Teaching Modelica for Mathematicians and Engineers

Modelica Educational Workshop
Berlin

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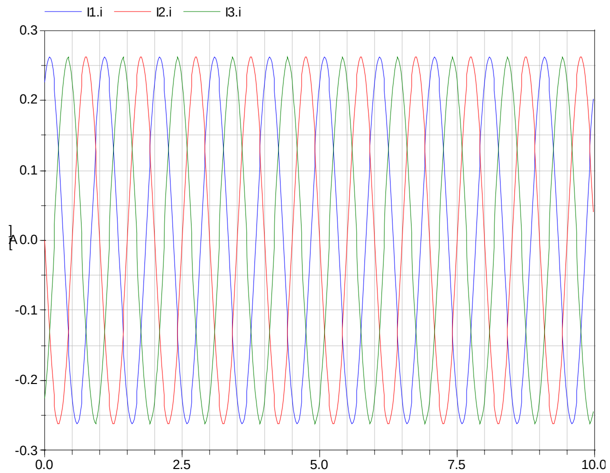
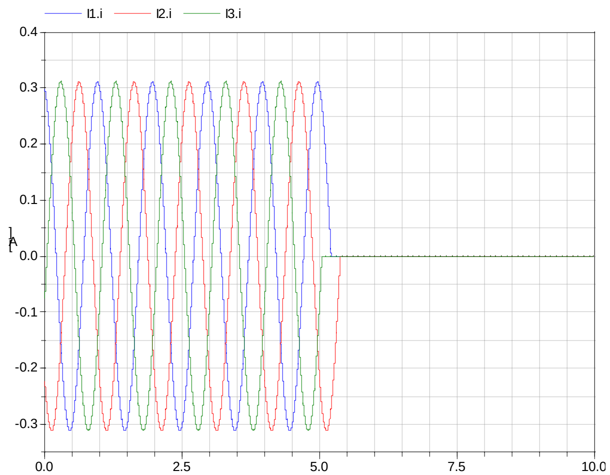
Outline

- Past Teaching Experience
  - Mathematicians
    - precognition, course objectives
  - Course Details
    - theoretical content, tools, exercises



- Discussion on Future Teaching Options
  - Mathematicians and Engineers
    - master students having less mathematical background
  - Tools and concepts
    - adaptation of previous course



Past Teaching (1999 – 2008)

- Course attendees (diploma-study in mathematics) [ca. 15]
  - good mathematical background
    - analysis and linear algebra topics
    - optimization (linear, nonlinear problems)
    - numerical methods (no ODEs)
    - theory on ordinary differential equations
    - familiar tools:Maple, Matlab (no Simulink)
    - basic programming knowledge (C/C++)
  - basic engineering background
    - simple mathematical modeling of physical components
      mechanics, electrical systems (static)
- Course objectives
  - engineering aspects
    - component and library development in Modelica
  - mathematical aspects
    - understand symbolic transformations and numerical issues

Past Teaching (1999 – 2008)

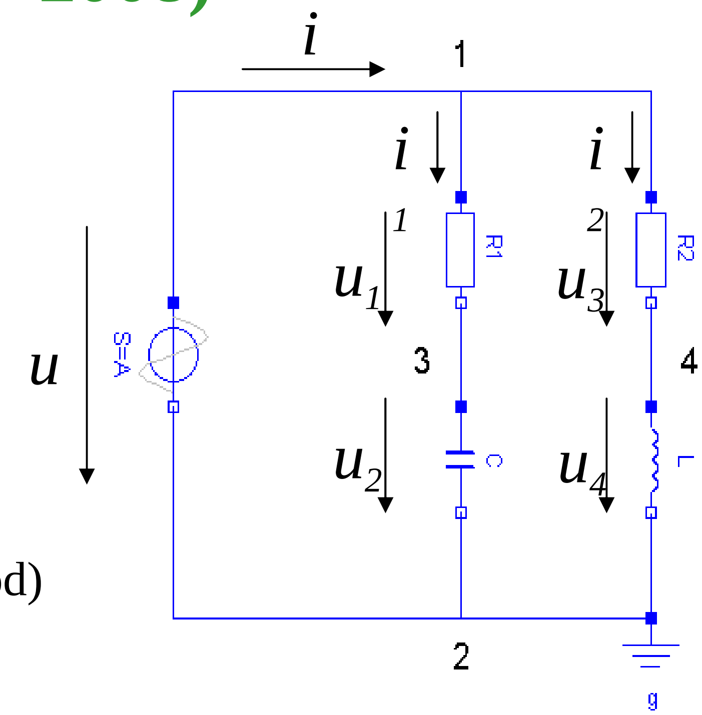
- Course details
  - 4 semester periods per week (13 weeks)
    - theory and practical exercises
  - learning by doing (small projects)
  - tools
    - Matlab-Simulink (1st project)
    - Dymola (Modelica projects)
  - exam
    - practical

      projects (development and explanation)
    - theory

      mathematical and modeling aspects

Past Teaching (1999 – 2008)

