Automated Configuration of Co-simulation with Domain Specific Hints

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FLANDERS MAKE MANUFACTURING INNOVATION NETWORK

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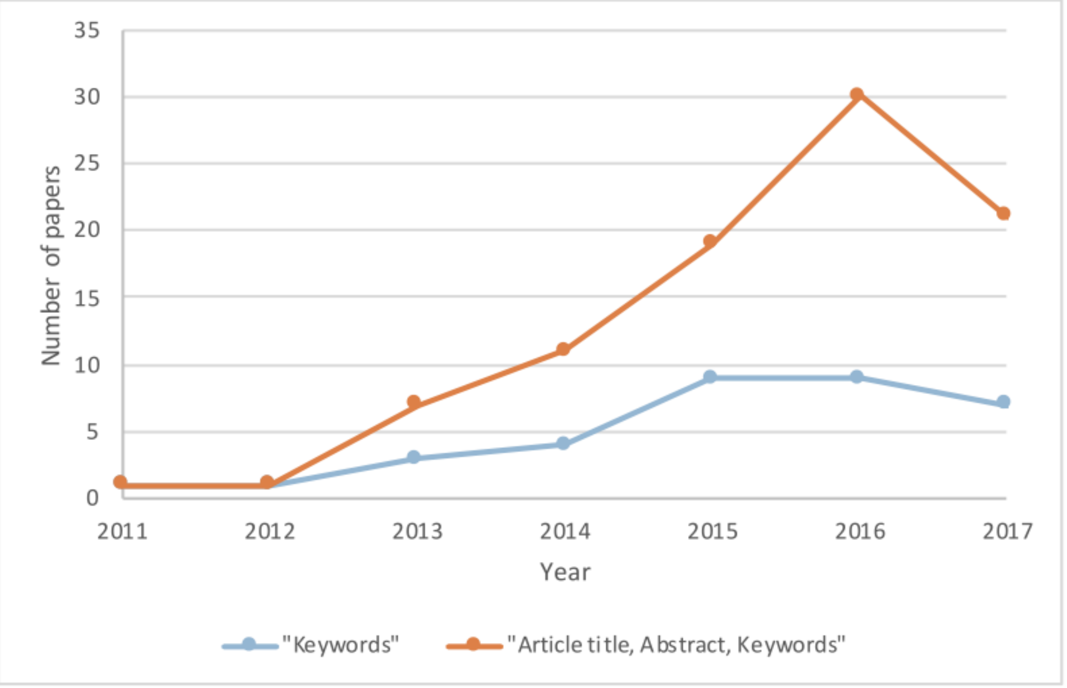
Co-simulation on the rise

