetReal    (fmiComponent c,
                         const fmiValueReference vr[], size_t nvr,
                         const fmiReal value[])
fmiStatus fmiSetInteger(fmiComponent c,
                         const fmiValueReference vr[], size_t nvr,
                         const fmiInteger value[])
```

- Identification by `valueReference`, defined in the XML description file for each variable

From the official FMI presentation (adapted)

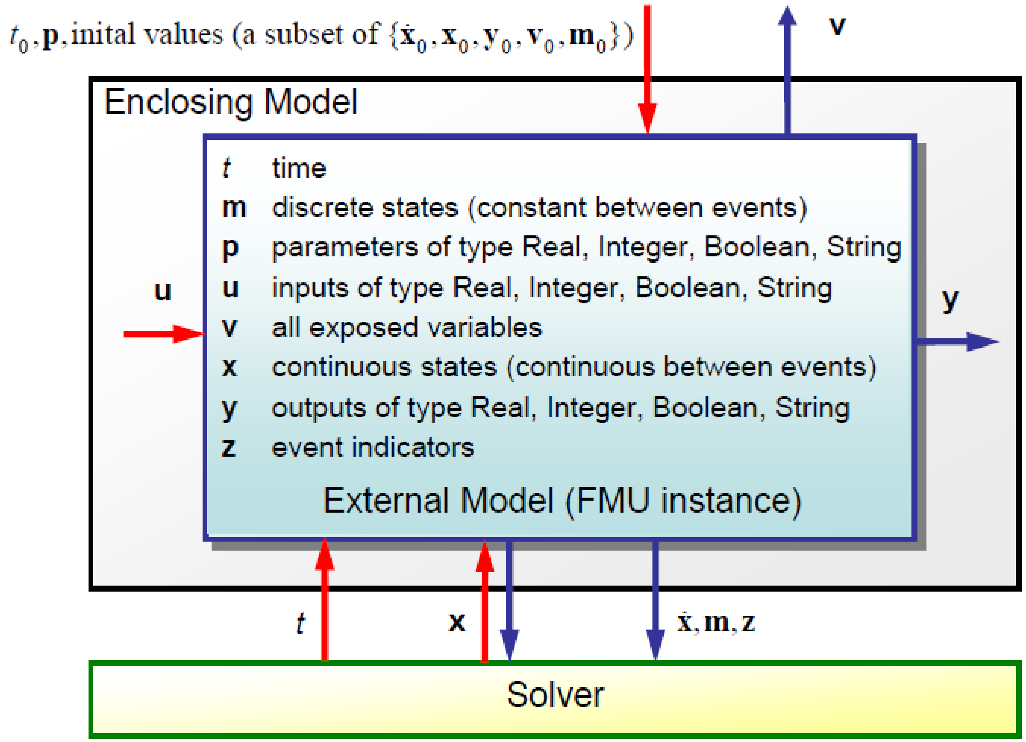
FMI for Model Exchange

- Import and export of input/output blocks (FMU – Functional Mock-up Unit)
- Described by
  - differential-, algebraic-, discrete equations,
  - with time-, state, and step-events
- FMU can be large (e.g. 100000 variables)
- FMU can be used in an embedded system (small overhead)
- FMUs can be connected together



From the official FMI presentation (adapted)

Signals of a Model Exchange FMU



For example: 10 input/output signals (u/y) for connection and
100000 internal variables (v) for plotting

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From the official FMI presentation (adapted)

Co-simulation

- Definition:
  - Coupling of several simulation tools
  - Each tool treats one part of a modular coupled problem
  - Data exchange is restricted to discrete communication points
