Hybrid Cosimulation: It's About Time

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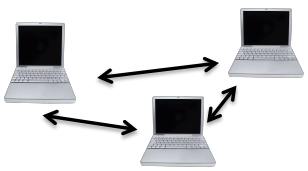
Agenda

Part I

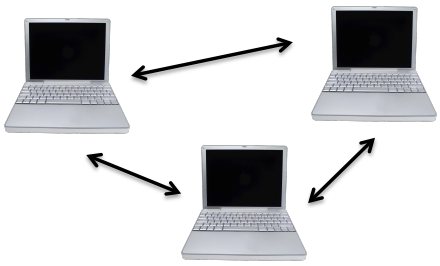
Functional Mockup Interface (FMI)



Part II

Hybrid Cosimulation with Superdense Integer Time

Part I
Functional Mock-up Interface (FMI)



What is FMI?

FMI

Functional Mock-up Interface (FMI) is a standard, not a tool.

Used for simulating the dynamics of complex heterogeneous systems.

Initiative from Daimler AG. Developed in a EU project called MODELISAR. Now maintained by Modelica Association.

Current version is 2.0. Supported by more than 50 tools (open source and commercial).

Functional Mock-Up Unit (FMU) is a model instance that can be used in a simulation.

FMU

An FMU is a zip file containing:
- An XML file describing static info (e.g., port names)
- C-files and dynamically loadable libraries implement the behavior.

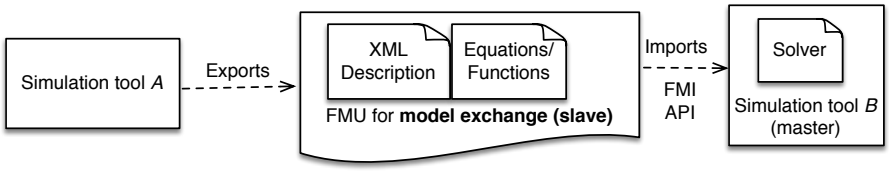
Master Algorithm (MA)

The MA orchestrates the execution of the FMUs.

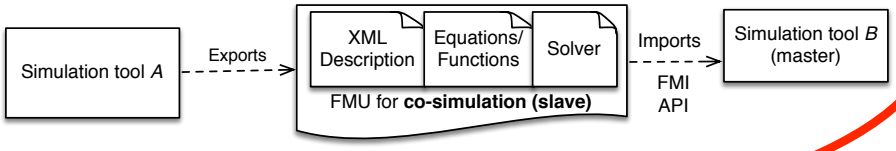
Master algorithms are not part of the standard.
It is “up to the tool” to implement them.

Model Exchange or Co-Simulation?

FMI for Model Exchange



FMI for Co-Simulation

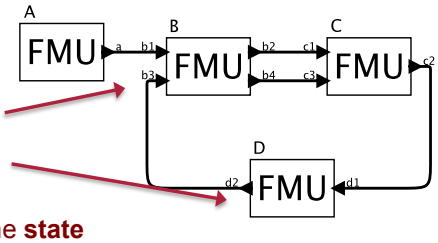


This talk concerns FMI for co-simulation

FMI 2.0 for co-simulation cannot model reactive systems

$$\texttt{init}_c : \mathbb{R}_{\geq 0} \rightarrow S_c$$
$$\texttt{set}_c : \bar{S_c} \times U_c \times \mathbb{V} \rightarrow S_c$$
$$\texttt{get}_c : S_c \times Y_c \rightarrow \mathbb{V}$$
$$\texttt{doStep}_c : S_c \times \mathbb{R}_{>0} \rightarrow S_c \times \mathbb{R}_{>0}$$

Set input values and **get** output values at distinct **communication points**.



doStep advances the **state** and the **time**.

Version 2.0 makes it impossible to implement a component with zero latency (e.g., cannot implement synchronous components).

There is an initiative now to introduce a third kind of FMU: **FMI for hybrid co-simulation.**

Our work concerns a possible solution for such a standard.

"There is the additional restriction in "slaveInitialized" state that it is not allowed to call fmi2GetXXX functions after fmi2SetXXX functions without an fmi2DoStep call in between."
(FMI standard 2.0, July 25, 2014, page 104)

"... communication step size (h_c). The latter must be > 0.0"
(FMI standard 2.0, July 25, 2014, page 100)

Part II
Hybrid Cosimulation with Superdense Integer Time

Superdense Time

Non-negative real numbers represent time in usual Newtonian sense.

Set of natural numbers

$$T = \mathbb{R}_+ \times \mathbb{N}$$

$$\tau \in T \qquad \tau = (t, n)$$

Every communication point is a member of ***T*** and ***T*** is totally ordered.

n is called the **microstep**, which indexes sequences of values at time ***t***.

Implementing Time

Specification uses real numbers, which is often approximated using floating-point numbers in implementations.

