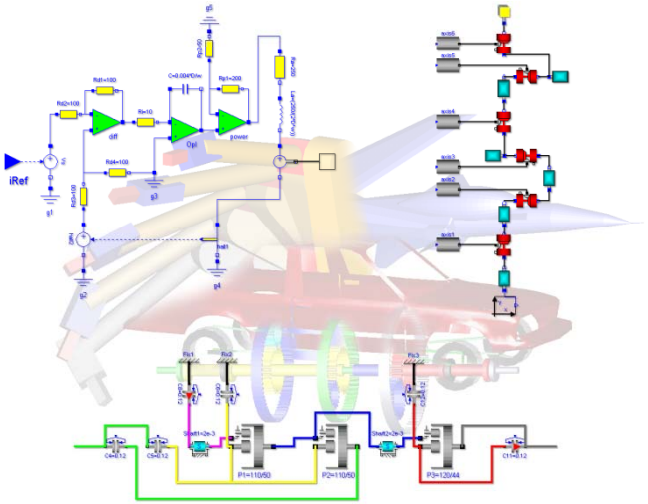
Research in Model-Based Product Development at PELAB in the MODPROD Center

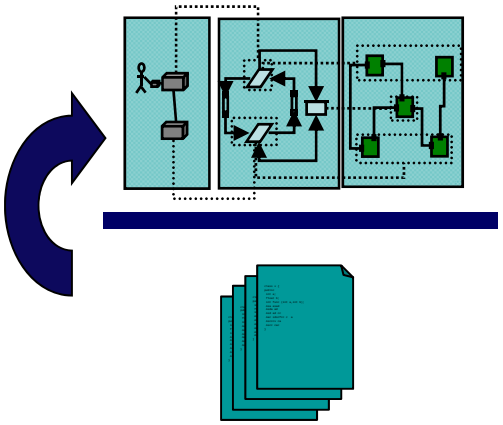
Presentation at MODPROD'2011

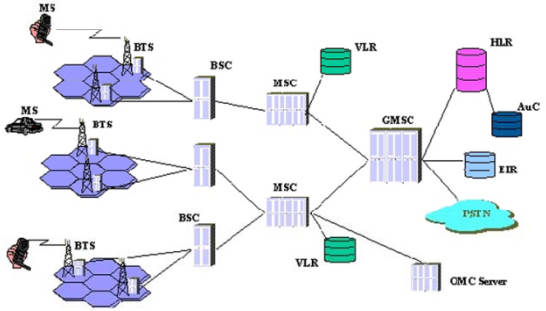
PELAB – Programming Environment Laboratory
Department of Computer and Information Science
Linköping University