  - Subsystems are solved independently between communication points
- Motivation:
  - Simulation of heterogeneous systems
  - Partitioning and parallelization of large systems
  - Multi-rate integration
  - Software-in-the-loop simulation
  - Hardware-in-the-loop simulation

FMI for Co-Simulation

- Master/slave architecture
- Considers different capabilities of simulation tools
- Support of simple and sophisticated coupling algorithms:
  - Iterative and straight forward algorithms
  - Constant and variable communication step size
- Allows (higher order) interpolation of continuous inputs
- Support of local and distributed co-simulation scenarios

- FMI for Co-Simulation does not define:
  - Co-simulation algorithms
  - Communication technology for distributed scenarios

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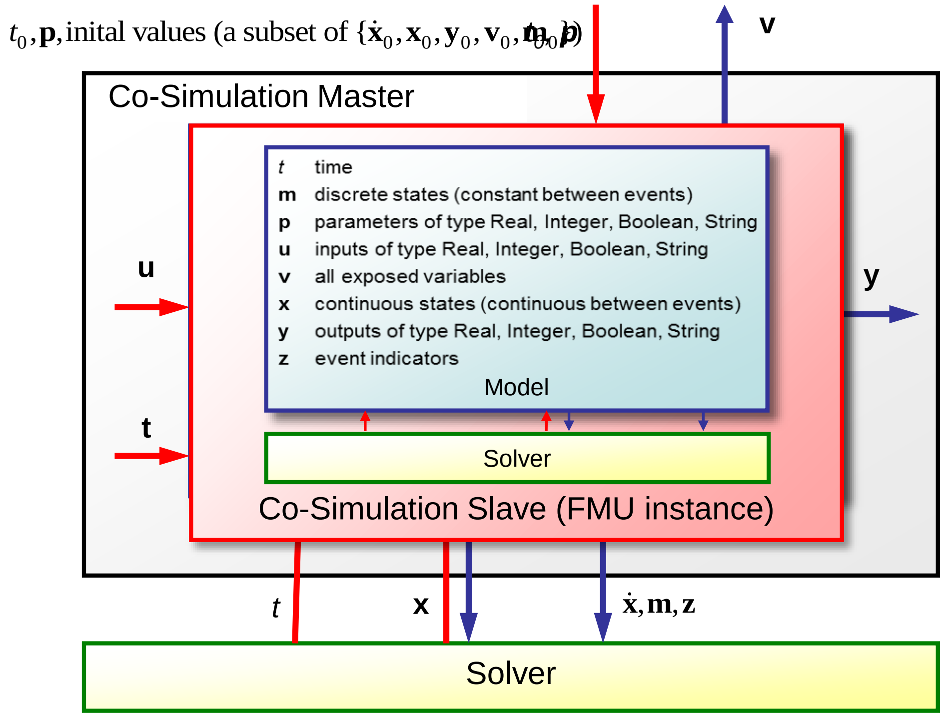
From the official FMI presentation (adapted)

FMI for Co-Simulation

- Signals of an FMU for Co-Simulation



  - Inputs, outputs, and parameters, status information
  - Derivatives of inputs, outputs w.r.t. time can be set/retreived for supporting of higher order approximation

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From the official FMI presentation (adapted)

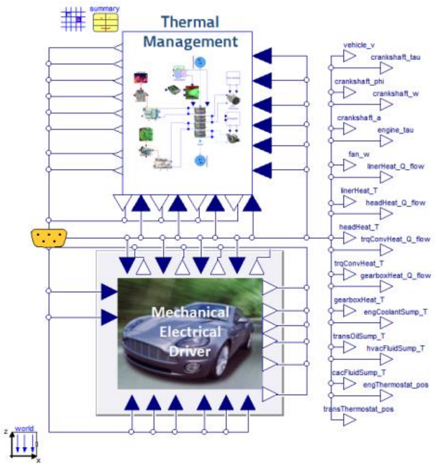
FMI: A BUSINESS MODEL INNOVATION

