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eFMI® Tutorial – Agenda

Part 1: eFMI® motivation and overview (40 min)

Part 2: Running use-case introduction (10 min)

Part 3: Hands-on demonstration in Dymola and

Software Production Engineering (former name CATIA ESP) (25 min)

Coffee break (30 min)

Part 3: Hands-on demonstration in Dymola and Software Production Engineering (former name CATIA ESP) (35 min)

Part 4: Live demonstration in TargetLink (30 min)

Part 5: Short presentation of further tooling (5 min)

Part 6: Conclusion (5 min)



Tutorial leader: Christoff Bürger



Presenter: Oliver Lenord BOSCH Invented for life



Presenter: Jörg Niere

dSPACE





Part 3: Hands-on demonstration in Dymola and Software Production Enginnering

eFMI® Tutorial – 15th International Modelica Conference – 9th of October 2023



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Tutorial requirements:

□ Own computer with Windows 10 or 11, 64-Bit, x86

You – i.e., every tutorial participant – should have gotten a software bundle with:

- □ This documentation (eFMI-Tutorial-Part-3.pdf in root directory)
- Preinstalled Dymola 2024x Beta 4 (/Dymola)
- □ Preinstalled Software Production Engineering (fomer name CATIA ESP) prototype (included in Dymola)
- □ Workdirectory where eFMUs will be generated and simulation artefacts stored (/work-directory)
- □ Modelica models we actually want to develop; for your reference if something goes wrong (/reference-models)
- □ eFMUs we actually want to build; for your reference if something goes wrong (/reference-eFMUs)
- □ Portable Microsoft Visual C++ and Microsoft Windows SDK required by Dymola (/portable-MSVC)
- Portable Java required by Software Production Engineering (/portable-Java)
- Portable Cppcheck (/portable-Cppcheck) and Python (/portable-Python) required for MISRA C:2012 compliance checks of production code
- □ Licenses of provided software (/licenses)





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Ok, lets get started!







The user interface for eFMI support in Dymola is provided by means of a Modelica library: DymolaEmbedded

Load DymolaEmbedded via the *eFMI* button in the *Tools* ribbon \rightarrow *Load Libraries...* \rightarrow *OK*:

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Other menu entries permit to build or delete eFMUs for whole package hierarchies and load their co-simulation stubs (this convenience use-cases will become clear throughout the tutorial).



Functional Mock-up Interface for

embedded systems





The following libraries are loaded:

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eFMI:

- Support library to ease adaptation of existing Modelica models for eFMI (mostly about MSL → eFMI table adapters)
- Public domain, © MA, MAP eFMI

eFMI_TestCases:

- eFMI application examples used for official cross-checks of eFMI tooling; Modelica tooling agnostic
- Public domain, © MA, MAP eFMI
- Contains our running use-case, M04

DymolaEmbedded:

- Interface for Dymola's eFMI facilities
- Provides means to configure eFMU generation & generate various eFMI containers

eFMI_TestCases_EmbeddedConfigurations:

- **eFMU generation configurations for** eFMI_TestCases
- Already contains a configuration for M04 (we will develop from scratch in the following)







Create a new eFMU generation configuration for the M04 controller:



Create package extending EmbeddedConfiguration:

- 1. *File* → *New* → *Package*, Name: MyM04eFMU
- 2. New package visible in *Package Browser & Projects* (not *Libraries*)
- 3. Double click MyM04eFMU; switch to Text ribbon
- 4. Add extends .DymolaEmbedded
 .EmbeddedConfiguration;
- 5. Switch to Graphics ribbon

Dymola and Software Production Engineering eFMU code generation can be configured from the diagram layer of MyM04eFMU.; it is an eFMU generation configuration.







Create a new eFMU generation configuration for the M04 controller:

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Ibraries Projects	only_clocked false V	Configures, whether the given model is either, (1) a system model with clocked sub-partitions for which only code will be generated or (2) if code is generated for the whole model (i.e., not only its clocked sub-partitions). If 'true', clock independent model parts are ignored and will not be computed by the generated eFMU. Using this flag, whole system models can be

Configure Dymola's GALEC code generation:

- 1. Double click model configuration
 - \rightarrow model_name
 - \rightarrow *Edit* (package tree icon)
 - → **Select** eFMI_TestCases .M04_DrivetrainTorqueControl .Controllers.Controller
 - $\rightarrow OK$
 - $\rightarrow OK$
- 2. Double click code configuration → obfuscate: None
 - $\rightarrow OK$
- 3. Double click integrator configuration
 - → sample_period: 5e-4
 - \rightarrow *solver_method*: Explicit Euler
 - $\rightarrow OK$