- Keyword analysis



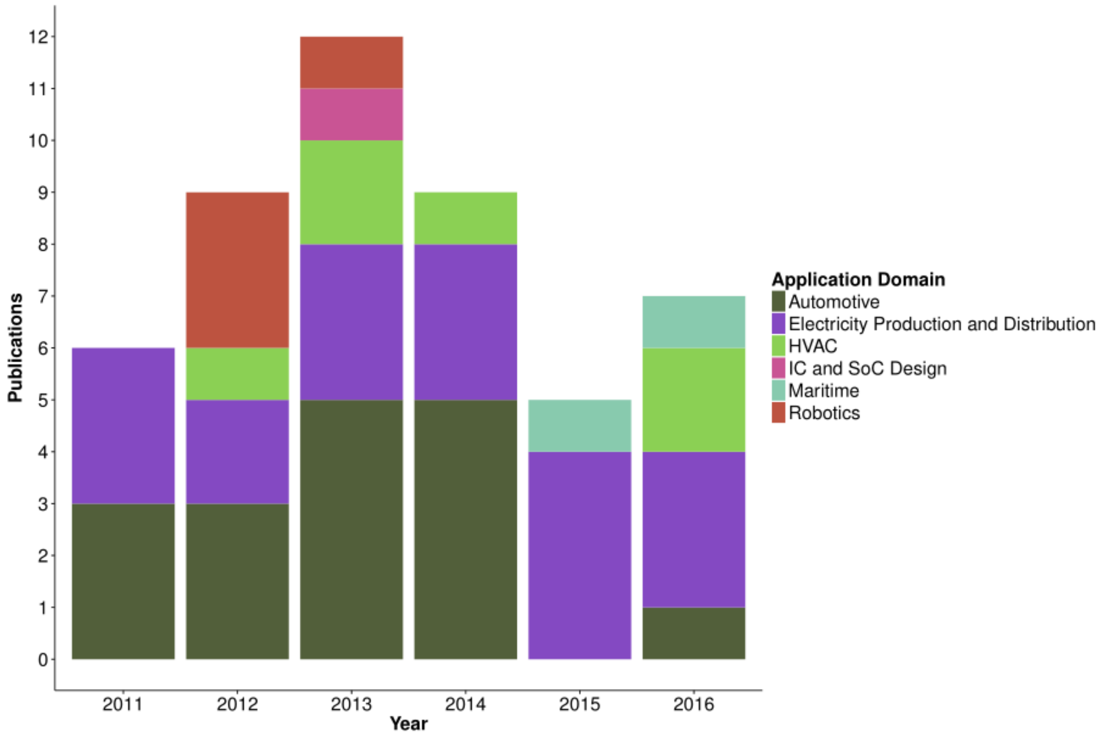
Co-simulation on the rise

- Research Projects

Project	Duration	Goals
COSIBA [2]	2000–2002	Formulate a co-simulation backplane for coupling electronic design automation tools, supporting different abstraction levels.
ODETTE [9]	2000–20003	Develop a complete co-design solution including hardware/software co-simulation and synthesis tools.
MODELISAR [8]	2008–2011	Improve the design of embedded software in vehicles.
DESTECS [4]	2010–2012	Improve the development of fault-tolerant embedded systems.
INTO-CPS [7]	2015–2017	Create an integrated tool chain for Model-Based Design of CPS with FMI.
ACOSAR [1]	2015–2018	Develop a non-proprietary advanced co-simulation interface for real time system integration.
OpenCPS [10]	2015–2018	Improve the interoperability between Modelica, UML and FMI.
ERIGrid [6]	2015–2020	Propose solutions for Cyber-Physical Energy Systems through co-simulation.
PEGASUS [11]	2016–2019	Establish standards for autonomous driving.
CyDER [3]	2017–2020	Develop a co-simulation platform for integration and analysis of high PV penetration.
EMPHYSIS [5]	2017–2020	Develop a new standard (eFMI) for modeling and simulation environments of embedded systems.

Co-simulation on the rise

- Applications



Co-simulation on the rise

- Surveys

On the Terminology and Structuring of Co-Simulation Methods

Irene
dwh GmbH Si
Vienn
irene.ha

ABSTRACT

The need for holistic simulation o
and more apparent, arising from
approached by different scientific
differences in terminology arisin
levels on which they meet as well
and structuring of current state-

CCS CONCEPTS

• **Computing methodologies** -
niques; *Simulation theory*;

KEYWORDS

Cosim
of Int
Powe

Fundamentals, Softwa

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Co-simulation: a Survey

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Modeling and simulation techniques are today extensively used both in industry and science. Parts of larger systems are, however, typically modeled and simulated by different techniques, tools, and algorithms. In addition, experts from different disciplines use various modeling and simulation techniques. Both these facts make it difficult to study coupled heterogeneous systems.

Co-simulation is an emerging enabling technique, where global simulation of a coupled system can be achieved by composing the simulations of its parts. Due to its potential and interdisciplinary nature, co-simulation is being studied in different disciplines but with limited sharing of findings.

In this survey, we study and survey the state-of-the-art techniques for co-simulation, with the goal of enhancing future research and highlighting the main challenges.

To study this broad topic, we start by focusing on discrete-event-based co-simulation, followed by continuous-time-based co-simulation. Finally, we explore the interactions be these two paradigms, in hybrid co-simulation.

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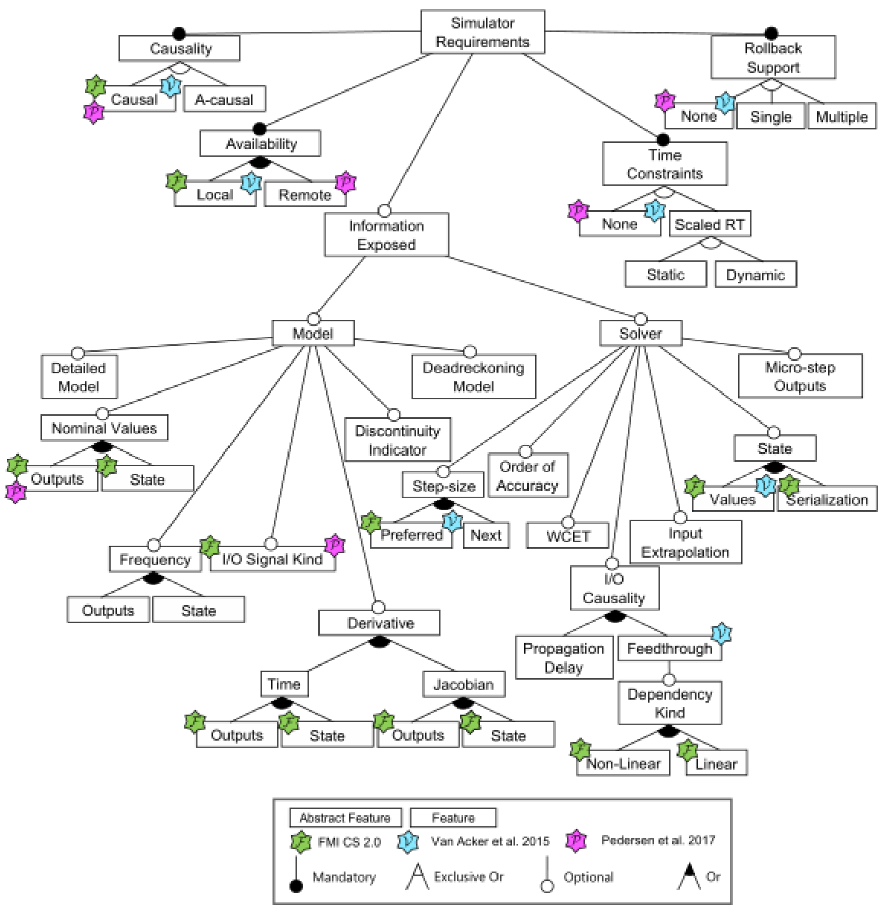