- FMI-compliant tools often allow liberally licensed export of models for distribution in the organisation and to partners
- Exported FMUs most often don’t require a license from the model authoring tool
- Deployment from few simulation specialists to designers, domain specialists, control engineers
  - One FMU used by many engineers (control design)
  - One FMU run on many cores (robust design)

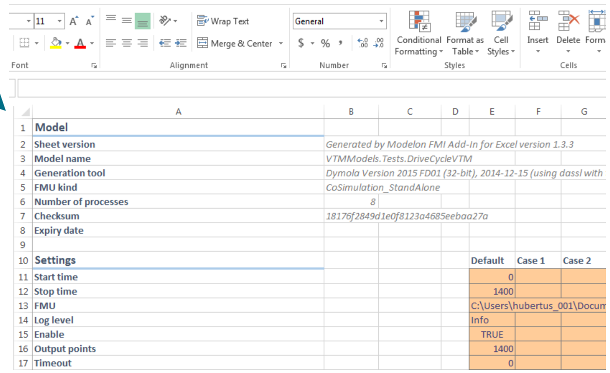
FMI: A BUSINESS MODEL INNOVATION

Separate the model authoring tool from the model execution tool !

TYPICAL FMI-BASED WORKFLOWS



Export: exported
FMU freely licensed



	A	B	C	D	E	F	G
1	Model						
2	Sheet version	Generated by Modelon FMI Add-In for Excel version 1.3.3					
3	Model name	VTMModels.Tests.DriveCycleVTM					
4	Generation tool	Dymola Version 2015 FD01 (32-bit), 2014-12-15 (using dassl with					
5	FMU kind	CoSimulation_StandAlone					
6	Number of processes	8					
7	Checksum	18176f2849d1e0f8123a4685eebaa27a					
8	Expiry date						
9							
10	Settings				Default	Case 1	Case 2
11	Start time				0		
12	Stop time				1400		
13	FMU				C:\Users\hubertus_001\Docum		
14	Log level				Info		
15	Enable				TRUE		
16	Output points				1400		
17	Timeout				0		

Model Authoring Tool(s)

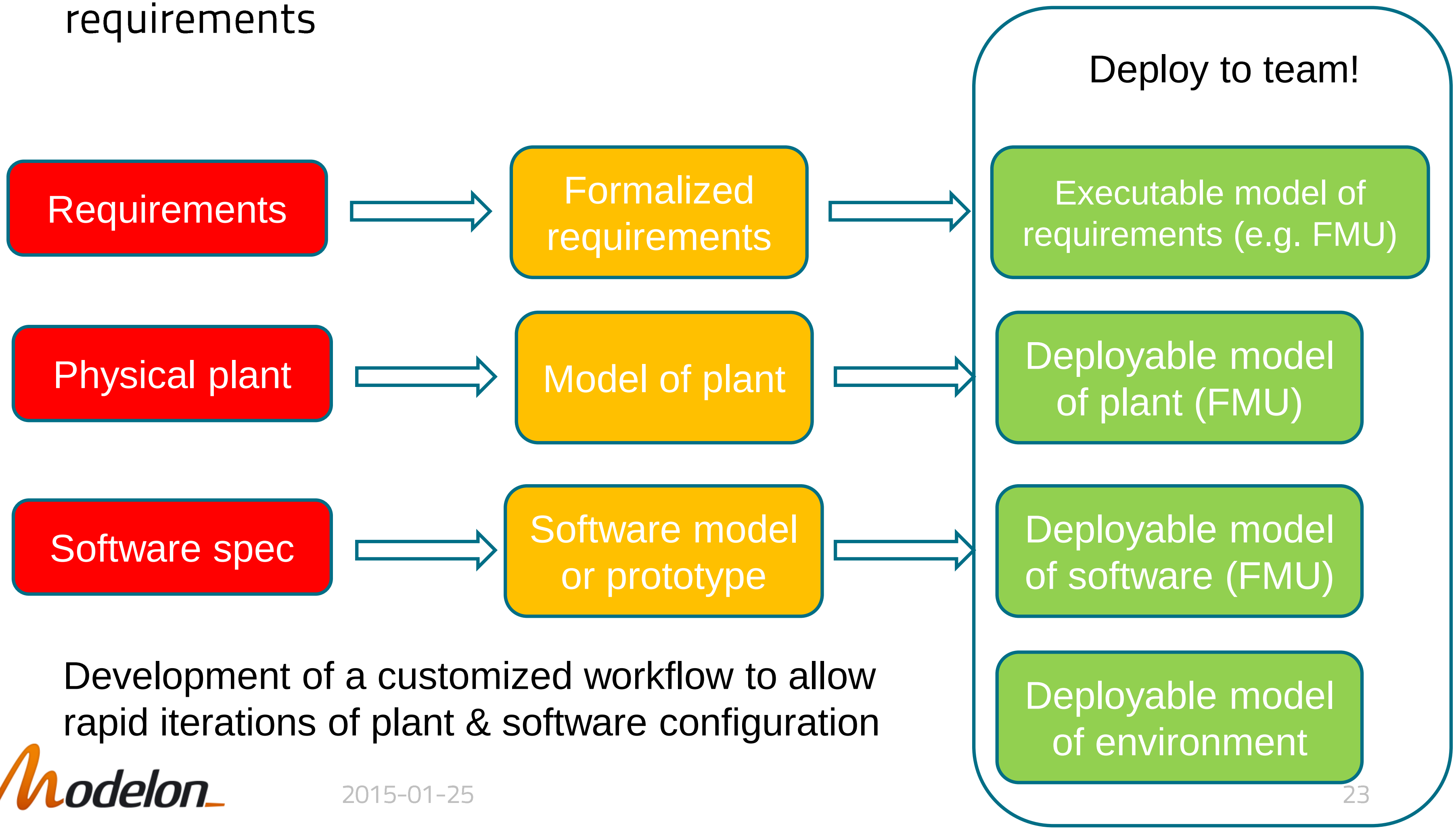
Low-cost Model Execution Platform