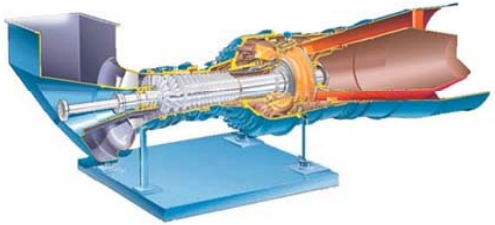
2011-02-08

Peter Fritzson



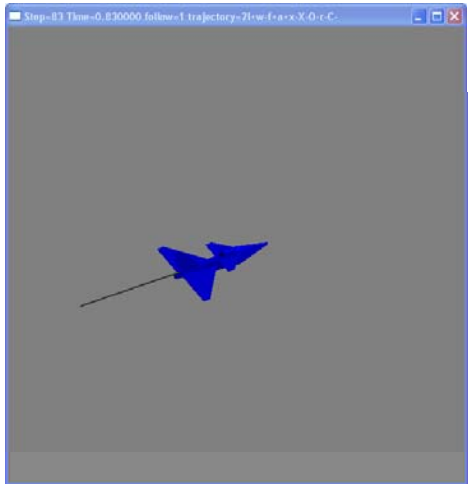


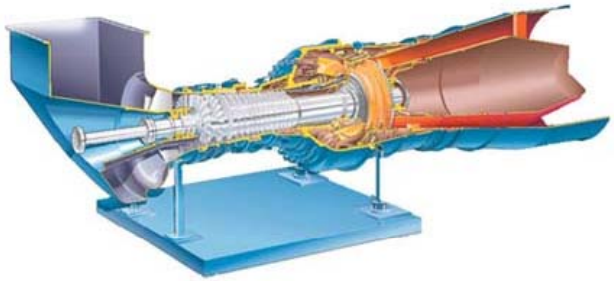


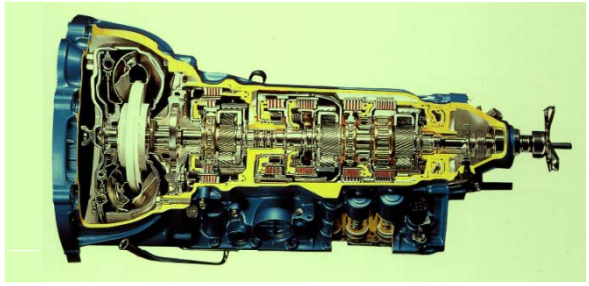


Examples of Complex Systems in Engineering

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







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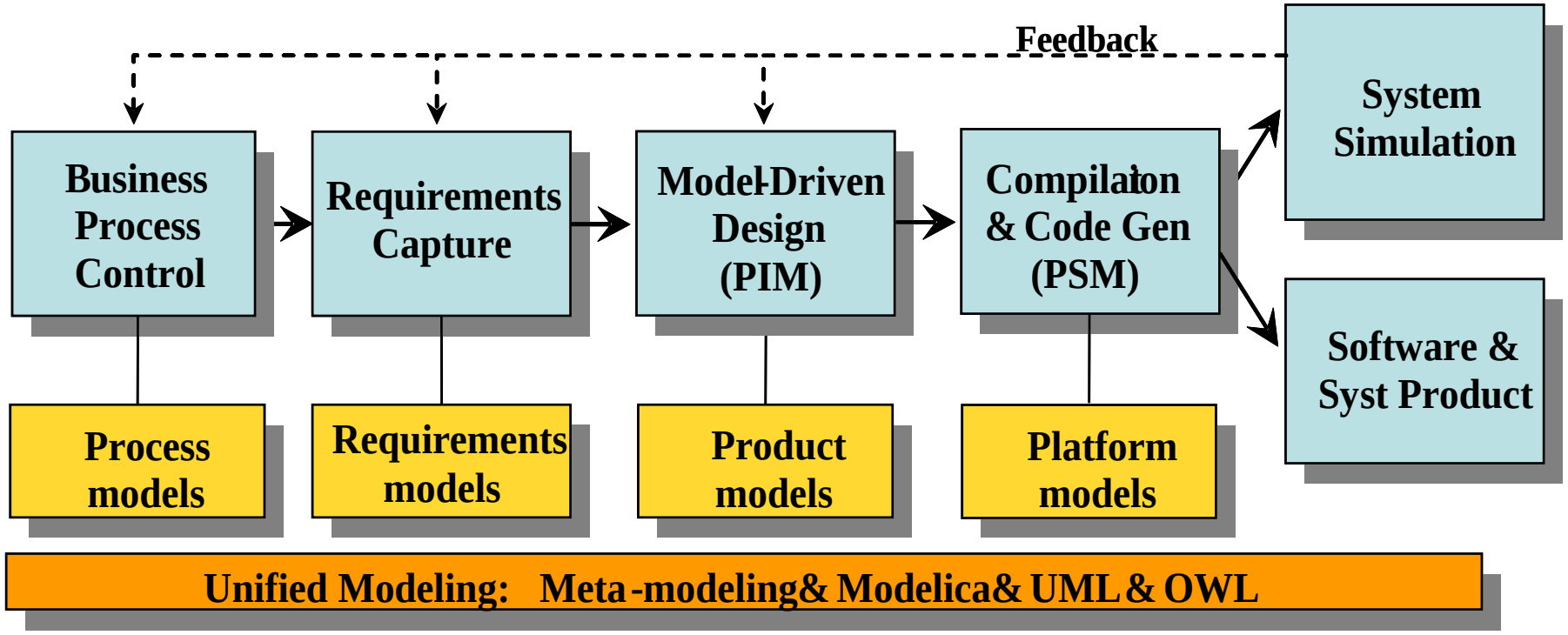
Vision of Integrated Model-Based Product Development



Vision of unified modeling framework for model-driven product development from platform independent models (PIM) to platform specific models (PSM)

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Open Source Modelica Consortium

Open Source Effort

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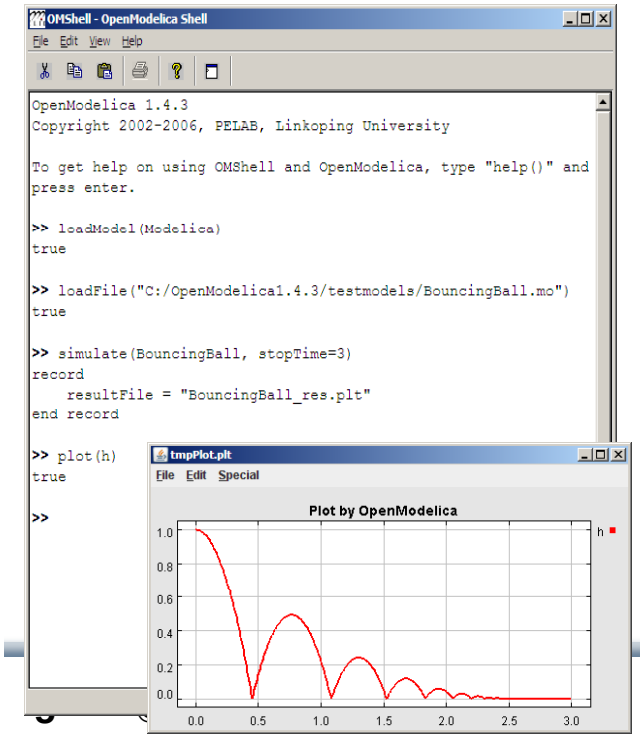
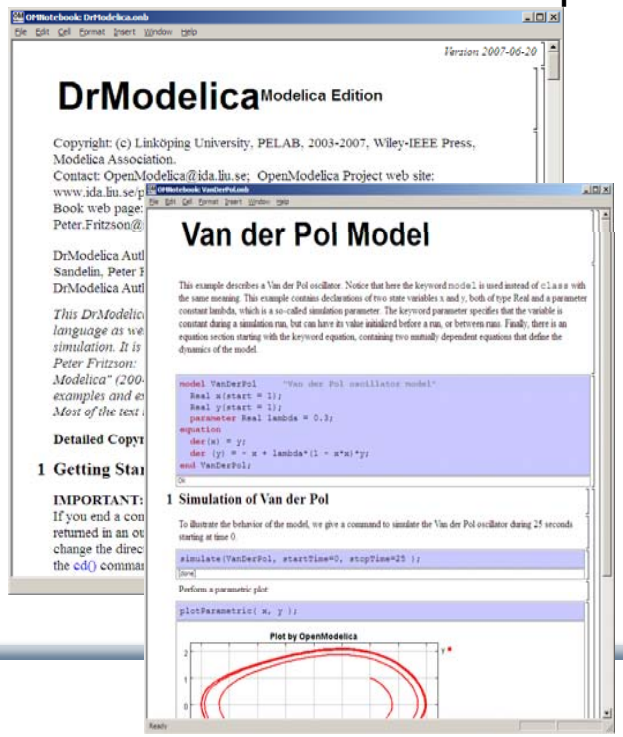
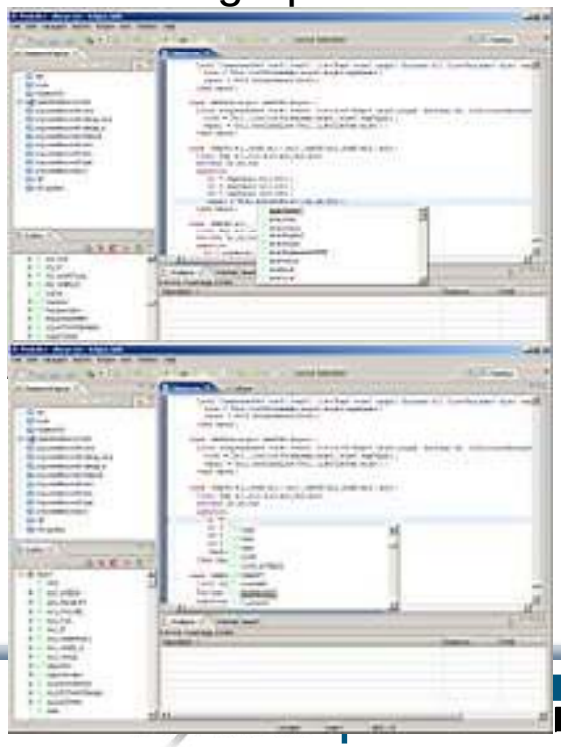
The OpenModelica Open Source Enviroment