- 1st course:
  Basic understanding of the principles
  using a simple electrical system
  - modeling
    - develop the DAE representation
      abstract mathematical view
    - understand numerical integration (Euler method)
    - sort the equation system (find causality)
  - simulation and implementation
    - using Matlab
    - using Simulink
    - using Dymola (flat representation)



$$u = A \cdot \sin(2\pi\ f\ t + \varphi)$$

$$u = u_1 + u_2,\ u = u_3 + u_4$$

$$i = i_1 + i_2$$

$$u_1 = R_1 i_1,\ u_3 = R_2 i_2,$$

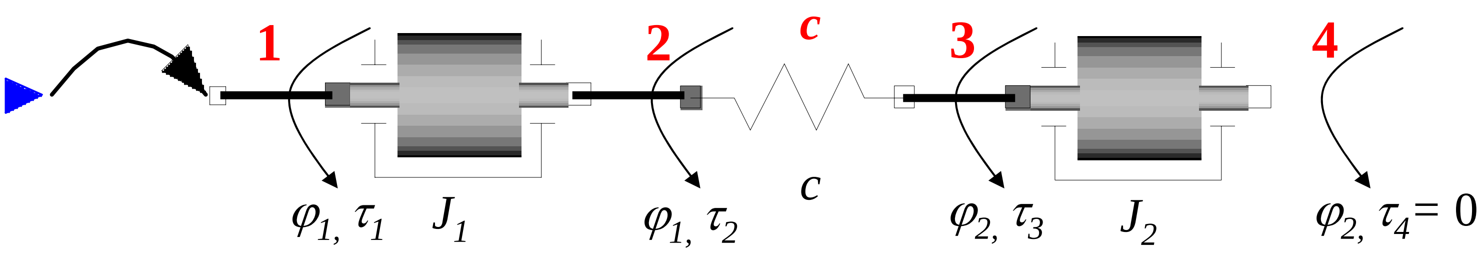
$$C\frac{du_2}{dt} = i_1,\ L\frac{di_2}{dt} = u_4$$

Past Teaching (1999 – 2008)

- 1st course project
  - basic understanding of the principles using a simple mechanical system
  - modeling
    - develop the DAE representation
    - understand numerical integration (Euler method)
    - sort the equation system (find causality)
  - simulation and implementation
    - using Matlab
    - using Simulink
    - using Dymola

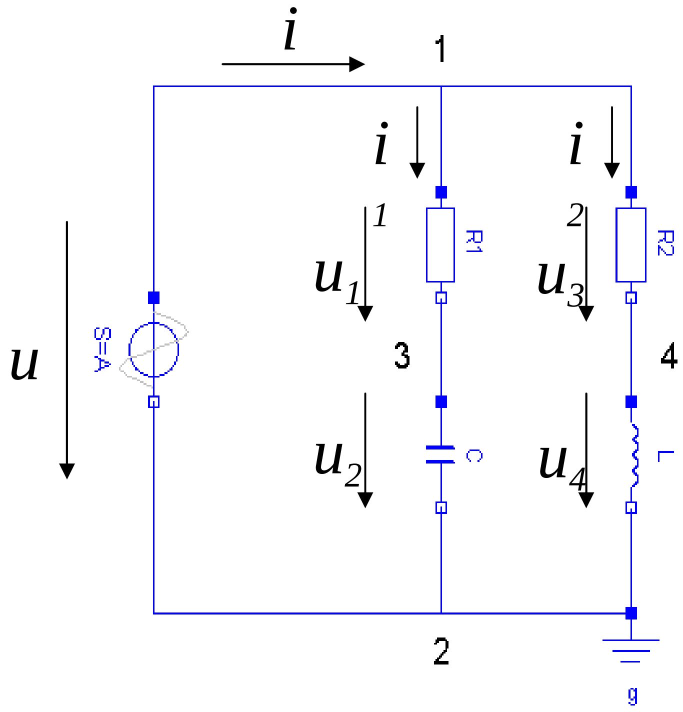
$$\tau_1 = u, \quad \omega_1 = \dot{\varphi}_1$$
$$J_1 \cdot \dot{\omega}_1 = \tau_1 + \tau_2$$
$$\tau_2 = c \cdot (\varphi_2 - \varphi_1)$$
$$0 = \tau_2 + \tau_3, \quad \omega_2 = \dot{\varphi}_2$$
$$J_2 \cdot \dot{\omega}_2 = \tau_3$$

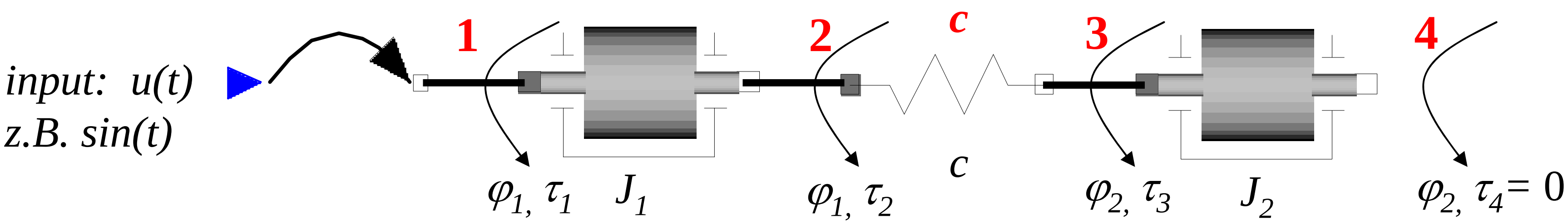
input: u(t)
z.B. sin(t)



Past Teaching (1999 – 2008)