May combine FMUs from several tools

- Additional work flow automation for
  - pre-processing,
  - model calibration,
  - post-processing,
  - analysis,
  - automated reporting
  - automated requirements verification

- True democratization of simulation
- Greatly improved utilization of models

AUTOMATED REQUIREMENTS VERIFICATION

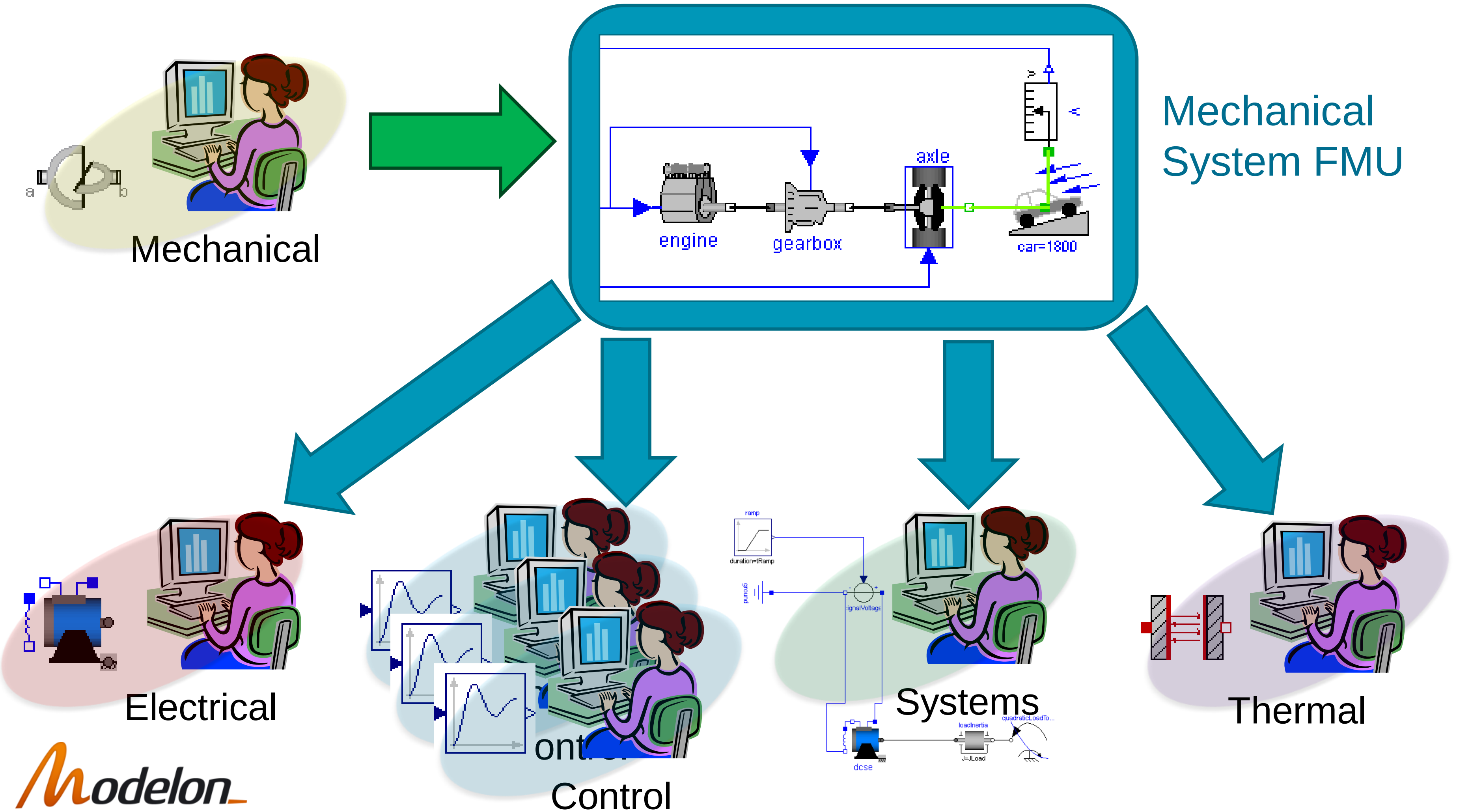
- Systems Engineering centric FMI-based workflow example: automated requirements verification for hardware and software requirements



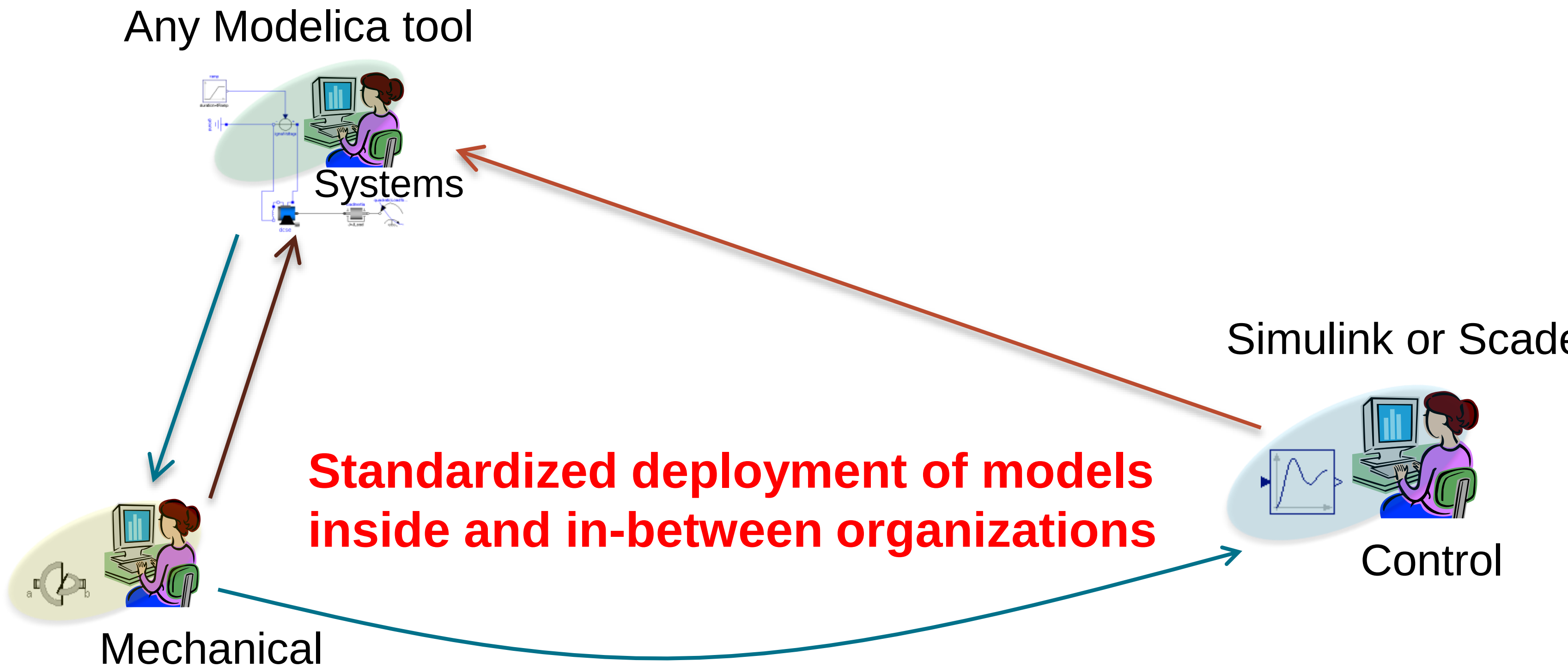
Development of a customized workflow to allow rapid iterations of plant & software configuration

MODEL DEPLOYMENT

- FMU deployed (native tool) to support multiple applications



ENTERPRISE MODEL DEPLOYMENT



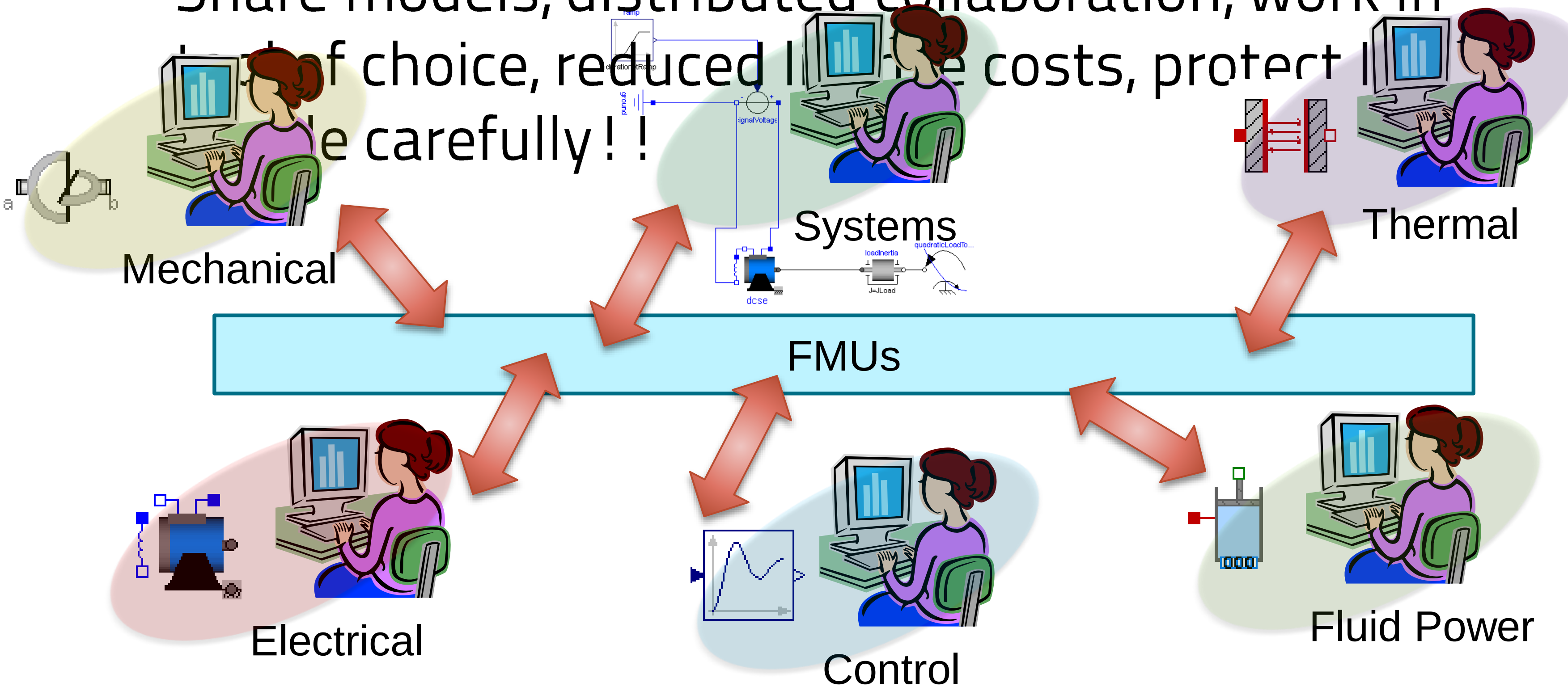
Standardized deployment of models inside and in-between organizations

"Daimer, QTronic and Vector describe how Mercedes-Benz currently uses virtual ECUs to validate transmission control software for about 200 variants of the Sprinter series in a highly automated way on Windows PC"

MULTIDOMAN COLLABORATION

with FMUs

- Engineers in different domains work ~~in one formalism/tool~~
  - Share models, distributed collaboration, work in ... of choice, reduced l... e costs, protect I... e carefully ! !