www.openmodelica.org

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







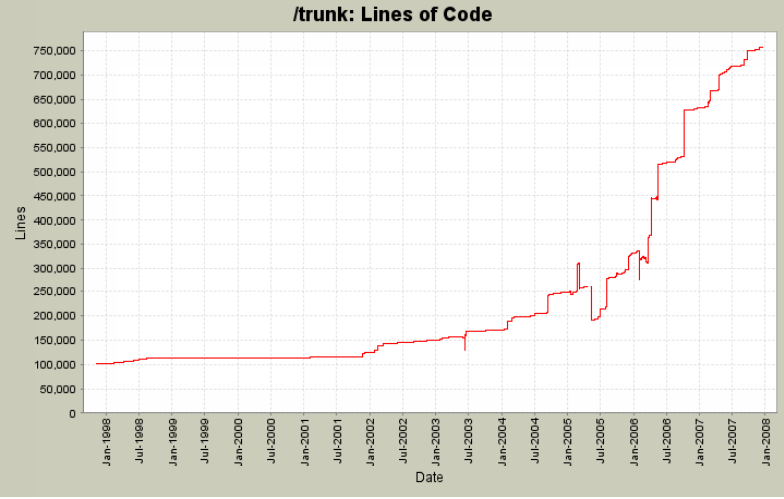
OSMC – International Consortium for Open Source Model-based Development Tools, 32 members Dec 2010

Founded Dec 4, 2007

Open-source community services

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

Code Statistics



Industrial members (18)

- **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**
- **Frontway AB, Sweden**
- **Equa Simulation AB, Sweden**
- **Evonik Energy Services, India**
- **IFP, Paris, France**
- **InterCAX, Atlanta, USA**
- **MOSTforWATER, Belgium**
- **MathCore Engineering AB, Sweden**
- **Maplesoft, Canada**
- **TLK Thermo, Germany**
- **VI-grade, Italy**
- **VTT, Finland**
- **XRG Simulation, Germany**

University members (14)

- **Linköping University, Sweden**
- **Hamburg University of Technology/TuTech, Germany**
- **FH Bielefeld, Bielefeld, Germany**
- **Technical University of Braunschweig,, Germany**
- **Technical University of Dortmund, Germany**
- **Université Laval, modelEAU, Canada**
- **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**

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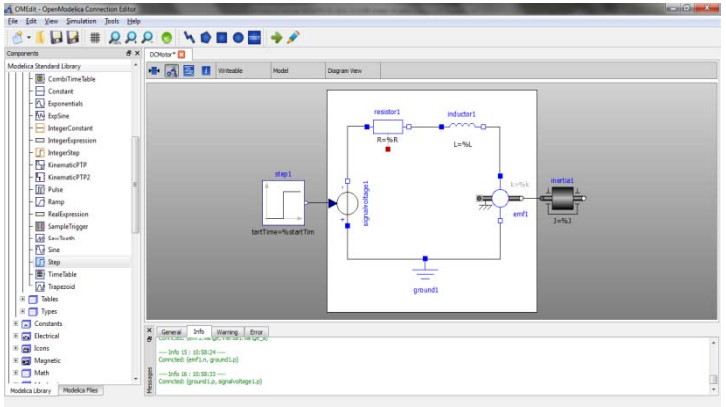
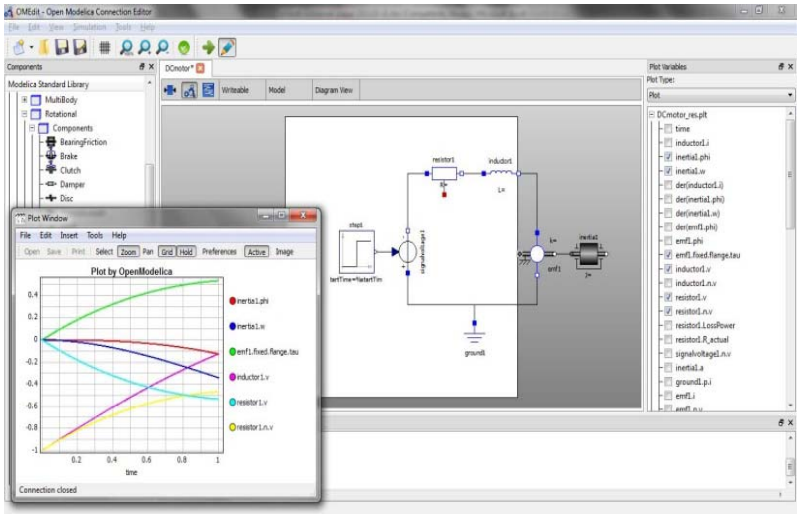
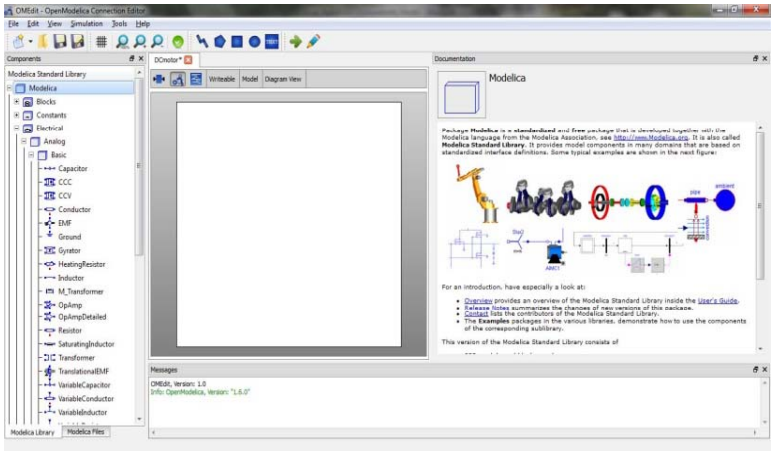
New OpenModelica Connection Editor OMEdit