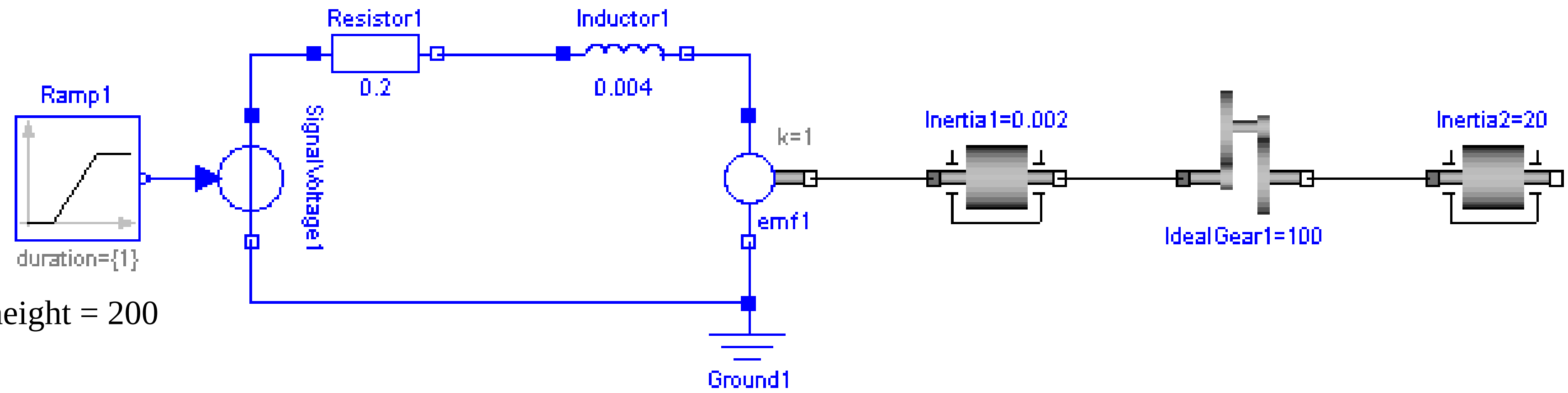
- 2nd course:
  Benefit of using Modelica
  Getting started with Dymola
  - examples from 1st course continued
  - modeling
    - drag and drop
    - library structure
    - find components
  - simulation
    - compile model
    - experiment setup
    - view and compare results





Past Teaching (1999 – 2008)

- 2nd course project
  - build up and simulate different physical systems
    - examples from 1st course
    - drive train
    - triple pendulum
    - …



height = 200

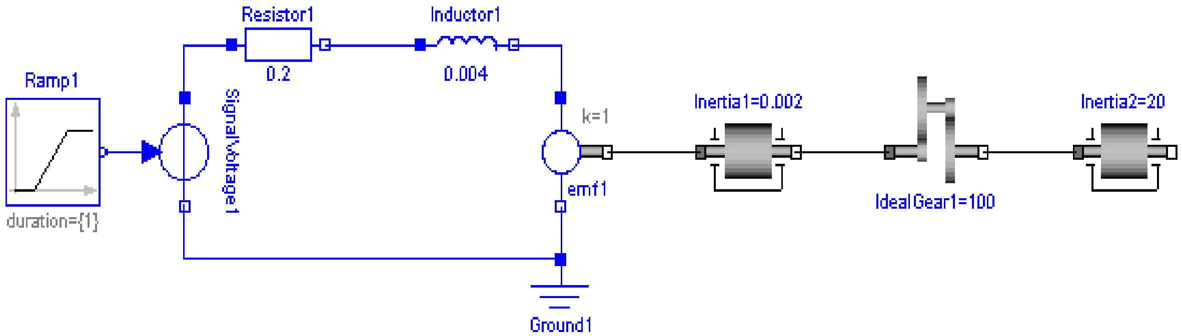
Past Teaching (1999 – 2008)

- 3rd course:
  Getting started with Modelica
  - flat Modelica
    - basic keywords

      model, parameter, equation, basic types, der, …
    - type attributes

      min, max, units, …
    - type classes

      library SIunits

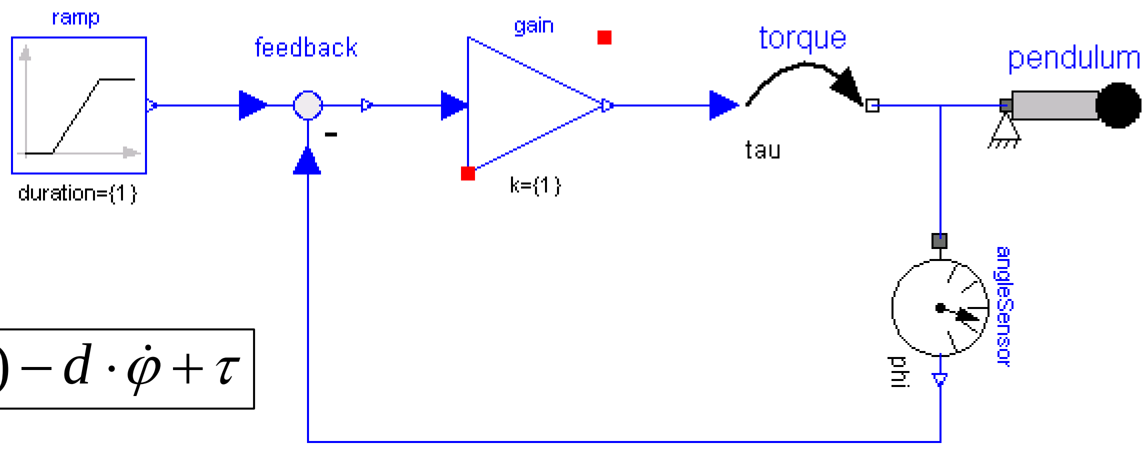


  - hierarchical Modelica
    - model and connector classes
    - connect statement

      basic principles of flow and potential variables

Past Teaching (1999 – 2008)

