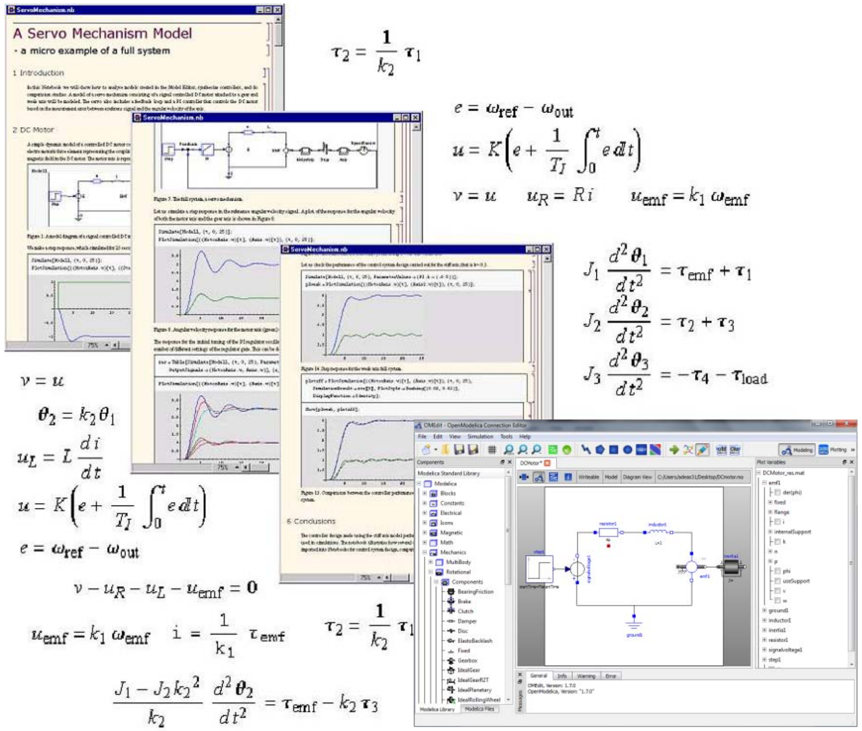
Introduction to Modelica modeling and the OpenModelica and MathModelica tools



Invited talk to workshop "Can Systems biology aid personalized medication?"

December 5, 2011

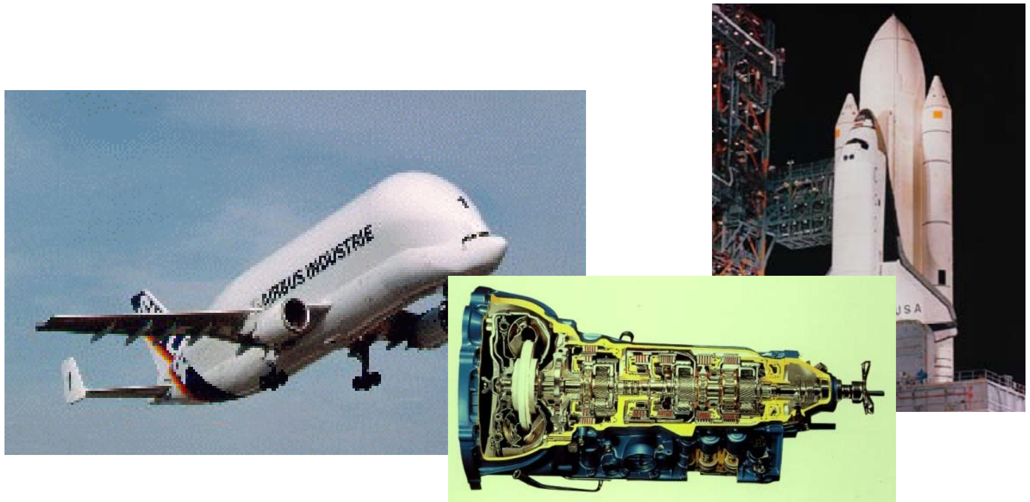
Peter Fritzson

Professor at Linköping University, Sweden
Vice Chairman of Modelica Association
Director of Open Source Modelica Consortium
peter.fritzson@liu.se

Linköpings universitet

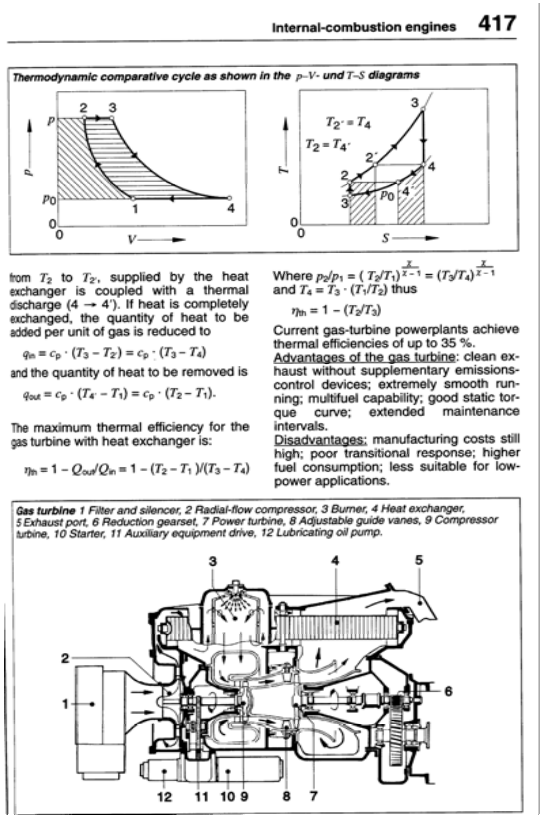
MODELICA

Introduction to Modelica



Modelica Background: Stored Knowledge

Model knowledge is stored in books and human minds which computers cannot access



Thermodynamic comparative cycle as shown in the p–V- und T–S diagrams

from T_2 to $T_{2'}$, supplied by the heat exchanger is coupled with a thermal discharge (4 → 4'). If heat is completely exchanged, the quantity of heat to be added per unit of gas is reduced to

$$q_{in} = c_p \cdot (T_3 - T_{2'}) = c_p \cdot (T_3 - T_4)$$

and the quantity of heat to be removed is

$$q_{out} = c_p \cdot (T_{4'} - T_1) = c_p \cdot (T_2 - T_1).$$

The maximum thermal efficiency for the gas turbine with heat exchanger is:

$$\eta_{th} = 1 - Q_{out}/Q_{in} = 1 - (T_2 - T_1)/(T_3 - T_4)$$

Where $p_2/p_1 = (T_2/T_1)^{\frac{\chi}{\chi-1}} = (T_3/T_4)^{\frac{\chi}{\chi-1}}$ and $T_4 = T_3 \cdot (T_1/T_2)$ thus

$$\eta_{th} = 1 - (T_2/T_3)$$

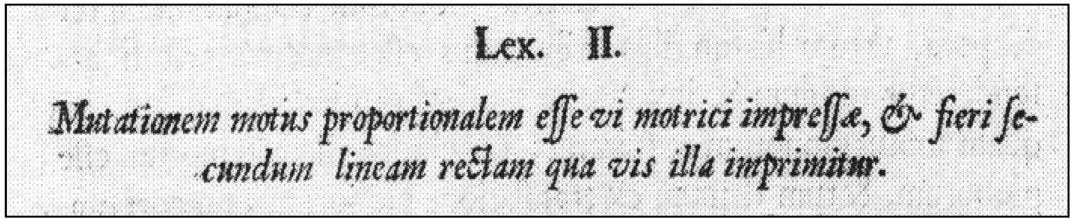
Current gas-turbine powerplants achieve thermal efficiencies of up to 35 %.

Advantages of the gas turbine: clean exhaust without supplementary emissions-control devices; extremely smooth running; multifuel capability; good static torque curve; extended maintenance intervals.

Disadvantages: manufacturing costs still high; poor transitional response; higher fuel consumption; less suitable for low-power applications.

Gas turbine *1 Filter and silencer, 2 Radial-flow compressor, 3 Burner, 4 Heat exchanger, 5 Exhaust port, 6 Reduction gearset, 7 Power turbine, 8 Adjustable guide vanes, 9 Compressor turbine, 10 Starter, 11 Auxiliary equipment drive, 12 Lubricating oil pump.*

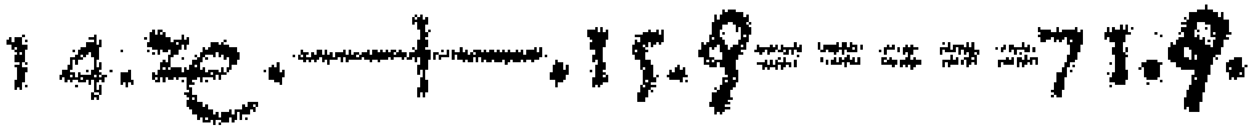
"The change of motion is proportional to the motive force impressed"
– Newton


Lex. II.

Mutationem motus proportionalem esse vi motrici impressæ, & fieri secundum lineam rectam qua vis illa imprimitur.

Modelica Background: The Form – Equations

- Equations were used in the third millennium B.C.
- Equality sign was introduced by Robert Recorde in 1557



Newton still wrote text (Principia, vol. 1, 1686)
"The change of motion is proportional to the motive force impressed "

CSSL (1967) introduced a special form of "equation":

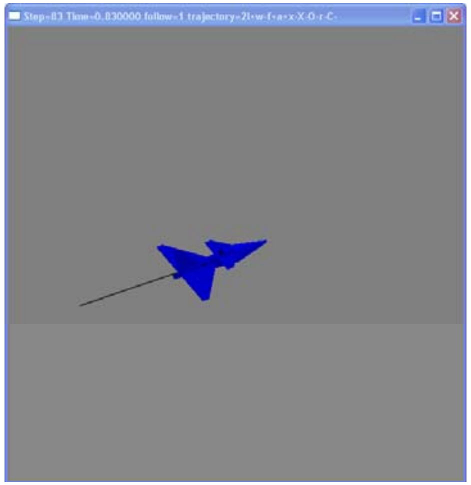
```
variable = expression
v = INTEG(F)/m
```

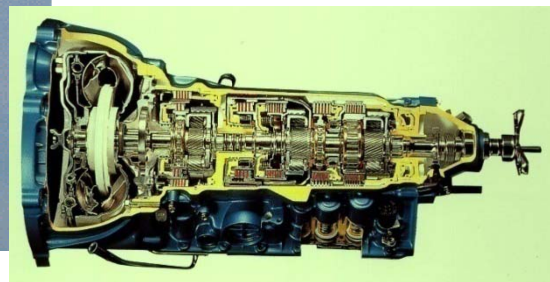
Programming languages usually do not allow equations!

What is Modelica?

A language for modeling of complex cyber-physical systems

- Robotics
- Control
- Automotive
- Aircraft
- Satellites
- Power plants
- Systems biology





What is Modelica?

A language for modeling of complex cyber physical systems

i.e., Modelica is **not** a tool

Free, open language specification:


MODELICA

Modelica® - A Unified Object-Oriented Language for Physical Systems Modeling

Language Specification

Version 2.2
February 2, 2005

by the

Modelica Association

Available at: www.modelica.org

There exist several free and commercial tools, for example:

- OpenModelica from OSMC
- MathModelica from MathCore
- Dymola from Dassault systems
- SimulationX from ITI
- MapleSim from MapleSoft

Modelica – The Next Generation Modeling Language

Declarative language

Equations and mathematical functions allow acausal modeling, high level specification, increased correctness

Multi-domain modeling

Combine electrical, mechanical, thermodynamic, hydraulic, biological, control, event, real-time, etc...

Everything is a class

Strongly typed object-oriented language with a general class concept, Java & MATLAB-like syntax

Visual component programming

Hierarchical system architecture capabilities

Efficient, non-proprietary

Efficiency comparable to C; advanced equation compilation, e.g. 300 000 equations, ~150 000 lines on standard PC

Modelica Acausal Modeling with Equations

What is *acausal* modeling/design?

Why does it increase *reuse*?

The acausality makes Modelica library classes *more reusable* than traditional classes containing assignment statements where the input-output causality is fixed.

Example: a resistor *equation*:

R*i = v;

can be used in three ways:

i := v/R;

v := R*i;

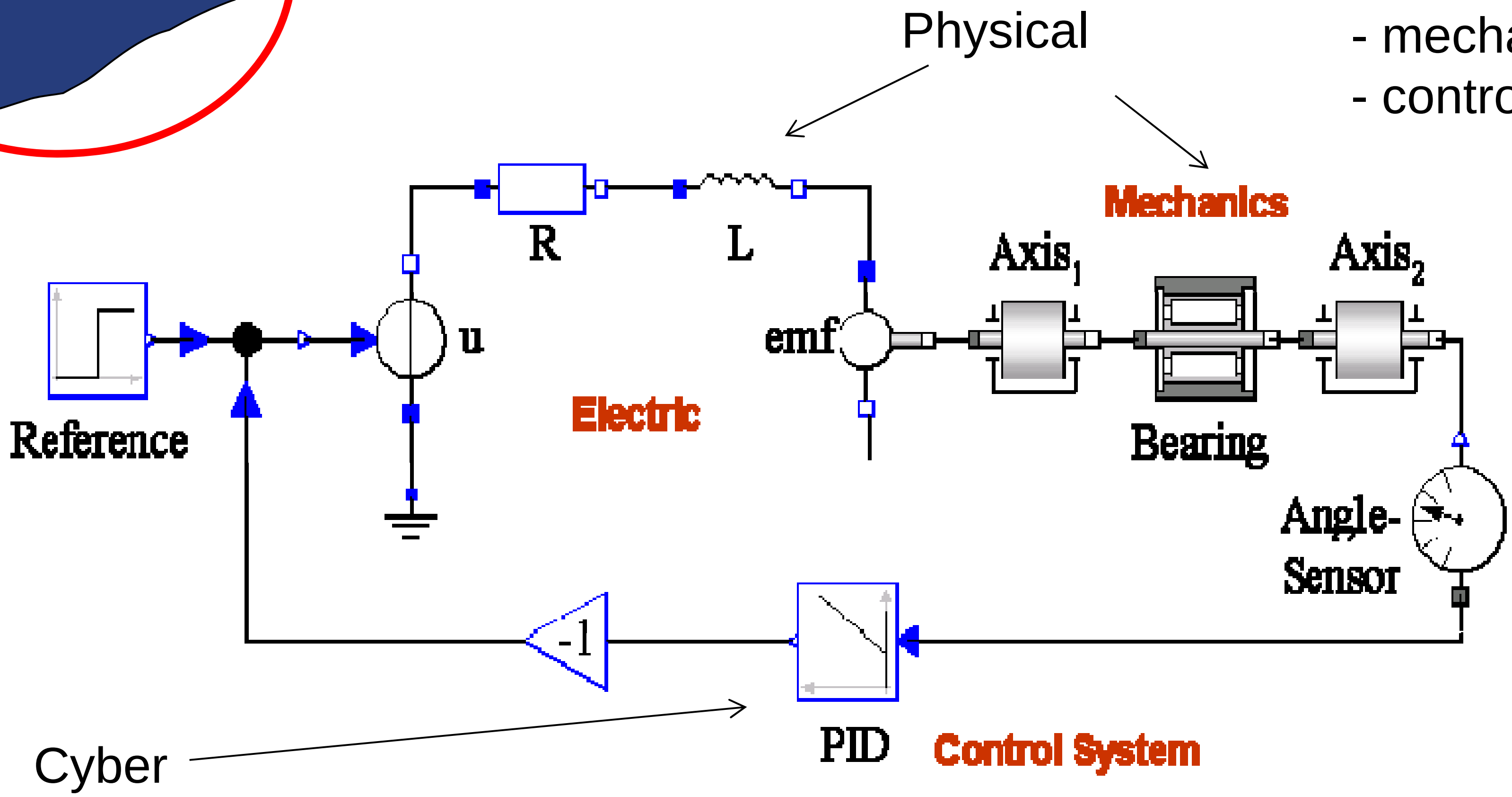
R := v/i;

What is Special about Modelica?

Multi-Domain Modeling

Cyber-Physical Modeling

3 domains
- electric
- mechanics
- control



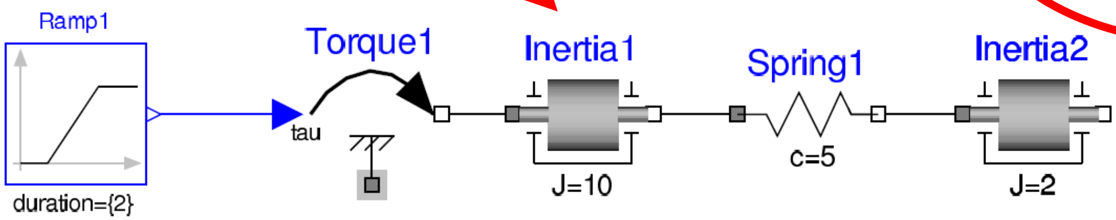
What is Special about Modelica?