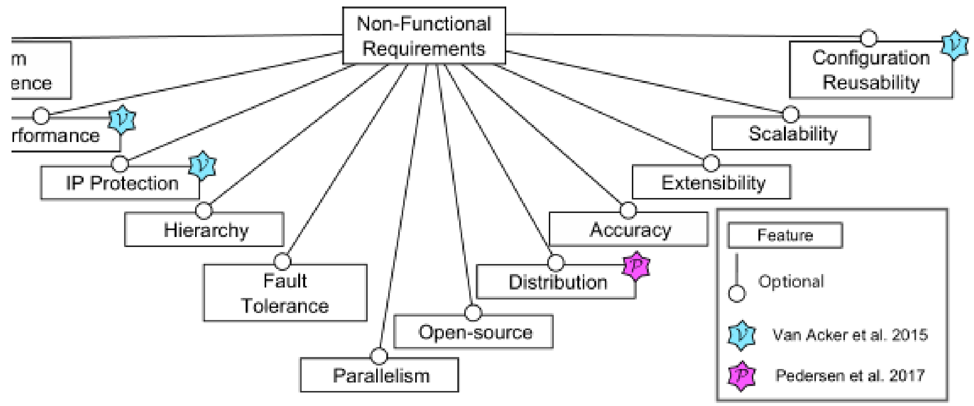

Industry Pains

Functional Mock-up Interface: An empirical survey identifies research challenges and current barriers

Gerald Schweiger[1] Cláudio Gomes[2] Georg Engel[1] Irene Hafner[3] Josef-Peter Schoeggl[4] Alfred Posch[5] Thierry Nouidui[6]

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Table 2. Expert assessment of current barriers for FMI based on a Seven-point Likert scale.

Score: Entirely agree (7) Mostly agree (6) Somewhat agree (5) Neither agree nor disagree (4) Somewhat disagree (3) Mostly disagree (2) Entirely disagree (1)	Mean	Median	Interpolated Median
Not a Barrier			
It is difficult to post-process simulation results	3.57	2.50	2.50
Concerns of industry/academia regarding FMI and IP protection	3.52	3.00	2.83
No pre-implemented Master Algorithms	4.08	3.00	3.25
Somewhat of a Barrier			
...d for co-simulation	4.52	4.00	3.75
...ion/industry) in defining and developing the FMI standard	4.12	4.00	3.81
	4.04	4.00	3.83
	4.27	4.00	3.83
	3.82	4.00	3.92
	4.07	4.00	4.00
Barrier			
FMI has limited support for hybrid co-simulation and it is not easily applicable	5.82	5.00	5.00
Lack of transparency in features supported by FMI tools	5.12	5.00	5.05
	5.14	5.00	5.17
...d academia	5.42	5.00	5.25
FMI has limited support for discrete co-simulation and it is not easily applicable	5.67	5.00	5.25

Not enough cooperation between theorists and practitioners.

Lack of tools that sufficiently support FMI

Difficult to implement FMUs

Insufficient documentation

Everyday Challenges

An Empirical Survey on Co-simulation: Promising Standards, Challenges and Research Needs

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* Not published: under review

Table 4: Experts' assessments: Current challenges. Score: Very Frequently (6) Frequently (5) Occasionally (4) Rarely (3) Very Rarely (2) Never (1).

	Mean	Median	Interp. Median
Difficulties in practical aspects, like IT-pre…	4.7	5.0	4.7
Numerical stability issues of co-simulation [48], [21], [49]…	4.4	4.0	4.3
Difficulties in how to define tolerances	4.3	4.0	4.0
Difficulties in choosing the right co-simulation orchestration algorithm (master).	3.6	3.0	3.4

Insufficient communication between theorists and practitioners

Judging the validity of the co-sim

Defining macro-step size.

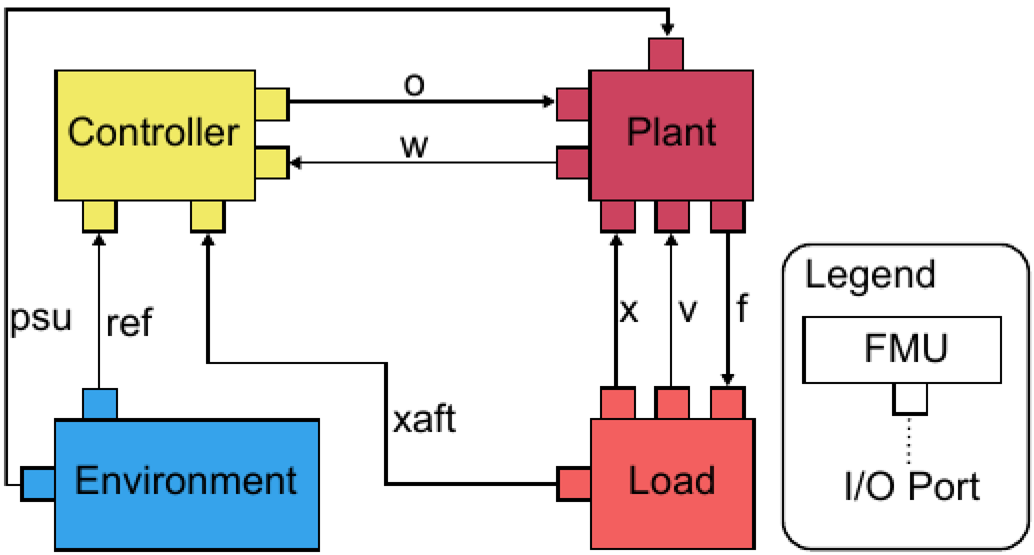
Algebraic loops.