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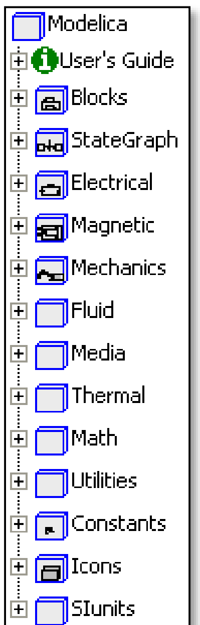
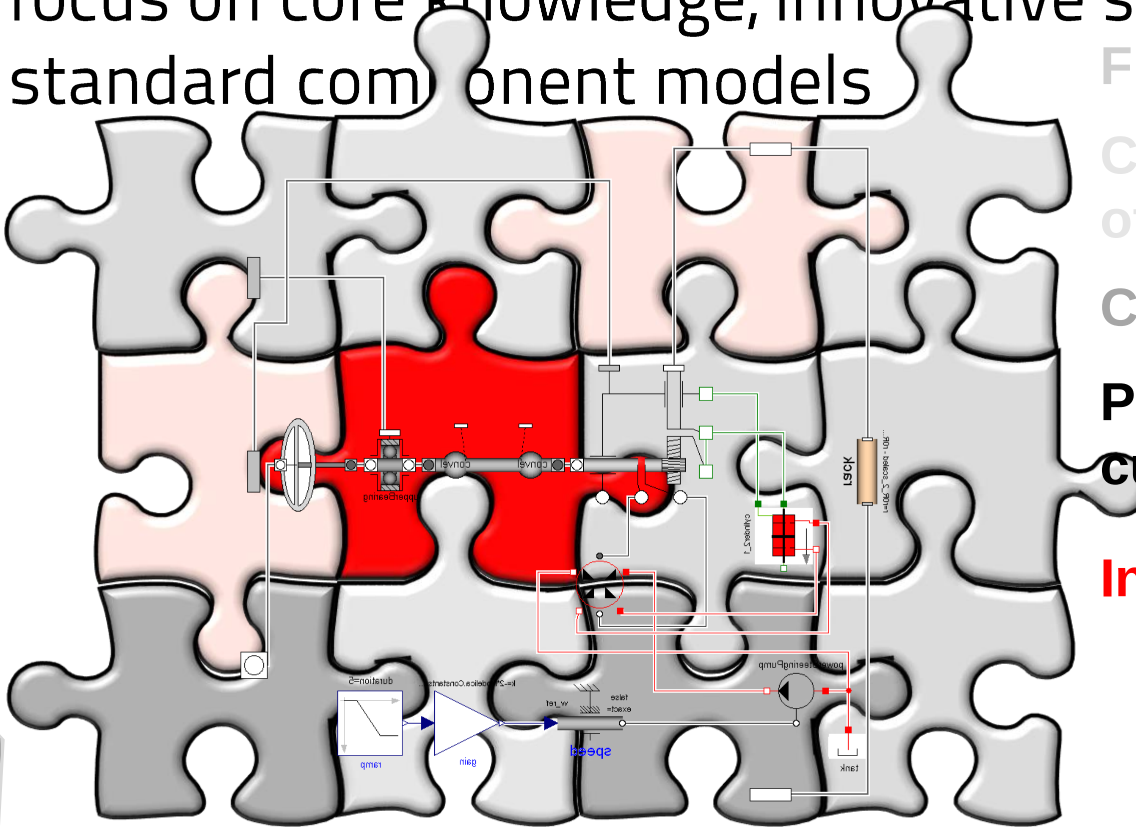
REUSABILITY

- Reusable models in standard Modelica language
  - Off-the-shelf model libraries and components, focus on core knowledge, innovative systems from standard component models





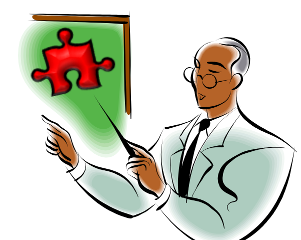
Free open source

Commercial off-the-shelf

Consulting services

Partners / suppliers / customers / academia

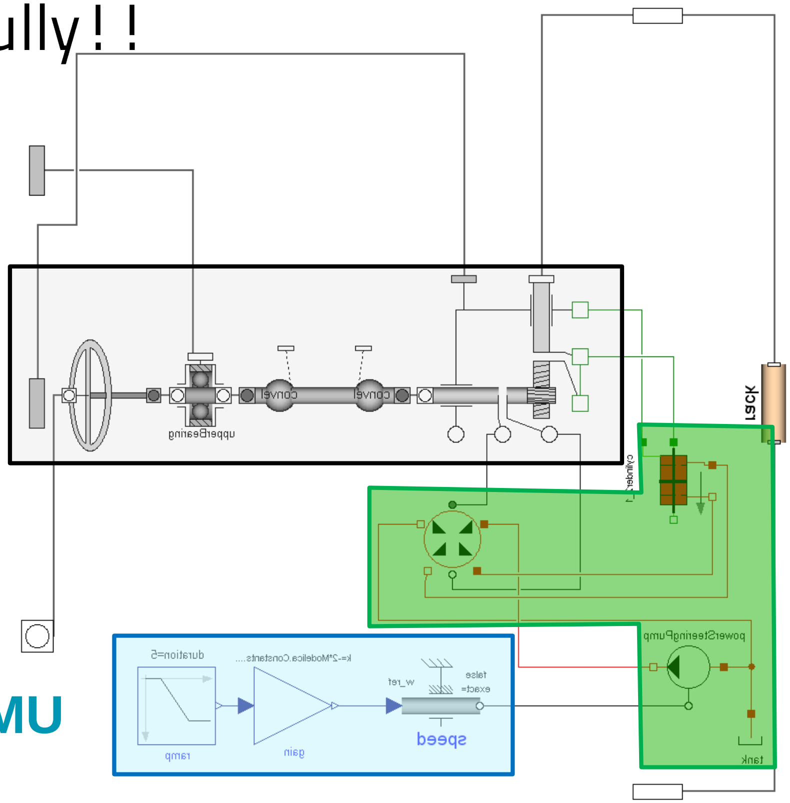
In-house



REUSABILITY

- Reusable models ~~in standard Modelica language~~ as FMUs
  - Compiled models generated internally, from suppliers, from partners, etc.
  - Protect IP as required
  - Couple carefully ! !