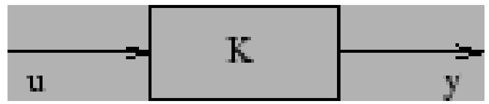
- 3rd course project
  - implement and simulate a Pendulum model
    - flat representation
      using predifined types (SIunits)
    - hierarchical representation (using Multibody library)
      animation
    - build up a simple controller to adjust the angle

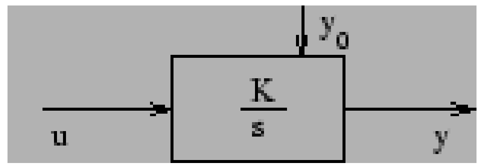


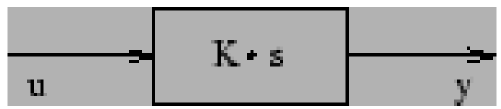
$$J \cdot \ddot{\varphi} = -m \cdot g \cdot L \cdot \cos(\varphi) - d \cdot \dot{\varphi} + \tau$$

Past Teaching (1999 – 2008)

- 4th course:
  Introduction to basic control techniques
  - examples
    - with/without feedback
  - Laplace-transformation
  - different mathematical formulations
    - functional description
    - block diagram
    - Step function response
  - standard controller
    - P-, D-, I-, PD-, PI-, PID-controller
- 4th course project
  - example from 3rd course continued
  - try different controller and compare results

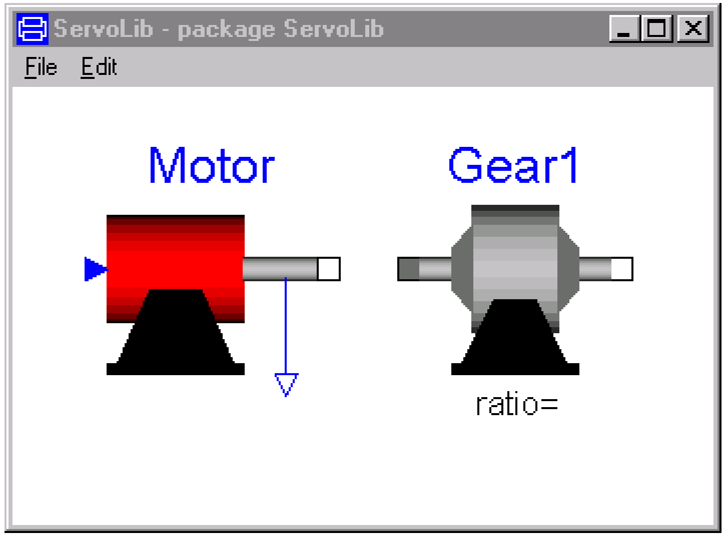






Past Teaching (1999 – 2008)

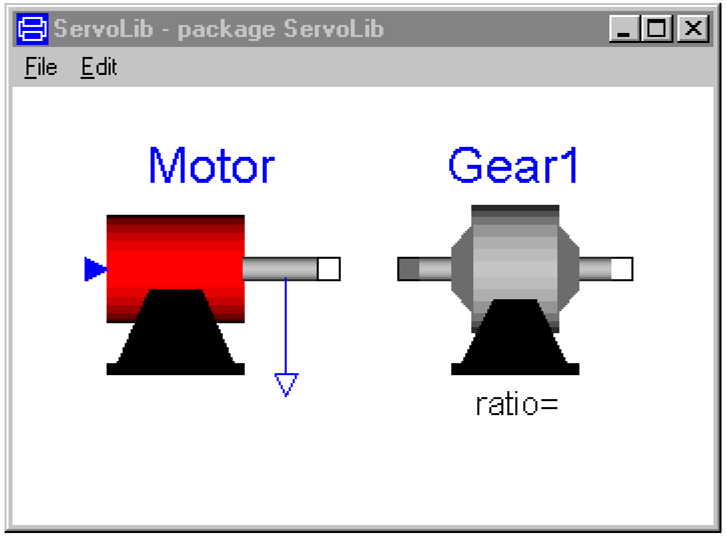
- 5th course:
  Build Libraries in Modelica
  - package concept
    - example using simple electrical component
  - modifier concept
  - build libraries in Dymola
    - icon layer, diagram layer
    - coordinate system
    - connector view
    - parameter settings



- 5th course project
  - build up a library
    - motor (including control scheme)
    - gear box (including friction elements)
  - adjust control parameter for suitable test cases

Past Teaching (1999 – 2008)

- 6th course:
  Build Libraries in Modelica
  - general connection concept
    - energy flow, domain specific potential and flow variables
    - discuss practical issues (rotational)
  - multidisciplinary modeling
  - parameter propagation
    - modifications
    - GUI in Dymola



- 6th course project
  - continue 5th course project

Past Teaching (1999 – 2008)

- 7th course:
  Advanced Modelica
  - class types
    - type, model, block, function, package, connector
  - algorithm versus equations
  - additional keywords
    - input, output, protected
  - matrices
    - definition, element access, operations, inline functions
  - example of general transfer function

