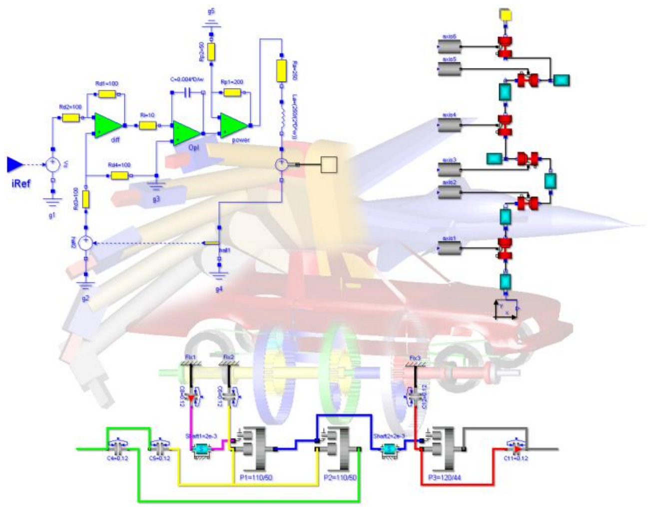
Research in Model-Based Product Development at PELAB in the MODPROD Center

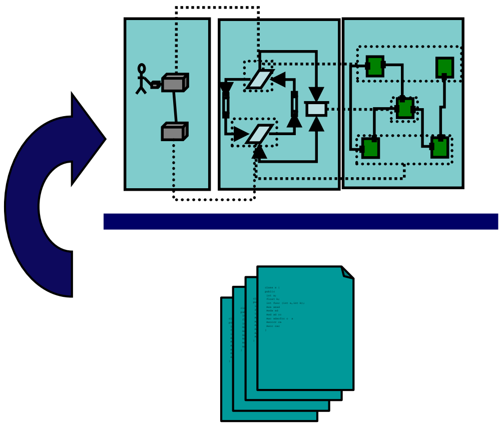
Presentation at MODPROD'2017

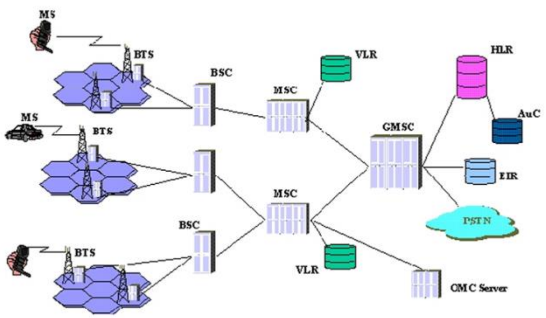
Department of Computer and Information Science
Linköping University

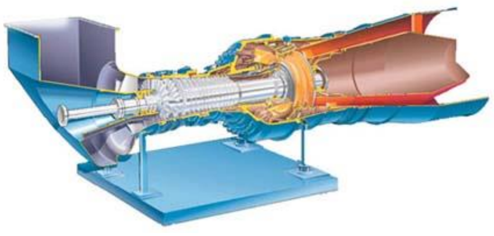
2017-02-07

Peter Fritzson, Adrian Pop, Lena Buffoni,
Bernhard Thiele, Martin Sjölund



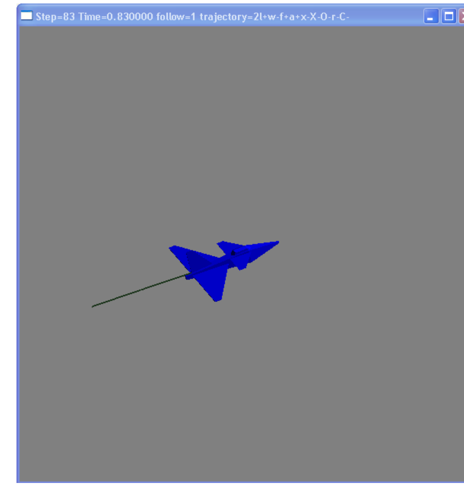


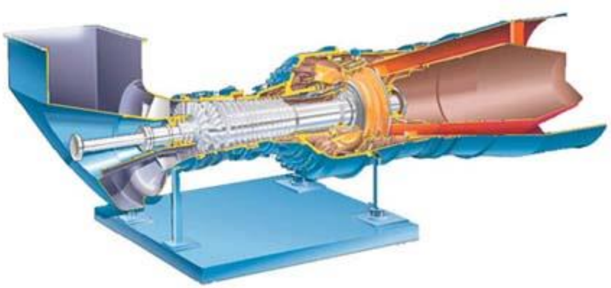


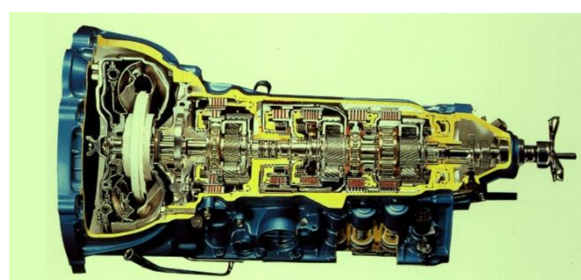


Examples of Complex Systems in Engineering

- Robotics
- Automotive
- Aircraft
- Mobile Phone Systems
- Business Software
- Power plants
- Heavy Vehicles
- Process industry



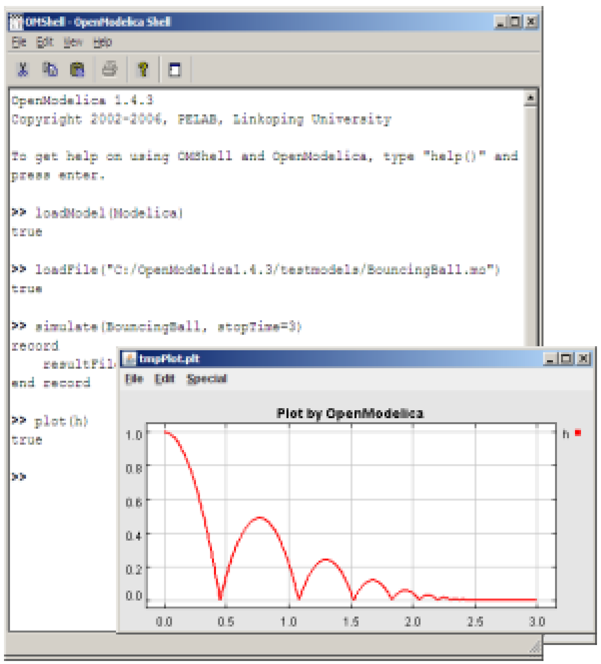


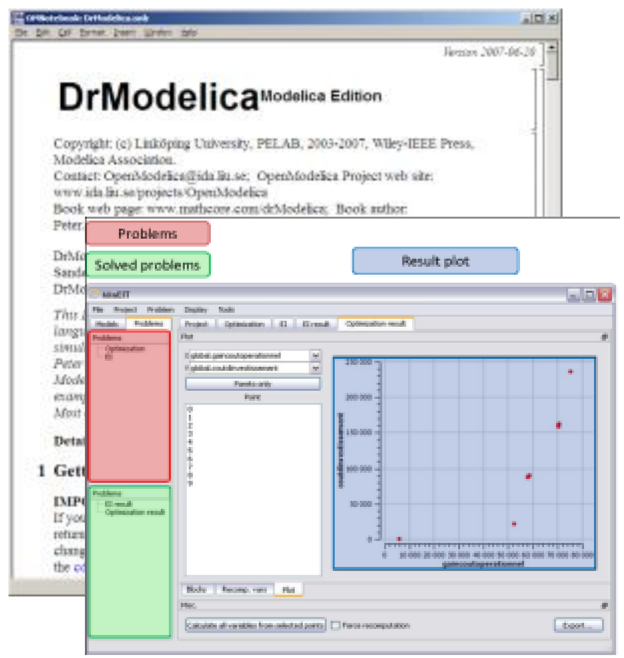


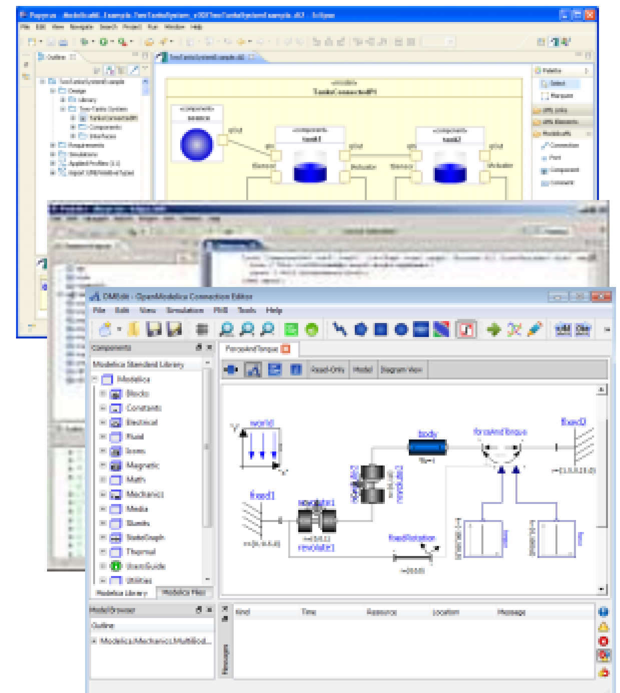
The OpenModelica Open Source Environment
www.openmodelica.org