Multi-Domain Modeling

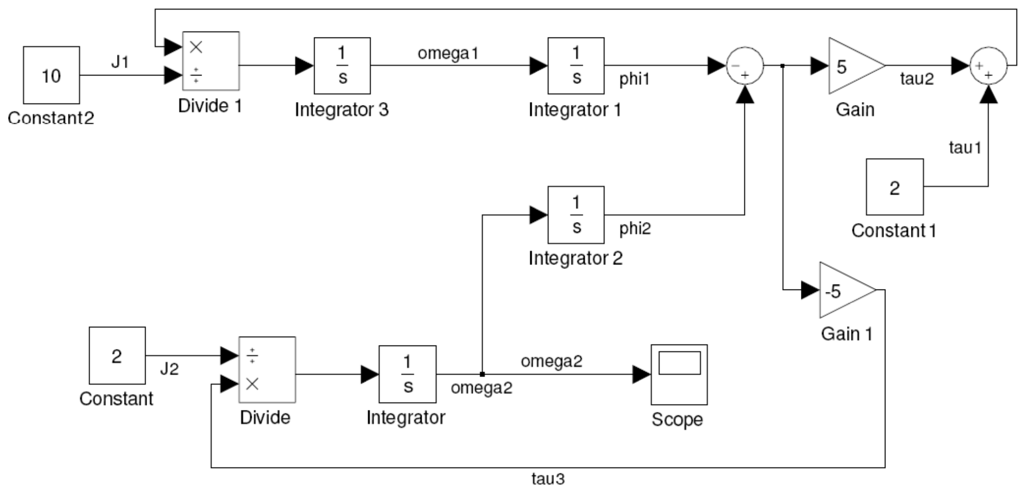
Visual Acausal Hierarchical Component Modeling

Keeps the physical structure

Acausal model (Modelica)



Causal block-based model (Simulink)

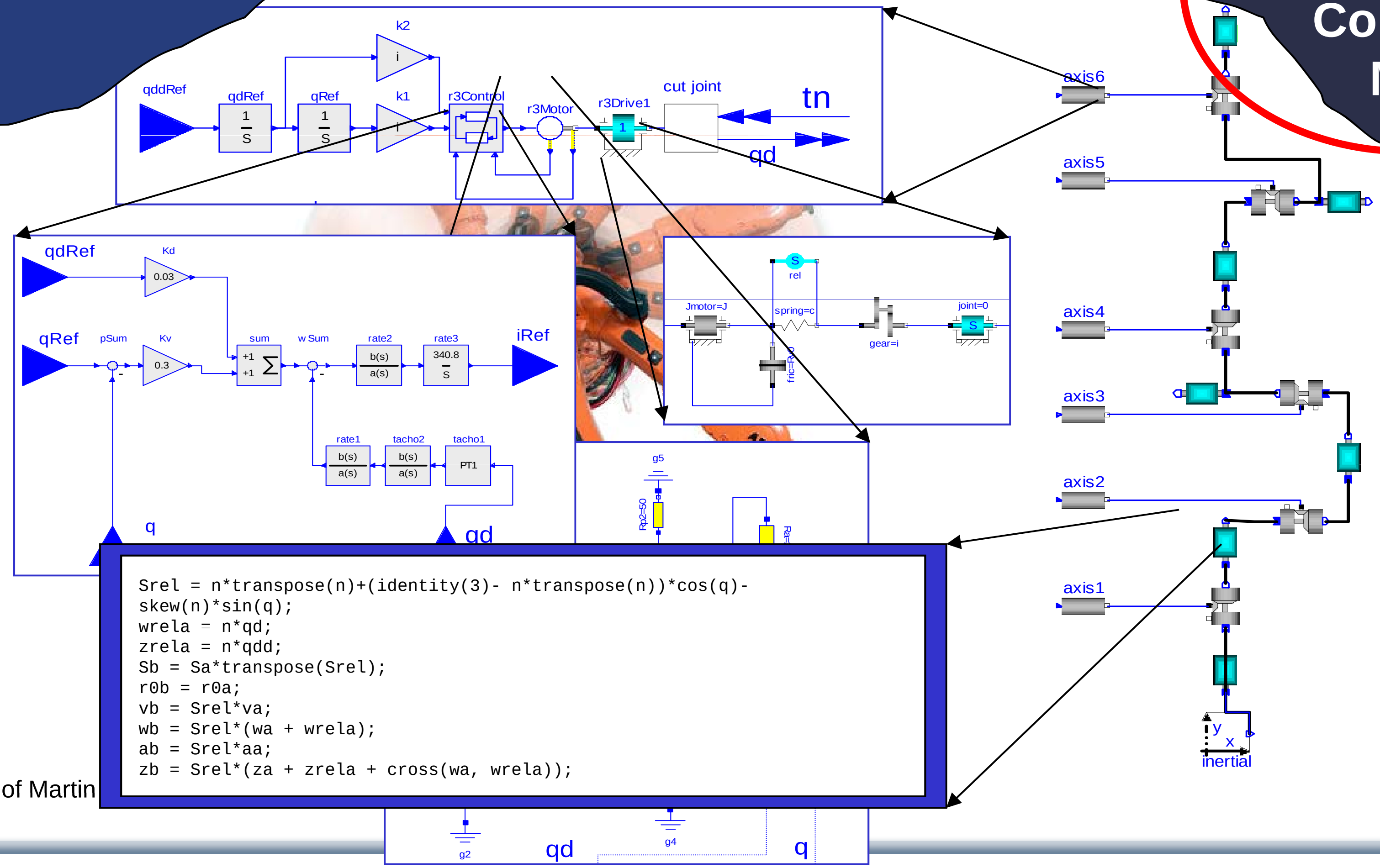


What is Special about Modelica?

Multi-Domain Modeling

Hierarchical system modeling

Visual Acausal Hierarchical Component Modeling




```
Srel = n*transpose(n)+(identity(3)- n*transpose(n))*cos(q)-
skew(n)*sin(q);
wrela = n*qd;
zrela = n*qdd;
Sb = Sa*transpose(Srel);
r0b = r0a;
vb = Srel*va;
wb = Srel*(wa + wrela);
ab = Srel*aa;
zb = Srel*(za + zrela + cross(wa, wrela));
```

Courtesy of Martin

Courtesy of Martin Otter

What is Special about Modelica?

Multi-Domain Modeling

Visual Acausal Hierarchical Component Modeling

A **textual *class-based* language**

Object-Orientation mainly used as structuring concept

Behaviour described declaratively using

- Differential algebraic equations (DAE) (continuous-time)
- Event triggers (discrete-time)

Variable declarations

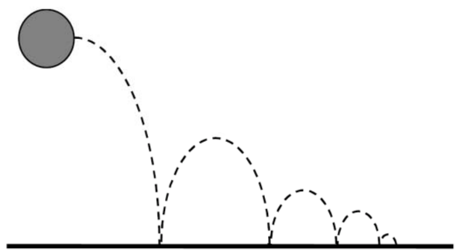
```
class VanDerPol  "Van der Pol oscillator model"
  Real x(start = 1)  "Descriptive string for x”;
  Real y(start = 1)  "y coordinate”;
  parameter Real lambda = 0.3;
equation
  der(x) = y;
  der(y) = -x + lambda*(1 - x*x)*y;
end VanDerPol;
```

Differential equations

Typed Declarative Equation-based Textual Language

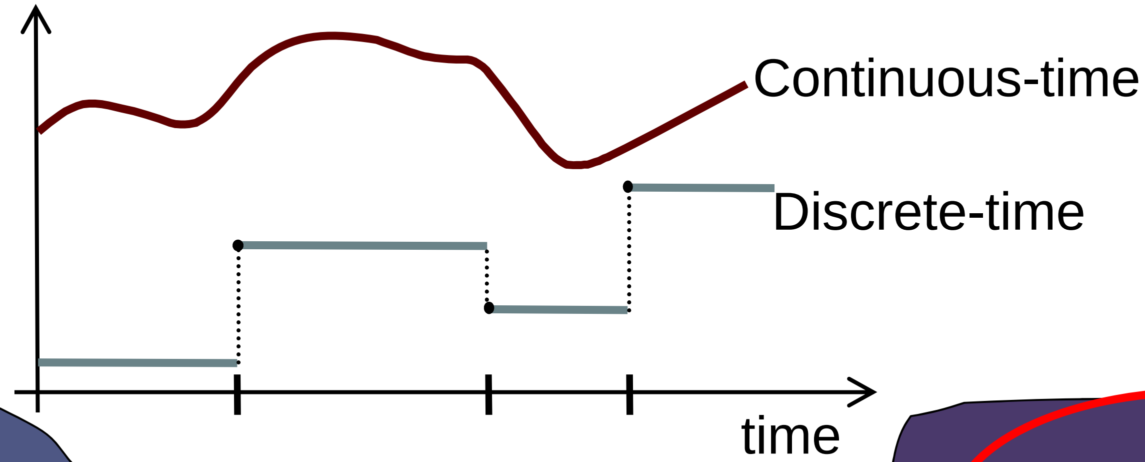
What is Special about Modelica?

Multi-Domain Modeling



Visual Acausal Component Modeling

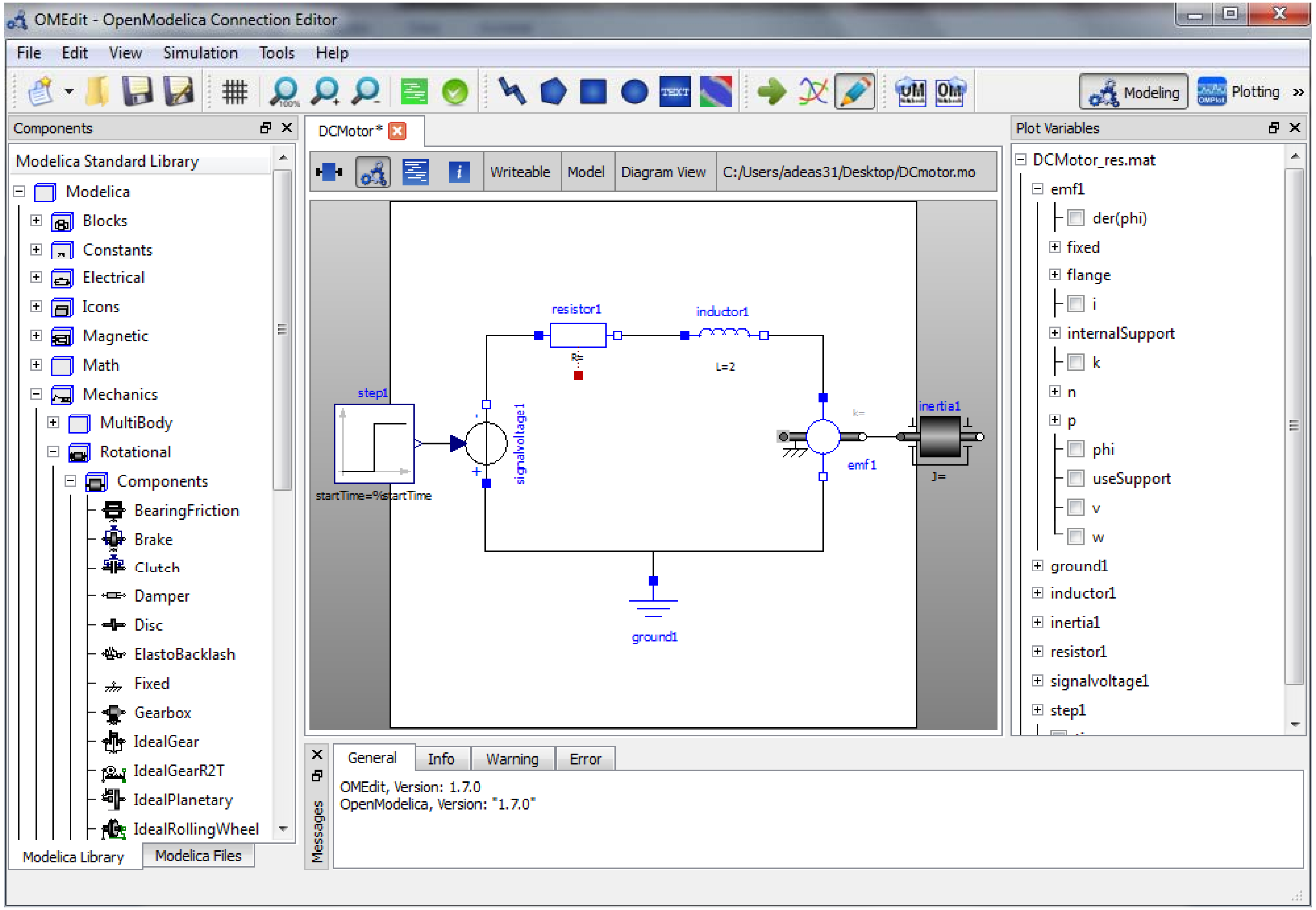
Hybrid modeling =
continuous-time + discrete-time modeling



Typed Declarative Equation-based Textual Language

Hybrid Modeling

Graphical Modeling - Using Drag and Drop Composition

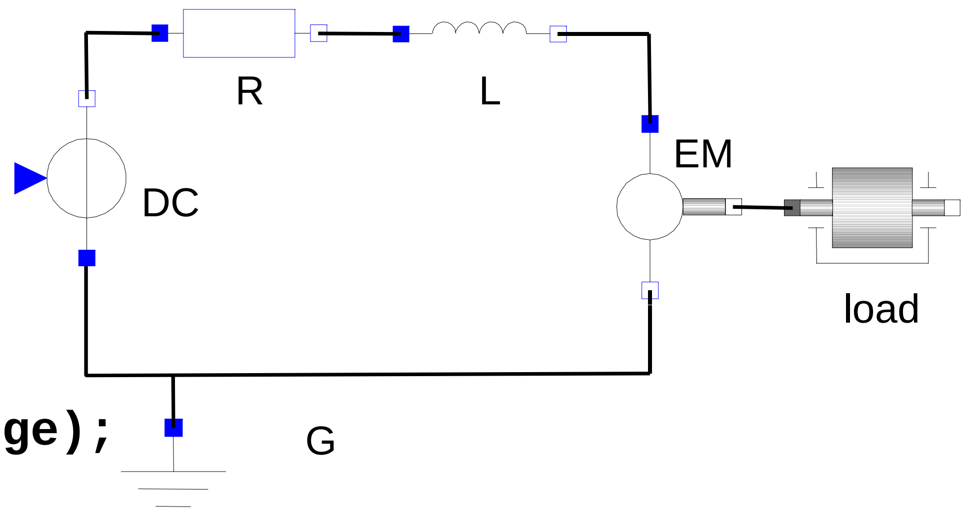


MODELICA

Multi-Domain (Electro-Mechanical) Modelica Model

- A DC motor can be thought of as an electrical circuit which also contains an electromechanical component

```
model DCMotor
   Resistor R(R=100);
   Inductor L(L=100);
   VsourceDC DC(f=10);
   Ground G;
   ElectroMechanicalElement EM(k=10,J=10, b=2);
   Inertia load;
equation
   connect(DC.p,R.n);
   connect(R.p,L.n);
   connect(L.p, EM.n);
   connect(EM.p, DC.n);
   connect(DC.n,G.p);
   connect(EM.flange,load.flange);
end DCMotor
```



Corresponding DCMotor Model Equations

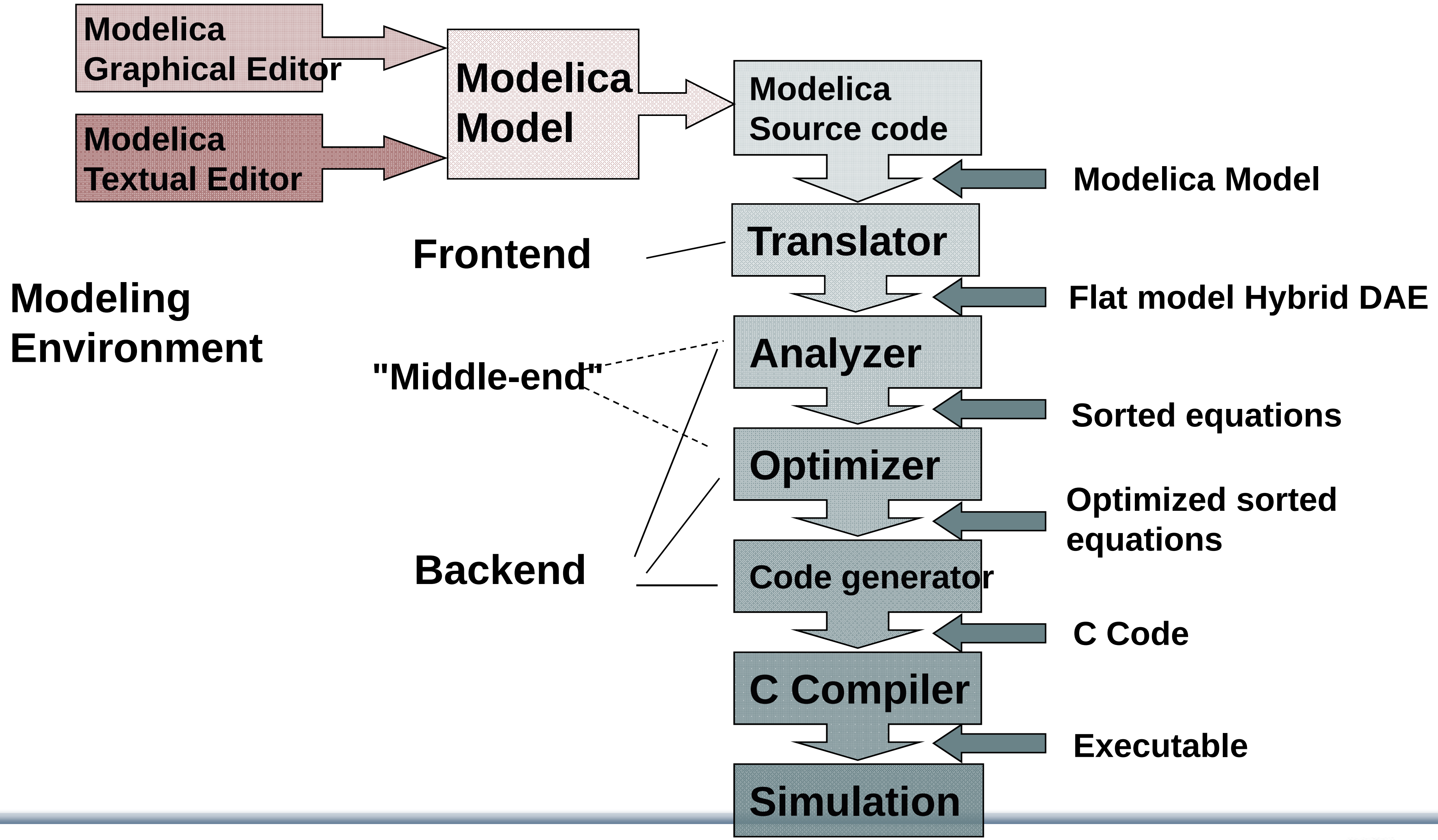
The following equations are automatically derived from the Modelica model:

```
0 == DC.p.i + R.n.i          EM.u == EM.p.v - EM.n.v              R.u == R.p.v - R.n.v
DC.p.v == R.n.v              0 == EM.p.i + EM.n.i                 0 == R.p.i + R.n.i
                             EM.i == EM.p.i                       R.i == R.p.i
0 == R.p.i + L.n.i           EM.u == EM.k * EM.ω                  R.u == R.R * R.i
R.p.v == L.n.v               EM.i == EM.M / EM.k
                             EM.J * EM.ω == EM.M - EM.b * EM.ω    L.u == L.p.v - L.n.v
0 == L.p.i + EM.n.i                                               0 == L.p.i + L.n.i
L.p.v == EM.n.v              DC.u == DC.p.v - DC.n.v              L.i == L.p.i
                             0 == DC.p.i + DC.n.i                 L.u == L.L * L.i'
0 == EM.p.i + DC.n.i         DC.i == DC.p.i
EM.p.v == DC.n.v             DC.u == DC.Amp * Sin[2 π DC.f * t]

0 == DC.n.i + G.p.i
DC.n.v == G.p.v                            (load component not included)
```