Problem: not safe to compare for equality (necessary in for instance a discrete-event formalism)

```
double r = 0.8;
double k = 0.7;
k = k + 0.1;
printf("%f,%f,%d\n",r,k,r==k);
```

```
0.800000,0.800000,0
```

r == k is false.

A solution should provide the following properties:

1. The time origin should not affect the precision.
2. Addition of time must be associative.

These items do not hold for floating-point numbers.

Continuous-Time (CT) and Discrete-event (DE) Signals

Represents the absent of a value.

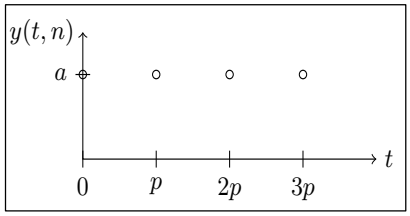
A signal ***x*** is a function of time.

$$x : T \rightarrow \mathbb{R} \cup \{\varepsilon\}$$

Note: An implementation do NOT need to implement absent explicitly.

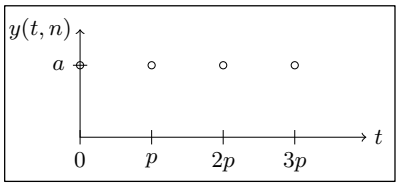
A **continuous-time** (**CT**) signal is one that has a non-absent value for all $\tau \in T$.

A **discrete-event** (**DE**) signal is one that has a non-absent value at only some $\tau \in D \subset T$, where D is a **discrete set**.

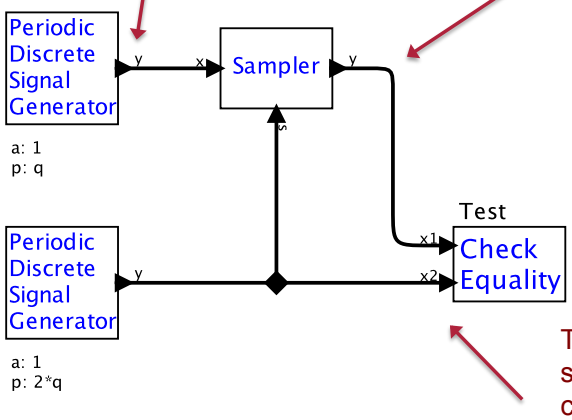


A signal is **discontinuous** at any time $t \in \mathbb{R}$ if there exist $n, m \in \mathbb{N}$ such that $x(t, n) \neq x(t, m)$.

Test Case: Simultaneous Events

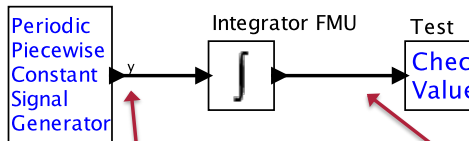


Samples exactly with period p=2*q

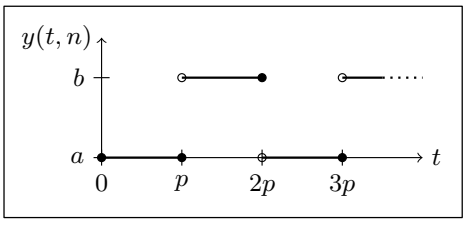


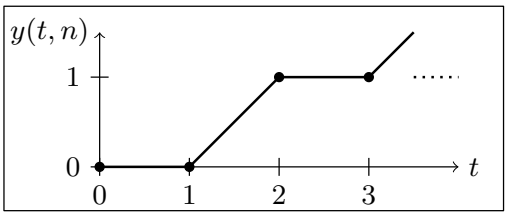
Test for well-defined notion of simultaneity. An example where correct implementation of time is needed.