- Advanced Interactive Modelica compiler (OMC)
  - Supports most of the Modelica Language
  - **Modelica** and **Python scripting**
- Basic environment for creating models
  - **OMShell** – an interactive command handler
  - **OMNotebook** – a literate programming notebook
  - **MDT** – an advanced textual environment in Eclipse

- **OMEdit** graphic Editor
- **OMDebugger** for equations
- **OMOptim** optimization tool
- **OM Dynamic optimizer** collocation
- **ModelicaML** UML Profile
- **MetaModelica** extension
- **ParModelica** extension







Research

Modeling-Language Design

Model-Based Co-simulation with FMI and TLM

Model Debugging

Model-Based Fault Analysis

Multi-Core based Simulation

Embedded System Real-Time Modeling

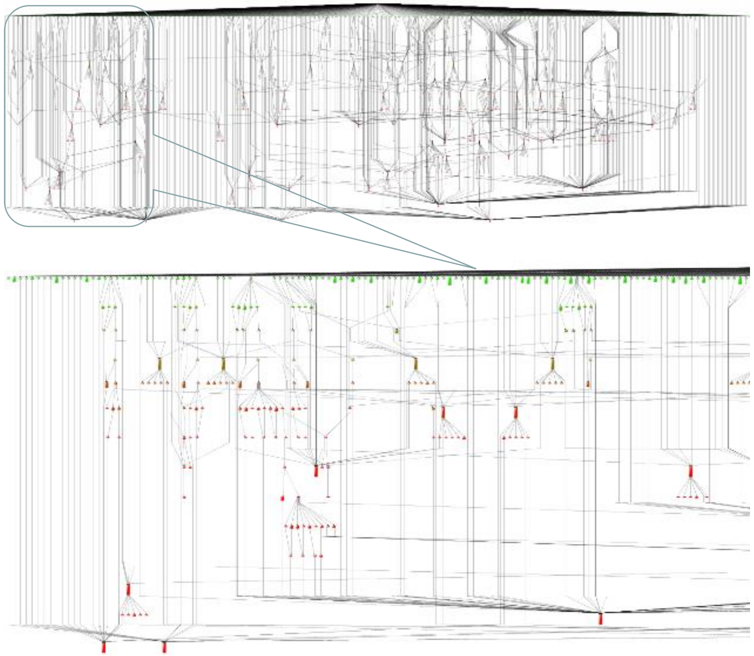
Modeling Support Environments

Parallel Execution Compilation to MultiCore

Mahder Gebremedhin

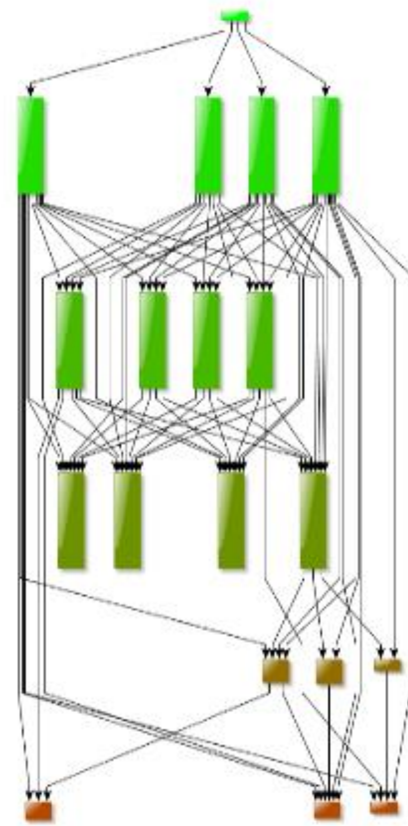
Compiling Models to Efficient Parallel Code
(scheduling on multiple cores)