Create a new eFMU generation configuration for the M04 controller:



Software Production Engineering is already default configured:

- 32-Bit and 64-Bit floating-point precision production codes
- 32-Bit and 64-Bit x86 ISA binary codes (self-contained static linked libraries)
- \Rightarrow 2 Production Code & 4 Binary Code containers







Investigate the eFMU generation configuration MyM04eFMU for the M04 controller:



All eFMU build activities are inherited from DymolaEmbedded.EmbeddedConfiguration:

- Available via the *extends* entry in the *Package Browser* & *Libraries* / *Projects* view (depending if configuration is write protected or not)
- Preconfigured with eFMU generation configuration
- Activities grouped according to eFMI container type:
 - Algorithm Code: Generate GALEC code
 - **Behavioral Model:** Derive experiment packages to configure test scenarios & tolerances; use experiment packages to generate respective Behavioral Models
 - Production Code: Generate & MISRA C:2012 check Software Production Engineering code
 - **Binary Code:** Generate Software Production Engineering binaries & Modelica proxies for cosimulating such; export FMU







Generate the eFMU configured in MyM04eFMU for the M04 controller:



Build the eFMU with Algorithm Code, 2x Production Code and 4x Binary Code containers:

- 1. Right click MyM04eFMU.build in the Package Browser / Projects view
 - \rightarrow Call Function...
 - $\rightarrow OK$
- 2. You can check the build log in the *Commands* window

Browse the generated eFMU:

- 1. Right click MyM04eFMU.browse_code in the Package Browser / Projects view
 - \rightarrow Call Function...
 - $\rightarrow OK$







Investigate the generated eFMU (MyM04eFMU/eFMU):



Contained containers:

Algorithm Code with GALEC code x64, 64-Bit floating-point precision Binary Code x86, 64-Bit floating-point precision Binary Code x64, 32-Bit floating-point precision Binary Code x86, 32-Bit floating-point precision Binary Code 64-Bit floating-point precision Production Code 32-Bit floating-point precision Production Code Content manifest listing all containers

Take some time to investigate the eFMU, e.g.:

- How cross references between manifests work
- Quality of generated GALEC code (self-contained / inlined, error handling of symbolic optimized linear equation systems, local vs. global variables etc)





Check the eFMU and its production codes:



Check MISRA C:2012 compliance of all production codes via Cppcheck:

1. Right click MyM04eFMU.ProductionCode
 .check_code in Package Browser / Projects view
 → Call Function...

 $\rightarrow OK$

2. Analyses reports for each production code are provided in your webbrowser (note, that block.c, the actual production code, satisfies MISRA)

Check eFMU with *eFMI Container Manager* and *eFMI Compliance Checker* (MAP eFMI released tools):

- 1. Right click MyM04eFMU.check_eFMU in the Package Browser / Projects view
 - \rightarrow Call Function...
 - $\rightarrow OK$







Congratulations, you are halfway through!



eFMU generation done.

Let's go on to Behavioral Models & software-in-the-loop (SiL) simulation.





For which target did we just generate binaries? How do I pick my embedded target?











Which kind of limitations on Modelica models exist? What is supported (signal buses, discrete, events, state machines, ...)?









Which kind of Modelica models / equation systems do not work? What about very stiff systems of equations?







What are the differences between Dymola & Software Production Engineering code configuration, Dymola C code generation, eFMI code generation and eFMU bundle configuration?









What is the *.alg file in the ACode_Dymola container of the eFMU?











Congratulations, you are halfway through!

See you in the second half of the hands-on after the coffee break!



eFMU generation done.

Let's go on to Behavioral Models & software-in-the-loop (SiL) simulation.







Congratulations, you are halfway through!

Welcome back to the second half of the hands-on!



eFMU generation done.

Let's go on to Behavioral Models & software-in-the-loop (SiL) simulation.







Generate eFMU co-simulation stub:

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1. Right click
MyM04eFMU.BinaryCode.build_binary_stub
in Package Browser / Projects view

→ Call Function...
→ OK

A new package 'MyM04eFMU.eFMU_SiL_Support' is generated. Its BinaryStub model is a Modelica proxy to the static linked libraries – and therefore production codes – generated by Software Production Engineering.