Mechanical FMU



Hydraulics FMU

Control/Actuation FMU

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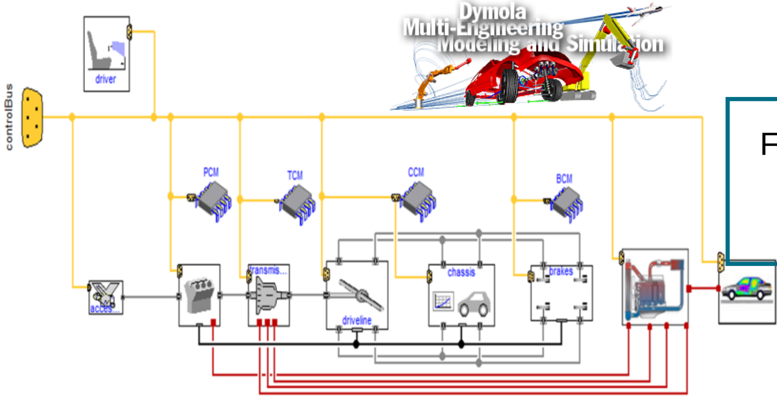
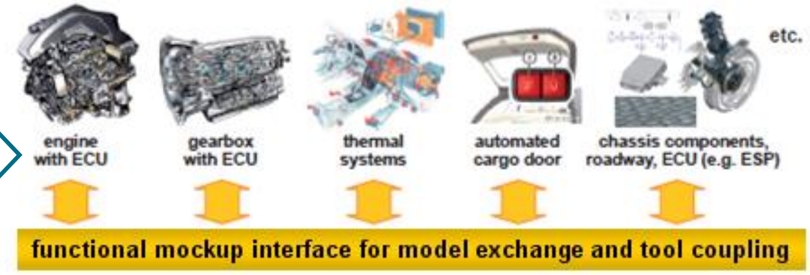
DEVELOPMENT TO DEPLOYMENT



FMU Export via Model Export

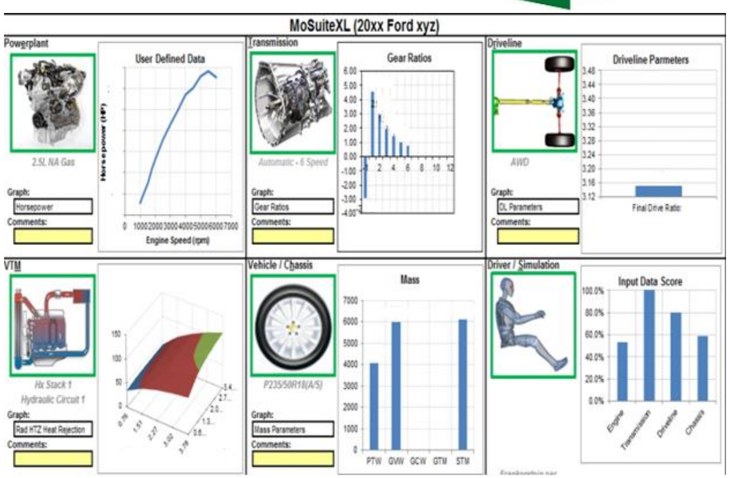
Functional Mockup Interface (FMI)



PyFMI

Custom GUI

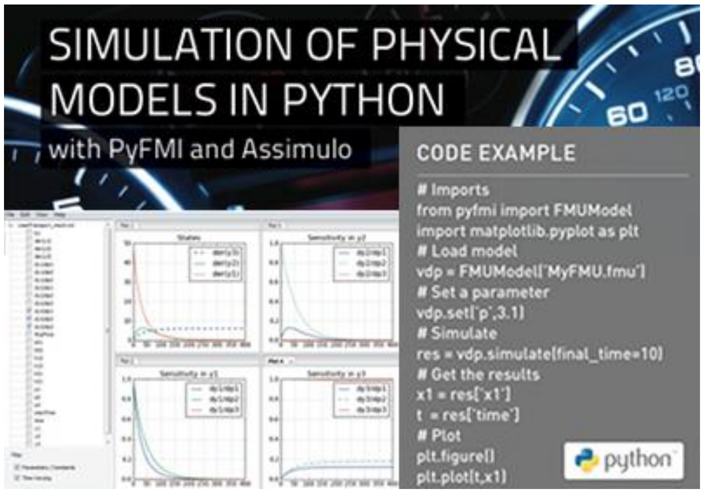
Excel



Parameters

Results

FMU Simulator



USE CASE: VIRTUALIZATION FOR CONTROLS

Virtualization: Objectives

Running accurate closed-loop simulation of the complete system –
On a PC

All engineers equipped with a virtual vehicle

System integration and feed-back within minutes

FMI

Silver

FMI

Virtual ECUs
Simulation of the ECUs, working as in the vehicle

Vehicle Simulation
High-fidelity, configurable

VIRTUAL INTEGRATION & TEST

Silver runs a virtual prototype:

- On standard Windows PC
- Connecting virtual control and virtual plant using SiL-technology