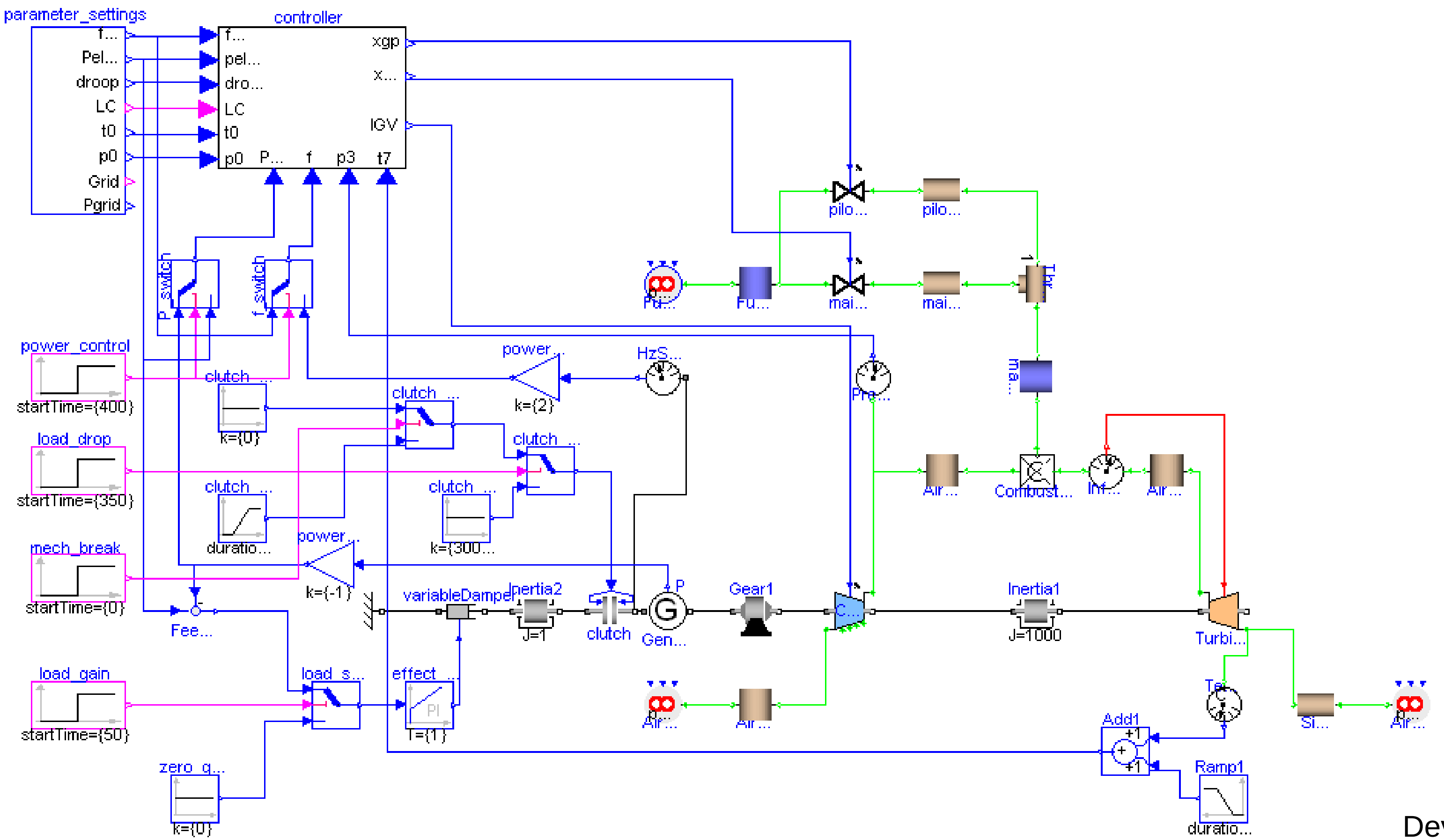
Automatic transformation to ODE or DAE for simulation:

$$\frac{dx}{dt} == f[x, u, t] \qquad\qquad g\left[\frac{dx}{dt}, x, u, t\right] == 0$$

Model Translation Process to Hybrid DAE to Code



Modelica in Power Generation
GTX Gas Turbine Power Cutoff Mechanism

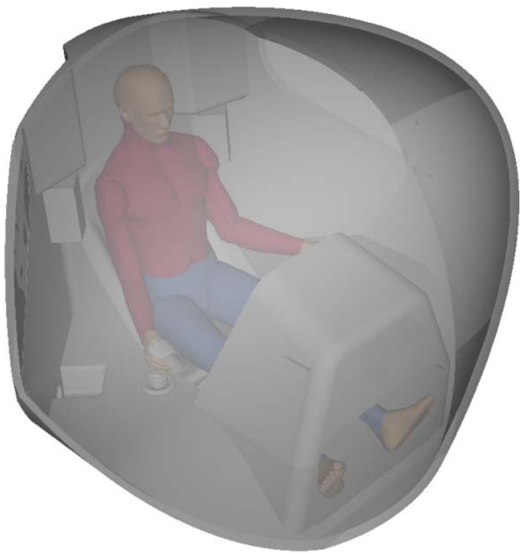


Courtesy of Siemens Industrial Turbomachinery AB, Finspång, Sweden

Developed by MathCore for Siemens

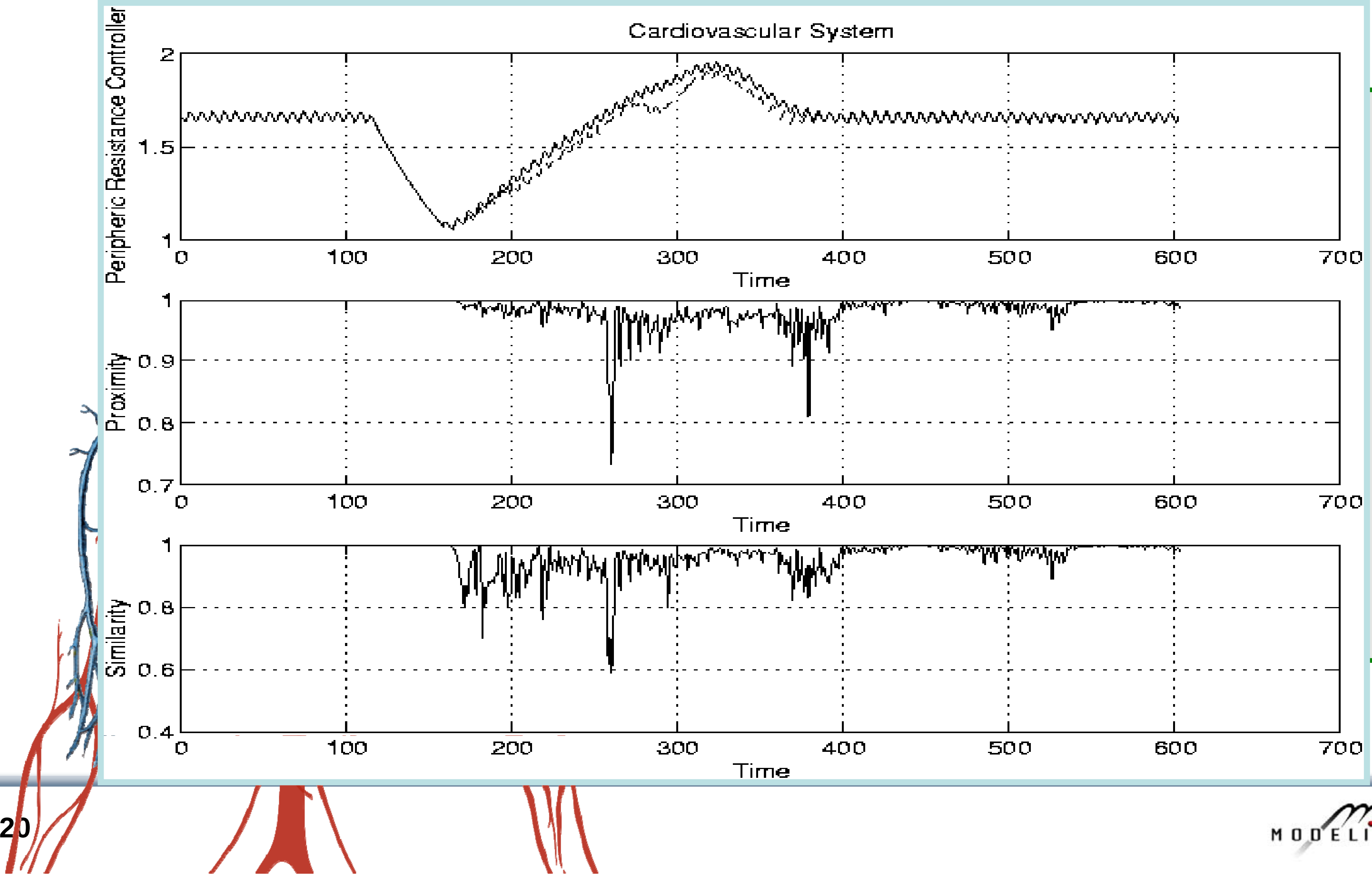
Application of Modelica in Robotics Models Real-time Training Simulator for Flight, Driving

- Using Modelica models generating real-time code
- Different simulation environments (e.g. Flight, Car Driving, Helicopter)
- Developed at DLR Munich, Germany
- Dymola Modelica tool



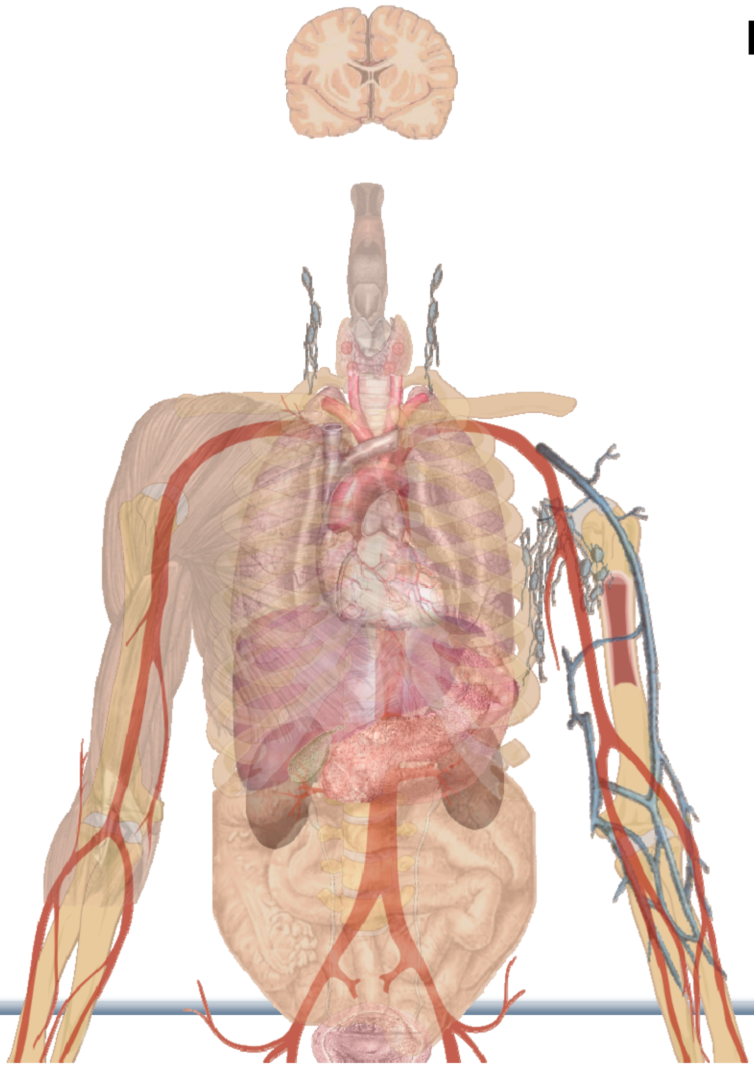
Courtesy of Martin Otter, DLR, Oberphaffe
Germany