Investigate generated eFMU co-simulation stub:

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Main characteristics of eFMU co-simulation stubs:

- Support multiple instantiation (each is atomic)
- All production codes available (32-Bit & 64-Bit floating-point precision simulation)
- Support modification, input-dependent initialization, recalibration & reinitialization
- Provide & assert eFMI error signals
- Preserve original model interface (dimensionalities, diagramatic layout of in- & output connectors etc)
- Provide sampling with period of generated eFMU
- "Just" a production code proxy (no additional equations; no solver required; "simply" implement GALEC block live-cycle)





Derive experiment package to define test scenarios & generate Behavioral Model container:

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File Graphics Docun	MyM04eFMU.BehavioralModel.build_tests ×	x - 0
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Model Layer	Derive from an existing model an experiment-package defining the test scenarios of a Dymola-administered Behavioral Model container. Each eBlock	pols
Model name Image: Comparison of the second sec	defines one test scenario of the Behavioral Model container. The generated package can be used to add the respective Behavioral Model container to the eFMU (i.e., generate reference results and manifest) and to software-in-the-loop (SiL) test the CATIA ESP production codes of the eFMU.	f a ∋nario of pective ∋st) and
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Derive experiment package from existing closed loop experiment:

- 1. Right click MyM04eFMU.BehavioralModel
 - .build_tests in Package Browser / Projects view
 - \rightarrow Call Function...
 - \rightarrow source_experiment
 - \rightarrow *Edit* (package tree icon)
 - \rightarrow select eFMI_TestCases
 - .M04_DrivetrainTorqueControl
 - .ReferenceTests
 - .Controller_ExplEuler_ClosedLoop
 - $\rightarrow OK$ $\rightarrow OK$





Scenario 1: controller

Functional Mock-up Interface for

embedded systems

Investigate the derived experiment package:







Define tolerances for the test scenarios of the experiment package:



Define absolute and relative tolerances for all floatingpoint precisions and test scenarios (i.e., SiL tests). We can use a default for all scenarios (here only a single): 1. Double click tolerances_default (labeld default) in Diagram view of the experiment package → set tolerances for M_motor output a follows absolute_x32 (M_motor=1e-3) relative_x32 (M_motor=1e-4) absolute_x64 (M_motor=1e-6) relative_x64 (M_motor=1e-8) → OK





Generate Behavioral Model container form the experiment package:

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Build the Behavioral Model container with reference results taken from simulation of the reference experiment Test ReferenceExperiment:

 Right click build of experiment package in Package Browser / Projects view
 → Call Function...

 $\rightarrow OK$

Browse the generated Behavioral Model container:

 Right click browse_container of experiment package in the Package Browser / Projects view → Call Function...

 $\rightarrow OK$







Investigate the generated Behavioral Model container (BModel_Dymola_699250432):



Container content:

XML manifest with

- Test scenarios
- Links to Algorithm Code manifest for variable names and types (in-, output, tuneable parameter) & sample period
- Variables → CSV column name links (multi-dimensions are flattened to individual columns)
- Tolerances for various floating-point precisions
 Reference trajectories in comma separated values (CSV)
 files (one file per test scenario)

Take some time to investigate the manifest and CSV file.





Conduct SiL test of Software Production Engineering generated production codes:



- Double click Test_SiL_Scenario_1 of the experiment package in Package Browser / Projects view
- 2. Switch to Simulation ribbon
 - \rightarrow Click Simulate button
- 3. Right click 'M_motor|match' in diagram plot → Plot Variable
 - → select act (actual SiL simulation trajectory)
 - \rightarrow select *ref* (expected reference trajectory)
- 4. Zoom into *Plot* window to see there are differences

Note, that the test did not fail (see *Logs* window & dashboards). If you tighten tolerances – e.g., change the 32-Bit floating-point precision tolerances to the 64-Bit ones – it will fail.





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Congratulations, you did it!



Let's do some advanced SiL stuff, like recalibration and reinitialization.



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Load prepared recalibration & reinitialization example for M04 controller:



1. Either, drag and drop model reference-models/Part-3/ RecalibrateAndReinitializeTest.mo in Package Browser / Projects view or load it via File → Open → Load...

The model has 4x M04 controller instances (eFMU cosimulation stub instances):

- 1. untuned: not modified, recalibrated nor reinitialized
- 2. parameterized: modified c_res & k_PI
 parameters, but not recalibrated nor reinitialized
- 3. tuned: unmodified, but via tuningBus runtime recalibrated c_res & k_PI parameters
- 4. tuned_and_reinitialized: like 3, but additionally at runtime reinitialized







All 4 controllers use the same production code for simulation (__defining_code modification set by the global record parameter in the upper left of the diagram).