Defining tolerances

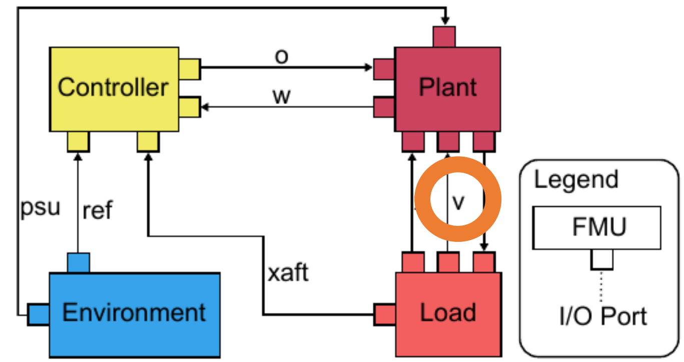
Automated Configuration

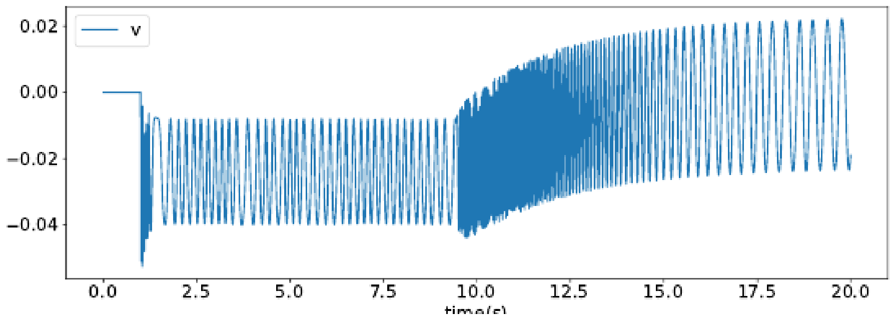
- Why is this so difficult?
- Why are adaptive step size algorithms not enough?

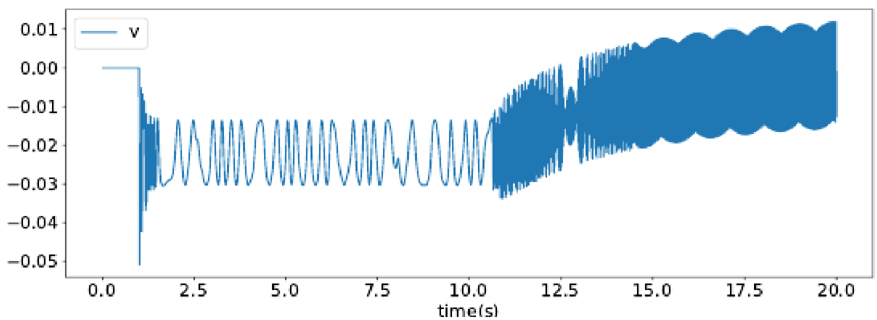
Motivating Example

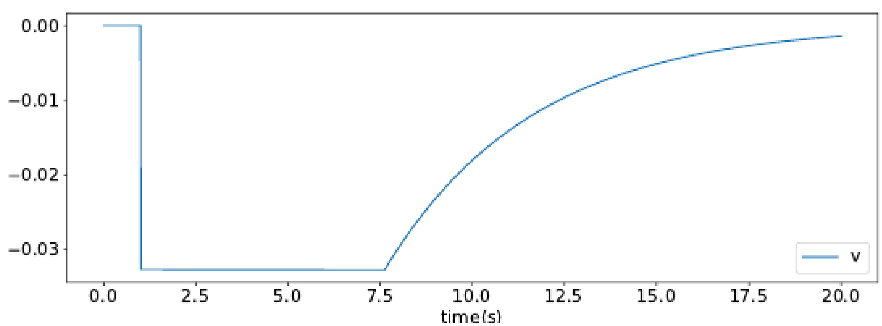


Example Behavior(s)

