#### APPLICATION OF MODEL-BASED TESTING TO DYNAMIC EVALUATION OF FUNCTIONAL MOCKUP UNITS

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#### MASTER ALGORITHM









## MOTIVATION

Barriers in FMI adoption (ordered by importance):

- Lack of transparency in features supported by FMI tools.
- Insufficient documentation and a lack of examples, tutorials, etc.
- It is difficult to implement FMUs.
- There is a lack of tools that sufficiently support FMI.
- Difficulties in practical aspects, like IT-prerequisites in cross-company collaboration.

Gerald Schweiger et al., "An Empirical

Standards, Challenges and Research Needs," *Simulation Modelling Practice* and Theory 95 (2019): 148–63.

https://doi.org/10.1016/j.simpat.2019.05

Survey on Co-Simulation: Promising

.001.



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## **RELATED WORK: GOAL**





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## **APPROACH OVERVIEW**

Model Based Testing (MBT):

the use of a model of the System-Under-Test (SUT) in order to guide test case generation.





- yEd Graph Editor: https://www.yworks.com/products/yed
- Graph ML Syntax: Brandes, Ulrik, Markus Eiglsperger, Jürgen Lerner, and Christian Pich. Graph Markup Language (GraphML), 2013.
- Modbat Tool: Artho, Cyrille Valentin, Armin Biere, Masami Haqiya, Eric Platon, Martina Seidl, Yoshinori Tanabe, and Mitsuharu Yamamoto. "Modbat: A Model-Based API Tester for Event-Driven Systems." In Hardware and Software: Verification and Testing, 8244:112-28. Cham: Springer International Publishing, 2013. https://doi.org/10.1007/978-3-319-03077-7\_8.



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### **EDGE IMPLEMENTATIONS**



#### FMU Supplier FMU Supplier Results

#### class FMIGraphModel extends ModBatGraphModel

#### // SUT and Time

var instance: IFmiComponent

**var** t = 0

. . .

#### // Edge Methods

def e\_Instantiate() = {

instance = instantiate(fmu, getGuid(fmu))

#### def e\_SetINIE() = {

// Pick a random var from the // INIE set of variables // Pick a value (e.g., nominal value), and // invoke the corresponding // instance operation. setVar(getRandomElement(INIE))

#### def e\_Terminate() = { val s = instance.terminate() assert(s == Fmi2Status.OK)

#### def e\_Step() = { // Choose a step size according to

// FMU Capabilities
var H = chooseH()
// Execute the step, and
// check if the step was carried out
val res = instance.doStep(t, H, true)
assert(res == Fmi2Status.OK)
t = t+H

#### def e\_Free() = { instance.freeInstance()

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#### **RELATED WORK: APPROACH**

#### THE DISTRIBUTED CO-SIMULATION PROTOCOL FOR THE INTEGRATION OF **REAL-TIME SYSTEMS AND SIMULATION ENVIRONMENTS**

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Krammer, Martin, Martin Benedikt, Torsten Blochwitz, Khaled Alekeish, Nicolas Amringer, Christian Kater, Stefan Materne, et al. "The Distributed Co-Simulation Protocol for the Integration of Real-Time Systems and Simulation Environments," 1-14. Bordeux, France: Society for Modeling & Simulation International, 2018. https://doi.org/10.5555/3275382.3275383.



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Address FMI-Specific Challenges:

- Many edges between same src and trg states





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- Edges shared by many src states









- Repeat operation a finite number of times





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- Decomposition: Edge and State merging



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## **EXPERIMENTS: OVERVIEW**





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#### **EXPERIMENTS: MODEL**





#### **EXPERIMENTS: STATISTICS**

Variable	Value
FMUs passing all tests.	77
FMUs failing at least one test.	55
Total FMUs tested (sum above two).	169
Failures analyzed	102



# **EXPERIMENTS: COMMON FAILURES**

1. The FMU does not recognize the value reference for a variable declared in its model description. Such a variable is set during initialization mode.

2. After an FMU is terminated, it fails when a variable belonging to the set X is queried.

3. The getRealStatus operation is not supported after an instance is terminated.



Figure 11: Calling sequence of Co-Simulation C functions in for



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# **EXPERIMENTS: COMMON FAILURES**

4. During stepping mode, a tunable parameter (i.e., a scalar variable with causality="parameter" and variability="tunable") is changed. The FMU then logs a message that it cannot be changed, and returns an error.





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# **EXPERIMENTS: COMMON FAILURES**

5. URI has multiple possible formats for the absolute path of a file, and some FMUs only support one. This causes a failure in the instantiation of the FMU.

6. The outputs are queried after a change in the inputs, without a doStep in-between, causing the FMU to return an error.

7. The reset operation (mandatory in the standard) is not implemented.

8. Some FMUs do not isolate instances in the sense that one failed operation in an instance of an FMU will affect the outcome of other operation calls in a different instance of the same FMU.

9. A variable was set with a value that is outside the scope of an FMU (even when picked respecting the boundaries set by the FMU).





#### LIMITATIONS

- FMI Cross Check repository is a moving target.

- 1000 Tests per FMU cover 95% of all cases for that FMU (including possible variables set and get.

- Most tests do not run co-simulations until the end (we have FMU Compliance Checker for that).

- Choice of default values for parameters can cause tests to fail for correct FMUs. Seldom happened (14 out of 14733 tests).

- Asynchronous operations not considered.





## **LESSONS LEARNED**

- FMUs mix numerical with model parameters

- Better documentation on what these do,
- Facilitate configuration of co-simulations
- FMUs do not disclose constraints on variables
  - Co-simulations crash and it's hard to know why.





#### HintCO – Hint-Based Configuration of Co-Simulations

**LESSONS LEARNED** 

Cláudio Gomes<sup>1,2</sup>, Bentley James Oakes<sup>1,2</sup>, Mehrdad Moradi<sup>1,2</sup>, Alejandro Torres Gámiz<sup>3</sup>, Juan Carlos Mendo<sup>3</sup>, Stefan Dutré<sup>4</sup>, Joachim Denil<sup>1,2</sup>, Hans Vangheluwe<sup>1,2</sup> <sup>1</sup>University of Antwerp, Belgium <sup>2</sup>Flanders Make vzw, Belgium <sup>3</sup>Boeing Research & Technology Europe, Madrid <sup>4</sup>Siemens, Belgium {claudio.gomes, mehrdad.moradi, bentley.oakes, joachim.denil, hans.vangheluwe}@uantwerpen.be, {alejandro.torresgamiz,juan.c.mendo}@boeing.com, stefan.dutre@siemens.com

- Different interpretations of feedthrough: the outputs are queried after a change in the inputs, without a doStep in-between, causing the FMU to return an error.

• Can be tested per FMU:  $get_c(set_c(s_c, u_c, v_1), y_c) \neq get_c(set_c(s_c, u_c, v_2), y_c)$ .



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7 (out of 113) FMUs implement feedthrough. Some tools changed approach in between versions.

After discussions in FMI Steering committee, FMUs (for FMI 2.0.1) should not support feedthrough.

Feedthrough is important for physical couplings:



Gomes, Cláudio, Bentley James Oakes, Mehrdad Moradi, Alejandro Torres Gamiz, Juan Carlos Mendo, Stefan Dutre, Joachim Denil, and Hans Vangheluwe. 2019. "HintCO - Hint-Based Configuration of Co-Simulations." In *International Conference on Simulation and Modeling Methodologies, Technologies and Applications*, 57–68. Prague, Czech Republic. https://doi.org/10.5220/0007830000570068.







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#### **THANK YOU!**





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