The c_res & k_PI parameter changes are all switches from the default value to the same new value, just at different time points (as modification before simulation or as recalibration during simulation):

- c_res: 4710 → 2710 at t = 0s or 0.25s (step runtime value)
- k_PI: $-73 \rightarrow -10$ at t = 0s or 0.6s (step1 runtime value)

Reinitalization is done at t = 0.7005s (booleanTable runtime value).







Tuning is enabled by modifying co-simulation subs:

- ___enable_tuning = true
- selecting/activating the tuned parameters via _____tuning_configuration
- \Rightarrow The tuning bus connector (:::) is enabled.

New recalibration parameter values are provided as runtime values connected to the tuning bus. Only tuning-activated parameters have to be provisioned.

Tuning configuration & bus types are provided in the generated eFMU co-simulation stub (drag and drop).

In this model: Tuneable parameters are selected by the global __tuning_configuration record parameter in the upper left

of the diagram.







Reinitialization is enabled by modifying eFMI cosimulation subs:

- __enable_reinitialization = true
- \Rightarrow The "stop push button" (\bigcirc) is enabled.

New reinitialization requests are provided as runtime values connected to the "stop push button". Such are locked until the next sampling; it is sufficient to signal at any point inbetween two samplings that a reinitialization is requested – it is not necessary to ensure reinitialize == true exactly at the sampling.







- 1. Simulate RecalibrateAndReinitializeTest
- 2. Plot M_motor of all 4 co-simulation stubs
- 3. Plot recalibrated (true, iff recalibration done)
- 4. Zoom into the plot at $0.0 \le t \le 1.05$

When do parameterized and tuned plots align? When does untuned align? Is the controller fast adapting in case of errors that require a system restart?

Good to remember:

- All controllers use same production code
- c_res & k_PI parameters change consistently:
 - c_res at t = 0s or 0.25s (step)
 - k PI at t = 0s or 0.6s (step1)
- Reinitalization at t = 0.7005s (booleanTable)







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- 2. Plot M_motor of all 4 co-simulation stubs
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- Reinitalization at t = 0.7005s (booleanTable)





Final touch – export eFMU as FMU:



- 1. Right click MyM04eFMU.BinaryCode.build_FMU in Package Browser / Projects view
 - \rightarrow Call Function...
 - $\rightarrow OK$

The exported FMU has all conditional parameters of the eFMU co-simulation stub fixed to their defaults:

- Recalibration & reinitialization: disabled, i.e., _____enable_tuning = false, _____enable_reinitialization = false
- Error signals: asserted, i.e.,

_assert_error_signals = true

 Internal sampling: embedded & fixed, i.e., embedd clock = true







Congratulations, you did it like a PRO!









Assume my embedded target platform provides functionality I like to reuse. How do I link it to my GALEC / production code?

How can I interface existing C code / binaries in my controller?









What is the minimal setup I need, starting from Dymola? Which eFMU containers are optional? Which eFMI features are optional?







We used a lot of Modelica

libraries.

What are all the eFMI libraries loaded in Dymola good for?



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Graphics
Documentation
Text
Simulation
Tools

Formatted
Image: Comparison of example of ex

 Support library to ease adaptation of existing Modelica models for eFMI (mostly about MSL → eFMI table adapters)

eFMI TestCases:

DymolaEmbedded - DymolaEmbedded (Read-Only) - [Documentation]

 eFMI application examples used for official cross-checks of eFMI tooling; Modelica tooling agnostic

DymolaEmbedded:

- Interface for Dymola's eFMI facilities
- eFMI_TestCases_EmbeddedConfigurations:
- **eFMU generation configurations for** eFMI_TestCases









Congratulations, you did it like a PRO!









eFMI® Tutorial – Agenda

Part 1: eFMI® motivation and overview (40 min)

Part 2: Running use-case introduction (10 min)

Part 3: Hands-on demonstration in Dymola and

Software Production Engineering (former name CATIA ESP) (25 min)

Coffee break (30 min)

Part 3: Hands-on demonstration in Dymola and Software Production Engineering (former name CATIA ESP) (35 min)

Part 4: Live demonstration in TargetLink (30 min)

Part 5: Short presentation of further tooling (5 min)

Part 6: Conclusion (5 min)



Tutorial leader: Christoff Bürger



Presenter: Oliver Lenord BOSCH Invented for life



Presenter: Jörg Niere

dSPACE