- Supports MSL 3.1
- Easy to use
- Rather stable
- Implemented in C++ Qt library







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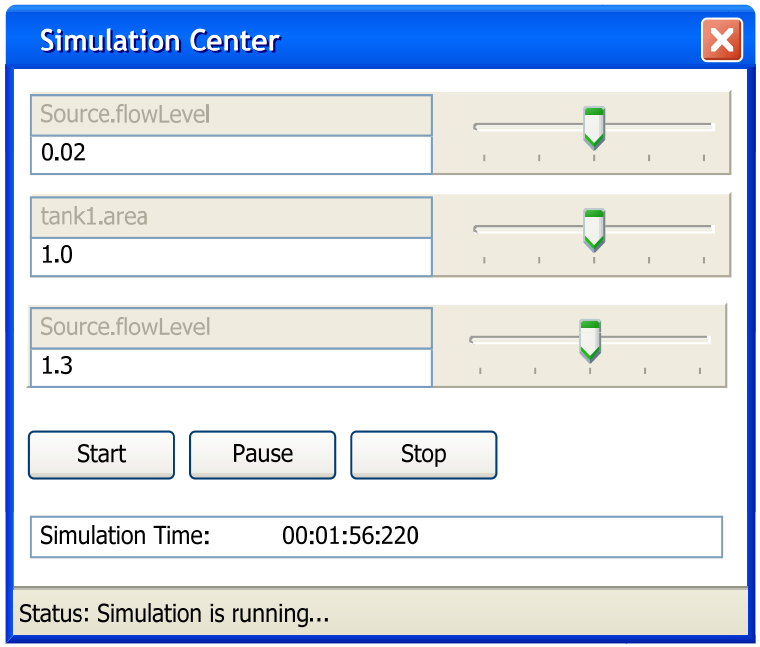
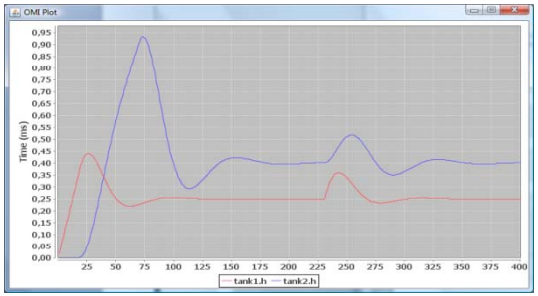
New Interactive Simulation with OpenModelica