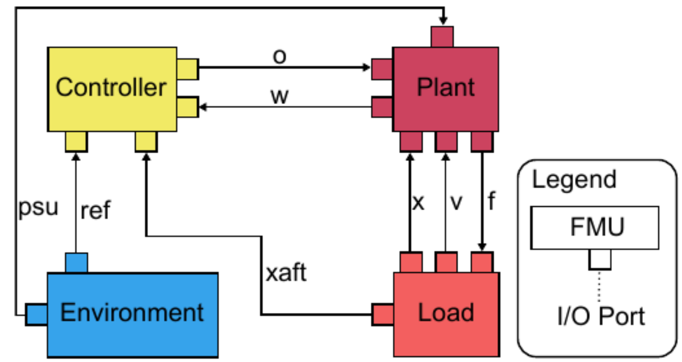


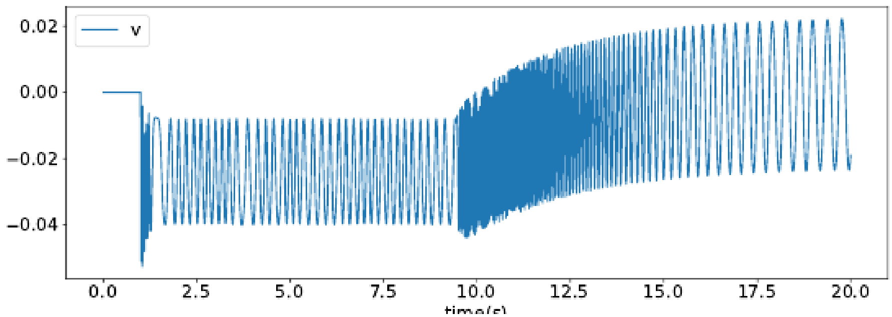


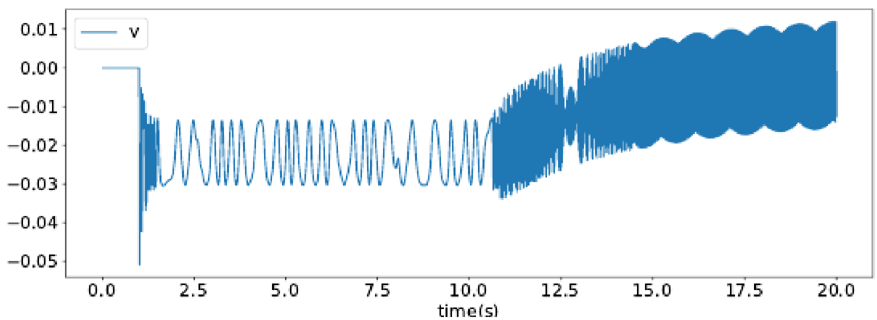


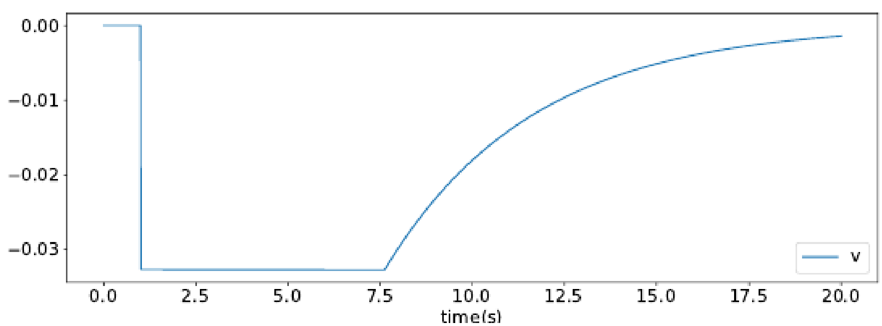


Example Behavior(s)









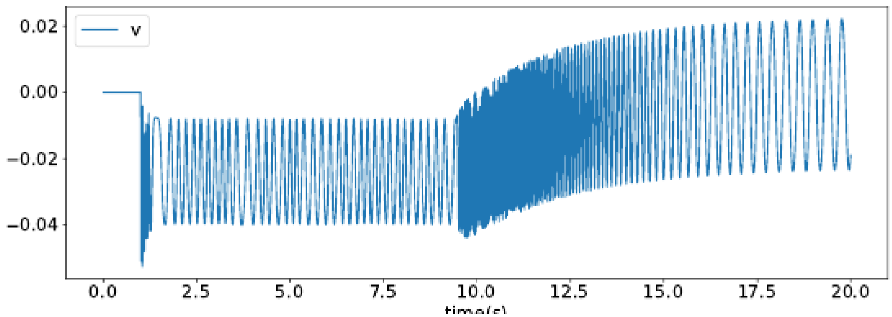
Solution:

Engineers have intuition (or past experience) on the correct behavior

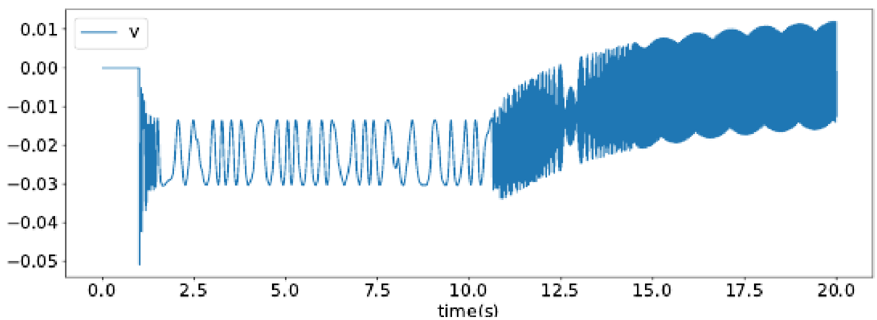
Example:
Controller is software running at 10000000Hz
Plant and Load are connected by a power connection (v*f)

Example Behavior(s)

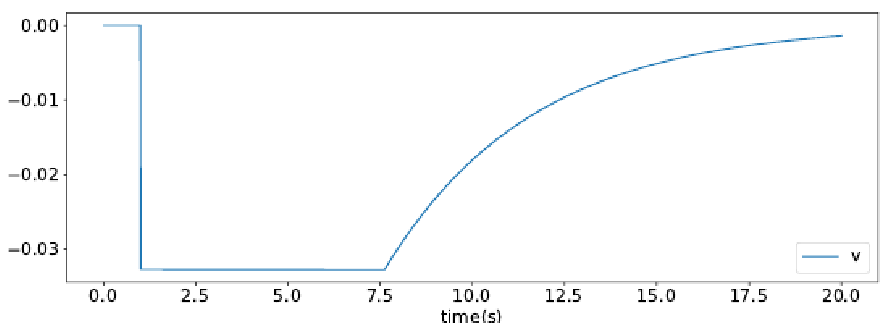
Why is this so difficult?



Fixed-step Jacobi,
step size 1×10^{-6} s,



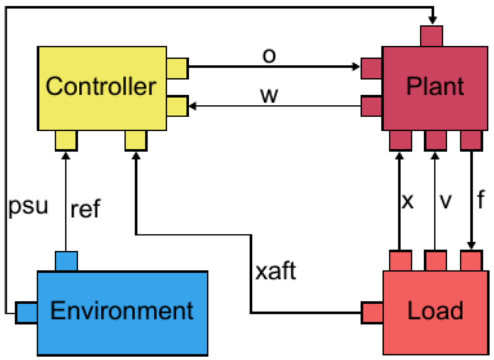
1st-order input interpolations,
step size 1×10^{-6} s,



