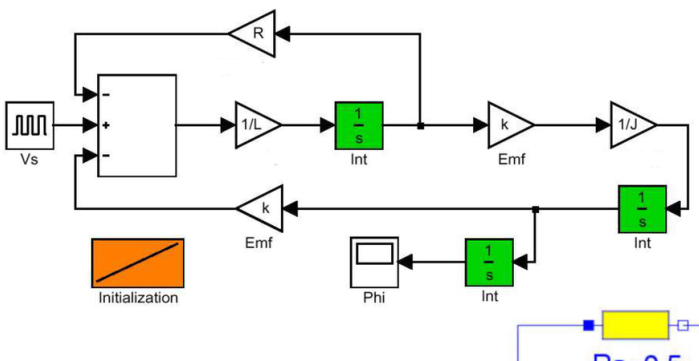
IsamDAE, an Implicit Structural Analysis Tool for Multimode DAE Systems

Benoît CAILLAUD, Mathias MALANDAIN, Joan THIBAULT
Inria, Univ Rennes, CNRS, IRISA, Hycomes team (Rennes, France)
benoit.caillaud@inria.fr – mathias.malandain@inria.fr – joan.thibault@irisa.fr

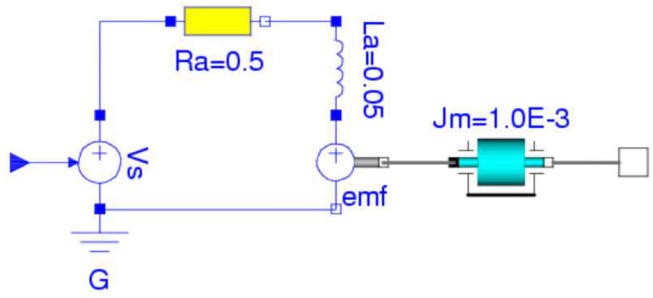
DAE FOR THE MODELING OF (LARGE) CYBER-PHYSICAL SYSTEMS

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



Block diagram in Simulink



Component diagram in Modelica

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

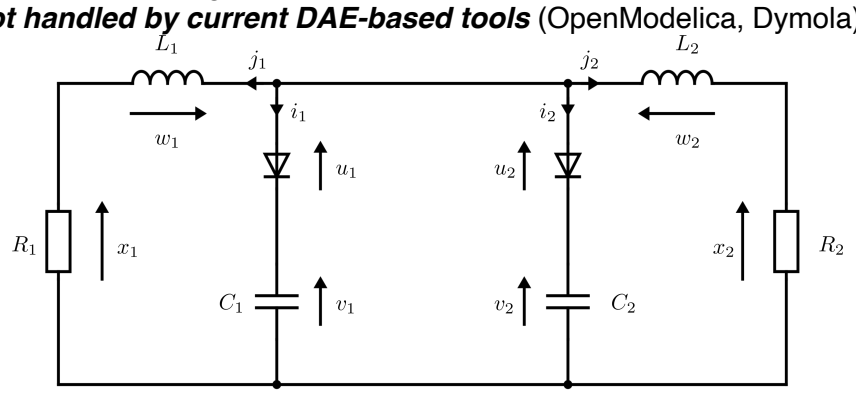
- In general, mDAE are poorly handled by existing tools
  - ➢ No *structural analysis* of mDAE at compile time

Reconfigurable systems → *Variable dimension* models

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

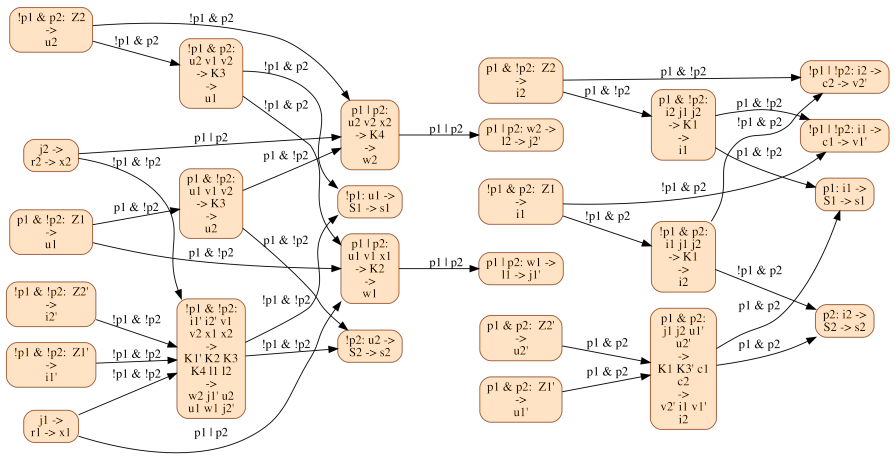
THE RLDC2 EXAMPLE

- 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*



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

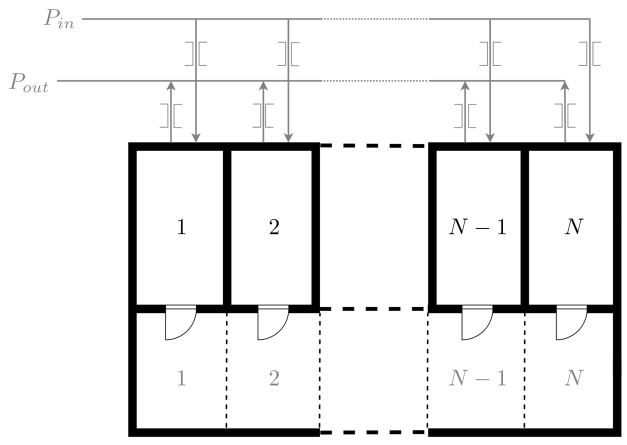
- ***Input:*** Ad hoc equation language used for declaring mDAE models
  - ➢ Implicit representation with BDD (preserves sparsity)
  - ➢ Structural analysis (from the Sigma-method) and block scheduling: adaptation of existing methods and novel algorithms
- ***Output:*** Detailed (but condensed) description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

Implementation

- About 25,000 lines of `OCaml` code
- Libraries: GuaCaml, `menhir`, `Mlbdd`, `pprint`, `xml-light`, `Snowflake`
- Software package: `GraphViz`

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

- Total number of blocks : affine function of *N*
- Empirical computational times: about $O(N^2)$
- *Up to N=150, ≥ 2500 equations, ≥ 10^{115} modes*