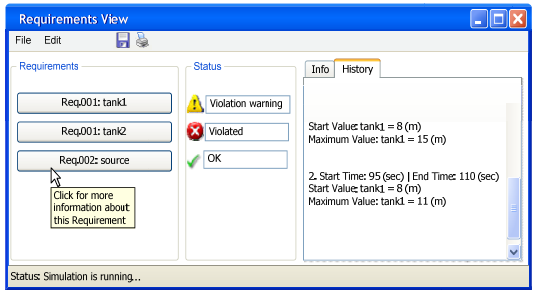
Simulation Control



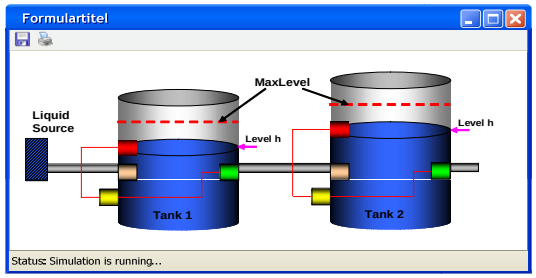
Examples of Simulation Visualization



Plot View



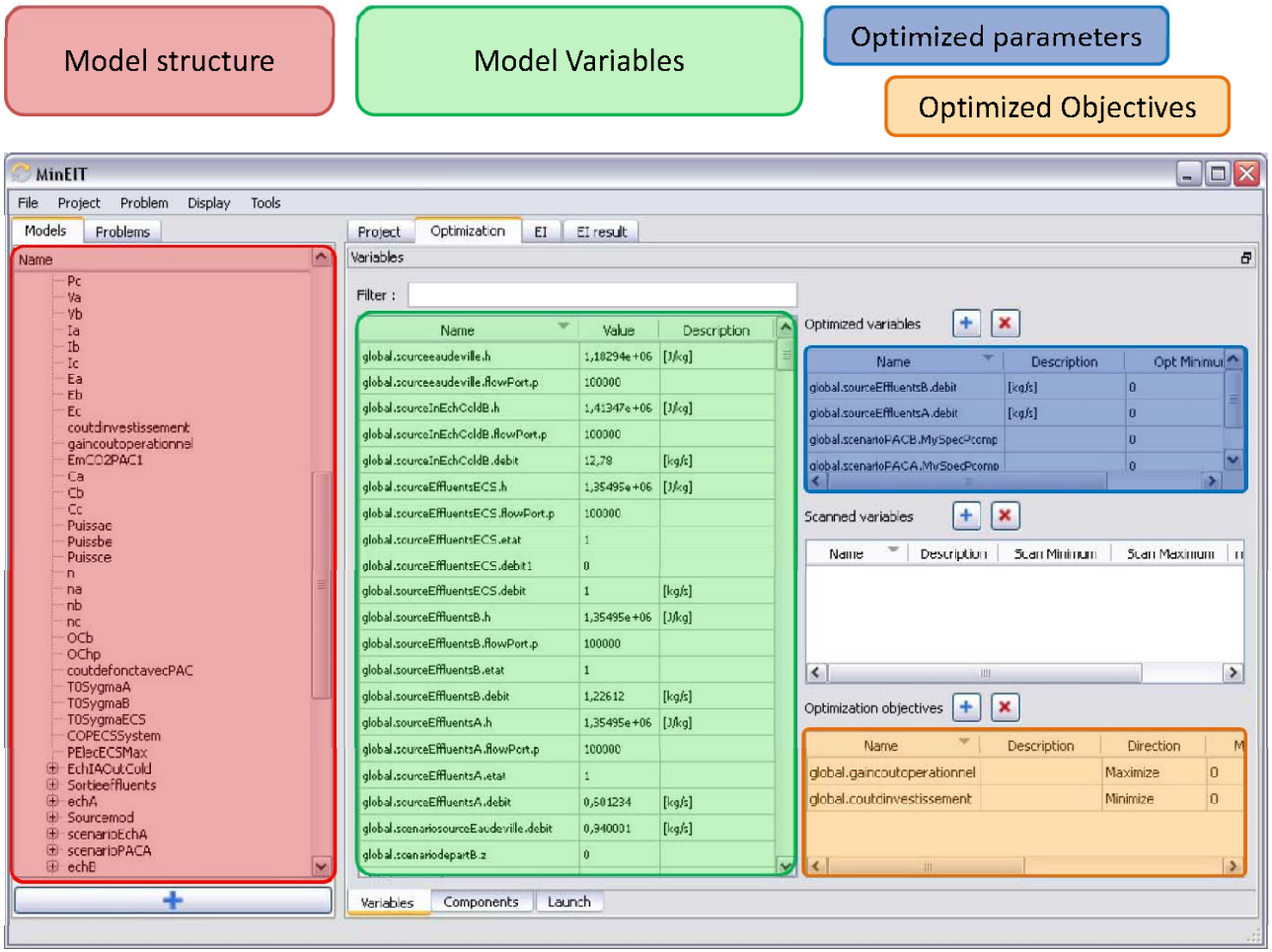
Requirements Evaluation View



Domain-Specific Visualization View

New OpenModelica Optimization Subsystem OMOptim

- Parameter optimization
- Currently using genetic optimization algorithms in OMOptim 0.9.



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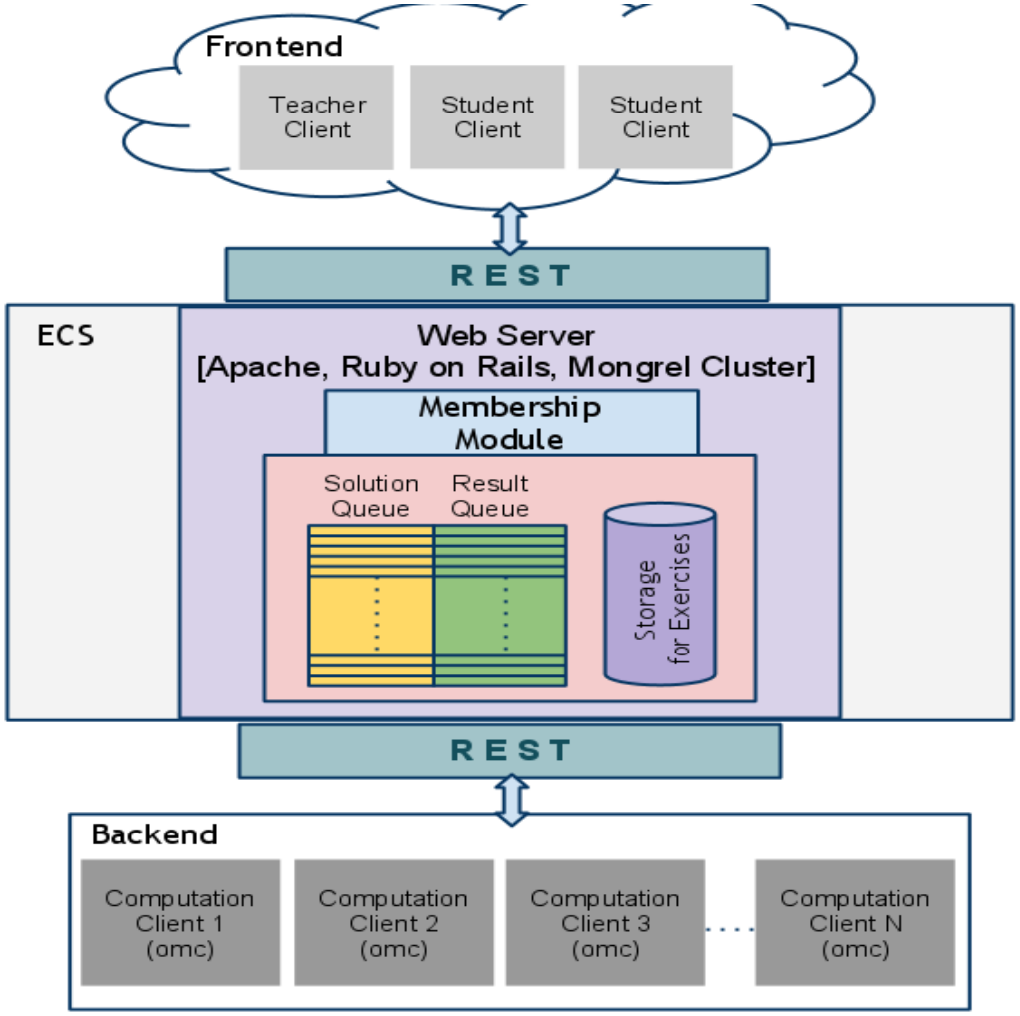
New Web Server Based Teaching/Learning Subsystem OMWeb