- Using compiled behavioural models from many different tools without sources
- Allowing efficient and intuitive communication definition
- Allowing simple interaction with the virtual prototype: User “drives” system

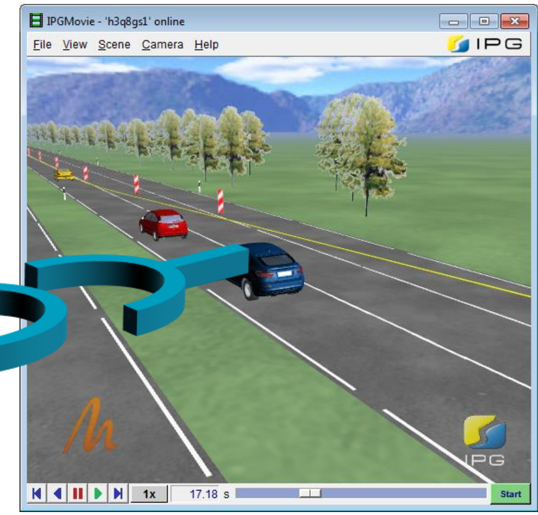
FMU export: any FMI compatible tool
FMU import: Silver

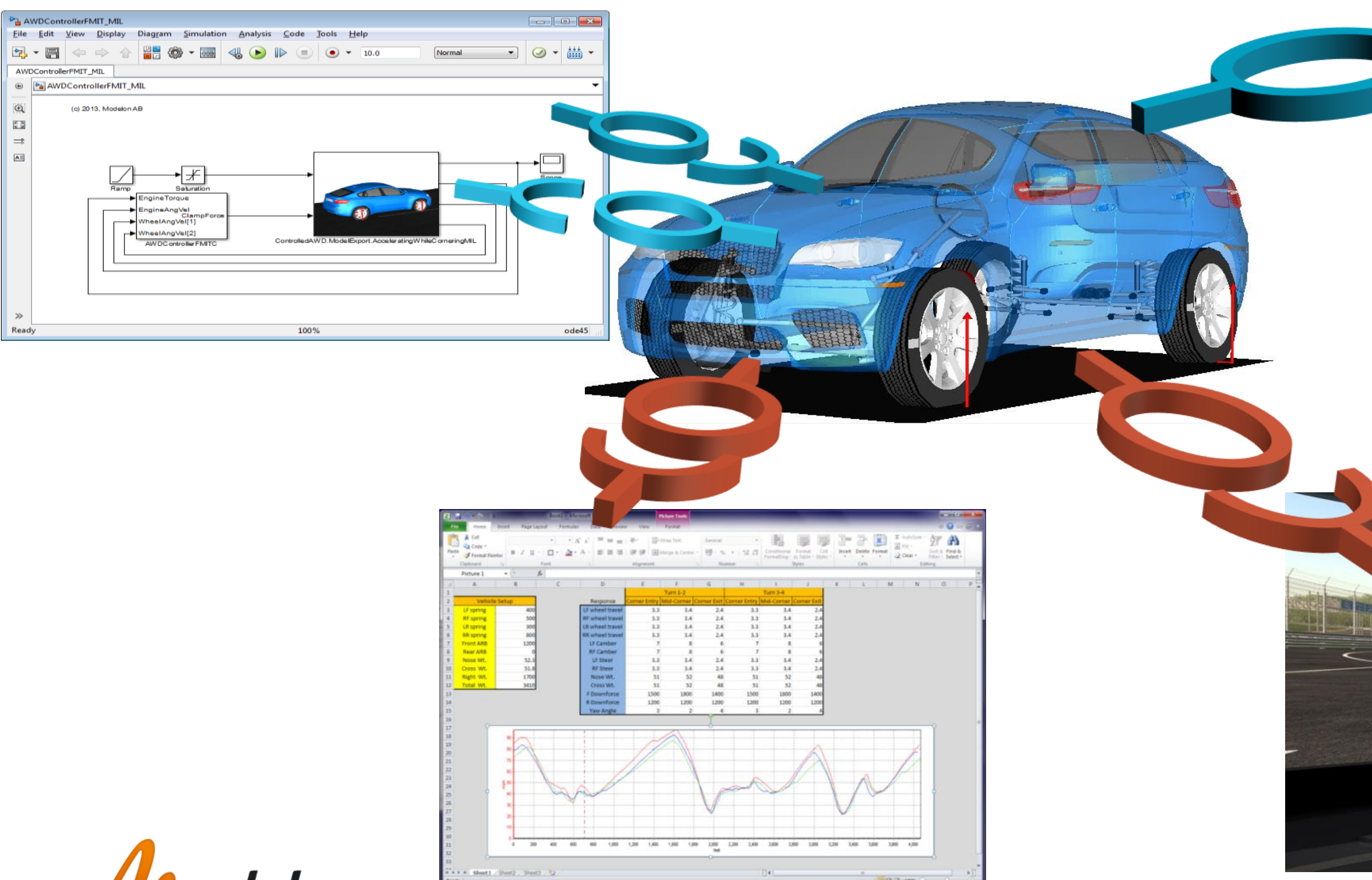
Silver allows:

- Easy sharing of information/results
- Use of simulation technology by non-specialists, without the simulation tool
- Protection of IP
- System behaviour on the laptop of every engineer (concurrent engineer.)
- Extremely fast change-validation-change cycles (few minutes!)
- Engineers immediately experience their changes in a system context

FMI ADVANTAGE

- Same model – different applications





Modelon


Dymola
Multi-Engineering
Modeling and Simulation
SCADE
SUITE
ANSYS
SIM
PACK
Wolfram SystemModeler
C/C++
QTronic
SIMULATION FOR ENGINEERING
Excel
MATLAB
SIMULINK
OpenModelica
IPG
Adams
ALL CONNECTED !