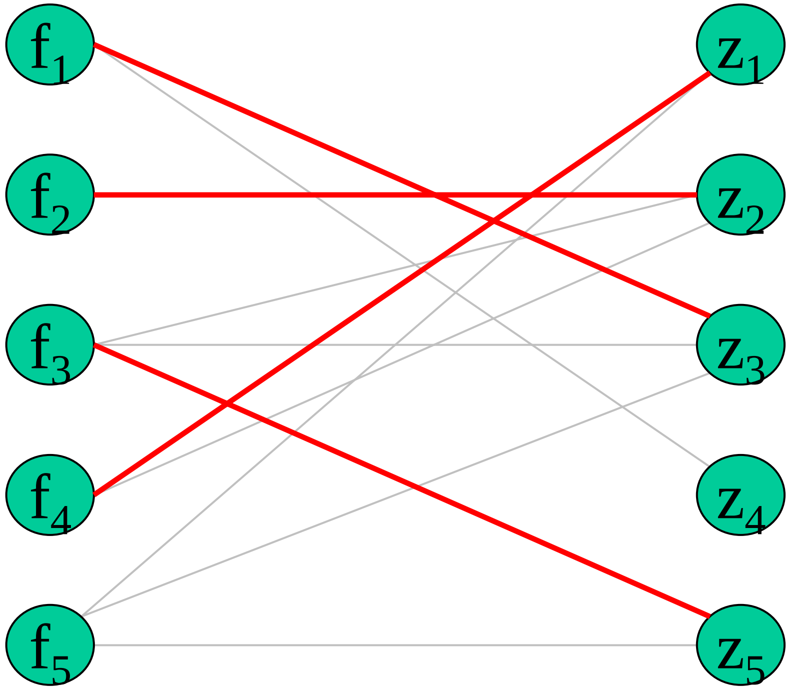
$$\dot{\mathbf{x}} = \begin{bmatrix} -\frac{a_2}{a_1} & -\frac{a_3}{a_1} & -\frac{a_4}{a_1} & -\frac{a_5}{a_1} \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \cdot \mathbf{x} + \begin{bmatrix} \frac{1}{a_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} \cdot u$$

$$y = \begin{bmatrix} b_2 - a_2\frac{b_1}{a_1} & b_3 - a_3\frac{b_1}{a_1} & b_4 - a_4\frac{b_1}{a_1} & b_5 - a_5\frac{b_1}{a_1} \end{bmatrix} \cdot \mathbf{x} + \frac{b_1}{a_1} \cdot u$$

- 7th course project
  - still continue 5th course project

Past Teaching (1999 – 2008)

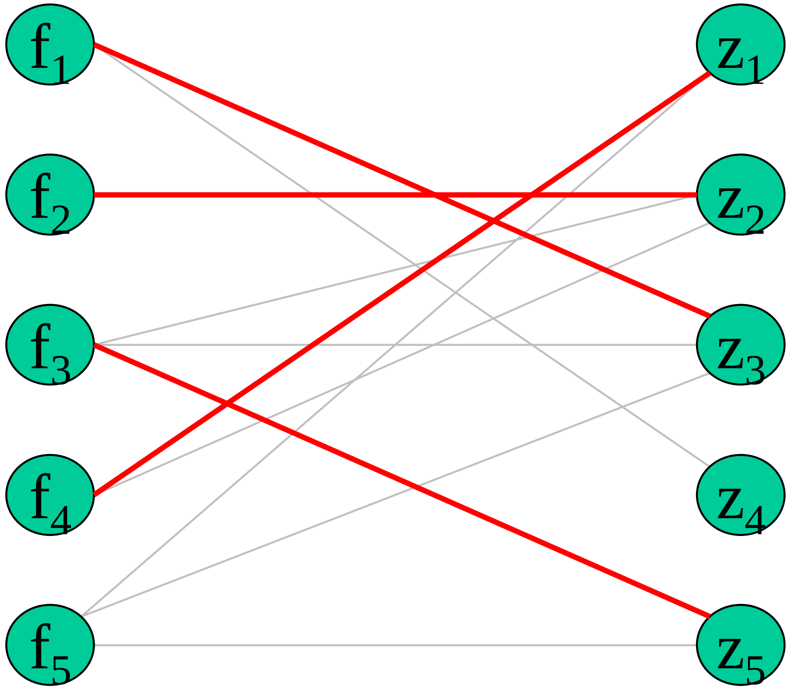
- 8th course:
  Symbolic transformation algorithm
  - mathematical DAE representation
  - regular (index 1) problems
  - matching algorithm
  - sorting (Tarjan algorithm)
  - BLT representation of adjacence matrix



- 8th course project
  - implement the BLT algorithm for random matrices

Past Teaching (1999 – 2008)

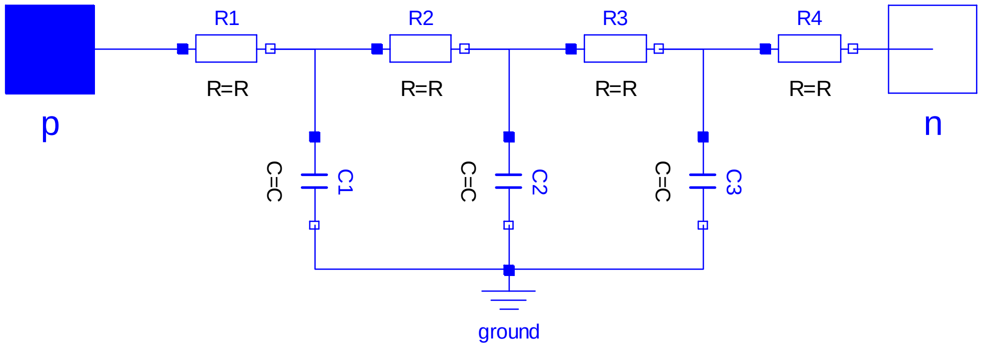
- 9th course:
  Higher Index problems
  - examples (mechanical, electrical)
    - mathematical DAE representation
    - definition of the structural and differential index
  - detect singular set of equations
    - Pantelides algorithm
  - dummy derivative method
  - state selection mechanism
  - initialization of models