Test Case: Integrating Discontinuous Signals



The output should be continuous

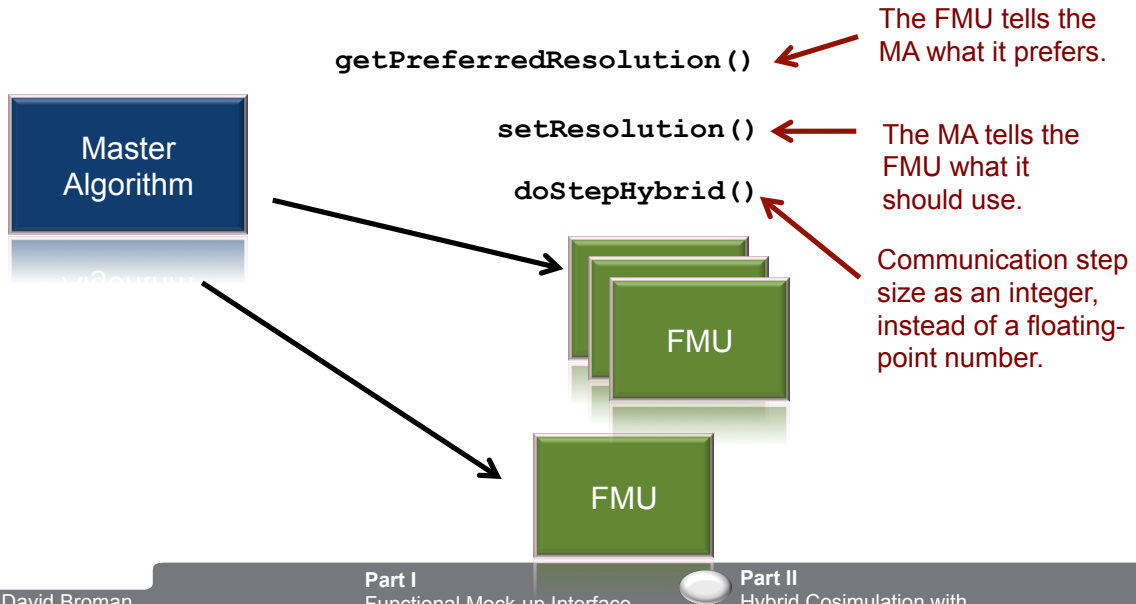




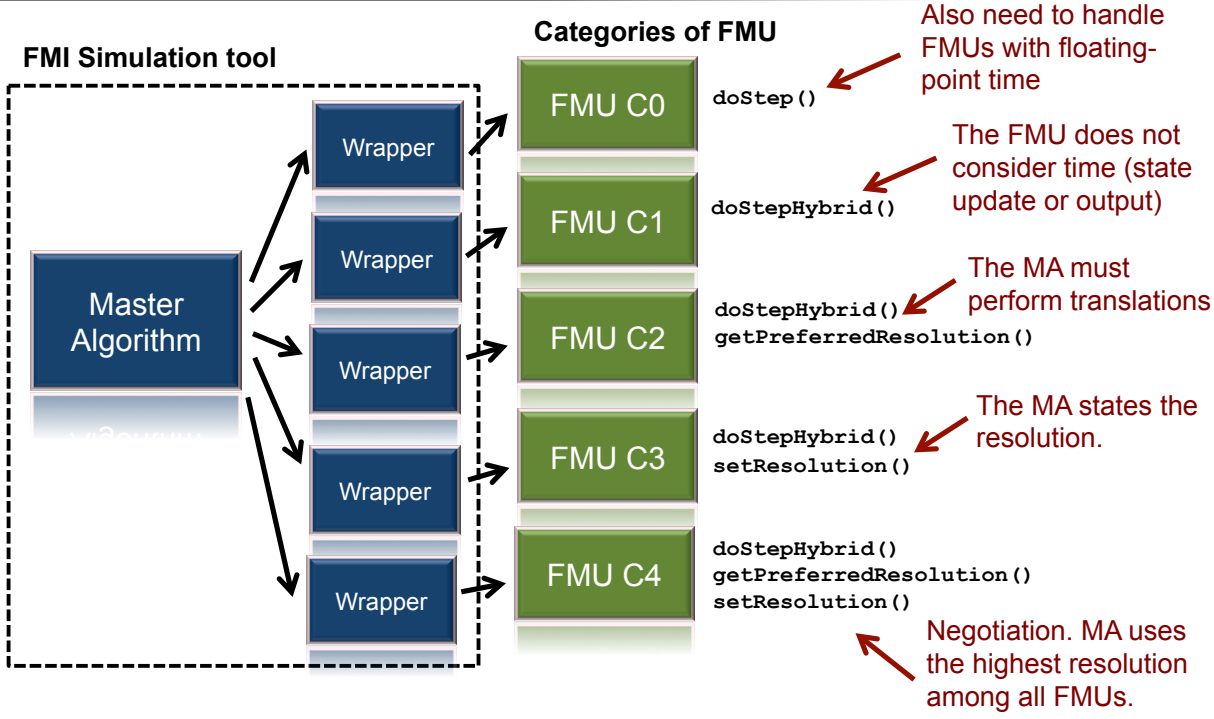
Extending FMI with Integer Time

What should the time resolution be?

Who determines the resolution?
The MA? The FMUs? The user?



Extending FMI with Superdense Integer Time



Conclusions

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Some key take away points:

- The current FMI standard 2.0 lacks the possibility of **hybrid co-simulation.**
- A possible extension can be based on **superdense time** and **integer time** with negotiation of resolution between FMUs and MA

Thanks for listening!

David Broman, Christopher Brooks, Lev Greenberg, Edward A. Lee, Michael Masin, Stavros Tripakis, and Michael Wetter. **Determinate Composition of FMUs for Co-Simulation.** In *Proceedings of the International Conference on Embedded Software (EMSOFT 2013)*, Montreal, Canada, 2013.

David Broman, Lev Greenberg, Edward A. Lee, Michael Masin, Stavros Tripakis, and Michael Wetter. **Requirements for Hybrid Cosimulation Standards.** In *Proceedings of 18th ACM International Conference on Hybrid Systems: Computation and Control (HSCC 2015)*, Pages 179-188, CPSWeek, Seattle, WA, USA, 2015.