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► **To cite this version:**

Benoit Caillaud, Mathias Malandain, Joan Thibault. Demo: IsamDAE, an Implicit Structural Analysis Tool for Multimode DAE Systems. HSCC 2020 - 23rd ACM International Conference on Hybrid Systems: Computation and Control, Apr 2020, Sydney, Australia. pp.1. hal-02545380

**HAL Id: hal-02545380**

**<https://inria.hal.science/hal-02545380v1>**

Submitted on 17 Apr 2020

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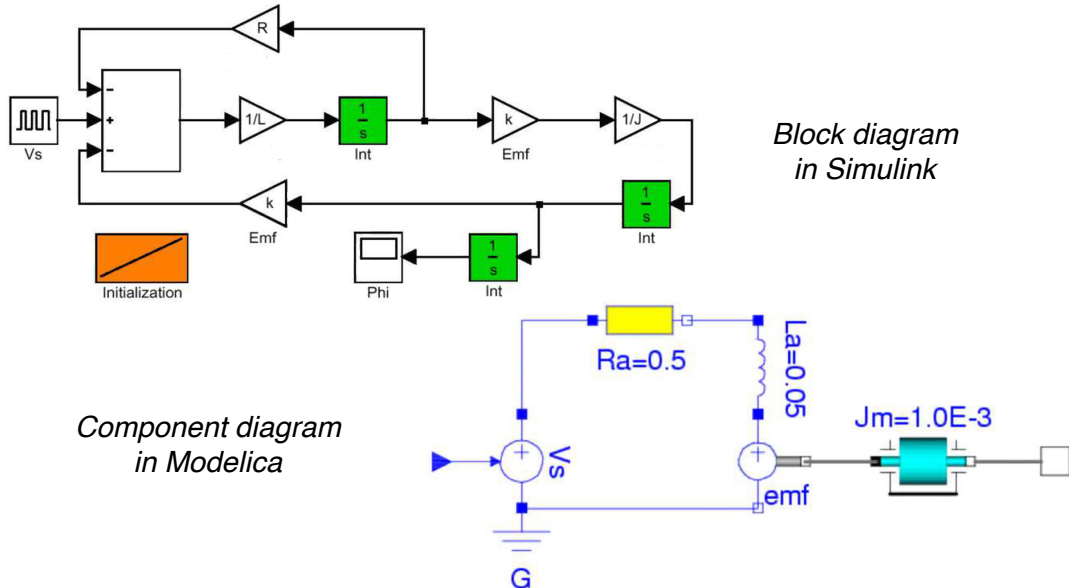
# Demo: IsamDAE, an Implicit Structural Analysis Tool for Multimode DAE Systems

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## DAE FOR THE MODELING OF (LARGE) CYBER-PHYSICAL SYSTEMS

### Large physical systems → *Differential-Algebraic Equations (DAE)*

- Components modeled with a few differential and/or algebraic equations
- Connections: algebraic equations (balance equations, Kirchhoff laws)
- **Pros:** compositional modeling, high reusability of physical components



### Non-smooth, or hybrid, systems → *Multimode DAE (mDAE)*

- In general, mDAE are poorly handled by existing tools
  - No proper *structural analysis* of mDAE at compile time

### Variable dimension systems → *Variable dimension models*

- (Dis)appearance of components in a CPS would be easily handled
- Such models are not handled by existing tools

## STRUCTURAL ANALYSIS OF DAE

### Handling DAE systems is harder than ODE

- No direct criterion to determine whether a DAE is determined
- Simulation code cannot be generated from the original model
- Compilation relies on *Structural Analysis (SA)*

### Structural analysis

- Graph-based (Pantelides method) or linear programming (Pryce's Sigma-method) algorithms
- Provides diagnosis about the model at compile time ('typechecking')
- Enables the generation of efficient simulation code:
  - equations are carefully differentiated, and grouped into the smallest possible *equation blocks*;
  - blocks are ordered ('scheduled') for the simulation of a time step