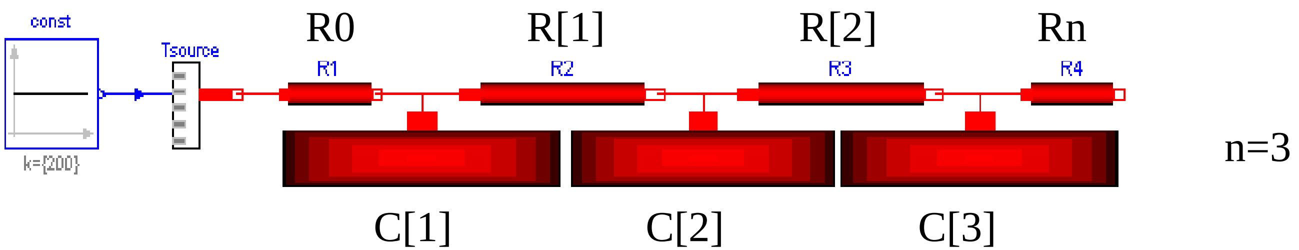
- 9th course project
  - continue 8th course project

Past Teaching (1999 – 2008)

- 10th course:
  Advanced Modelica
  - arrays of component
    - for-loop, variable number of connect statements
  - example
    - transmission line model
  - introduce basic heat flow library

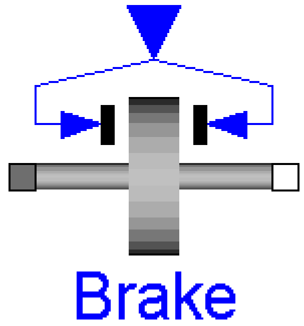


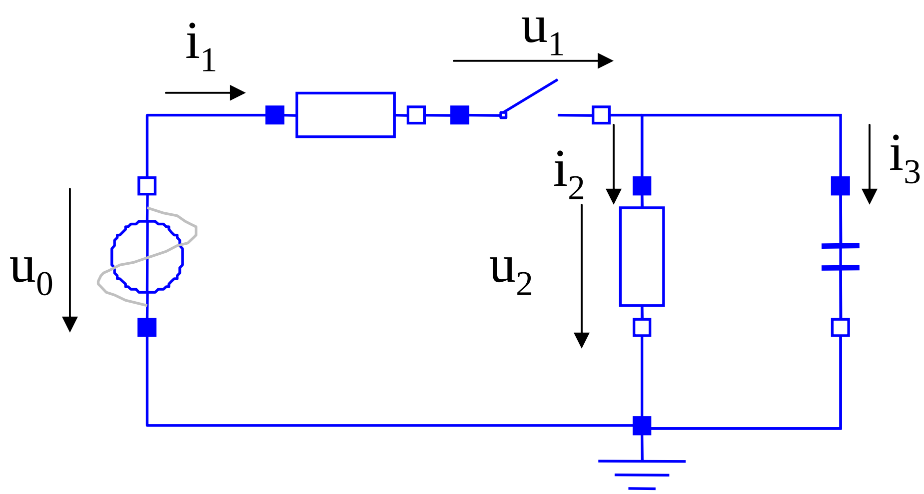
- 10th course project
  - simulate the temperature distribution of an isolated bar



Past Teaching (1999 – 2008)

- 11th course:
  Model discontinuities
  - Modelica Standard library
    - digital controller
    - electrical switch or diode (not ideal)
    - clutch and brake model
  - Modelica language elements
    - if-then-else, when, noEvent, smooth, reinit, pre, …
  - symbolic transformation
    - synchronous equation