Modelica Examples – Systems Biology

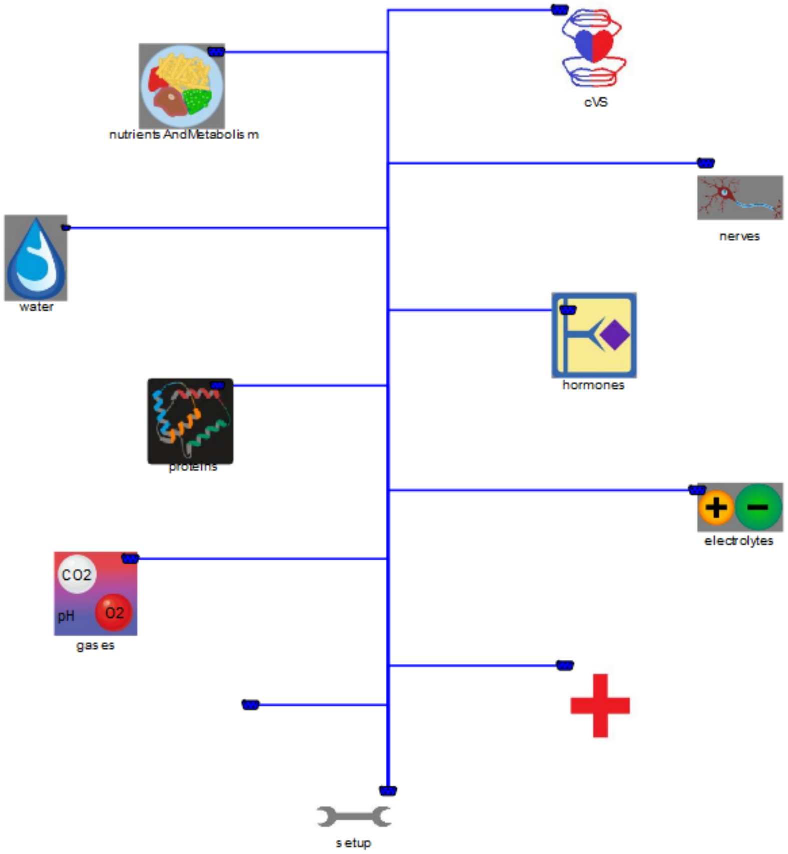


MODELICA

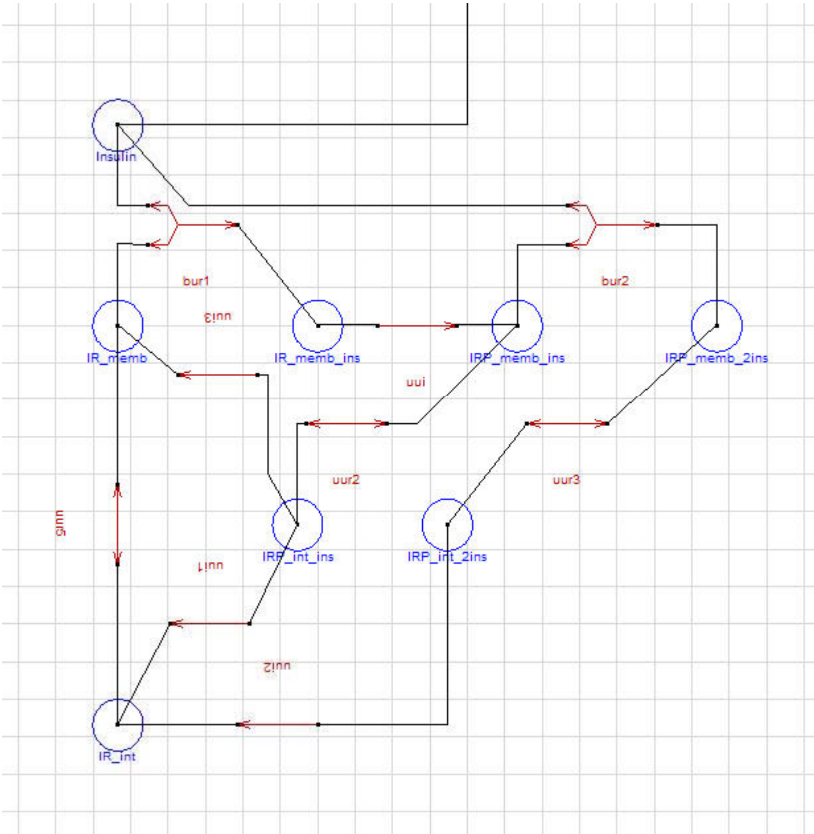
Modelica Examples – Systems Biology

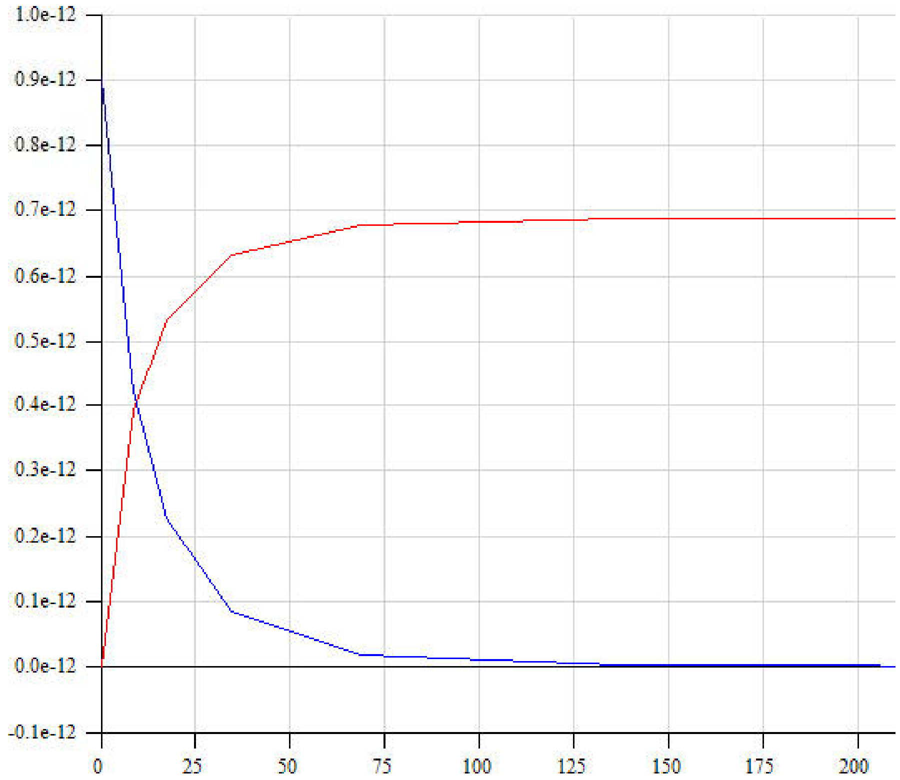


HumMod
Kofranek et Al., Charles University, Prag

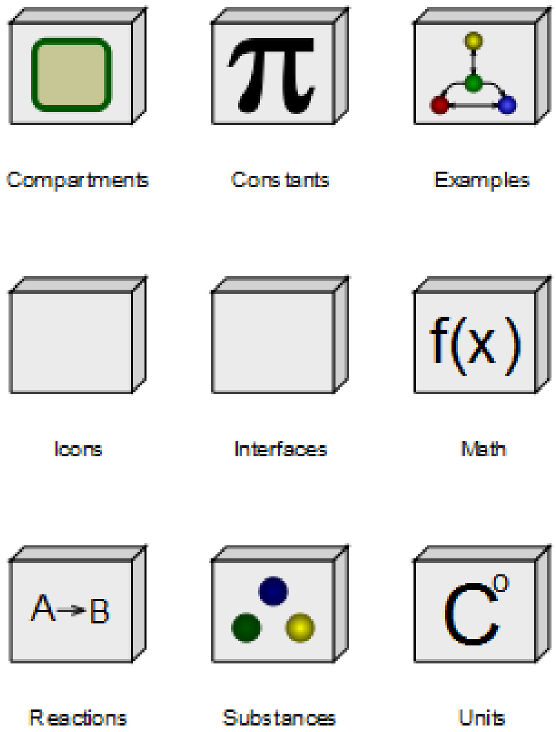


Cell Biology Insulin Receptor Model (Sedgehat et al)
Modelica Modeling Using a free PathWay Library (BioChem)





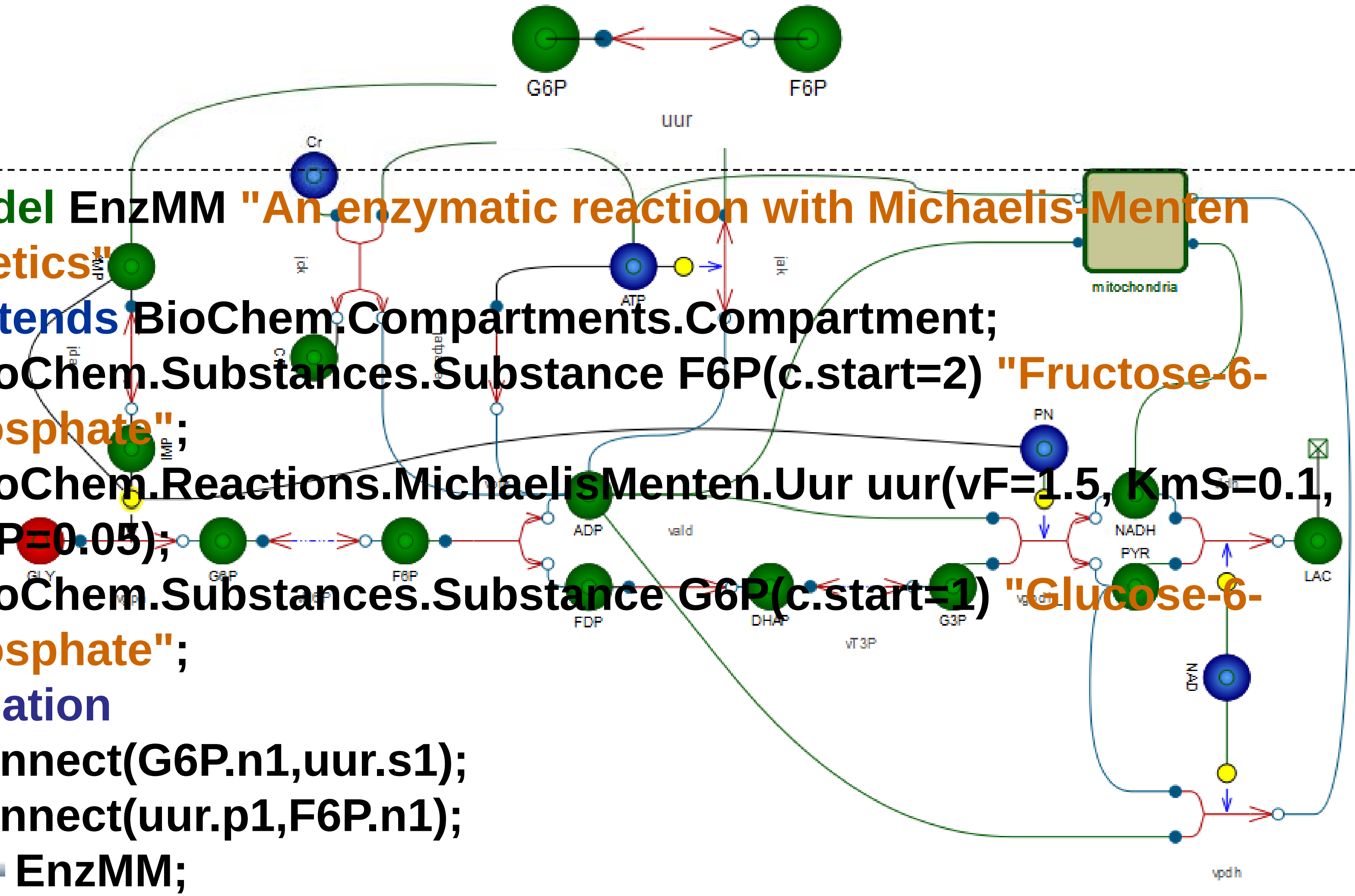
The BioChem Library for PathWay Modeling



- Free Open Source Library
- Originally Developed at PELAB/IDA LIU 2003-2006, continued development at MathCore Engineering AB and LIU
- Also used for SBML to Modelica mapping

Several BioChem Slides, Courtesy of Jan Brugård, MathCore Engineering AB/ Wolfram Research

Introductory Modelica Example using BioChem




```
model EnzMM "An enzymatic reaction with Michaelis-Menten
kinetics"
  extends BioChem.Compartments.Compartment;
  BioChem.Substances.Substance F6P(c.start=2) "Fructose-6-
phosphate";
  BioChem.Reactions.MichaelisMenten.Uur uur(vF=1.5, KmS=0.1,
KmP=0.05);
  BioChem.Substances.Substance G6P(c.start=1) "Glucose-6-
phosphate";
equation
  connect(G6P.n1,uur.s1);
  connect(uur.p1,F6P.n1);
end EnzMM;
```


MODELICA

Modelica Standard Library
Open Source, Developed by Modelica Association

The Modelica Standard Library contains components from various application areas, including the following sublibraries:

• Blocks	Library for basic input/output control blocks
• Constants	Mathematical constants and constants of nature
• Electrical	Library for electrical models
• Icons	Icon definitions
• Fluid	1-dim Flow in networks of vessels, pipes, fluid machines, valves, etc.
• Math	Mathematical functions
• Magnetic	Magnetic.Fluxtubes – for magnetic applications
• Mechanics	Library for mechanical systems
• Media	Media models for liquids and gases
• SIunits	Type definitions based on SI units according to ISO 31-1992
• Stategraph	Hierarchical state machines (analogous to Statecharts)
• Thermal	Components for thermal systems
• Utilities	Utility functions especially for scripting

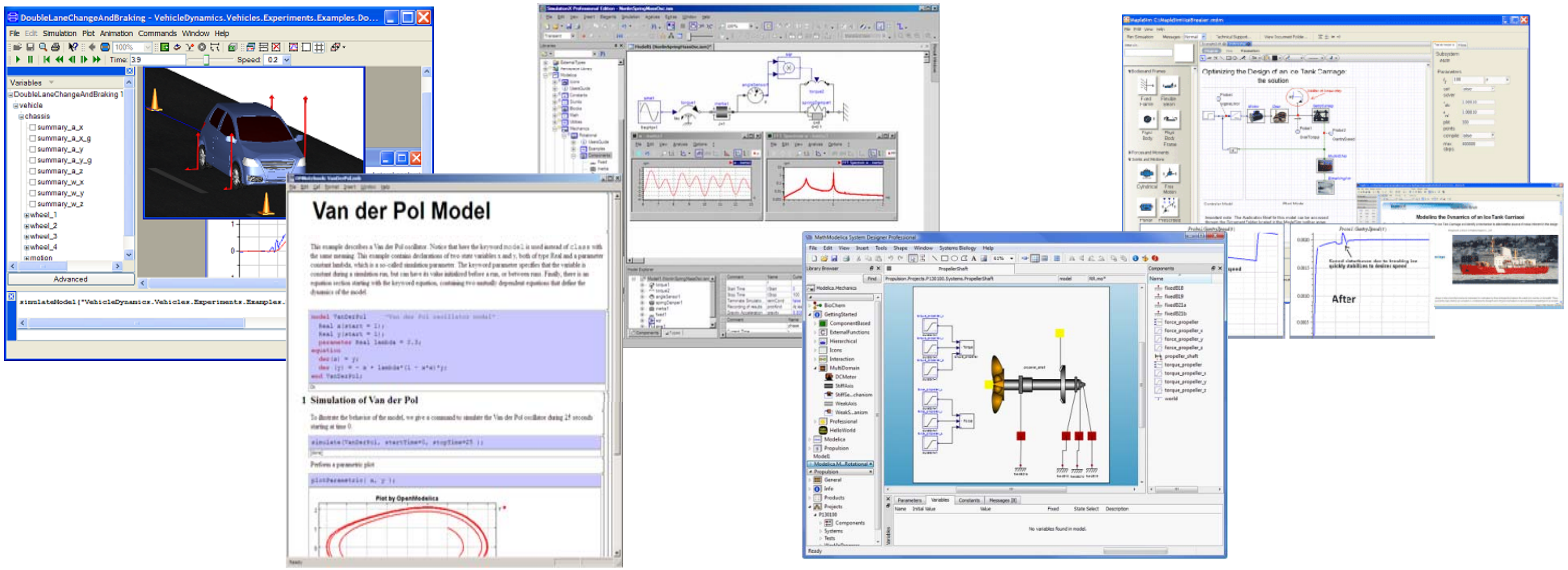
Brief Modelica History

- First Modelica design group meeting in fall 1996
  - International group of people with expert knowledge in both language design and physical modeling
  - Industry and academia
- Modelica Versions
  - 1.0 released September 1997
  - 2.0 released March 2002
  - 2.2 released March 2005
  - 3.0 released September 2007
  - 3.1 released May 2009
  - 3.2 released May 2010
  - 3.3 planned Spring 2012
- Modelica Association established 2000
  - Open, non-profit organization

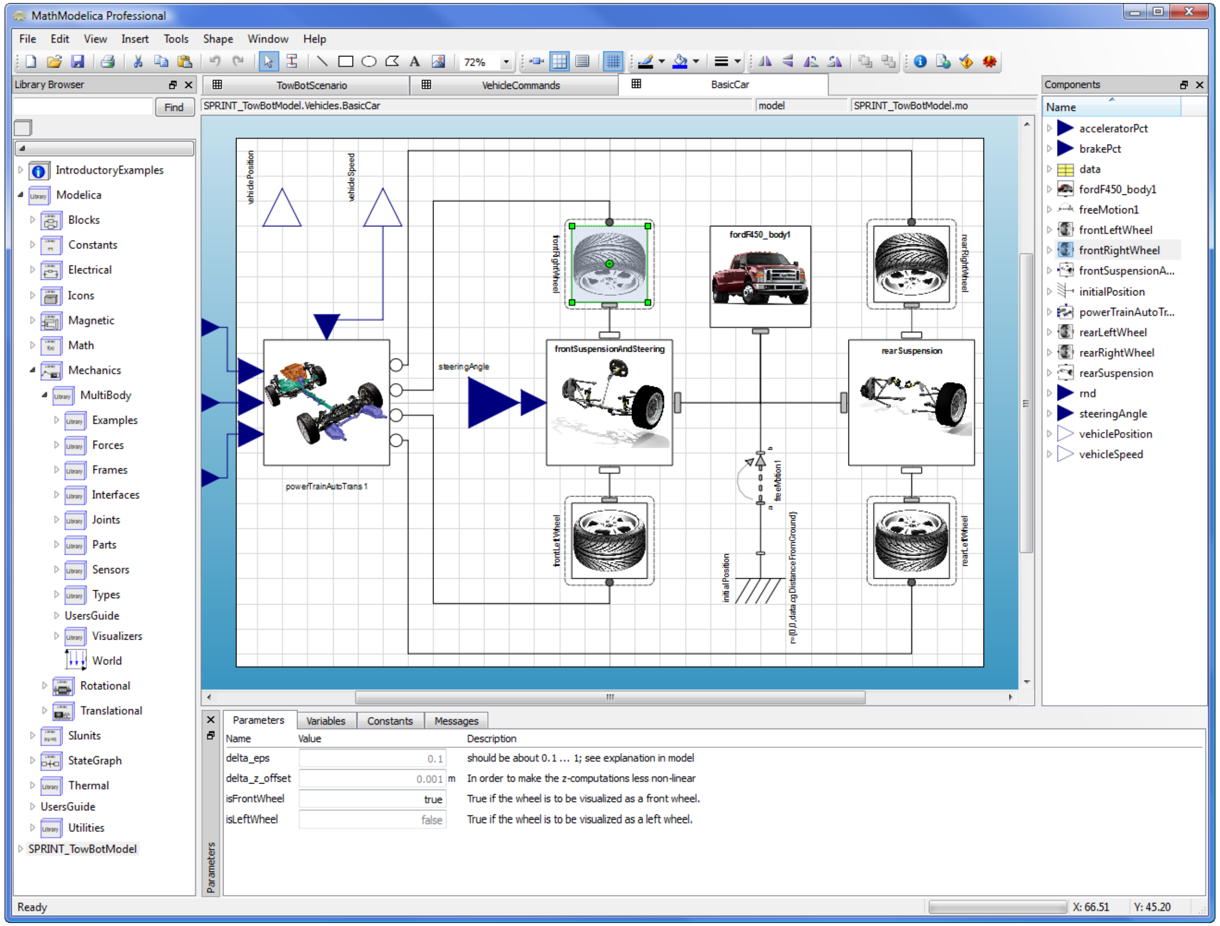
Modelica Conferences

- The 1st International Modelica conference October, 2000
- The 2nd International Modelica conference March 18-19, 2002
- The 3rd International Modelica conference November 5-6, 2003 in Linköping, Sweden
- The 4th International Modelica conference March 6-7, 2005 in Hamburg, Germany
- The 5th International Modelica conference September 4-5, 2006 in Vienna, Austria
- The 6th International Modelica conference March 3-4, 2008 in Bielefeld, Germany
- The 7th International Modelica conference Sept 21-22, 2009, Como, Italy
- The 8th International Modelica conference March 20-22, 2011 in Dresden, Germany
- **The 4th Int. OpenModelica Workshop, Febr 6, 2012, Linköping, Sweden**