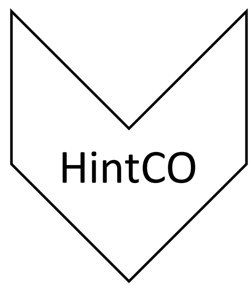
Combination of:
1st-order input interpolations,
causality preservation,
and energy conservation,
in selected signals

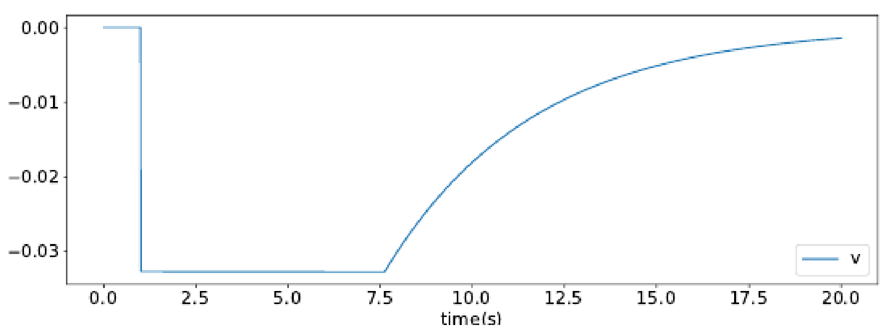
Configuration Effort

Grand Challenge



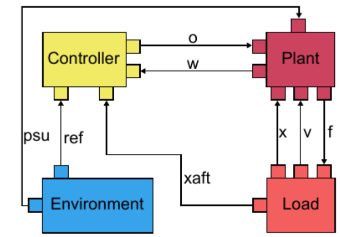
Controller is software running at 10000000Hz
Plant and Load are connected by a power connection (v*f)





Combination of:
1st-order input interpolations,
causality preservation,
and energy conservation,
in selected signals

Grand Challenge - Detail



Controller is software running at 10000000Hz
Plant and Load are connected by a power connection (v*f)

Problem 1. *For a given set of properties P, a coupled model M, find a master algorithm*

$$\mathcal{A} = \langle C, L, H, (f)_{i \in \mathbb{N}} \rangle ,$$

that maximizes the size of the set

$$\{p : p \in P, M \models p \Leftrightarrow [\![M]\!]_{\mathcal{A}} \models p\} ,$$

FMUs (interpolations/extrapolations), and connections

Step size

Set/Get/DoStep invocation sequence

Real behavior of the coupled model

Co-sim behavior

Contrib. A – Hint Language

Controller is software running at 1e6 Hz

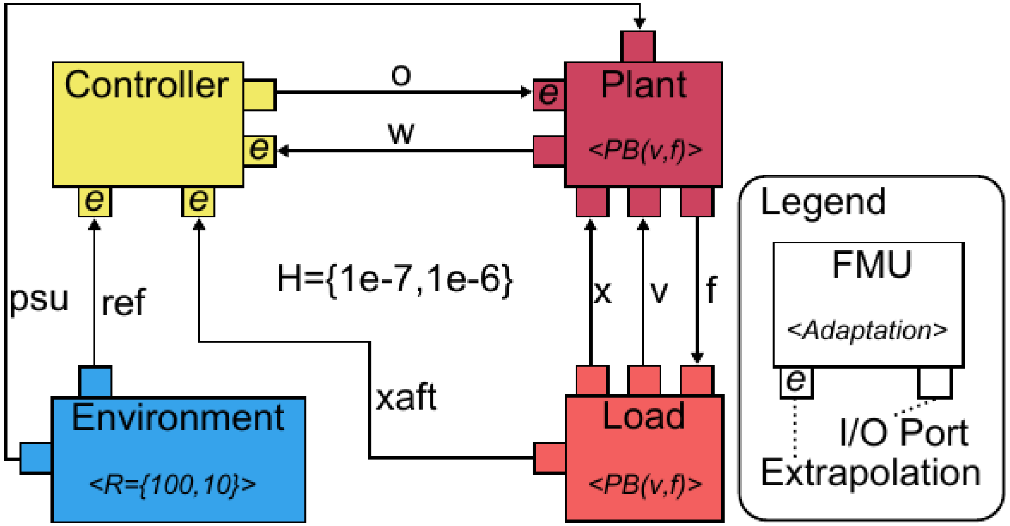
```
Hint ExecRate{
            description "Controller FMU is software."
            statements {
                Property ExecRate
                    FMUProperty FMU1.exec_rate == val 1.0e+6 hz
            }
            scope Globally
            pattern Universality:always-the-case-that ExecRate holds
        }
```

Plant and Load are connected by a power connection (v*f)

```
Hint PowerBond{
            description "Plant and Load FMUs
                        share a power connection."
            statements{
                Property PowerBond
                    Plant.f hinted-to-be PowerBondHint with Load.v
            }
            scope Globally
            pattern Universality:always-the-case-that PowerBond holds
        }
}
```