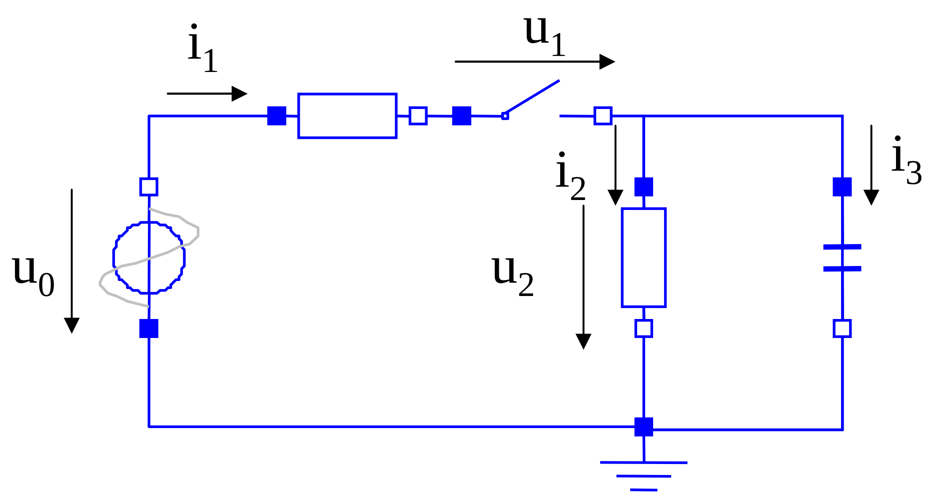




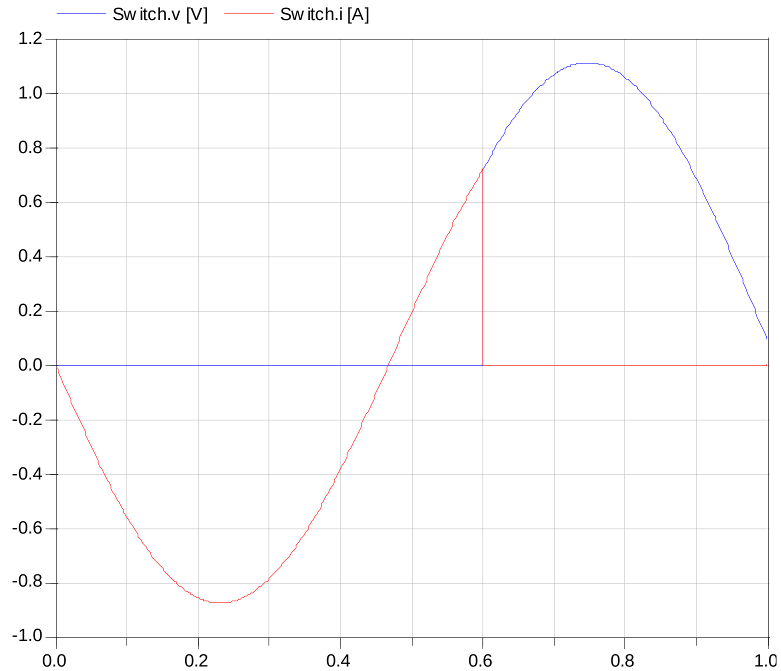
- 11th course project
  - implement examples
    - hysteresis function
    - pulse width modulation block

Past Teaching (1999 – 2008)

- 12th course:
  Model Discontinuities
  - numerical issues
    - stiffness ("not ideal" switch)
    - time versus state events
    - rounding errors
    - event iterations



- 12th course project
  - implement further examples
    - bouncing ball
    - …



Past Teaching (1999 – 2008)

- 12th course:
  Model Discontinuities
  - numerical issues
    - stiffness ("not ideal" switch)
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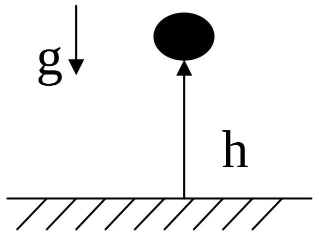
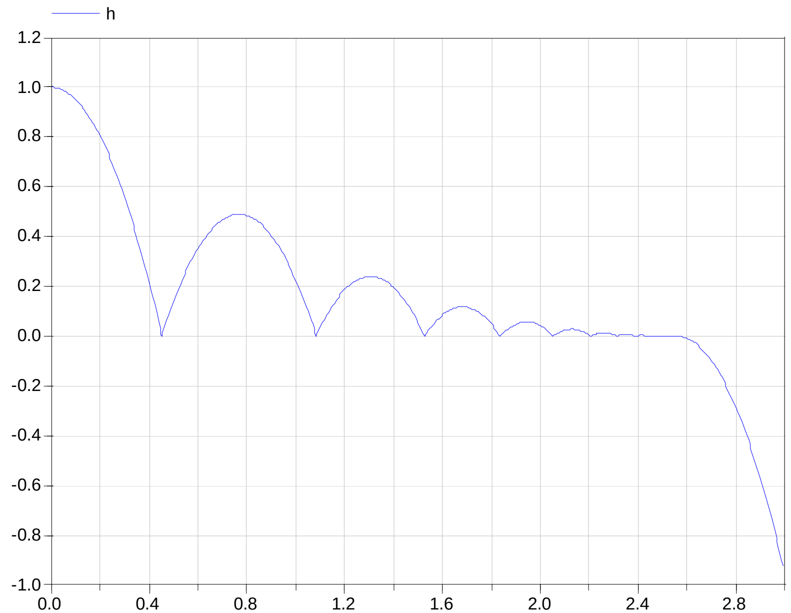
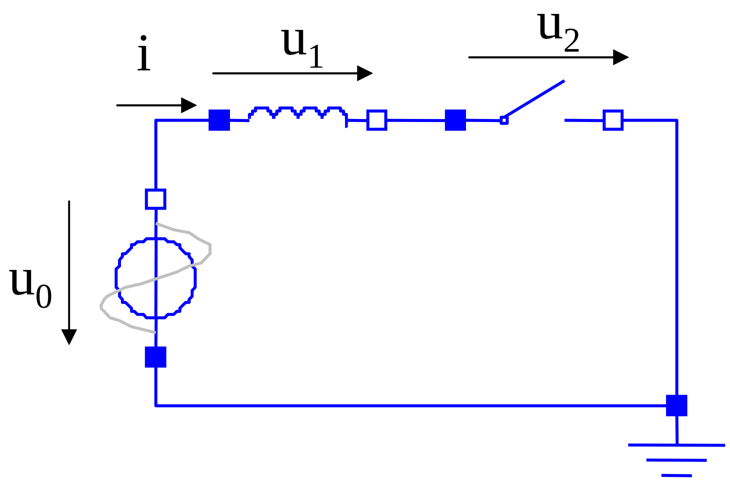