Modelica.Electrical.Spice3.Examples.Spice3BenchmarkFourBitBinaryAdde



Original task system of Four Bit Binary Adder model

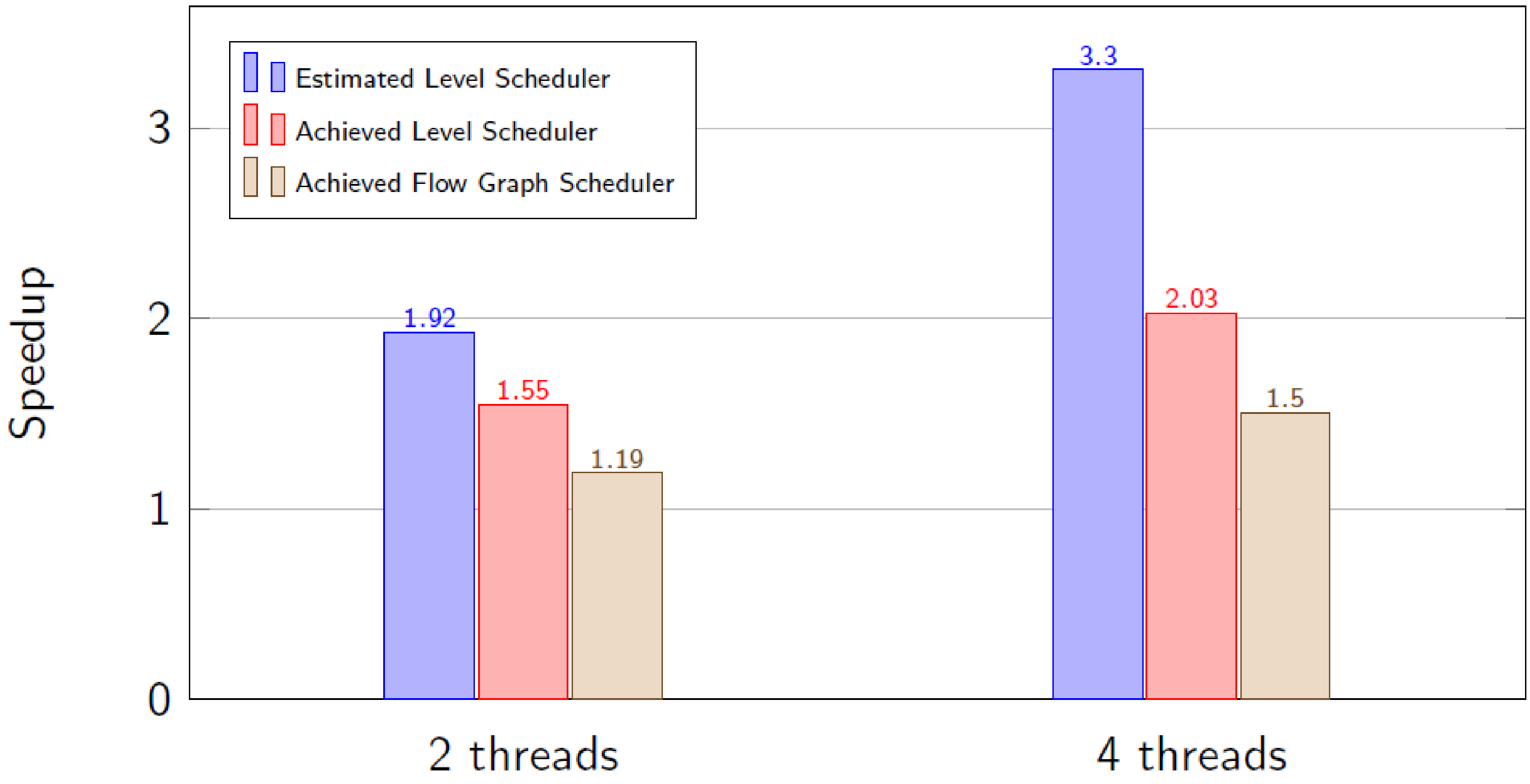
1122 Tasks
1360 Edges



Task system after clustering for level scheduler

18 Tasks
72 Edges

Speedup using Dynamic Scheduling on 4-core laptop Modelica Model CaurLowPassSC



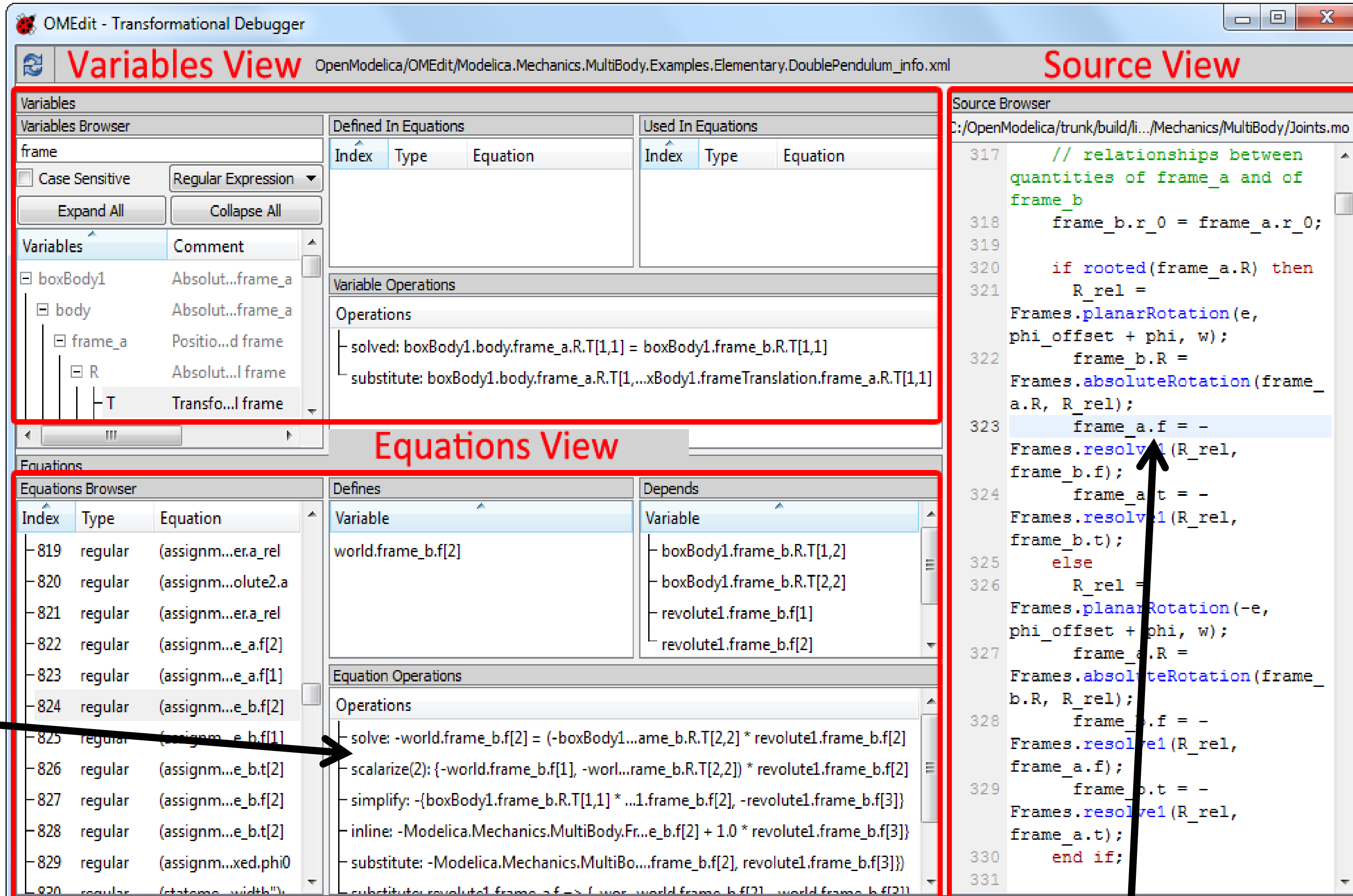
Model Debugging and Performance Analysis

Martin Sjölund,
Adeel Asghar, Adrian Pop
Dept Computer and Information Science
Linköping University

Integrated Static-Dynamic OpenModelica Equation Model Debugger

Efficient handling of **Large** Equation Systems

Showing equation transformations of a model:

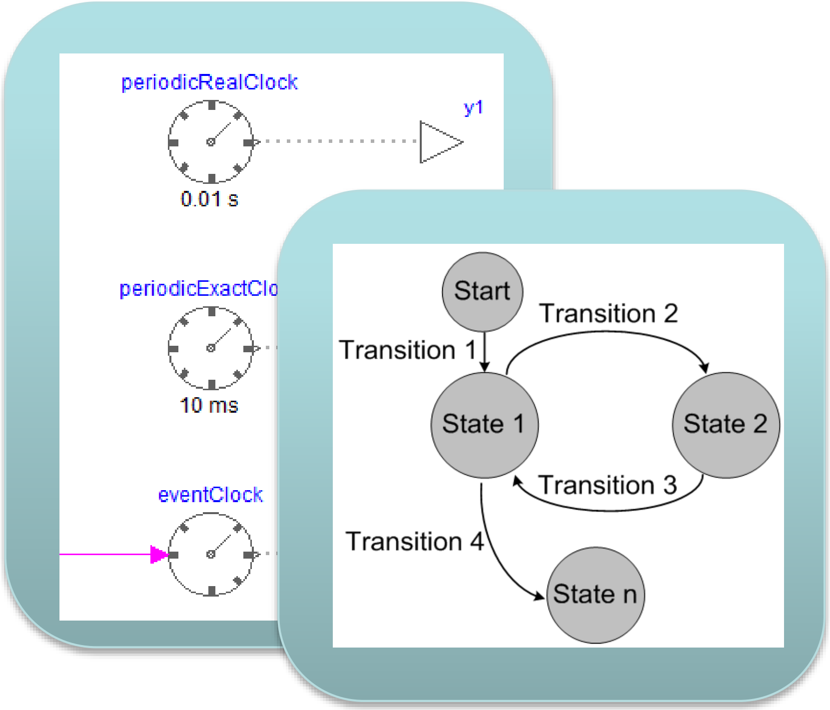


Mapping dynamic run-time error to source model position

Research on Debugging in OPENCPS Project

Debugging of new features

- clocked synchronous models
- real-time debugging and event tracing
- graphic support for state machine debugging



Critical for efficient usability by industrial partners!

Co-simulation, FMI, Modeling Traceability, etc.

Adrian Pop, Alachew Mengist, Lennart Ochel, Robert Braun, Adeel Asghar, Arunkumar Palanisamy

Traceability Support in OpenModelica Using Open Services for Lifecycle Collaboration (OSLC)

Traceability between requirements, models, and simulation artifacts

Alachew Mengist, Adrian Pop,
Adeel Asghar, Peter Fritzson

See separate Talk on wednesday

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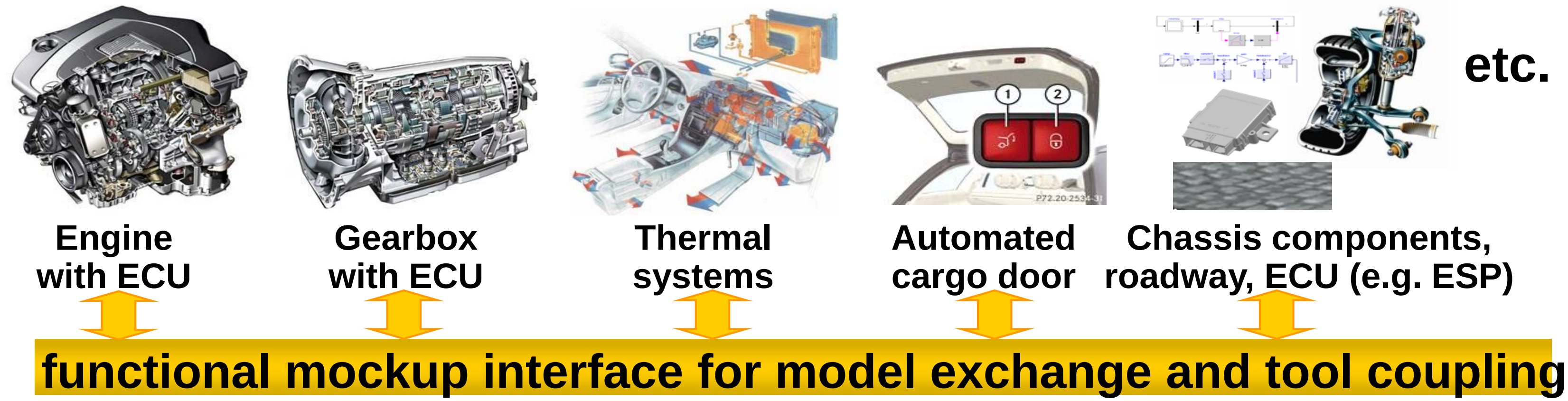
General Tool Interoperability & Model Exchange Functional Mock-up Interface (FMI)



courtesy Daimler

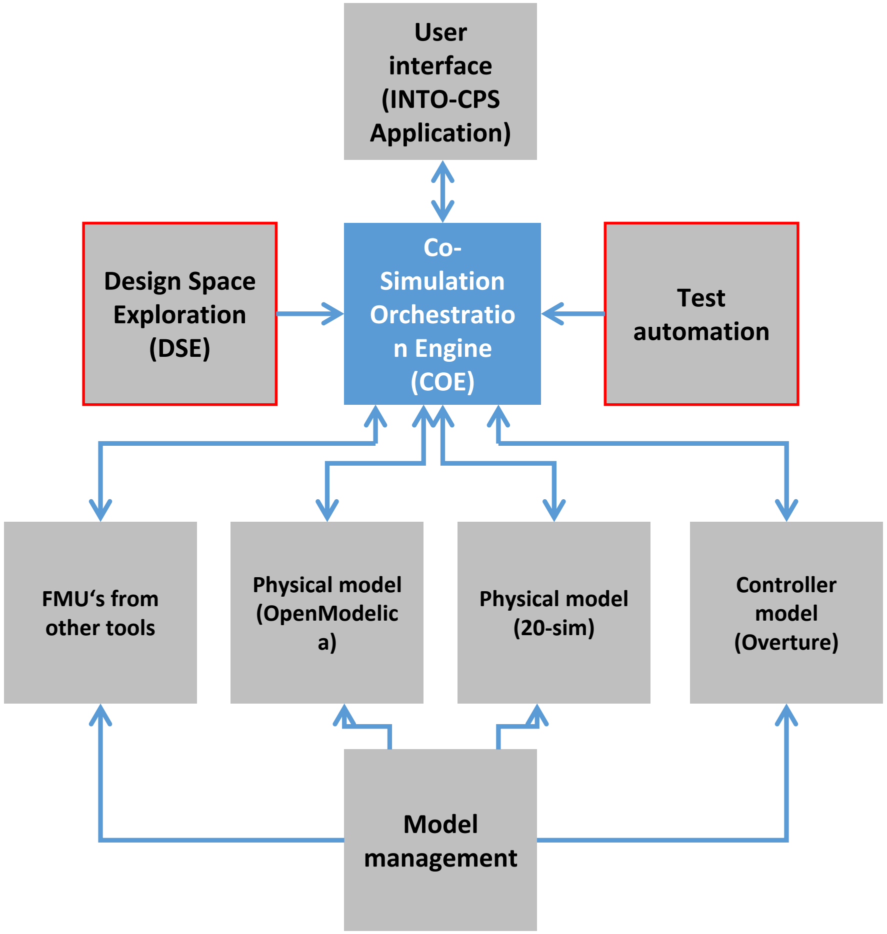
- FMI development was started by ITEA2 MODELISAR project. FMI is a Modelica Association Project now
- **Version 1.0**
- FMI for Model Exchange (released Jan 26,2010)
- FMI for Co-Simulation (released Oct 12,2010)
- **Version 2.0**
- FMI for Model Exchange and Co-Simulation (released July 25,2014)
- **> 60 tools** supporting it (https://www.fmi-standard.org/tools)