Modelica Environments and OpenModelica

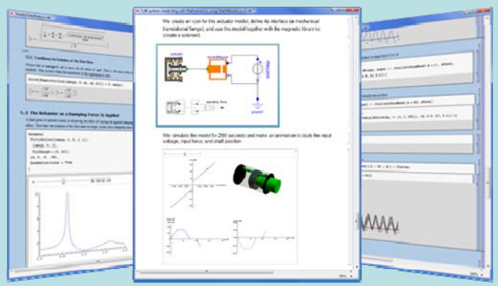


MathModelica – MathCore / Wolfram Research



- Wolfram Research
- USA, Sweden
- General purpose
- Mathematica integration
- www.wolfram.com
- www.mathcore.com

Mathematica



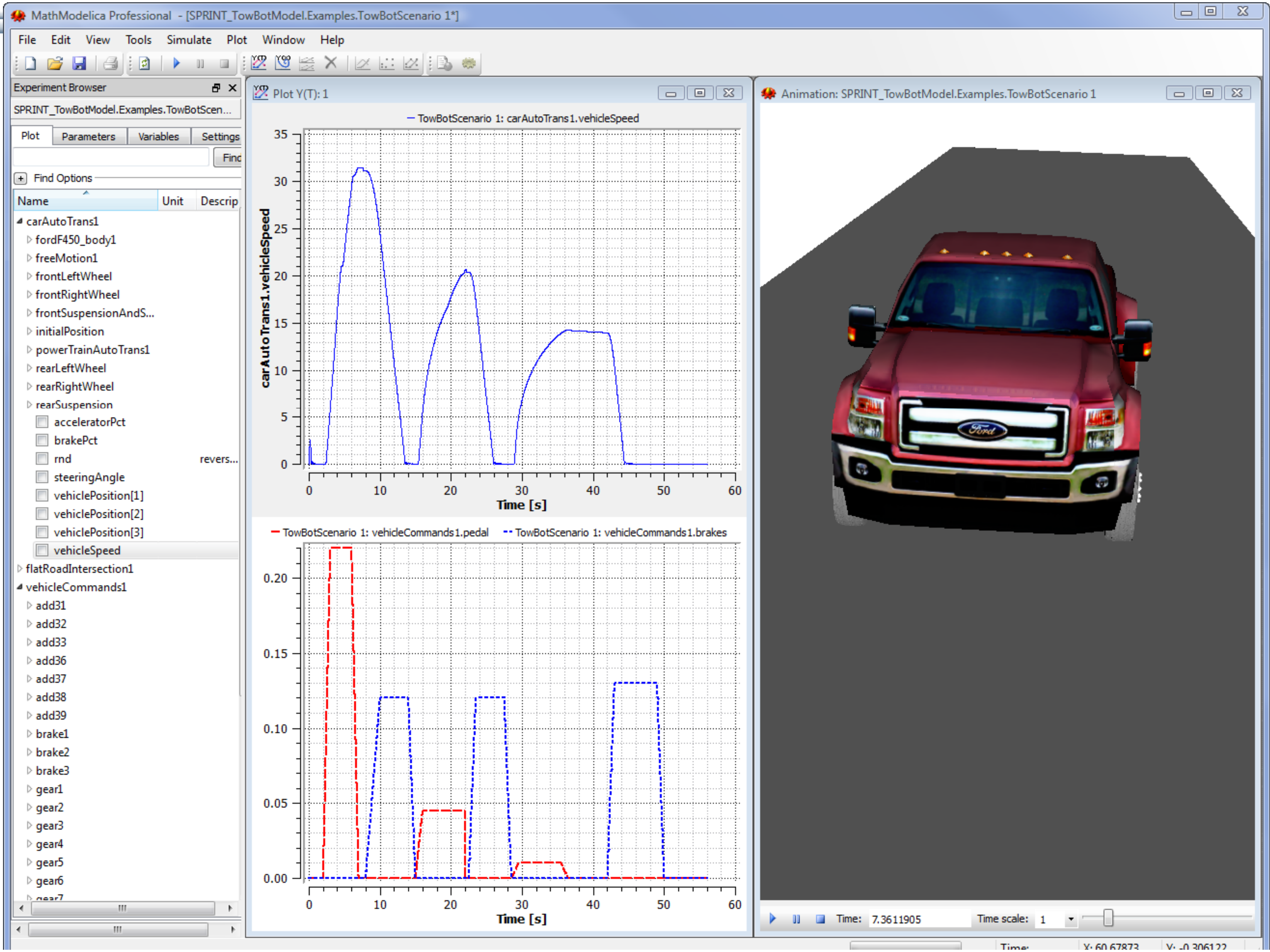
Simulation and analysis

Car model graphical view

Courtesy Wolfram Research

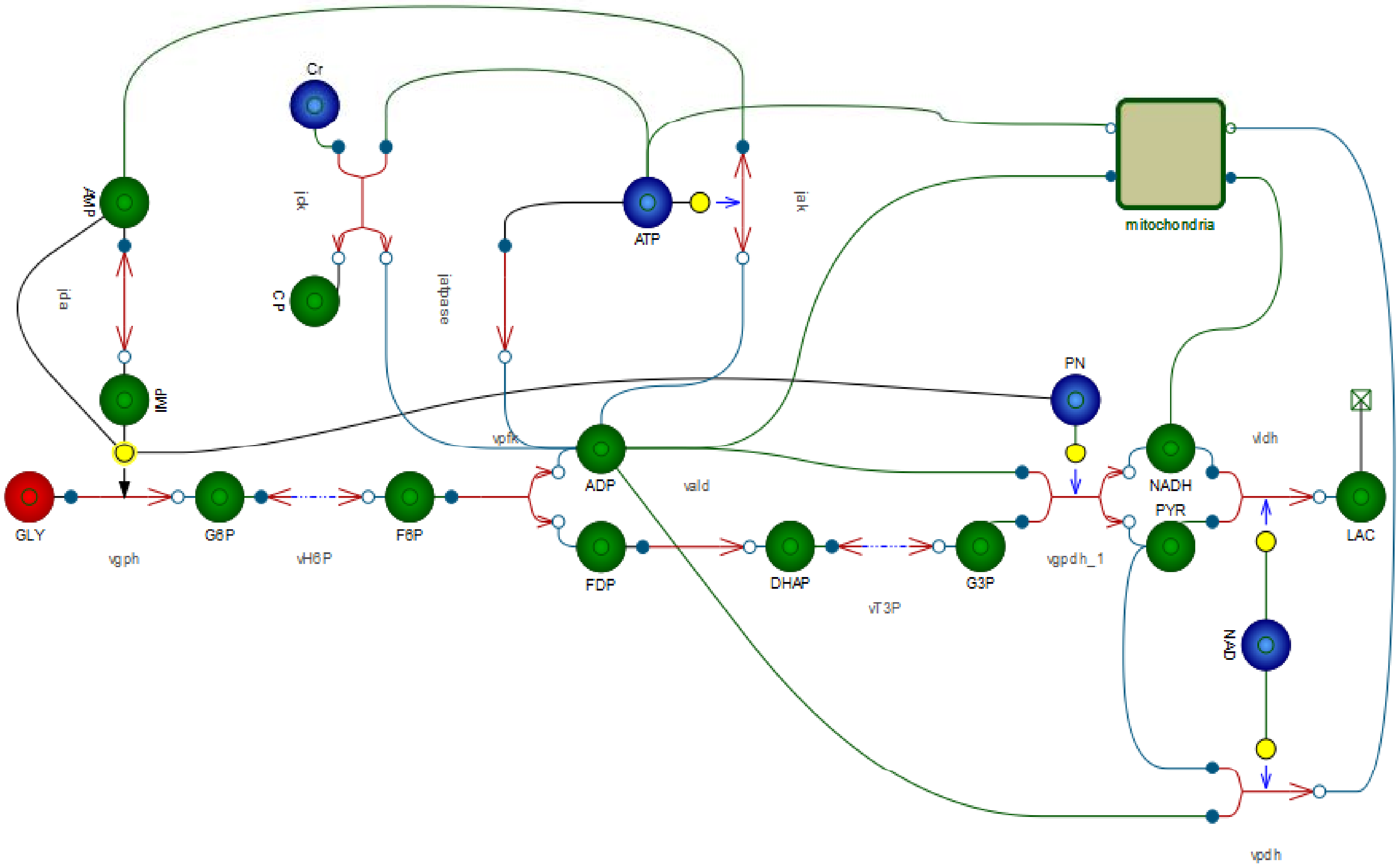
MODELICA

MathModelica – Car Model Simulation & Animation

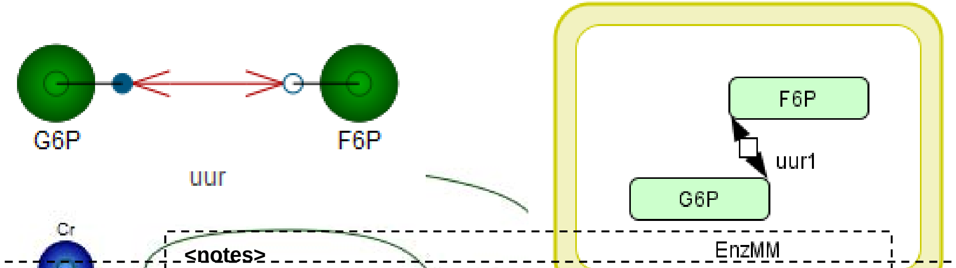


Courtesy Wolfram Research

PathWay Model Using BioChem and MathModelica



Introductory SBML to Modelica Example




```
model EnzMM "An enzymatic reaction with Michaelis-Menten kinetics";
  extends BioChem.Compartments.Compartment;
  BioChem.Substances.Substance F6P(c.start=2) "Fructose-6-phosphate";
  BioChem.Reactions.MichaelisMenten.Uur uur(vF=1.5, KmS=0.1, KmP=0.05);
  BioChem.Substances.Substance G6P(c.start=1) "Glucose-6-phosphate";
equation
  connect(G6P.n1,uur.s1);
  connect(uur.p1,F6P.n1);
end EnzMM;
```

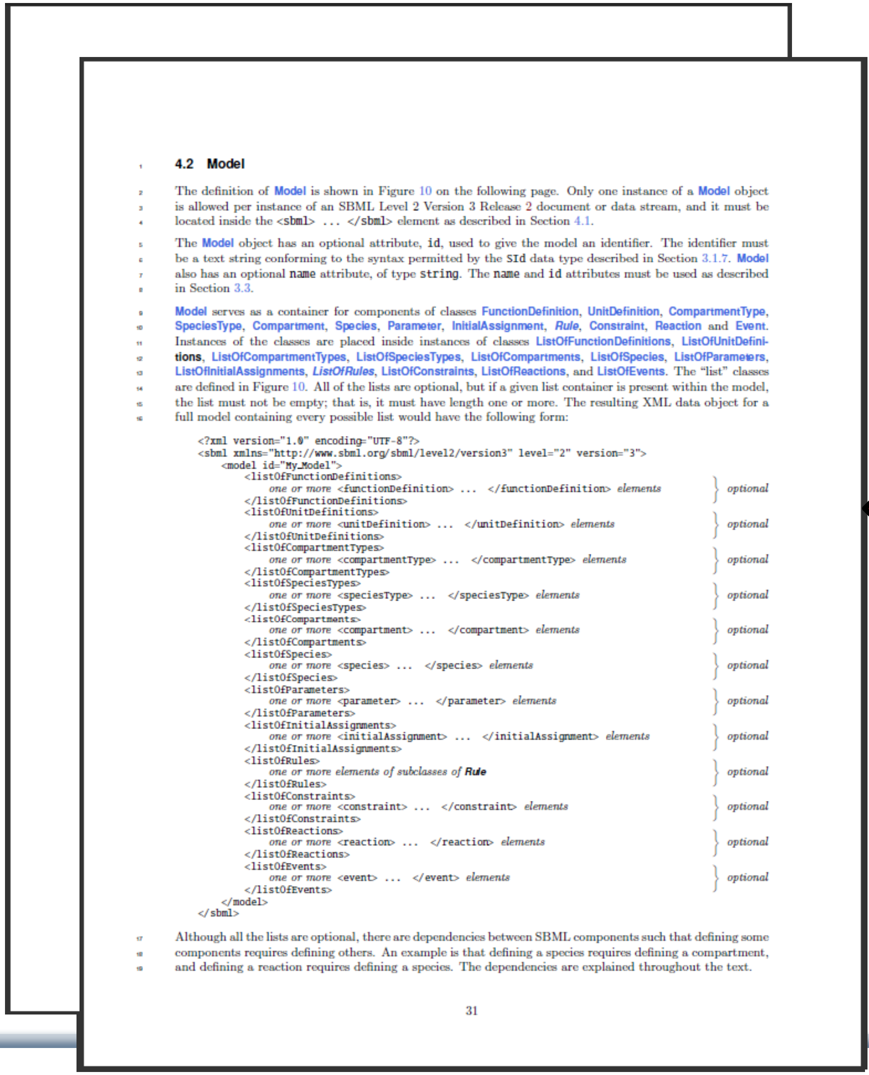

```
<?xml version="1.0" encoding="UTF-8"?>
<sbml xmlns="http://www.sbml.org/sbml/level2" level="2" version="1">
 <model id="MyExample">
  <listOfCompartments>
   <compartment id="EnzMM" size="1"/>
  </listOfCompartments>
  <listOfSpecies>
   <species id="G6P" compartment="EnzMM">
    <notes>
     <html xmlns="http://www.w3.org/1999/xhtml">
      <p>
      A substance with variable concentration.
      </p>
     </html>
    </notes>
   </species>
   <species id="F6P" compartment="EnzMM">
    <notes>
     <html xmlns="http://www.w3.org/1999/xhtml">
      <p>
      A substance with variable concentration.
      </p>
     </html>
    </notes>
   </species>
  </listOfSpecies>
  <listOfReactions>
   <reaction id="uur1">
    <notes>
     <html xmlns="http://www.w3.org/1999/xhtml">
      <p>
      Uni-uni reversible simple Michaelis-Menten.
      </p>
     </html>
    </notes>
    <listOfReactants>
     <speciesReference species="G6P"/>
    </listOfReactants>
    <listOfProducts>
     <speciesReference species="F6P"/>
    </listOfProducts>
    <kineticLaw>
     <math xmlns="http://www.w3.org/1998/Math/MathML">
      <apply>
       <divide/>
       <apply>
        <minus/>
        <apply>
         <divide/>
         <apply>
          <times/>
          <ci> vF </ci>
          <ci> G6P </ci>
         </apply>
         <ci> KmS </ci>
        </apply>
        <apply>
         <divide/>
         <apply>
          <times/>
          <ci> vR </ci>
          <ci> F6P </ci>
         </apply>
         <ci> KmP </ci>
        </apply>
       </apply>
       <apply>
        <plus/>
        <cn type="integer"> 1 </cn>
        <apply>
         <divide/>
         <ci> G6P </ci>
         <ci> KmS </ci>
        </apply>
        <apply>
         <divide/>
         <ci> F6P </ci>
         <ci> KmP </ci>
        </apply>
       </apply>
      </apply>
     </math>
     <listOfParameters>
      <parameter id="KmS" name="Forward Michaelis-Menten constant" value="1"/>
      <parameter id="KmP" name="Reverse Michaelis-Menten constant" value="1"/>
      <parameter id="vF" name="Forward maximum velocity" value="1"/>
      <parameter id="vR" name="Reverse maximum velocity" value="1"/>
     </listOfParameters>
    </kineticLaw>
   </reaction>
  </listOfReactions>
 </model>
</sbml>
```

SBML/Modelica Translator

- As the standard modeling language within systems biology applications SBML
  - has a wide range of ready-made models available.
  - a large user base with knowledge about the language and its applications

- By creating a translator to Modelica we can give the users access to a much richer language, offering new possibilities.

The Translation Challenge



4.2 Model

The definition of Model is shown in Figure 10 on the following page. Only one instance of a Model object is allowed per instance of an SBML Level 2 Version 3 Release 2 document or data stream, and it must be located inside the `<sbml> ... </sbml>` element as described in Section 4.1.