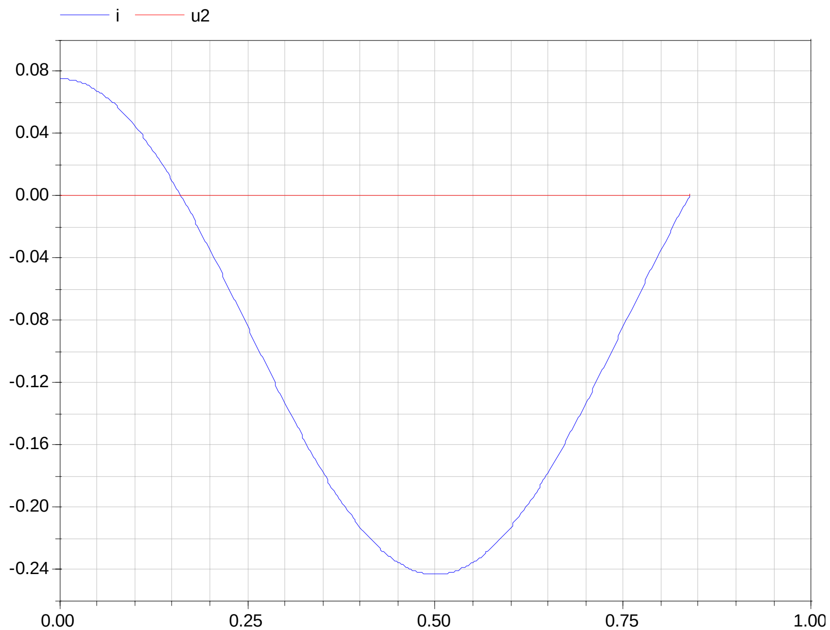
- 12th course project
  - implement further examples
    - bouncing ball
    - …



Past Teaching (1999 – 2008)

- 13th course:
  Model Discontinuities
  - varying higher index problems
  - examples
    - mechanical, electrical
  - symbolic transformation
    - analyse singularity
    - dummy derivative method





- 13th course project
  - run and analyse examples
    - introduce dummy
      derivative terms in branches

Past Teaching (1999 – 2008)

- 13th course:
  Model Discontinuities
  - varying higher index problems
  - examples
    - mechanical, electrical
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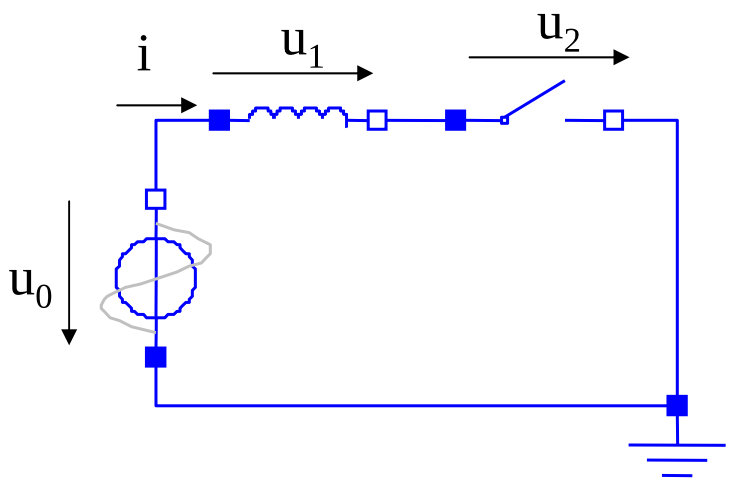

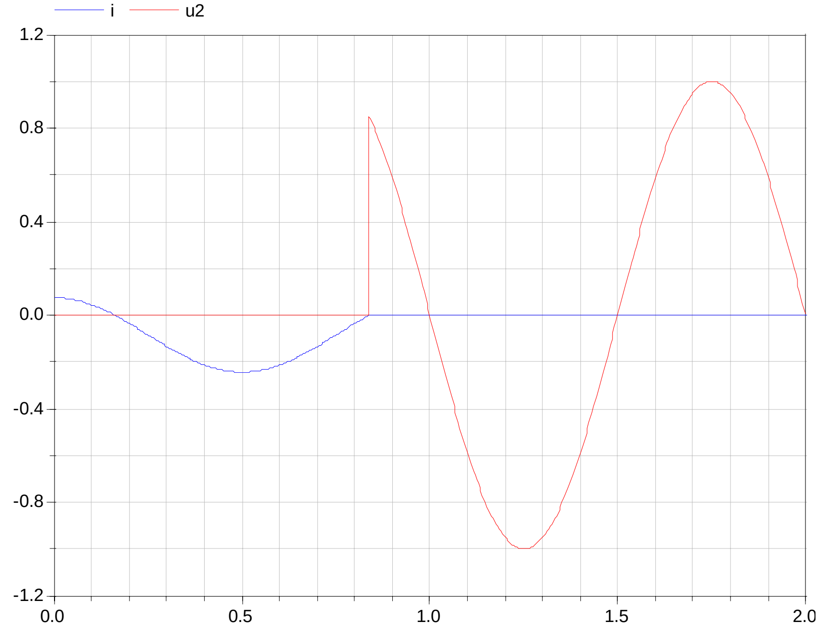

- 13th course project
  - run and analyse examples
    - introduce dummy
      derivative terms in branches

Discussion on Future Teaching Options

- Course attendees
  - master-study in „Optimization and Simulation“
  - mathematicians and engineers
    - mechanical, electrical, mechatronics,…
  - heterogeneous background in mathematics and engineering
- Course objectives
  - engineering aspects
    - component and library development in Modelica
  - mathematical aspects
    - understand symbolic transformations and numerical issues
- Tools
  - licencing issues
    - **OpenModelica (SimForge)**, Dymola, MapleSim, MathModelica
- Applications / Projects