Enhanced FMI Co-simulation, Run-time, and Master Simulation Tool – Work in OPENCPS Project

- Further **extensions** to the FMI standard to support TLM-based co-simulation including support for SKF mechanical bearing models
- **Enhanced run-time** for efficient co-simulation of FMUs, including FMUs from OpenModelica and Papyrus
- General **Master** simulation tool support for FMI

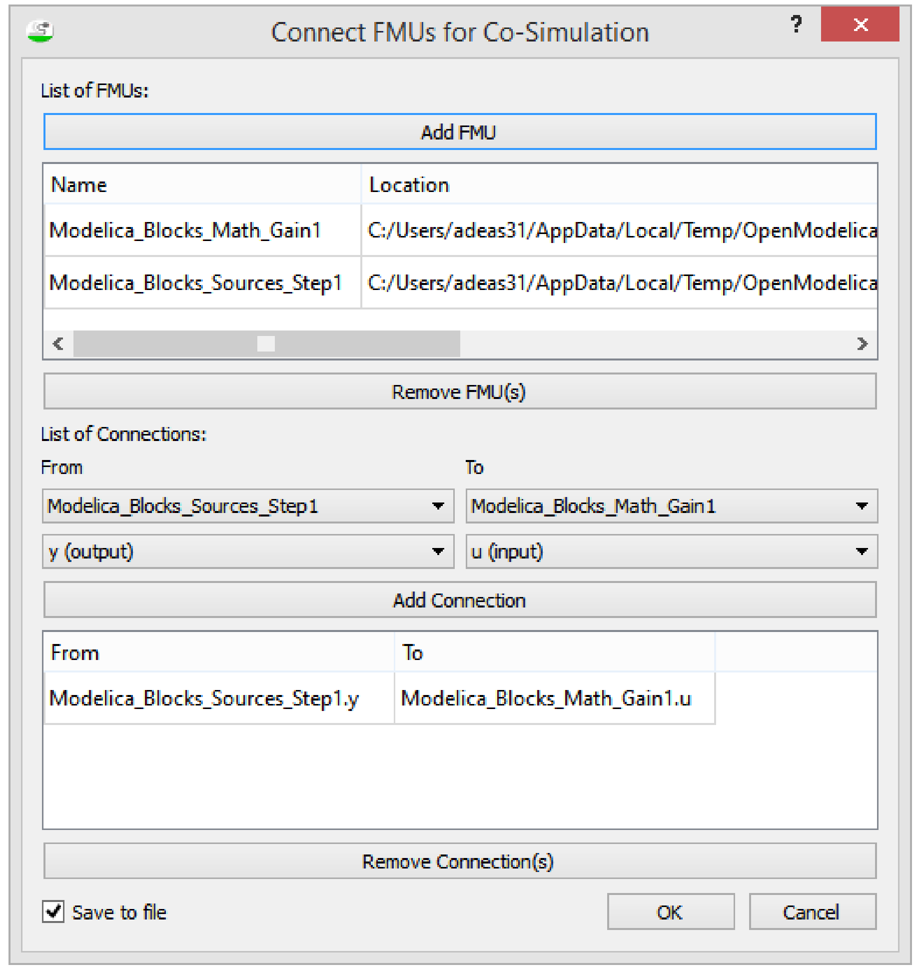
MODELICA pelab

INTO-CPS: Co-Simulation Framework Vision

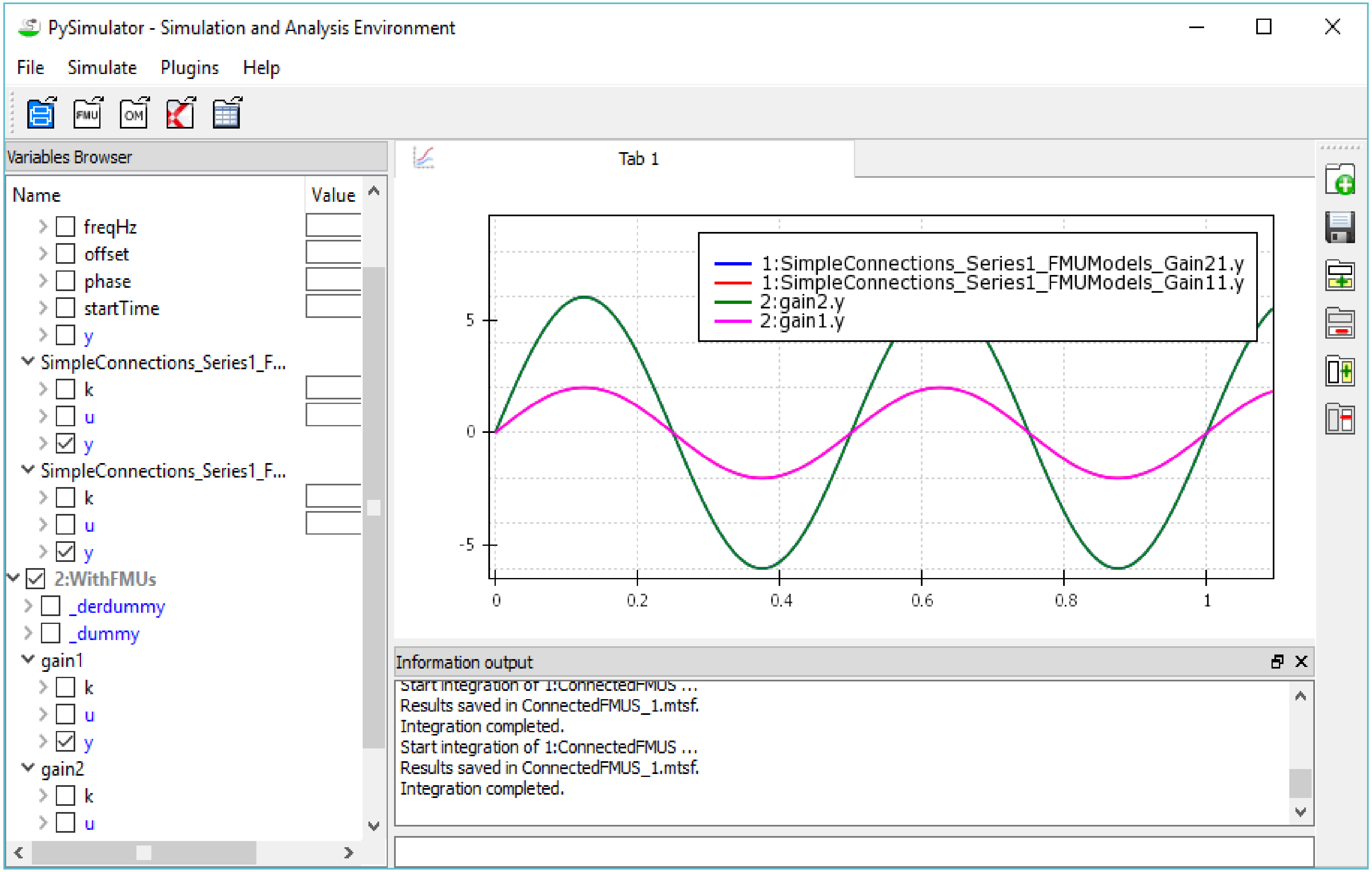


PyModSimA: Simulation of Connected FMUs

- Create a **model** containing **several FMUs** connected to each other.
- **XML** format is used to define connections between FMUs.
- **Connect** FMUs using the graphical user interface.

