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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

**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 16,000 lines of Ocaml code
- Libraries: menhir, mlbdd, Ocaml-Tools, pprint, xml-light
- 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, \(O(N^2)\) modes

 Scaling-up of the structural analysis by IsamDAE

- The total number of blocks is an affine function of \(N\)
- Experimental computation times: about \(O(N^2)\)