MSC Software
Java
SIMULATIONX
Powered by ITI
LMS
A Siemens Business
python
Model Interface
Calibration Software
LabVIEW
NATIONAL INSTRUMENTS
MapleSim
Modelon

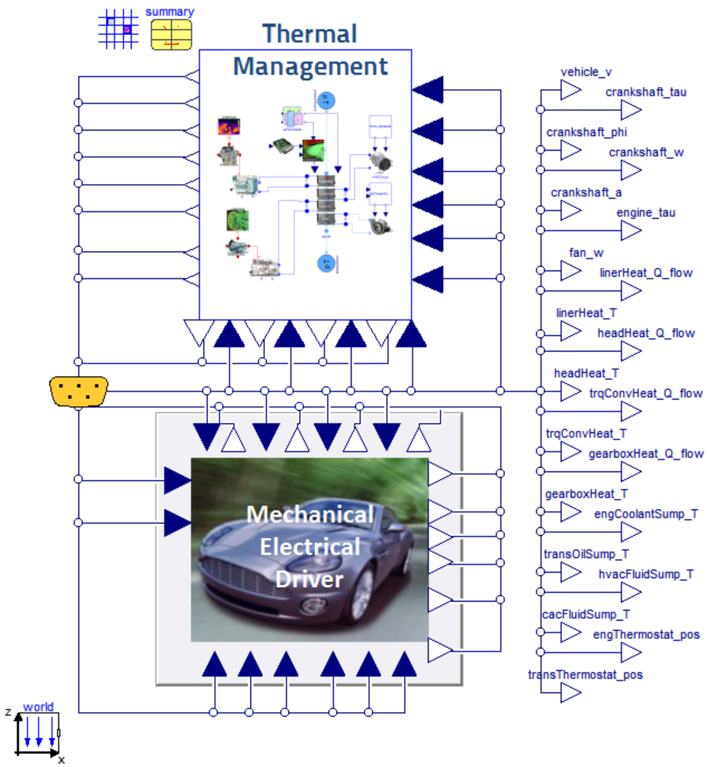
PART II

Tutorial Overview

TUTORIAL OVERVIEW

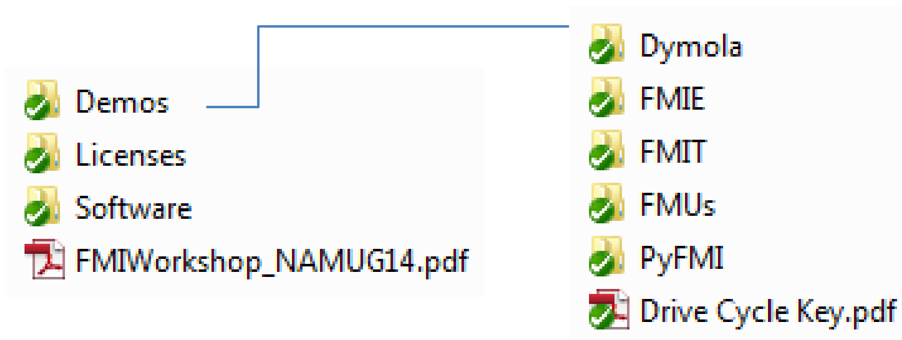
- Goal: demonstrate FMI-based workflows in several FMI compliant tools with hands-on exercises
  - Modelica model (vehicle thermal management)
  - FMU creation
  - FMU import, simulation, and post-processing
- FMI is a standard but we need tools to work with it
- Several tools are provided to support tutorial, both open source and commercial (evaluation licenses)
- Choose exercises based on interest and tools (note some have tool pre-requisites, i.e. MATLAB/Simulink)
- FULL DISCLOSURE: tutorial based on tools in use at or developed by Modelon (full list of FMI-compliant tools at www.fmi-standard.org)

TUTORIAL USE CASE



GETTING STARTED

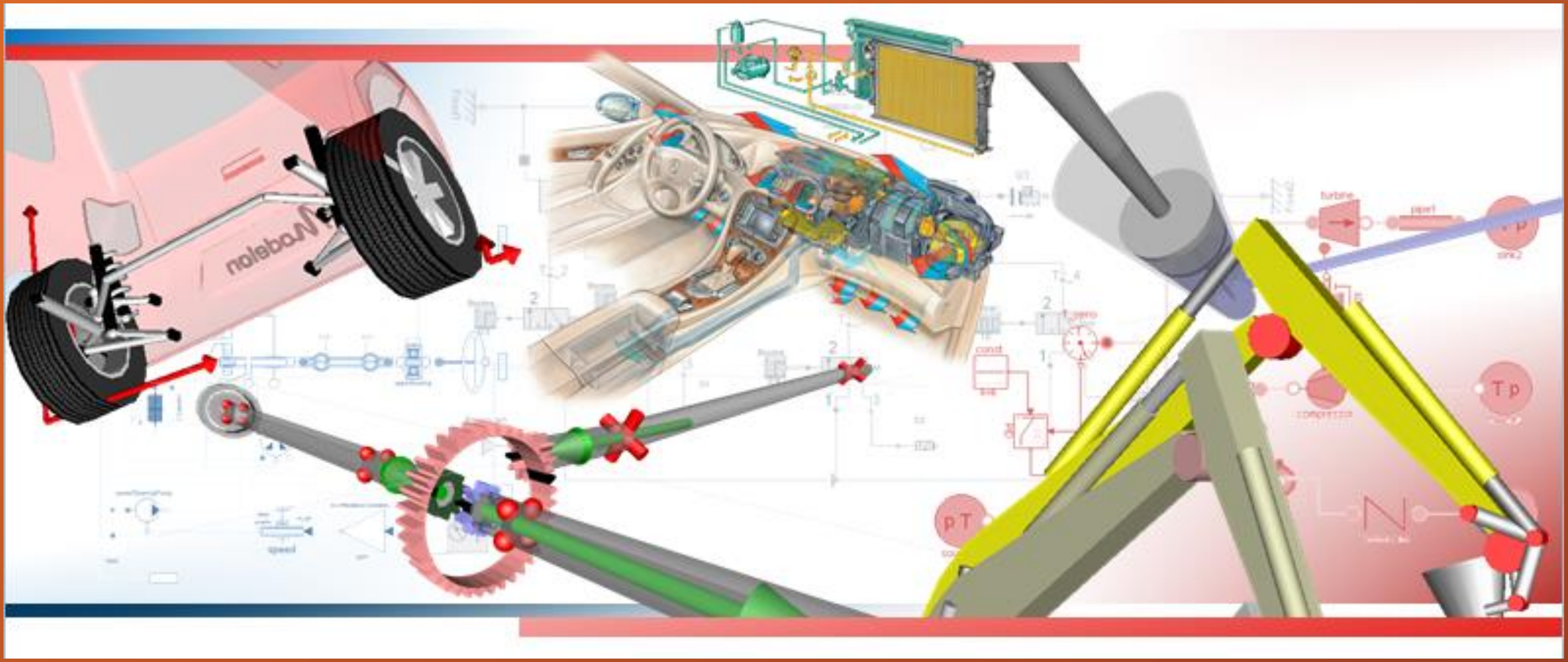
- USB sticks passed around with all tutorial files (instructions, software, licenses, sample files, FMUs)



- Public link: https://app.sugarsync.com/iris/wf/D1068299_77975033_6553767
- Open FMIWorkshop_Incose.pdf with full tutorial instructions
- Feel free to try your own FMI tools with workshop
- Ask questions if you need help or have problems

LICENSING LOGISTICS

- Dymola
  - Full Dymola license required for FMI import and export
- MATLAB/Simulink
  - FMI Toolbox (evaluation license provided) + MATLAB/Simulink required for FMU import into Simulink
  - FMU export from Simulink also requires Simulink Coder
  - Sample FMUs are 32 bit and require MATLAB/Simulink 32 bit
- Excel
  - FMI Add-in for Excel (evaluation license provided)
  - Requires 32 bit Microsoft Office
- Evaluation licenses expire on February 14th, 2015 but all FMUs included with tools execute with demo licenses per Users' Guide (contact Modelon for more information)



THANK YOU FOR YOUR ATTENTION

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