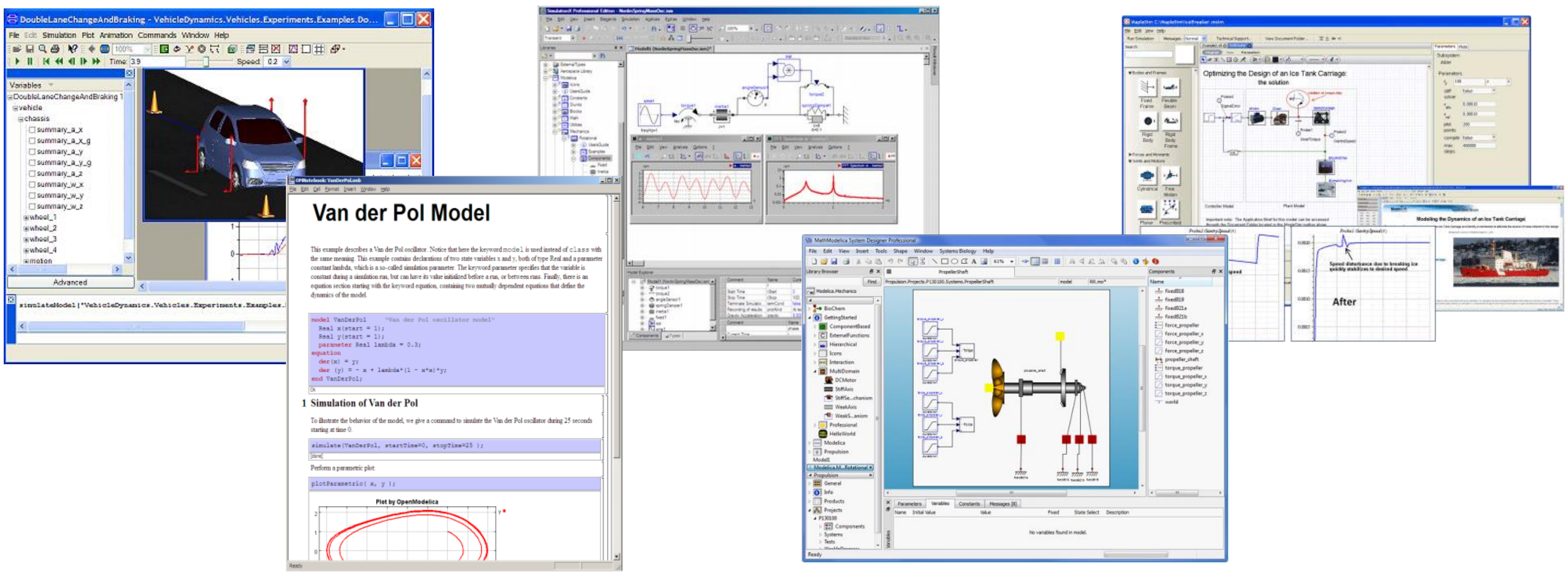


PyModSimA: Co-Simulation of FMUs in Pysimulator



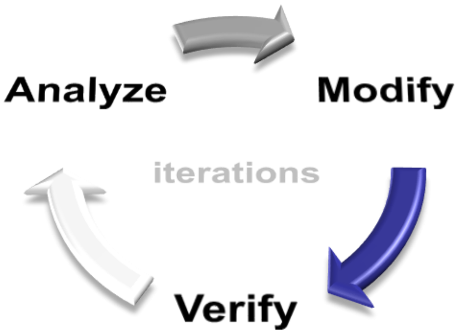
Dynamic Verification/Testing of Requirements vs Usage Scenario Models

Lena Buffoni, Wladimir Schamai, Peter Fritzson and contributions from MODRIO partners



vVDR Method –
virtual Verification of Designs vs Requirements

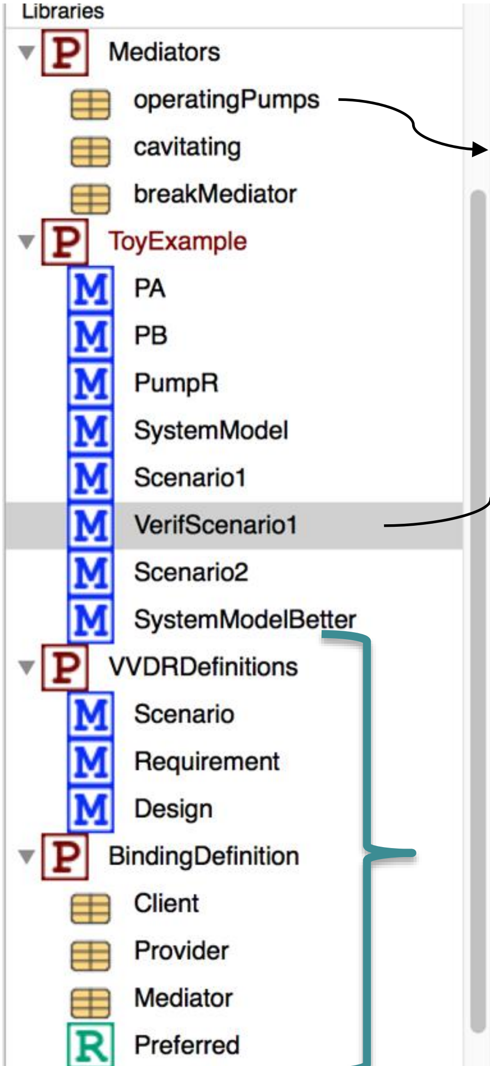
Actor	Task	Created Artifact
	Formalize Requirements	RMM Requirement Monitor Models
	Formalize Designs	DAM Designs Alternative Models
	Formalize Scenarios	SM Scenario Models
AUTOMATED	Create Verification Models *	VM Verification Models
AUTOMATED	Execute and Create Report	Reports 
	Analyze Results	



Goal: Enable on-demand verification of designs against requirements using automated model composition at any time during development.

MODELICA pelab

Support of vVDR in Modelica within OMEdit in OpenModelica




```
record operatingPumps
  extends  Mediator(mType = "Boolean",
  clients = {Client(modelID = "ToyExample.PumpR", component = "inOperation")},
  providers = {Provider(modelID = "ToyExample.PA", template = "if %getPath.on then 1 else 0"),
    Provider(modelID = "ToyExample.PB", template = "if (%getPath.volFlowRate) > 0 then 1 else 0")}
           );
end operatingPumps;
```

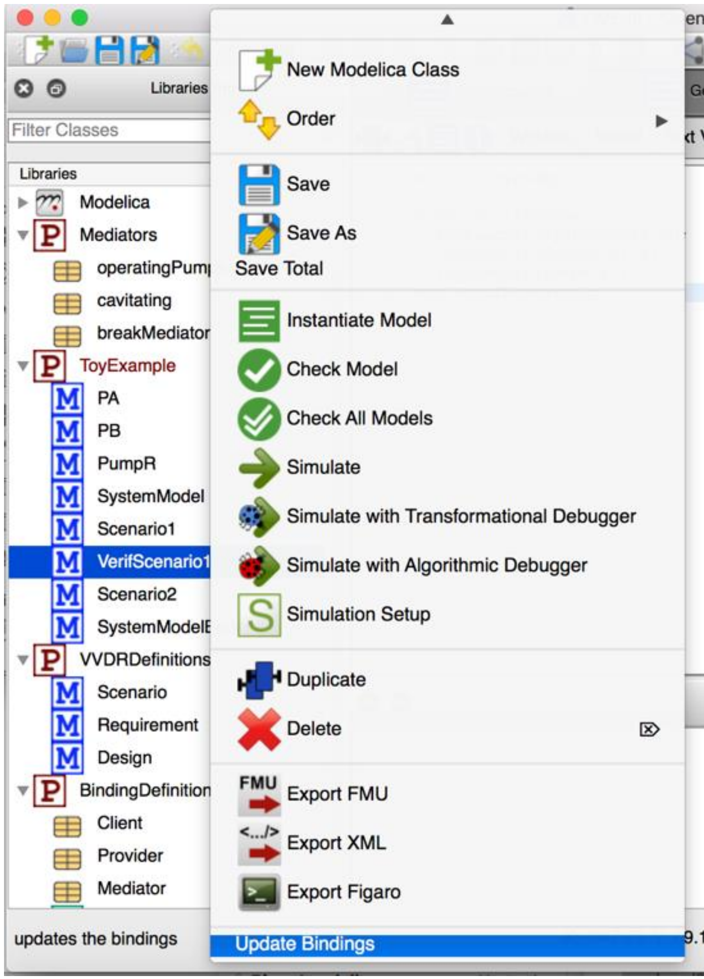
```
within ToyExample;

model VerifScenario1
  ToyExample.SystemModel md;
  ToyExample.Scenario1 s1;
  ToyExample.PumpR r1;
end VerifScenario1;
```

vVDR concepts in **standard Modelica**

- **mediators** mapped to **records**
- **requirements**, **design**, **scenarios** mapped to Modelica classes

Single Scenario Generation




```
within ToyExample;

model VerifScenario1
  ToyExample.SystemModel md;
  ToyExample.Scenario1 s1;
  ToyExample.PumpR r1;
end VerifScenario1;
```