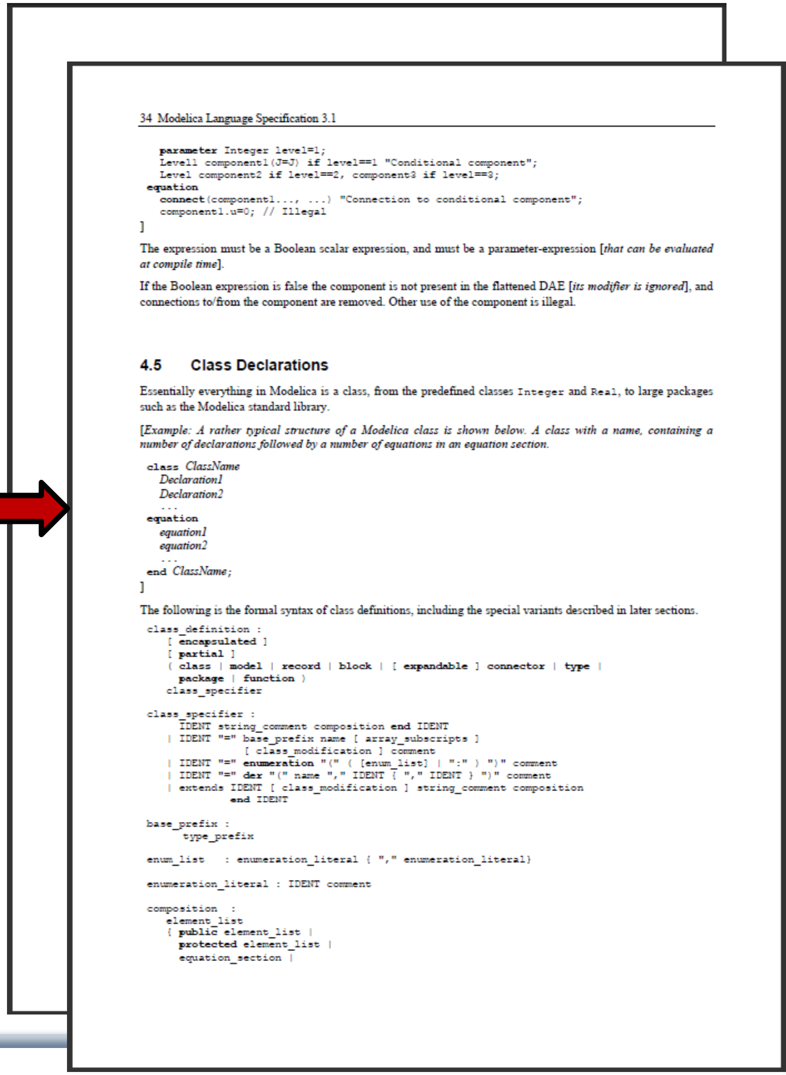
The Model object has an optional attribute, `id`, used to give the model an identifier. The identifier must be a text string conforming to the syntax permitted by the `SId` data type described in Section 3.1.7. Model also has an optional `name` attribute, of type `string`. The `name` and `id` attributes must be used as described in Section 3.3.

Model serves as a container for components of classes FunctionDefinition, UnitDefinition, CompartmentType, SpeciesType, Compartment, Species, Parameter, InitialAssignment, *Rule*, Constraint, Reaction and Event. Instances of the classes are placed inside instances of classes ListOfFunctionDefinitions, ListOfUnitDefinitions, ListOfCompartmentTypes, ListOfSpeciesTypes, ListOfCompartments, ListOfSpecies, ListOfParameters, ListOfInitialAssignments, *ListOfRules*, ListOfConstraints, ListOfReactions, and ListOfEvents. The "list" classes are defined in Figure 10. All of the lists are optional, but if a given list container is present within the model, the list must not be empty; that is, it must have length one or more. The resulting XML data object for a full model containing every possible list would have the following form:

```
<?xml version="1.0" encoding="UTF-8"?>
<sbml xmlns="http://www.sbml.org/sbml/level2/version3" level="2" version="3">
    <model id="My_Model">
        <listOfFunctionDefinitions>
            one or more <functionDefinition> ... </functionDefinition> elements      } optional
        </listOfFunctionDefinitions>
        <listOfUnitDefinitions>
            one or more <unitDefinition> ... </unitDefinition> elements              } optional
        </listOfUnitDefinitions>
        <listOfCompartmentTypes>
            one or more <compartmentType> ... </compartmentType> elements            } optional
        </listOfCompartmentTypes>
        <listOfSpeciesTypes>
            one or more <speciesType> ... </speciesType> elements                    } optional
        </listOfSpeciesTypes>
        <listOfCompartments>
            one or more <compartment> ... </compartment> elements                    } optional
        </listOfCompartments>
        <listOfSpecies>
            one or more <species> ... </species> elements                            } optional
        </listOfSpecies>
        <listOfParameters>
            one or more <parameter> ... </parameter> elements                        } optional
        </listOfParameters>
        <listOfInitialAssignments>
            one or more <initialAssignment> ... </initialAssignment> elements        } optional
        </listOfInitialAssignments>
        <listOfRules>
            one or more elements of subclasses of Rule                               } optional
        </listOfRules>
        <listOfConstraints>
            one or more <constraint> ... </constraint> elements                      } optional
        </listOfConstraints>
        <listOfReactions>
            one or more <reaction> ... </reaction> elements                          } optional
        </listOfReactions>
        <listOfEvents>
            one or more <event> ... </event> elements                                } optional
        </listOfEvents>
    </model>
</sbml>
```

Although all the lists are optional, there are dependencies between SBML components such that defining some components requires defining others. An example is that defining a species requires defining a compartment, and defining a reaction requires defining a species. The dependencies are explained throughout the text.

31



34 Modelica Language Specification 3.1

```
  parameter Integer level=1;
  Level1 component1(J=J) if level==1 "Conditional component";
  Level component2 if level==2, component3 if level==3;
equation
  connect(component1..., ...) "Connection to conditional component";
  component1.u=0; // Illegal
]
```

The expression must be a Boolean scalar expression, and must be a parameter-expression [*that can be evaluated at compile time*].

If the Boolean expression is false the component is not present in the flattened DAE [*its modifier is ignored*], and connections to/from the component are removed. Other use of the component is illegal.

4.5 Class Declarations

Essentially everything in Modelica is a class, from the predefined classes `Integer` and `Real`, to large packages such as the Modelica standard library.

[*Example: A rather typical structure of a Modelica class is shown below. A class with a name, containing a number of declarations followed by a number of equations in an equation section.*

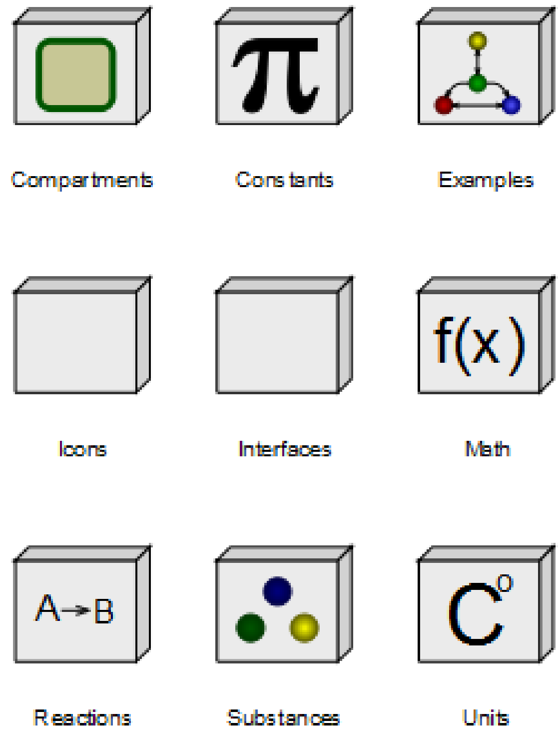
```
class ClassName
  Declaration1
  Declaration2
  ...
equation
  equation1
  equation2
  ...
end ClassName;
]
```

The following is the formal syntax of class definitions, including the special variants described in later sections.

```
class_definition :
   [ encapsulated ]
   [ partial ]
   ( class | model | record | block | [ expandable ] connector | type |
     package | function )
   class_specifier

class_specifier :
     IDENT string_comment composition end IDENT
   | IDENT "=" base_prefix name [ array_subscripts ]
           [ class_modification ] comment
   | IDENT "=" enumeration "(" ( [enum_list] | ":" ) ")" comment
   | IDENT "=" der "(" name "," IDENT { "," IDENT } ")" comment
   | extends IDENT [ class_modification ] string_comment composition
         end IDENT

base_prefix :
     type_prefix

enum_list   : enumeration_literal { "," enumeration_literal}

enumeration_literal : IDENT comment

composition  :
   element_list
   { public element_list |
     protected element_list |
     equation_section |
```


MODELICA

Using the BioChem Library and MathModelica for Translation



- Finding a mapping between SBML and the more expressive and general Modelica language
- “Catch” Modelica constructs and map them
- Restrict how the Modelica models are built
  - BioChem library
  - Wizards introduced

Verification of the SBML-Modelica Translator Part of MathModelica

Models from BioModels database have been used to verify if models that are imported to *MathModelica* and exported from give the same result as the simulation published on the database.

	Test models	Succeeded
Import	216	212 (98%)
Simulation	212	208 (98%)
Export	18	18 (100%)

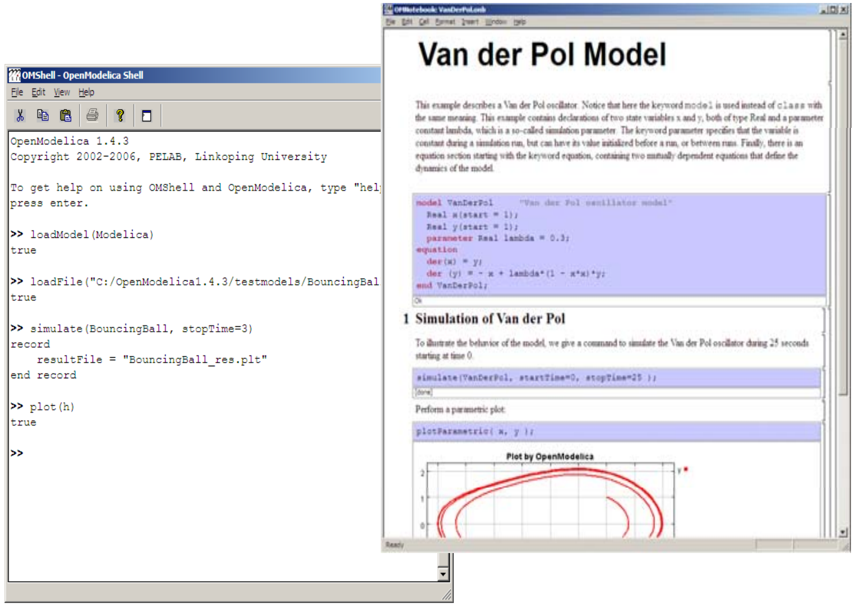
Comparison With Other Tools

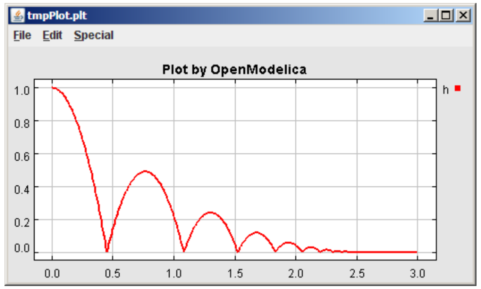
Models from BioModels database have been used to verify if different tools give the same result as the simulation published on the database.

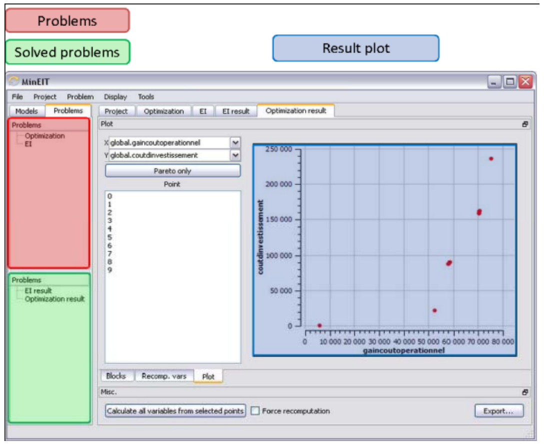
	Test models
MathModelica	98% (42 of 43)

MODELICA

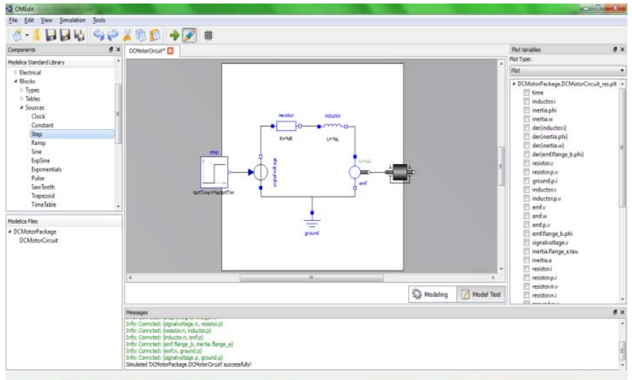
OpenModelica, www.openmodelica.org
The Most Complete Open Source Modelica Tool







- OpenModelica
- Open Source Modelica Consortium (OSMC)
- International
- Open source
- www.openmodelica.org

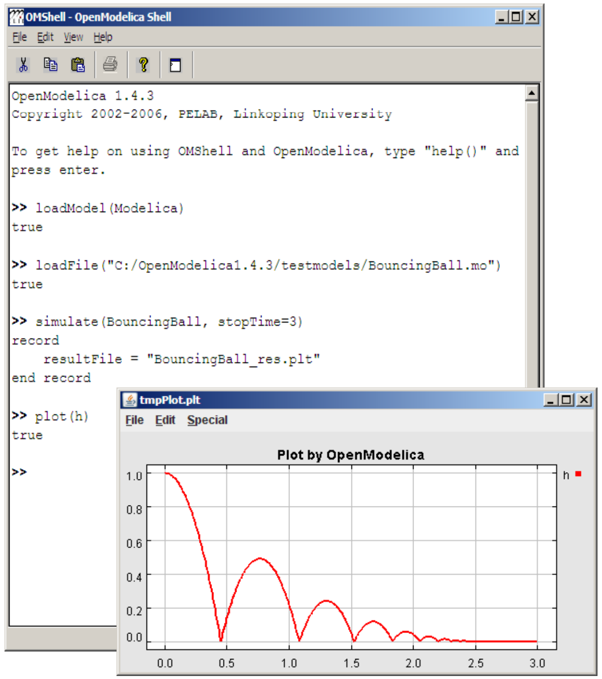


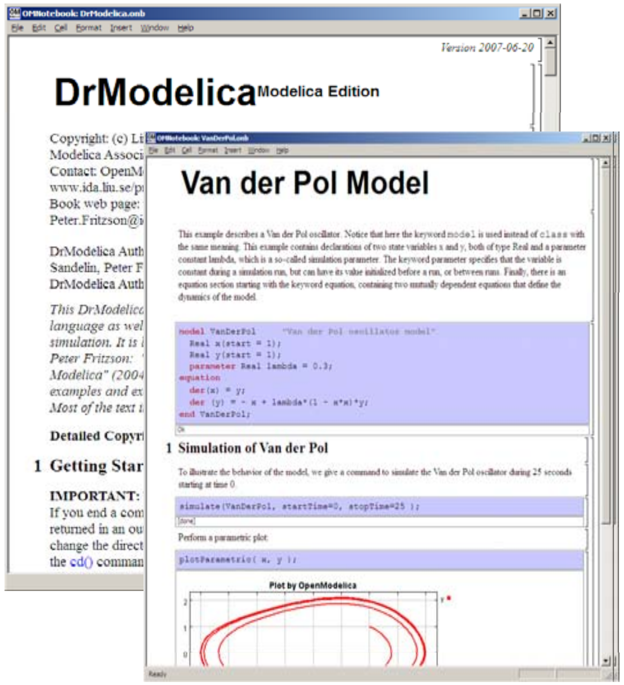
- OMEdit, graphical editor
- OMOptim, optimization subsystem

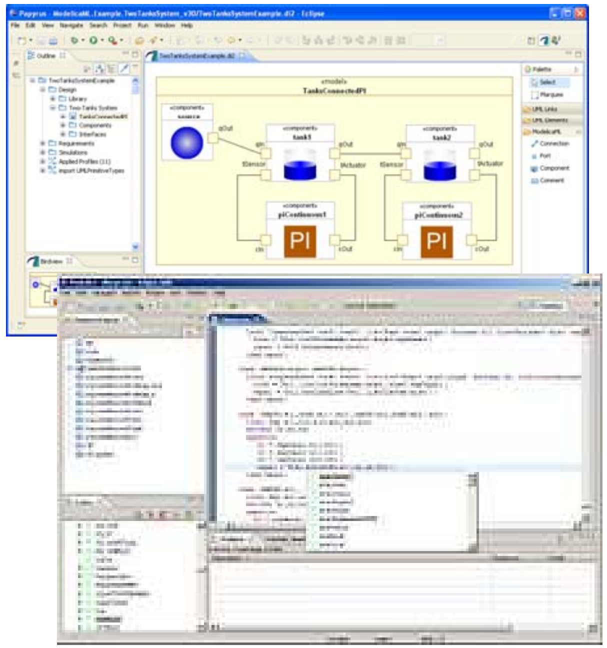
OpenModelica (cont.)