- Runs on ordinary web server
- Teachers provide modeling exercises
- Students send in solutions
- Running of simulations through server
- Lila EU project



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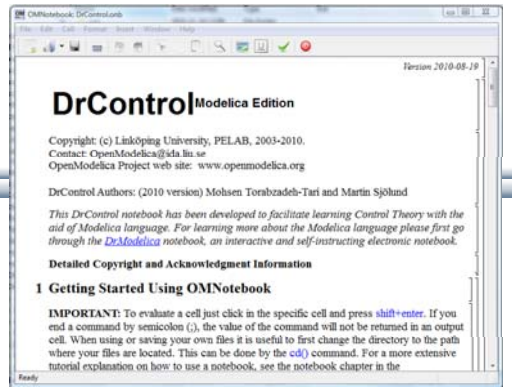
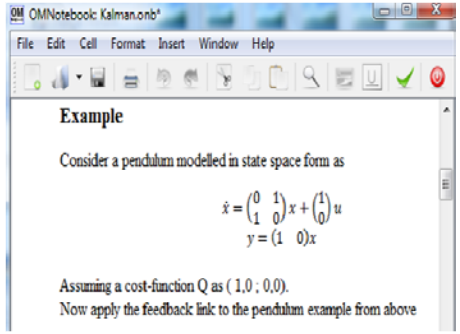
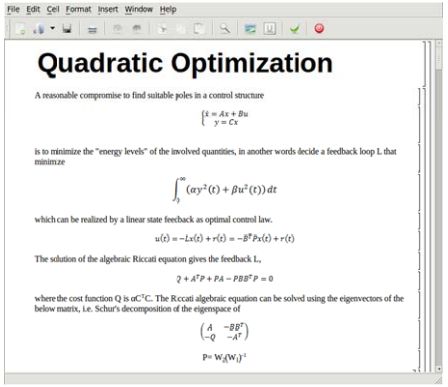
New DrControl Interactive Electronic Book



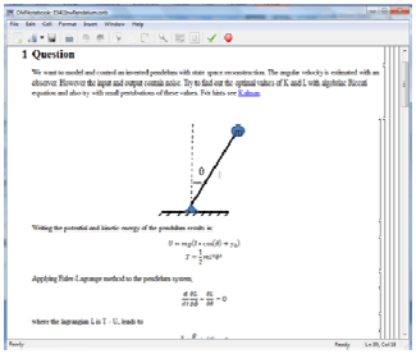
Examples

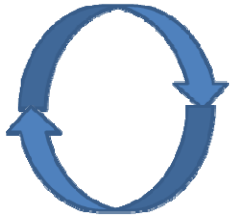


Theory

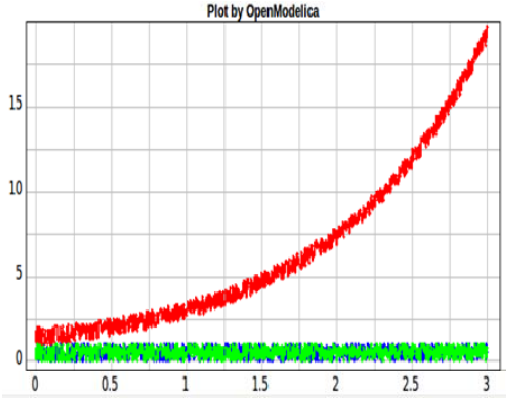


Questions





Experimentation



Models

```
model stateSpaceNoise
  StateSpaceWithNoise stateSpace;
   Modelica.Blocks.Sources.Exponentials ref(
    outMax=4,riseTime=1,riseTimeConst=1,
    fallTimeConst=0.2,offset=0,startTime=-1);
initial equation
  stateSpace.x[1]=1;
  stateSpace.x[2]=0;
equation
  connect(ref.y, stateSpace.u[1]);
end stateSpaceNoise;
```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Research

Modeling-Language Design

Modeling Support Environments

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Important Questions

- Design of modeling languages for modeling complex (physical) systems (**Modelica**) including precise semantics, extensibility, etc.
- How to engineer complex engineering systems of both **hardware and software** in a consistent and safe manner?
- Compilation of models for efficient (real-time) execution on **multi-core** architectures
- Traceability from **requirements** to models to implementation