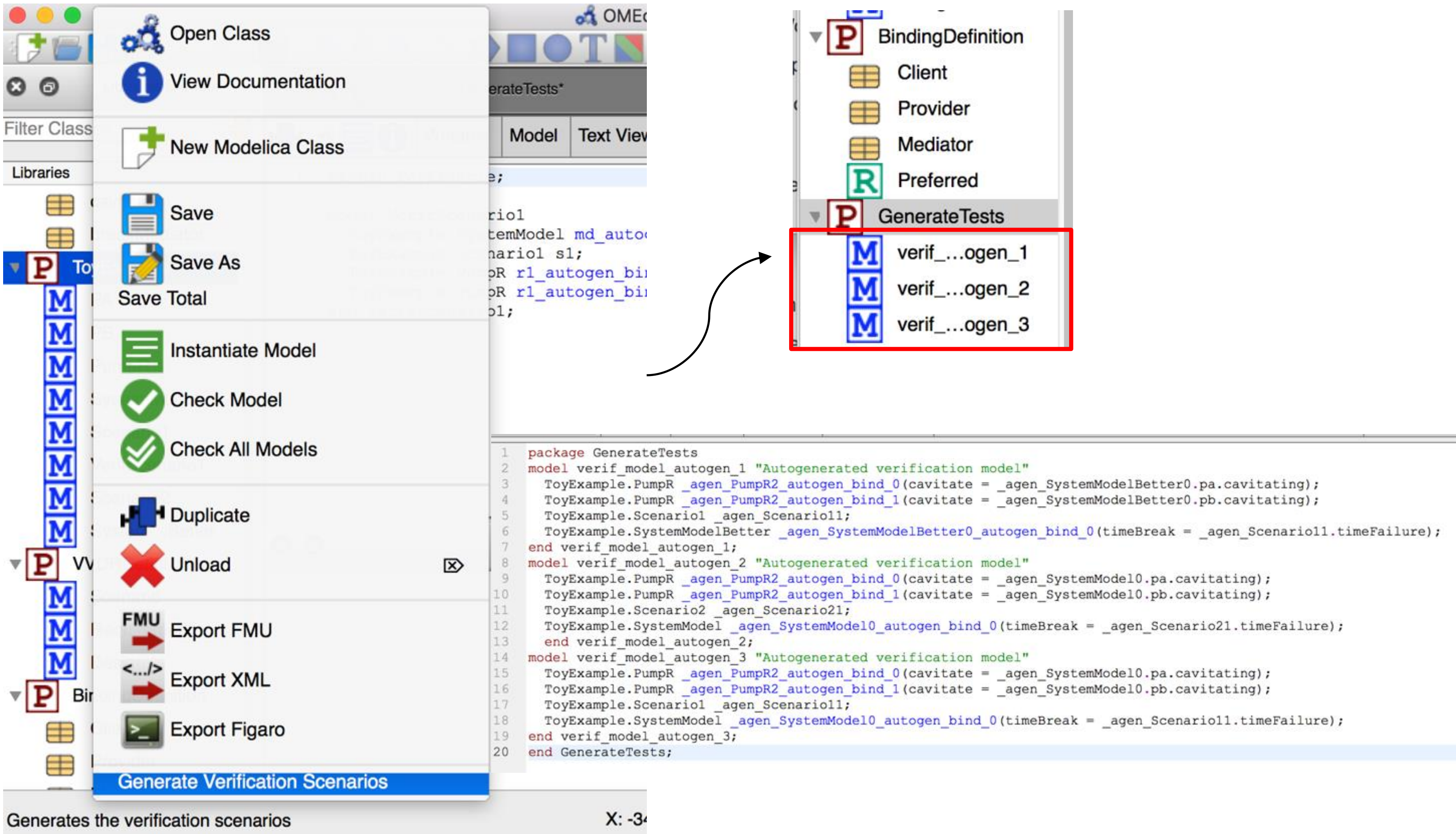
```
within ToyExample;

model VerifScenario1
  ToyExample.SystemModel md_autogen_bind_0(timeBreak = s1.timeFailure);
  ToyExample.Scenario1 s1;
  ToyExample.PumpR r1_autogen_bind_0(cavitate = md_autogen_bind_0.pa.cavitating);
  ToyExample.PumpR r1_autogen_bind_1(cavitate = md_autogen_bind_0.pb.cavitating);
end VerifScenario1;
```

Generating correct number of requirement instances

Connecting the **design** model and the **requirement**

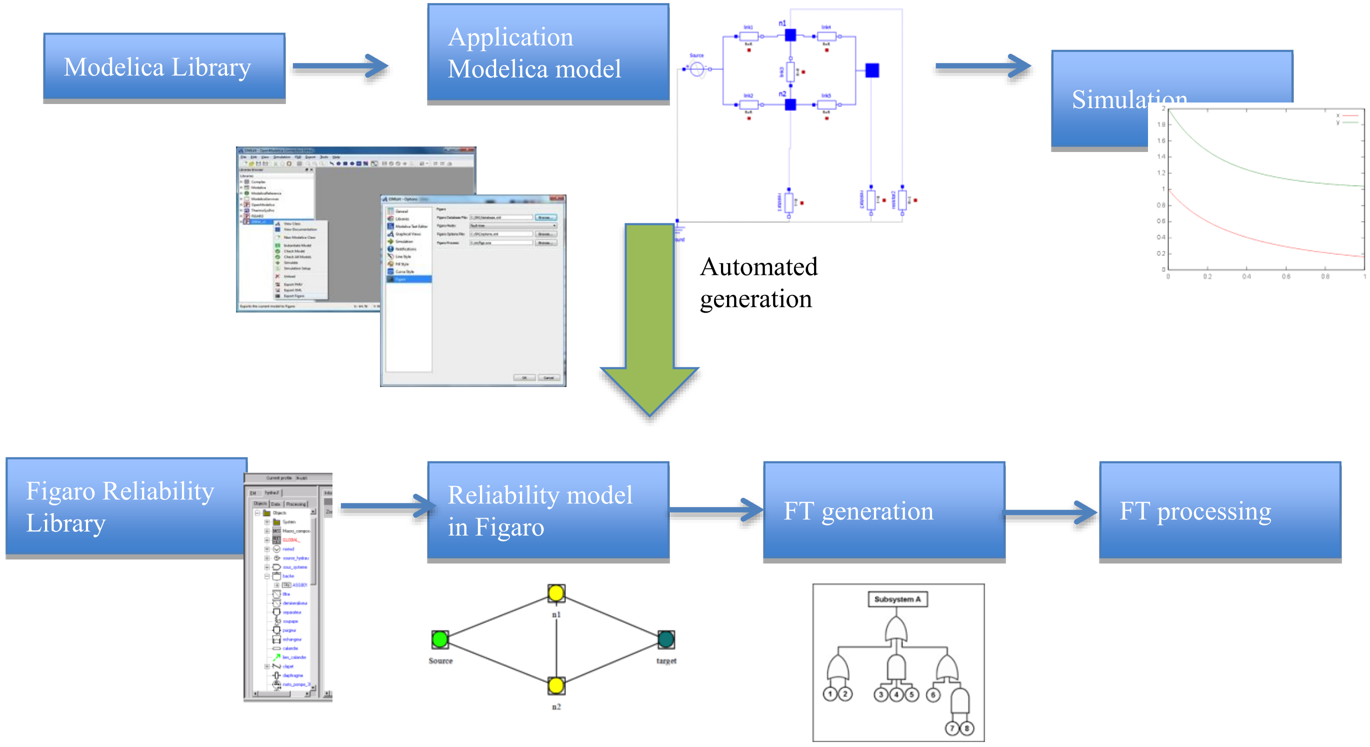
Batch Scenario Generation



Model-based Failure Mode and Effects Analysis

(Marc Bouissou and Lena Buffoni)

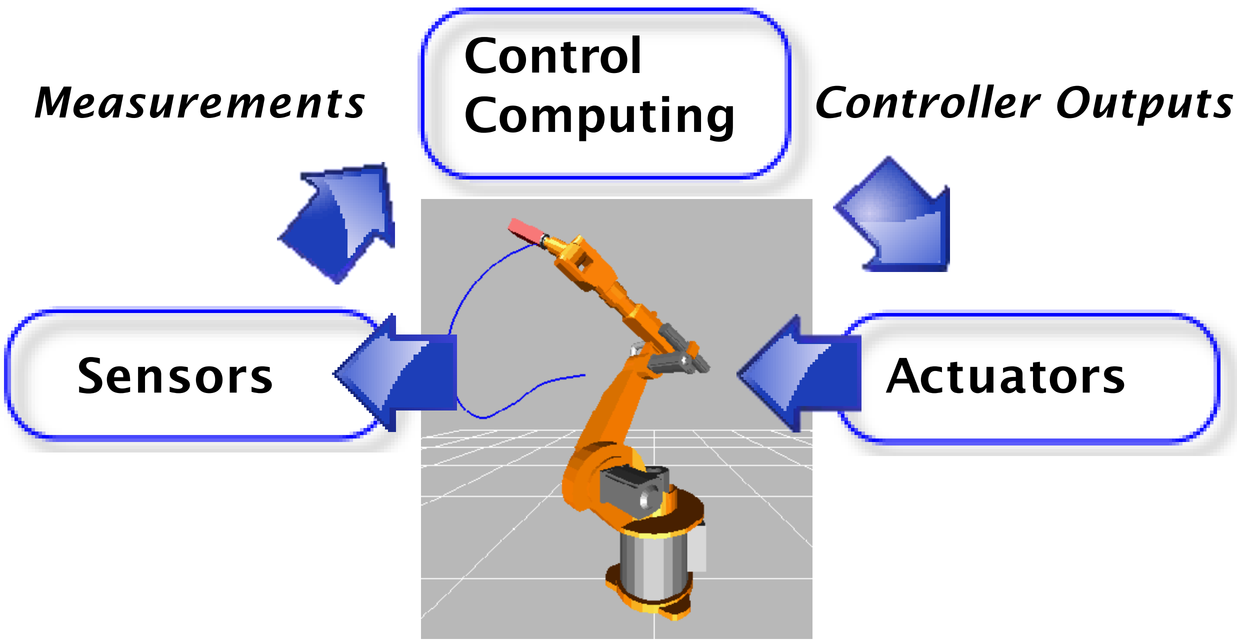
- Modelica models augmented with reliability properties can be used to generate reliability models in Figaro, which in turn can be used for static reliability analysis
- Prototype in OpenModelica integrated with Figaro tool