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

- **ModelicaML –** UML Profile
- **MetaModelica –** symbolic manipulation







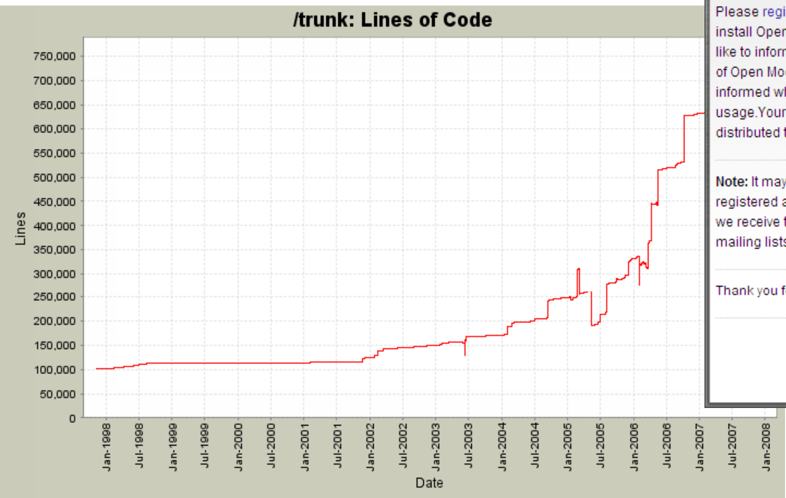
OSMC – Open Source Modelica Consortium
38 organizational members November 2011

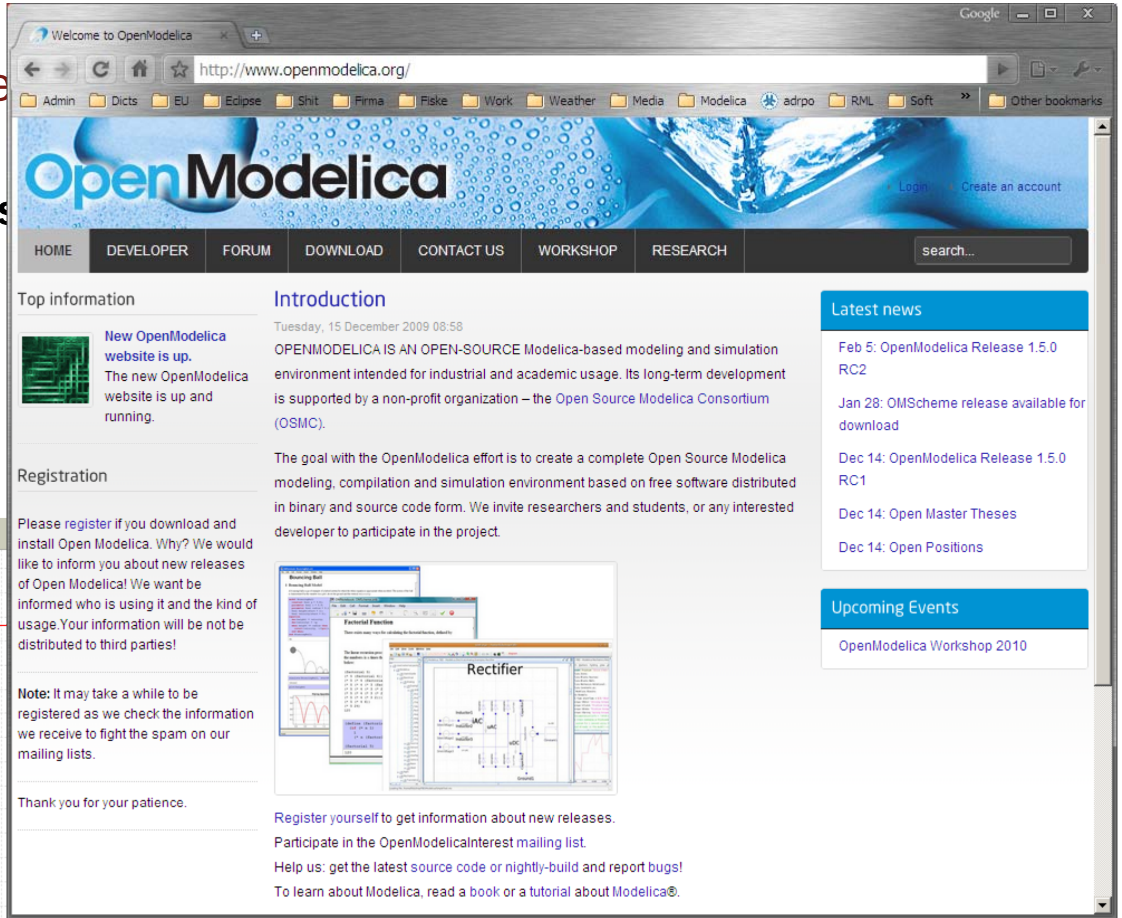
Founded Dec 4, 2007

Open-source community service

- **Website and Support Forum**
- **Version-controlled source bas**
- **Bug database**
- **Development courses**
- **www.openmodelica.org**

Code Statistics





MODELICA

OSMC 38 Organizational Members, Nov 2011
(initially 7 members, 2007)

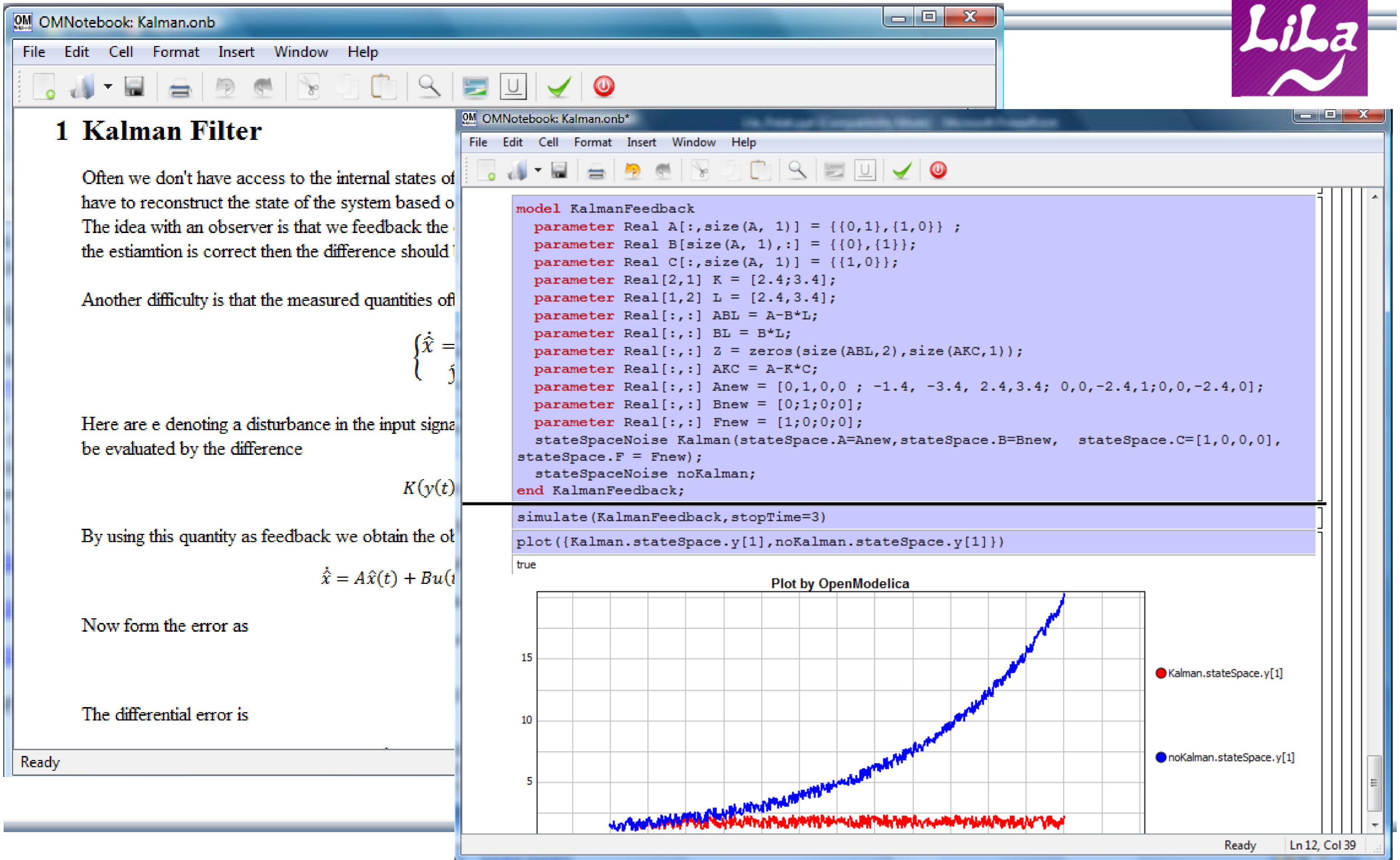
Companies and Institutes (17 members)

- ABB Corporate Research, Sweden
- Bosch Rexroth AG, Germany
- Siemens Turbo Machinery AB, Sweden
- CDAC Centre for Advanced Computing, Kerala, India
- CEIT Institute, Spain
- Creative Connections, Prague, Czech Republic
- Fraunhofer FIRST, Berlin, Germany
- Frontway AB, Sweden
- Equa Simulation AB, Sweden
- Evonik Energy Services, Dehli, India
- IFP, Paris, France
- InterCAX, Atlanta, USA
- Wolfram/ MathCore USA, Sweden
- Maplesoft, Canada
- TLK Thermo, Germany
- VI-grade, Italy
- VTT, Finland
- XRG Simulation, Germany

Universities (17 members)

- Linköping University, Sweden
- Hamburg University of Technology/TuTech, Germany
- Technical University of Berlin, Germany
- FH Bielefeld, Bielefeld, Germany
- Technical University of Braunschweig, Institute of Thermodynamics, Germany
- Technical University of Dortmund, Process Dynamics Group, Germany
- Université Laval, modelEAU, Canada
- University of Maryland, USA
- Georgia Tech, Atlanta, USA
- Griffith University, Australia
- Politecnico di Milano, Italy
- Mälardalen University, Sweden
- Technical University Dresden, Germany
- Telemark University College, Norway
- Ghent University, Belgium
- Ecoles des Mines, CEP, Paris, France
- University of Ljubljana, Slovenia

OMnotebook Interactive Electronic Notebook Here Used for Teaching Control Theory



OpenModelica Demo

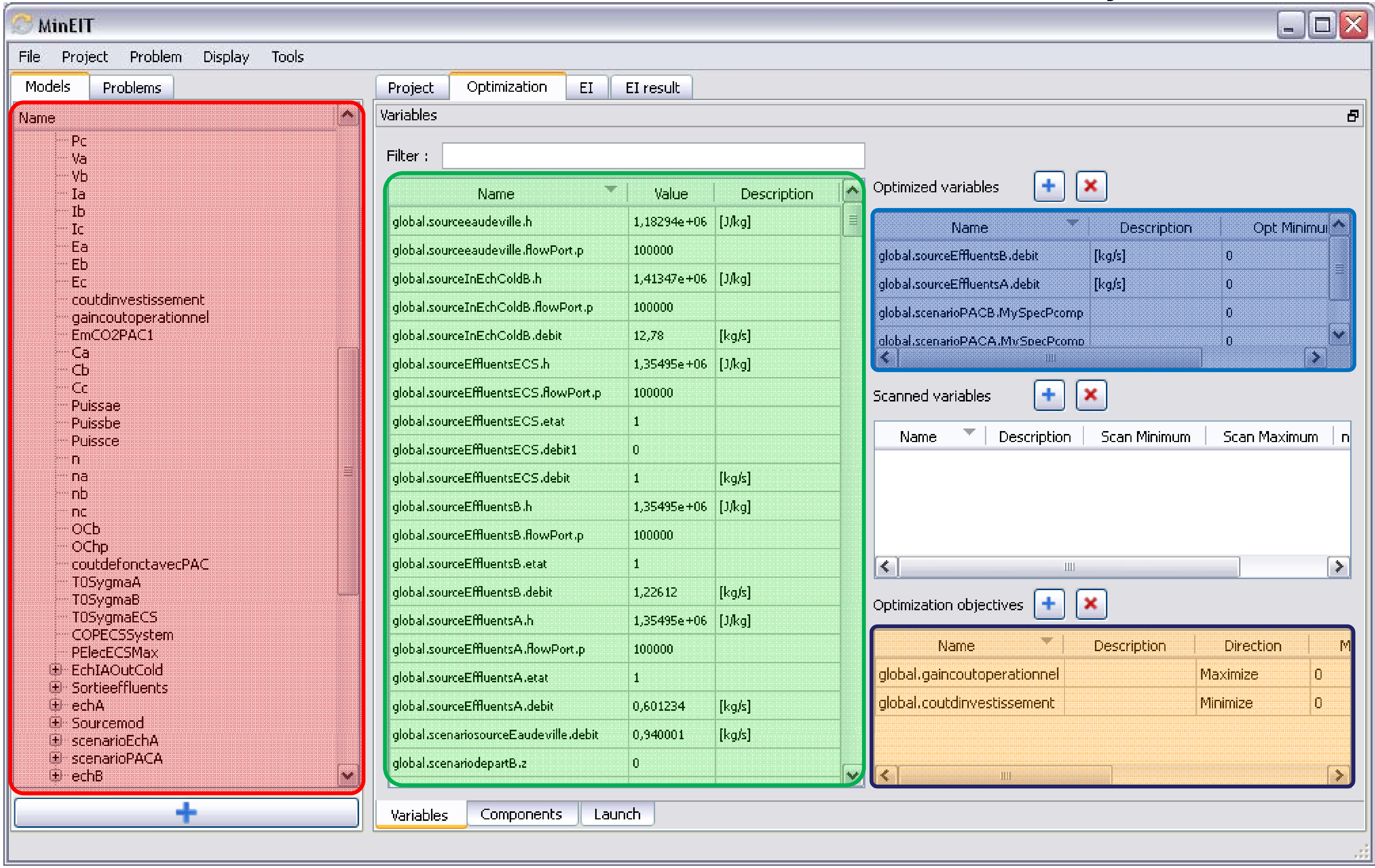
OMOptim – Optimization (1)

Model structure

Model Variables

Optimized parameters

Optimized Objectives



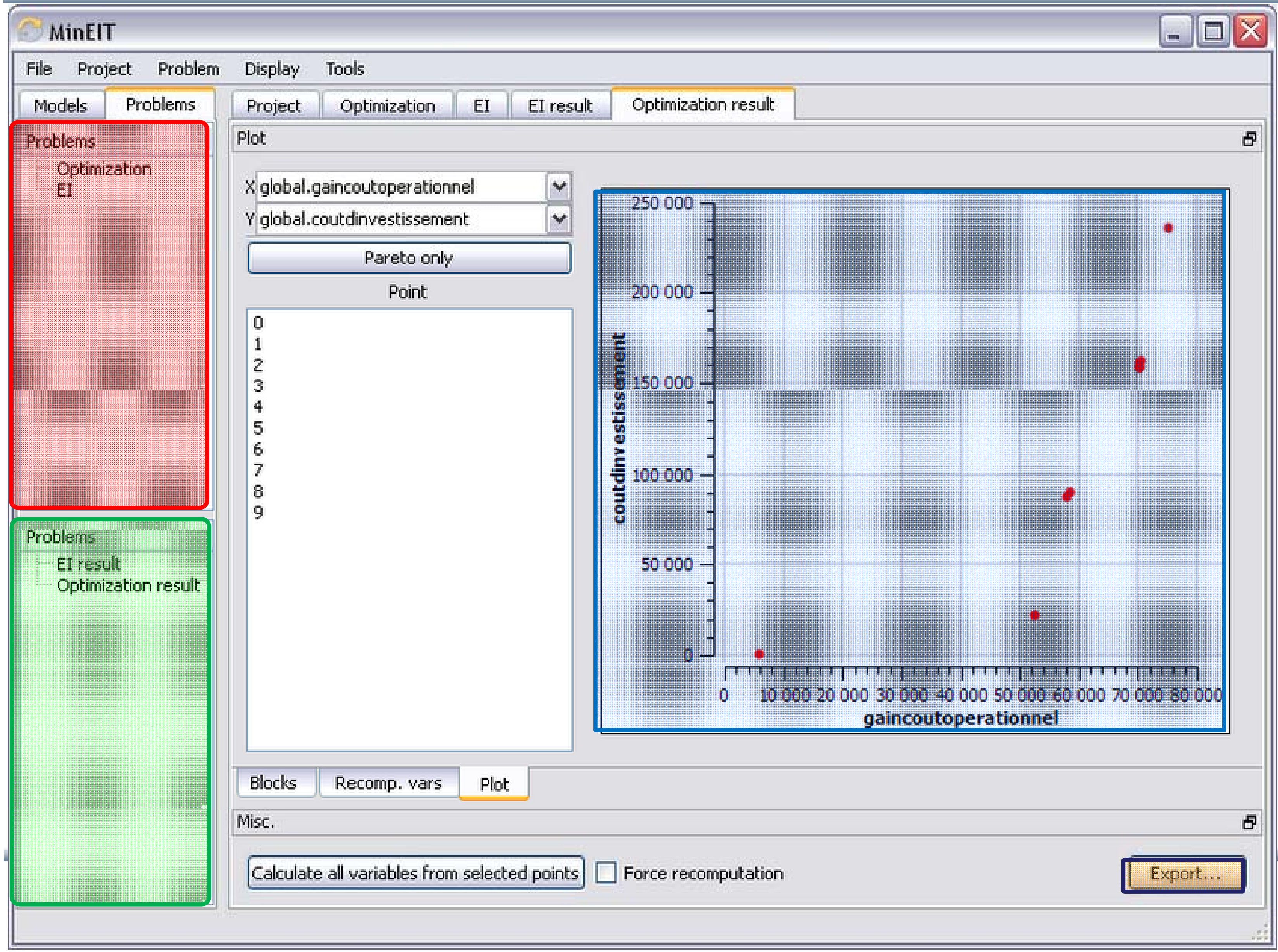
OMOptim – Optimization (2)

Problems

Solved problems

Result plot

Export result data .csv



Pareto Front

Modelica Language Interoperability
External Functions – C, FORTRAN 77

It is possible to call functions defined outside the Modelica language, implemented in C or FORTRAN 77

```
function polynomialMultiply
  input  Real a[:], b[:];
  output Real c[:] := zeros(size(a,1)+size(b, 1) - 1);
external
end polynomialMultiply;
```

The body of an external function is marked with the keyword **`external`**

If no language is specified, the implementation language for the external function is assumed to be C. The external function `polynomialMultiply` can also be specified, e.g. via a mapping to a FORTRAN 77 function:

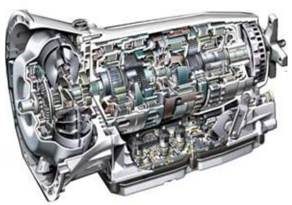
```
function polynomialMultiply
  input  Real a[:], b[:];
  output Real c[:] := zeros(size(a,1)+size(b, 1) - 1);
external "FORTRAN 77"
end polynomialMultiply;
```