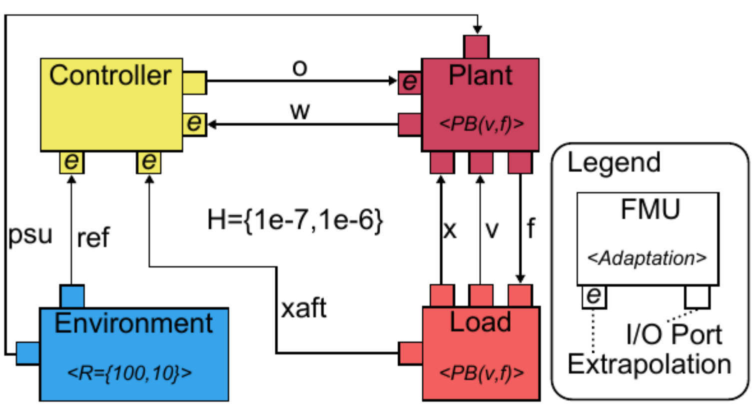
Contrib. B – Exploration

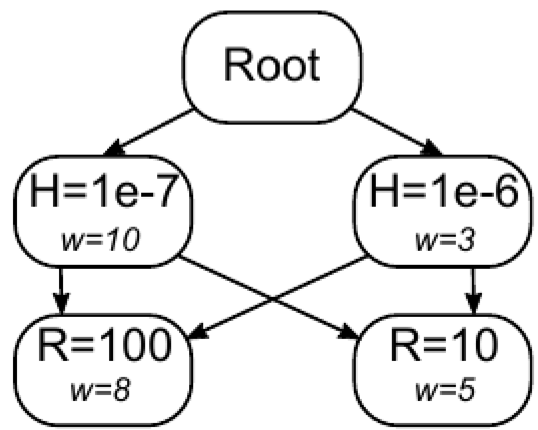
- Search Space Encoding:
  - Set of all communication step sizes
  - Set of all operation sequences
  - Set of all adaptations (e.g., interpolation, energy conservation, etc…) applied to FMUs



Contrib. B – Exploration

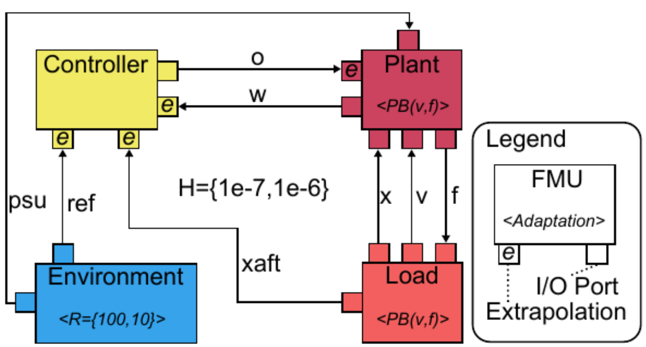
- Priority Variant Generation:
  - Compact representation of variants in a diagram, and
  - Prioritizes walk in that diagram

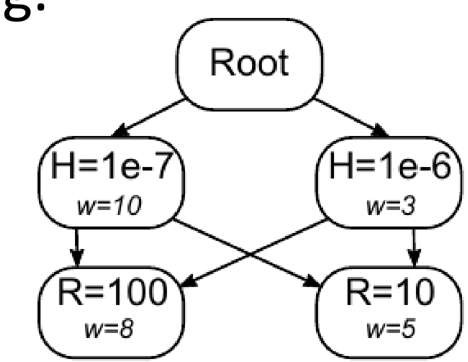


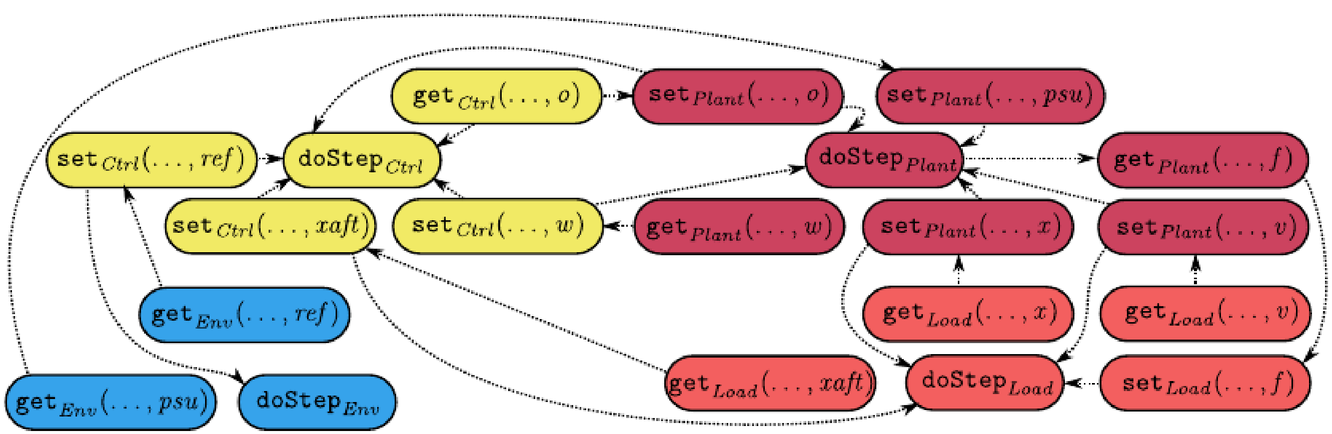


Contrib. B – Exploration

- Variant Execution:
  - Determine feasible operation ordering.