Real-time Simulation and State-Machine support in Modelica

Bernhard Thiele
Dept Computer and Information Science
Linköping University

Real-Time Control System Applications



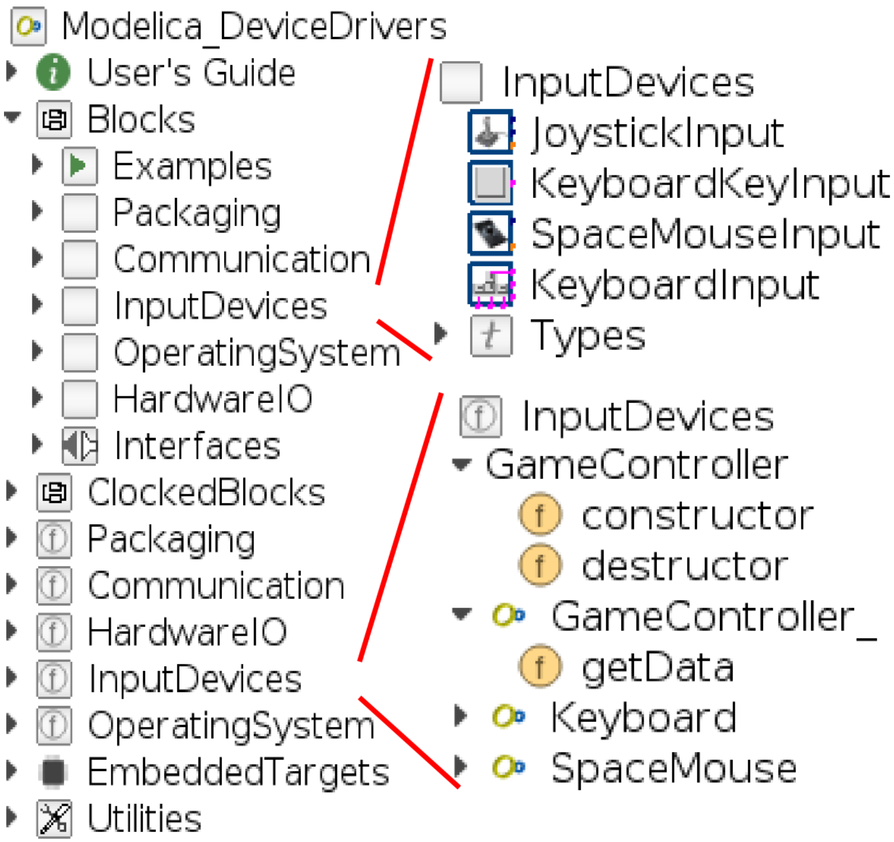
Goal: Interactive Real-Time Simulations

- Human-in-the-Loop (HITL) simulators (including flight, driving, and marine training simulators),
- Hardware-in-the-Loop (HIL) simulators

Needed:

- Synchronize simulation with "wall clock" time
- Access hardware devices

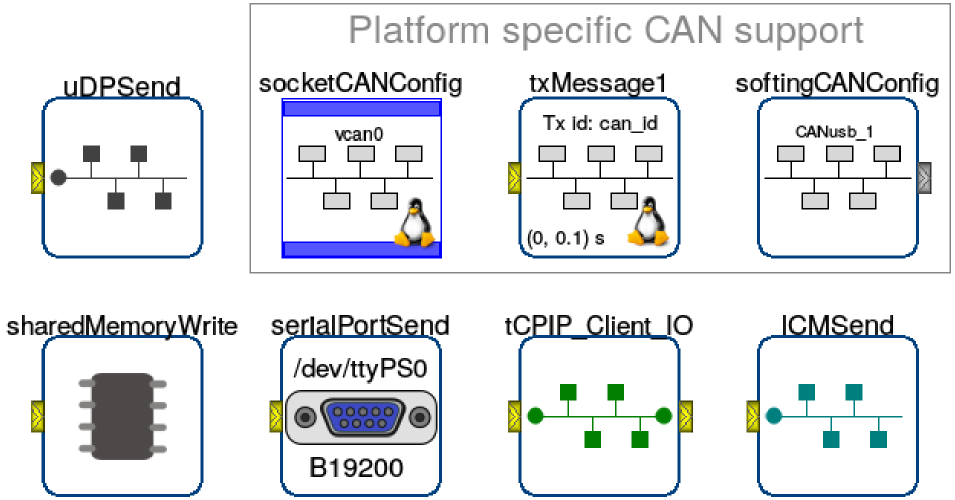
Approach: Modelica_DeviceDrivers Library (MDD)

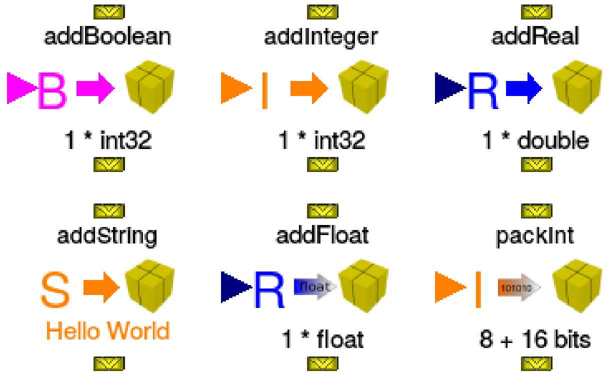


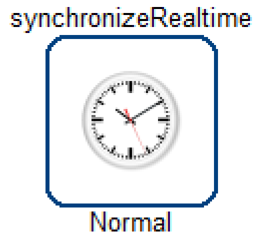
- Free library for interfacing hardware drivers
  https://github.com/modelica/Modelica_DeviceDrivers
- Layered Design:
  - Block Layer: Drag & drop graphical interface
  - Function Layer: Modelica (external C) functions
    C-Code Layer: OS specific C code

Featured MDD Blocks (Mostly Cross-Platform)

Communication





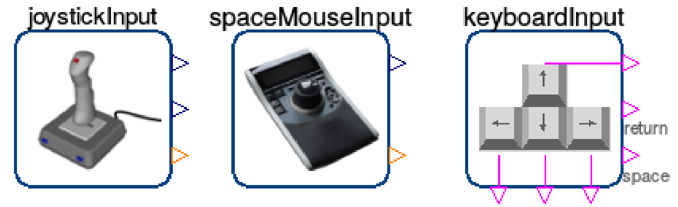


Alternatively:

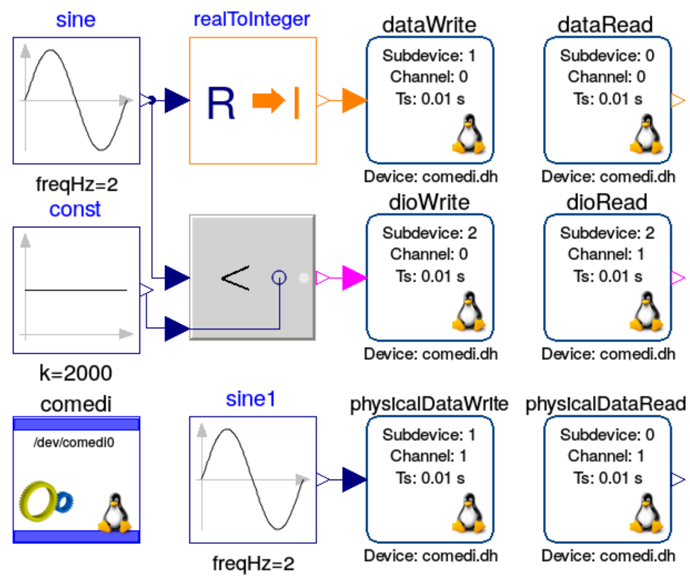
OMC sim. flag

-rt=1

Input Devices



Hardware I/O (Linux only)



Challenge of Non-Modelica Standard Constructs

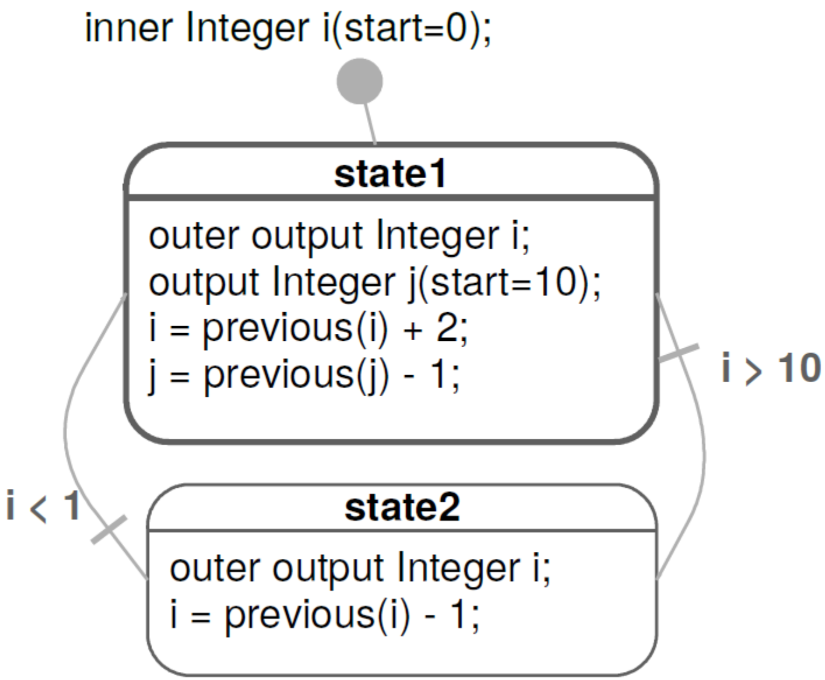
The MDD library was initially developed using the Dymola tool by Bernhard Thiele Tobias Bellmann. Support in OpenModelica poses a challenge:

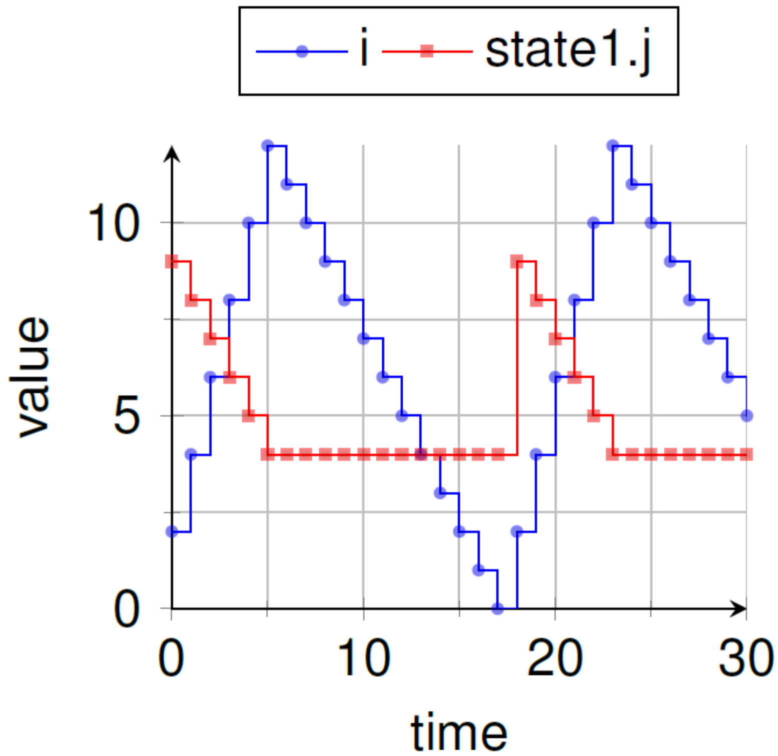
- MDD is using some **non-Modelica standard** conforming constructs; the MDD code could be partly rewritten to be more conformant, but some **constructs** are **essential**
- Important parts of MDD are now **supported** by **OpenModelica** (thanks to Volker Waurich and others!)
- However, there remain parts which are not yet supported

Plans for the MDD Library

- **Extend** MDD library coverage in OpenModelica
- **Advocate** OM+MDD library as **low-cost and low-effort** solution for **interactive** simulations, particularly in combination with low-latency Linux kernels (e.g. available in Linux distributions like Ubuntu)
- Further library **improvements** and extensions
- Extend the scope of MDD library to **support** restricted **embedded** systems (Martin Sjölund will discuss this later in this talk)

State Machines in Modelica 3.3: Simple Example





Modelica State-Machines in OpenModelica

- Modelica 3.3 introduced language elements for clocked (discrete-time) state machines
- State-Machine textual constructs now supported by OpenModelica (ongoing work to support graphical editing)
- Further plans:
  - Support state-machines in the *new* OMC compiler front-end
  - **Efficient code-generation** suitable for restricted **embedded** targets
  - **Traceability** from **models to** generated **code** fragments (support debugging of state machines, facilitate V&V activities)

Embedded Systems Real-time Control Using OpenModelica

Martin Sjölund
Dept Computer and Information Science
Linköping University

Modelica_DeviceDrivers: Embedded Targets

- Modelica_DeviceDrivers
  - UsersGuide
  - Blocks
  - ClockedBlocks
  - Packaging
  - Communication
  - HardwareIO
  - InputDevices
  - OperatingSystem
  - EmbeddedTargets
    - AVR
      - Blocks
        - Microcontroller
        - ADC
        - DigitalReadBoolean
        - DigitalWriteBoolean
        - PWM
        - SynchronizeRealtime
      - Functions
      - Constants
      - Types
      - Examples
  - Utilities
  - Incubate

- Explicitly model the hardware available in the microcontroller.
- The library includes external objects that deal with the microcontroller constants and flags.
- The AVR package handles Atmel's ATmega microcontrollers and includes analog and digital I/O as well as real-time synchronization.

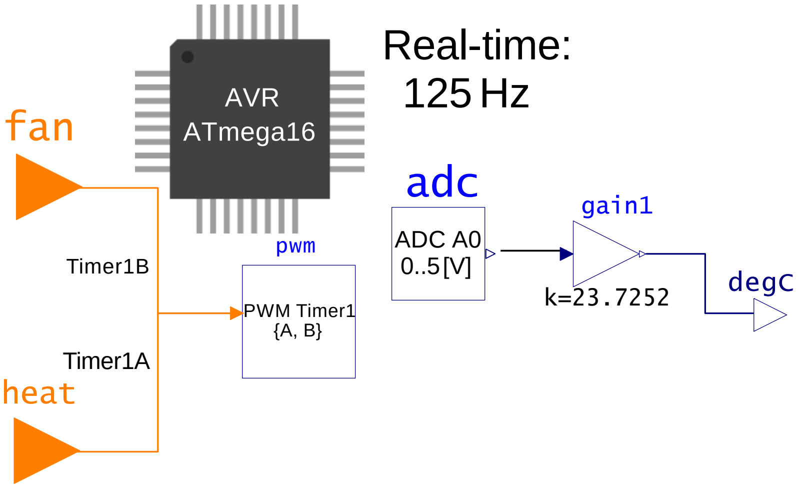
Single Board Heater System (SBHS)

One of the AVR examples included in MDD is the *Single Board Heater System* (SBHS, http://sbhs.fossee.in/), which was developed by IIT Bombay and is used for teaching and learning control systems. It consists of:

- Heater assembly
- Fan
- Temperature sensor
- AVR ATmega16 microcontroller
- Associated circuitry

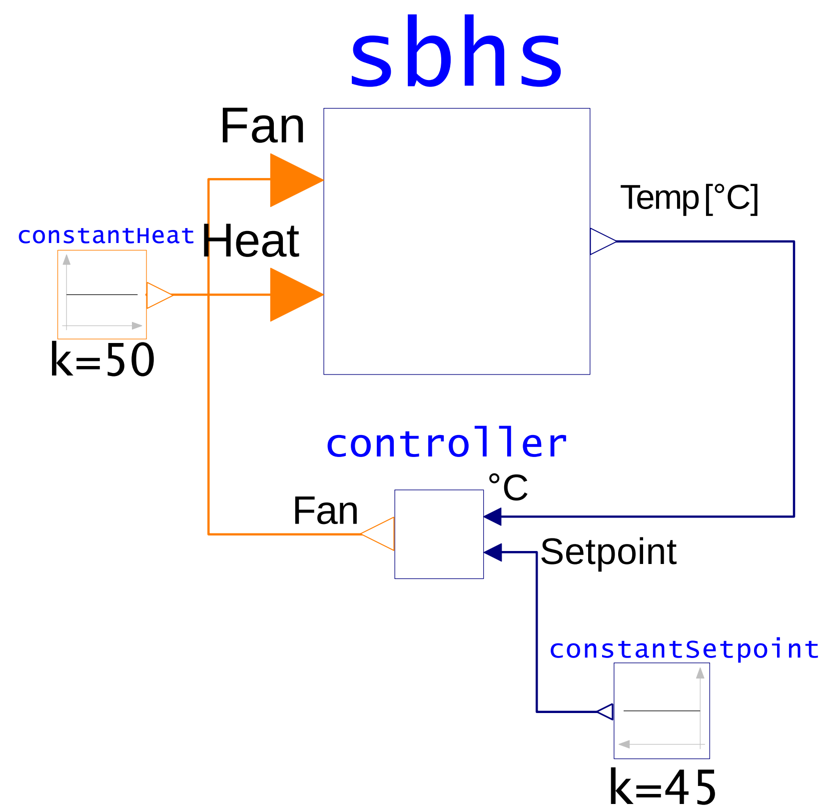
Modeling the SBHS

- Uses a real–time controller (here set @125 Hz).
- Uses pulse width modulation (PWM) to control the heater and fan.
- Uses an analog–to–digital converter (ADC) block to read the temperature (0V=0C, linear gain; the SBHS does the rest in hardware).
- Includes code for the LCD (not shown in the diagrams).



Controlling temperature using the fan

- The example feeds the heat assembly a constant (PWM) voltage.
- It then includes a PID controller with a fixed setpoint, trying to keep the temperature at a constant 45℃ by sending a PWM signal to the fan.

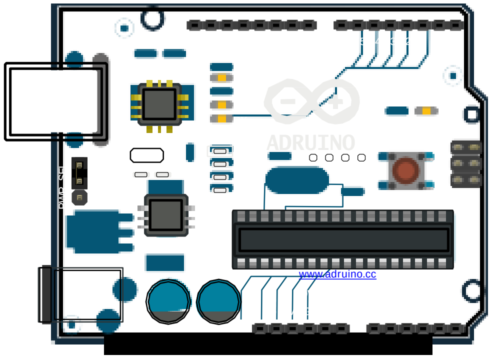


Code Generator

- Designed to support as many targets as possible.
- Supports few Modelica constructs.
- Focuses on generating good code with small footprint.
- Unsupported constructs such a linear systems are rejected.
- Reasonably predictable execution times.
- FMU-like interface (statically linked).

Target Agnostic

- No support for Atmel AVR or Arduino in the compiler.
- Compiler generates simple C code without use of OS or C library.
- Not a single malloc call, even during initialization.
- All hardware I/O and clocks is handled by the Modelica_DeviceDrivers library.



SBHS controller using MDD and the new code generator