## THE ISAMDAE TOOL

### Structural analysis for mDAE, in an 'all-modes-at-once' fashion

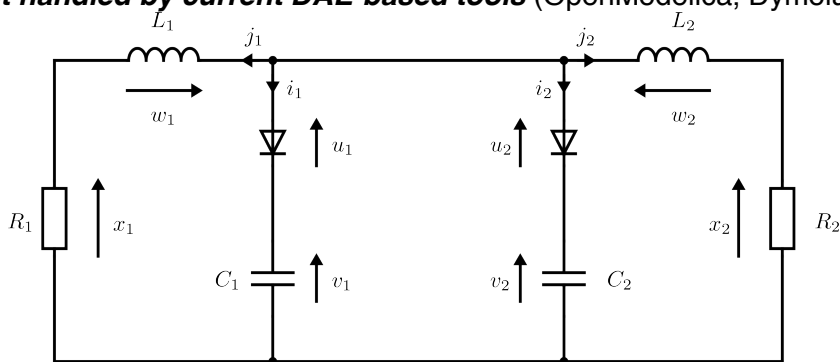
- **Input:** Ad hoc equation language used for declaring mDAE models
  - Implicit representation with BDD (preserves sparsity)
  - Structural analysis (from the Sigma-method) and block scheduling: adaptation of existing methods and novel algorithms
- **Output:** Detailed (but condensed) description of the simulation blocks and their dependencies, in all modes

### Implementation

- About 16,000 lines of OCaml code
- Libraries: menhir, mlbdd, OCaml-Tools, pprint, xml-light
- Software package: GraphViz

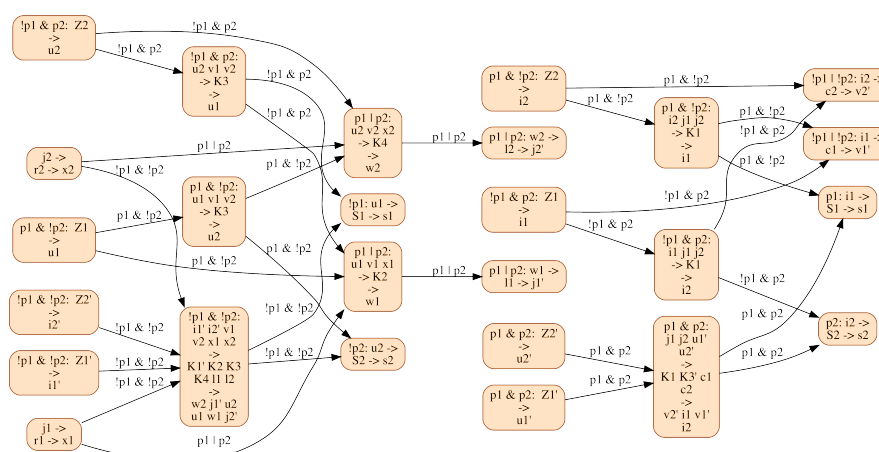
## THE RLDC2 EXAMPLE

- Two RLC circuits with ideal diodes, in parallel
- Mode-dependent structure: differentiation orders for the equations, as well as the resulting equation blocks, depend on the mode
- **Not handled by current DAE-based tools** (OpenModelica, Dymola)



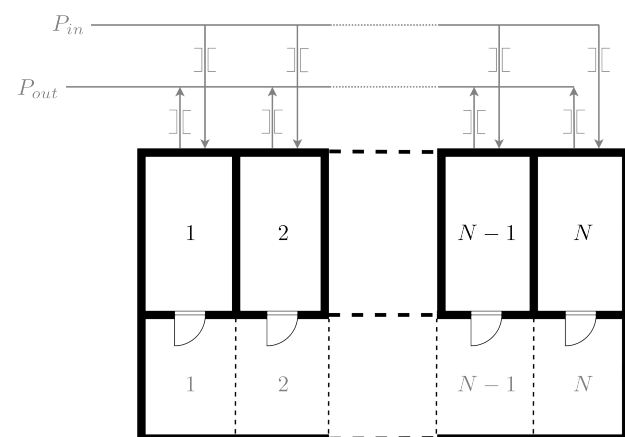
### Mode-dependent structural analysis by IsamDAE

- Checks that the model is determined in all modes
- Generates the mode-dependent scheduling graph shown below
- In each mode: description of the (*ODE-like*) blocks to be compiled into simulation code + dependencies (for their scheduling)
  - ✓ Same results, in each mode, as those of standard structural analysis



## THE BUILDING EXAMPLE

- **Scalable model:** single-story building with  $N$  rooms and doors
- Instantaneous mode transitions when a door is opened or closed
- Variables taken into account: pressures, temperatures →, air masses, enthalpies, heat and mass flows (compressible air)
- For  $N$  rooms :  $16N+5$  equations and variables,  $6^{N/2}$  modes



### Scaling-up of the structural analysis by IsamDAE

- The total number of blocks is an affine function of  $N$
- Experimental computation times: about  $O(N^3)$