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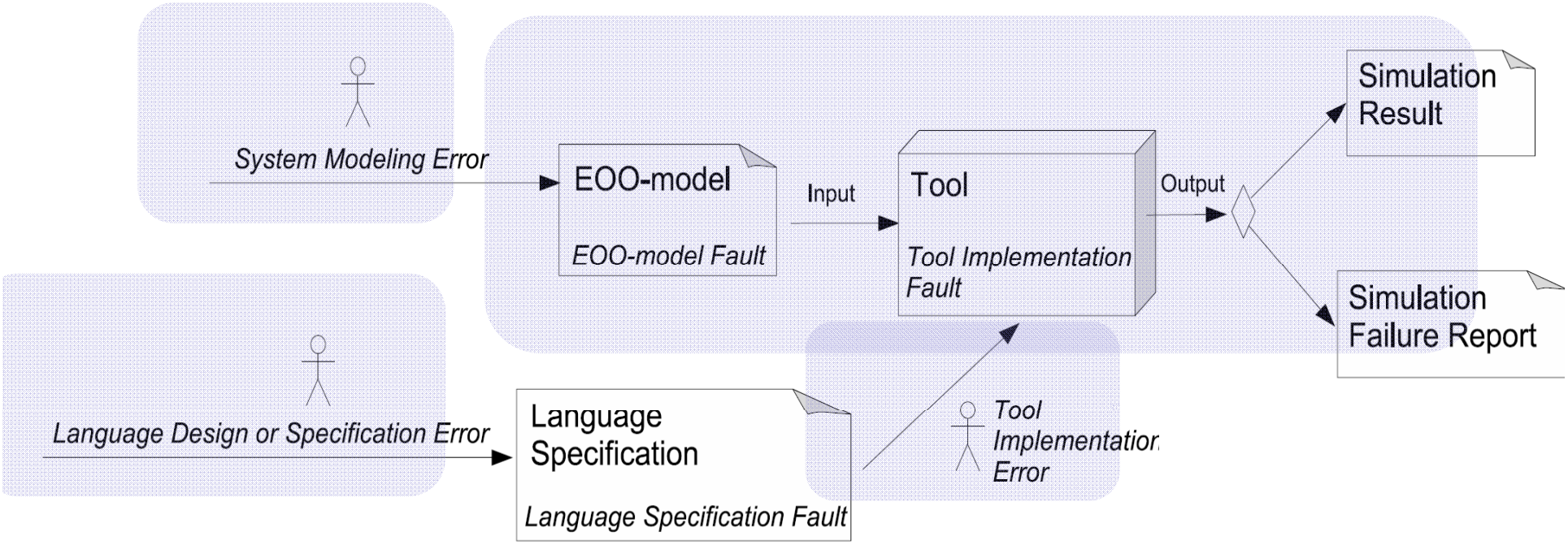
Context of Using of Semantics for Checking



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Current Semantics and MetaModelica/Modelica 4 Work

- Defining **Core language MKL** (Modeling Kernel Language) and Core MetaModelica for expressing **base semantics**
- Other **constructs** should be **expressible** in the Core language
- Defining **extensible meta-modeling**/meta-programming language primitives (e.g. MetaModelica)
- Define compiler and core library in MetaModelica, migrated to Modelica 4

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Integrated Hardware-Software Modeling

ModelicaML
UML Profile for Modelica

SysML-Modelica Integration

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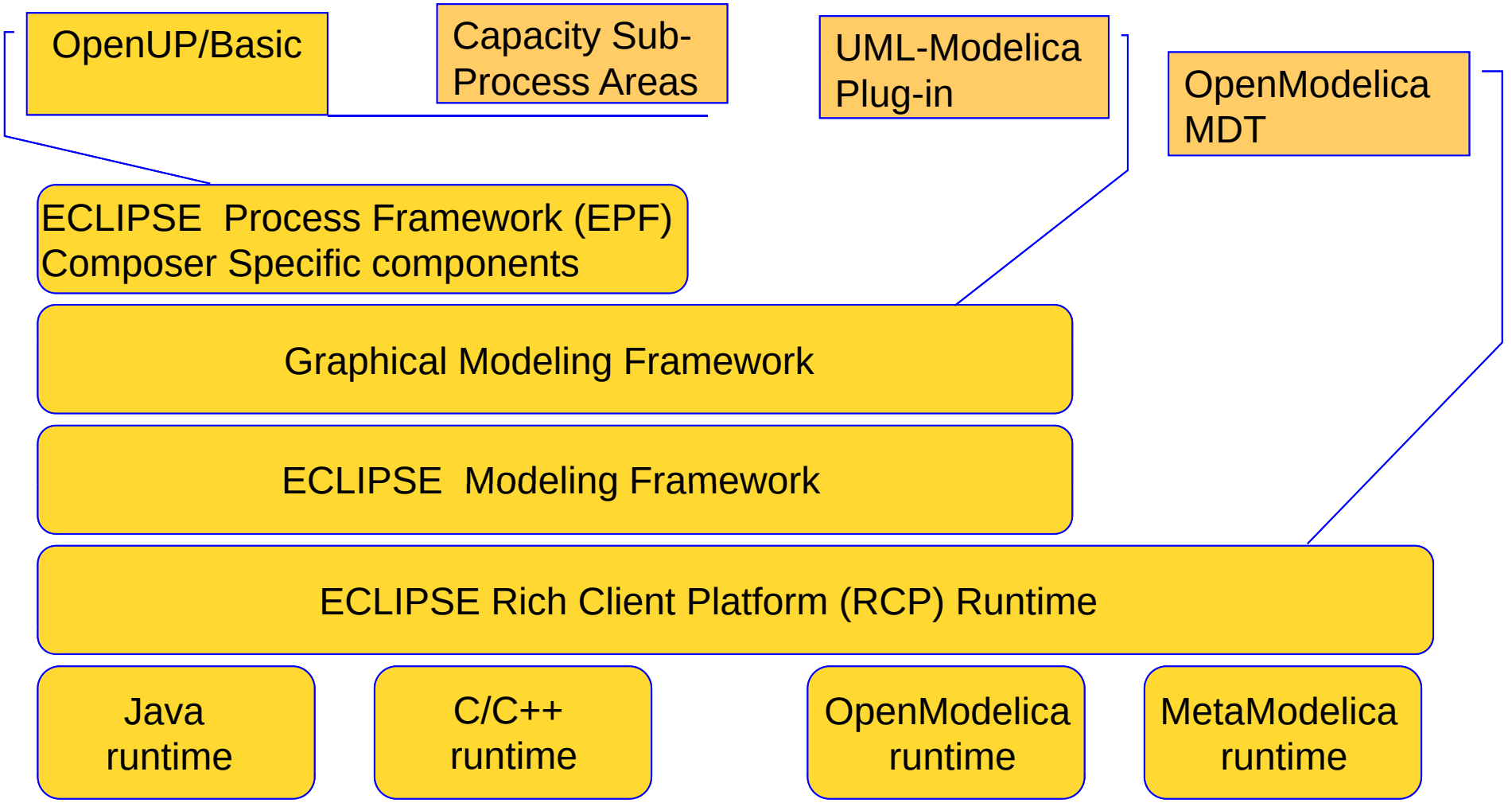
Using ECLIPSE as Integration Platform