Topological Order:

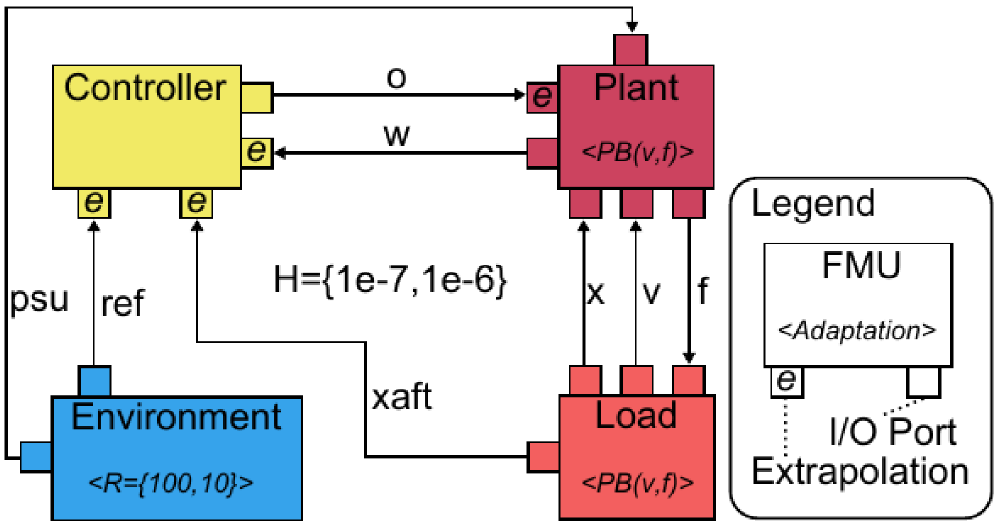
1. $\texttt{get}_{Env}(\ldots, ref)$
2. $\texttt{set}_{Ctrl}(\ldots, ref)$
3. $\texttt{get}_{Plant}(\ldots, w)$
4. $\texttt{set}_{Ctrl}(\ldots, w)$
5. $\texttt{get}_{Load}(\ldots, xaft)$
6. $\texttt{set}_{Ctrl}(\ldots, xaft)$
7. $\texttt{get}_{Ctrl}(\ldots, o)$
8. $\texttt{set}_{Plant}(\ldots, o)$
9. $\texttt{doStep}_{Ctrl}$
10. $\texttt{get}_{Env}(\ldots, psu)$
11. $\texttt{set}_{Plant}(\ldots, psu)$
12. $\texttt{get}_{Load}(\ldots, x)$
13. $\texttt{set}_{Plant}(\ldots, x)$
14. $\texttt{get}_{Load}(\ldots, v)$
15. $\texttt{set}_{Plant}(\ldots, v)$
16. $\texttt{doStep}_{Plant}$
17. $\texttt{get}_{Plant}(\ldots, f)$
18. $\texttt{set}_{Load}(\ldots, f)$
19. $\texttt{doStep}_{Load}$
20. $\texttt{doStep}_{Env}$

Contrib. B – Exploration

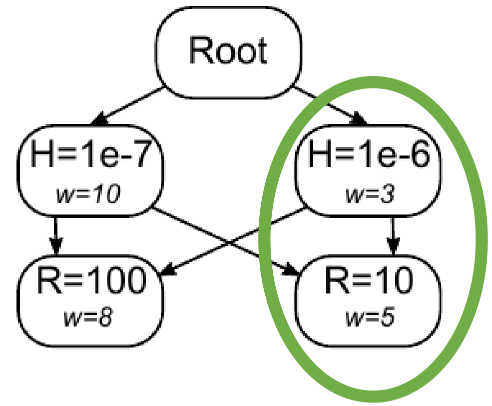
- Translating Hints to Adaptations:

  1. *For each FMU with a software controller hint, add an extrapolation adaptation to each of its input ports and to each of the input ports that are connected to its outputs.*
  2. *If there are multiple software hints with different configured frequency rates, define the scenario step size to be the inverse of the minimum of the frequency rates, and define the appropriate multi-rate adaptations on the software FMUs.*
  3. *For each PowerBond hint, add a power bond adaptation to each of the FMUs sharing the bond.*
  4. *Select the FMUs that are not affected by any hint, and add a multi-rate adaptation (if not already defined) with alternative step sizes at different orders of magnitude, and two alternative first order input approximations (interpolation and extrapolation). Higher weights are given to smaller step sizes and interpolations.*
  5. *If the co-simulation step has not been defined yet, define multiple alternative co-simulation steps with different orders of magnitude. Higher weights are given to smaller step sizes.*

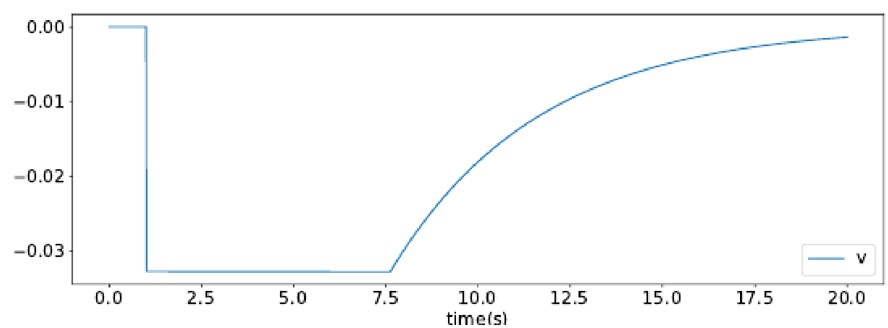
Results



Controller
o
w
e
e
e
e
Plant
<PB(v,f)>
psu
ref
H={1e-7,1e-6}
x
v
f
xaft
Environment
<R={100,10}>
Load
<PB(v,f)>
Legend
FMU
<Adaptation>
e
I/O Port
Extrapolation



Root
H=1e-7
w=10
H=1e-6
w=3
R=100
w=8
R=10
w=5



0.00
−0.01
−0.02
−0.03
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
time(s)
v

Summary

- Practitioners need more support for configuration of co-simulations
  - Existing master algorithms are not sufficient without extensive fine tuning.
- There is no general way of obtaining the real behavior of a coupled system,
  - So we propose to leverage engineer’s knowledge and past experience.
- We provide a tool to tackle this problem.

Questions

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Demo