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

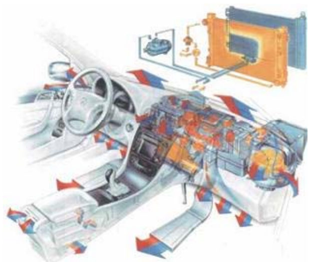
The FMI development is part of the MODELISAR 29-partner project

- FMI development initiated by **Daimler**
- Improved Software/Model/Hardware-in-the-Loop Simulation, of **physical** models and of **AUTOSAR** controller models from **different vendors** for automotive applications with **different levels of detail**.
- **Open Standard**
- **14 automotive use cases** for evaluation
- **> 10 tool vendors** are supporting it

Engine with ECU

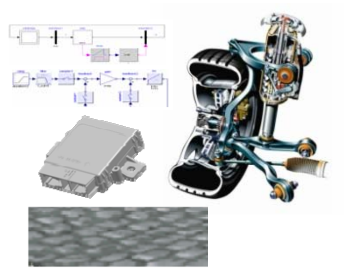


Gearbox with ECU



Thermal systems

Automated cargo door



Chassis components, roadway, ECU (e.g. ESP)

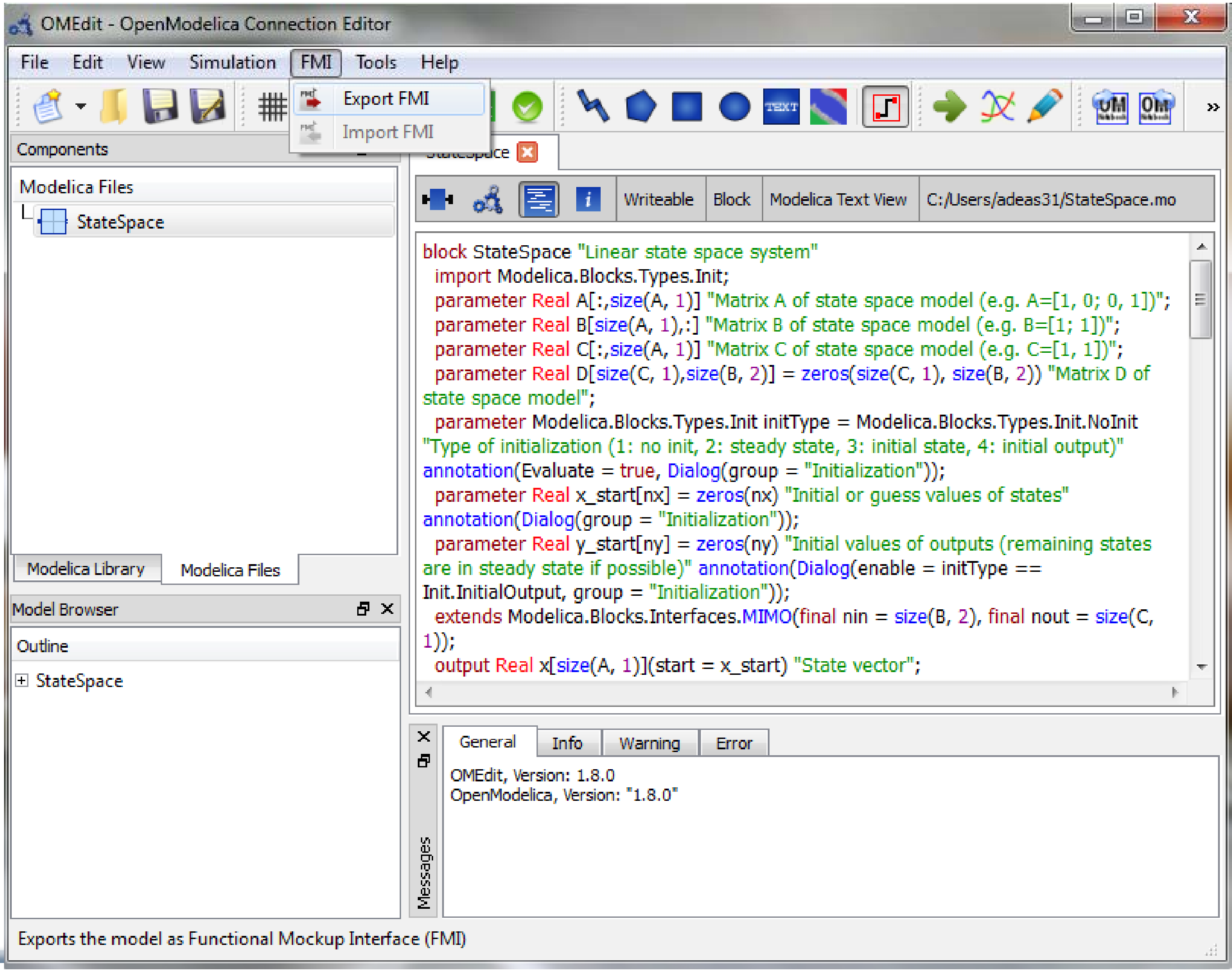
etc.

functional mockup interface for model exchange and tool coupling

courtesy Daimler

OpenModelica FMI Export and Import

- Export: translateModelFMU(A)
- importFMU("A.fmu")



Faster Simulation – Compiling Modelica to Multi-Core

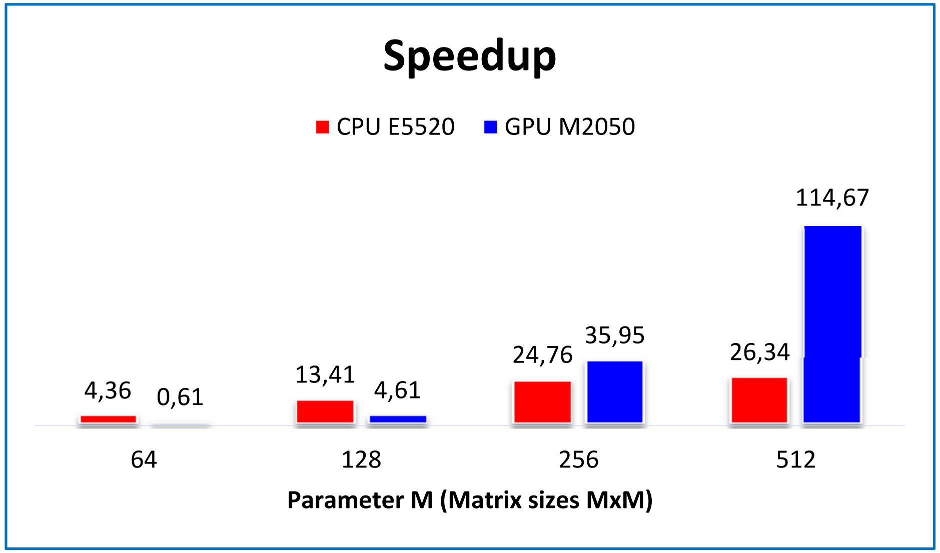
- **Automatic Parallelization of Mathematical Models**
  - Parallelism over the numeric solver method.
  - Parallelism over time.
  - **Parallelism over the model equation system**
    - ... with fine-grained task scheduling
- **Coarse-Grained Explicit Parallelization Using Components**
  - The programmer partitions the application into computational components using strongly-typed communication interfaces.
    - Co-Simulation, Transmission-Line Modeling (TLM)
- **Explicit Parallel Programming**
  - Providing general, easy-to-use explicit parallel programming constructs within the *algorithmic* part of the modeling language.
    - OpenCL, CUDA, ...

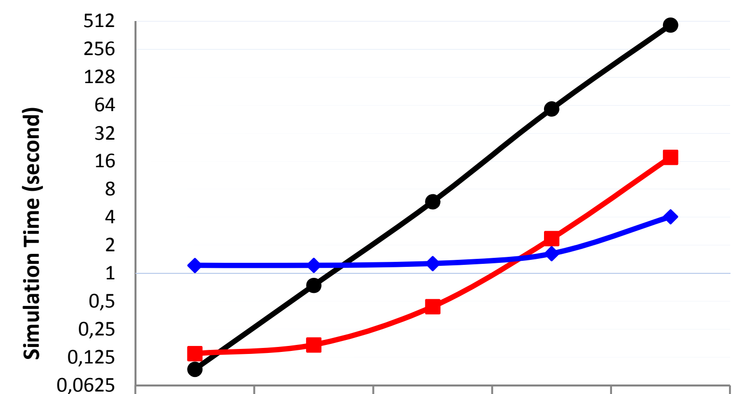
ParModelica – Parallel Modelica Extension
Matrix Multiplication using *Kernel function*

Gained speedup

- **Intel Xeon E5520 CPU (16 cores) 26**
- **NVIDIA Fermi-Tesla M2050 GPU (448 cores) 115**

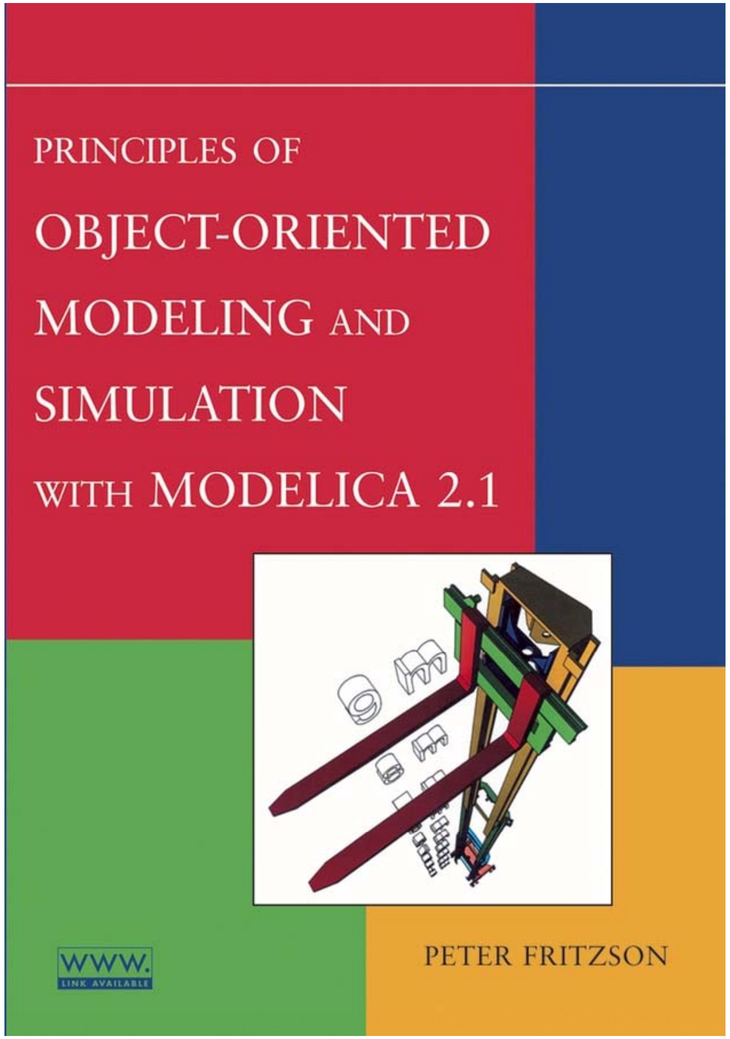
Speedup comparison to sequential algorithm on Intel Xeon E5520 CPU





	32	64	128	256	512
CPU E5520 (Serial)	0,093	0,741	5,875	58,426	465,234
CPU E5520 (Parallel)	0,137	0,17	0,438	2,36	17,66
GPU M2050 (Parallel)	1,215	1,217	1,274	1,625	4,057

Get More Information, Download Software



Peter Fritzson

Principles of Object Oriented Modeling and Simulation with Modelica 2.1

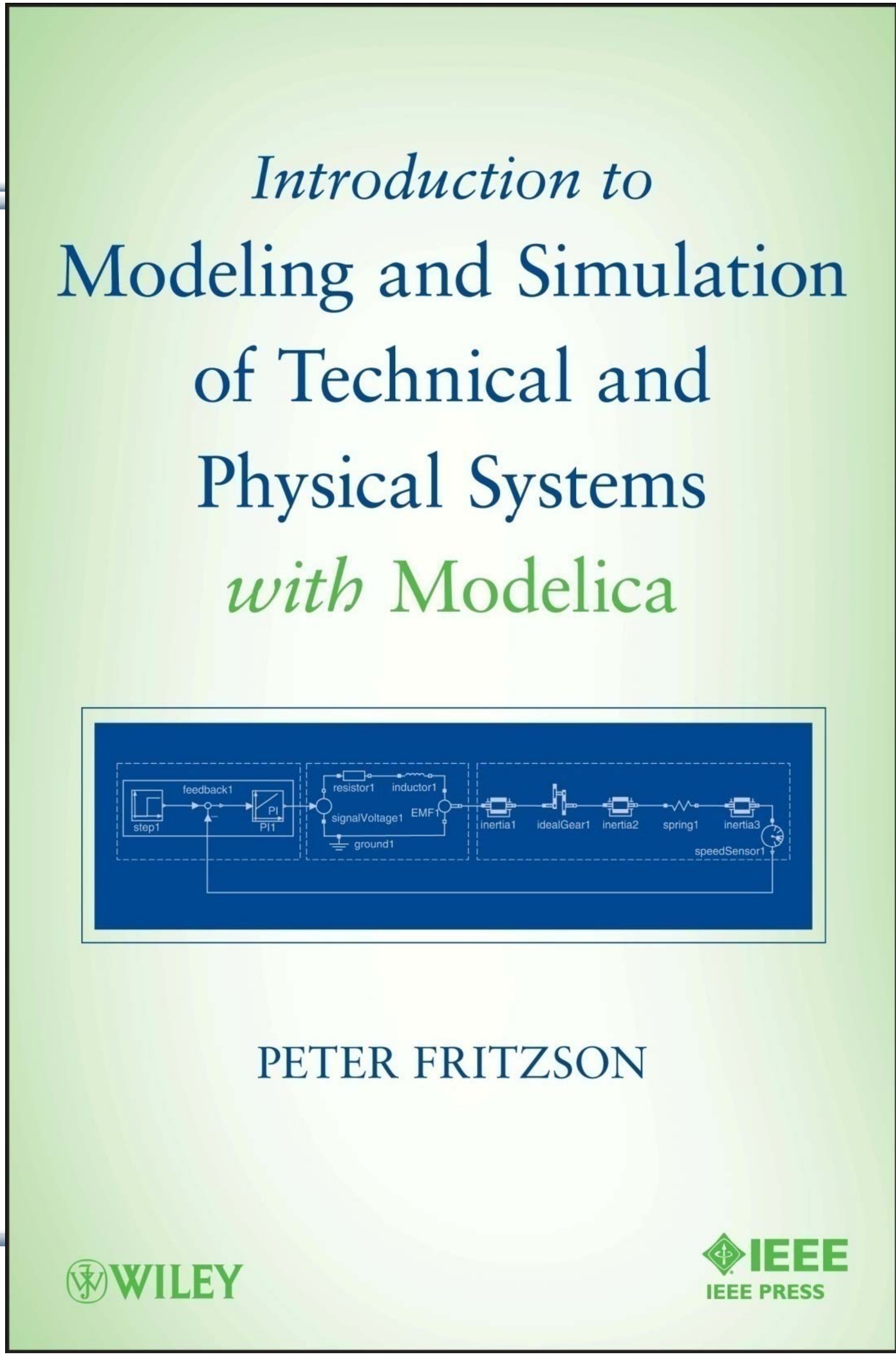
Wiley-IEEE Press, 2004, 940 pages

- OpenModelica
  - www.openmodelica.org
- Modelica Association
  - www.modelica.org

New Introductory Book
September 2011
232 pages

Wiley
IEEE Press

For Introductory
Short Courses on
Object Oriented
Mathematical Modeling



Announcements, Coming Workshops

- **Call for Presentations**

- **OpenModelica Workshop**
  - Feb 6, 2012. www.openmodelica.org, Linköping, Sweden
    Applications and tool developments in the OpenModelica Open Source Effort.

- **MODPROD Workshop on Model-Based Development**
  - Feb 7-8, 2012, www.modprod.liu.se, Linköping, Sweden

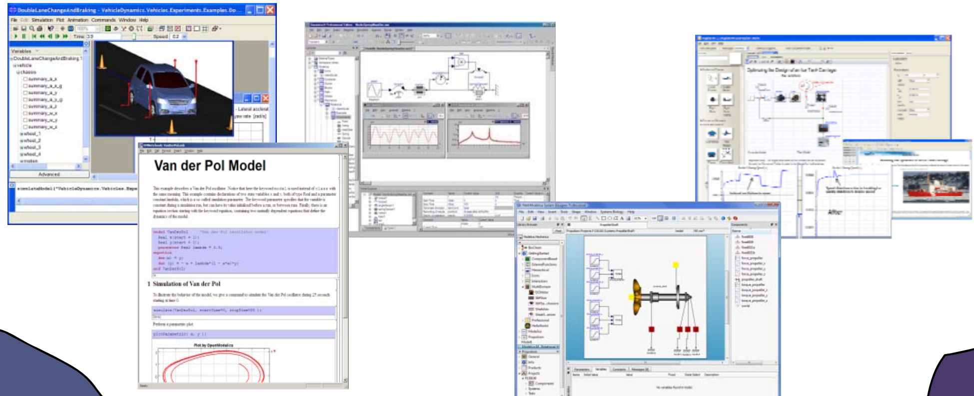
Summary

Multi-Domain
Modeling

Visual Acausal
Component
Modeling

MODELICA

www.modelica.org – Language, Standard Library
www.openmodelica.org – Open Source Tool



Typed
Declarative
Textual Language

Thanks for listening!

Hybrid
Modeling