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ModelicaML – UML Profile for Modelica
1st Generation (2006-2008)

- Extension of SysML subset
- Features:
  - Supports Modelica constructs
  - Modelica generic class modeling
  - Modelica syntax in definitions
  - Equation-based modeling
  - Simulation modeling

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ModelicaML UML Profile, 2nd Generation
SysML/UML to Modelica OMG Standardization
(with Wladimir Schamai, 2009 – Now)

- ModelicaML is a UML Profile for SW/HW modeling
  - Applicable to “pure” UML or to other UML profiles, e.g. SysML
- Standardized Mapping UML/SysML to Modelica
  - Defines transformation/mapping for **executable** models
  - Being **standardized** by OMG
- ModelicaML
  - Defines graphical concrete syntax (graphical notation for diagram) for representing Modelica constructs integrated with UML
  - Includes graphical formalisms (e.g. State Machines, Activities, Requirements)
    - Which do not exist in Modelica language
    - Which are translated into executable Modelica code
  - Is defined towards generation of executable Modelica code
  - Current implementation based on the Papyrus UML tool + OpenModelica

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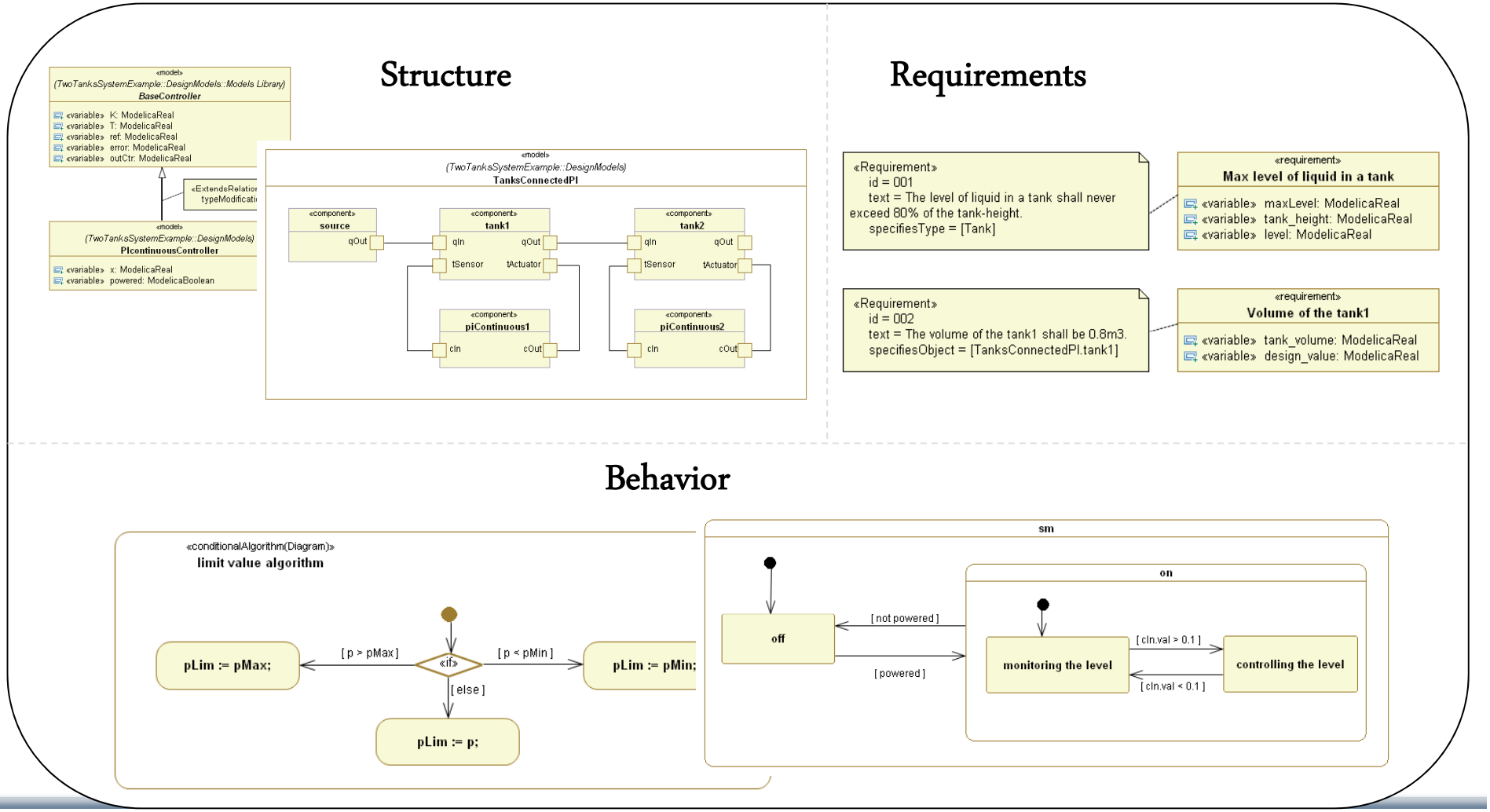
ModelicaML: Graphical Notation



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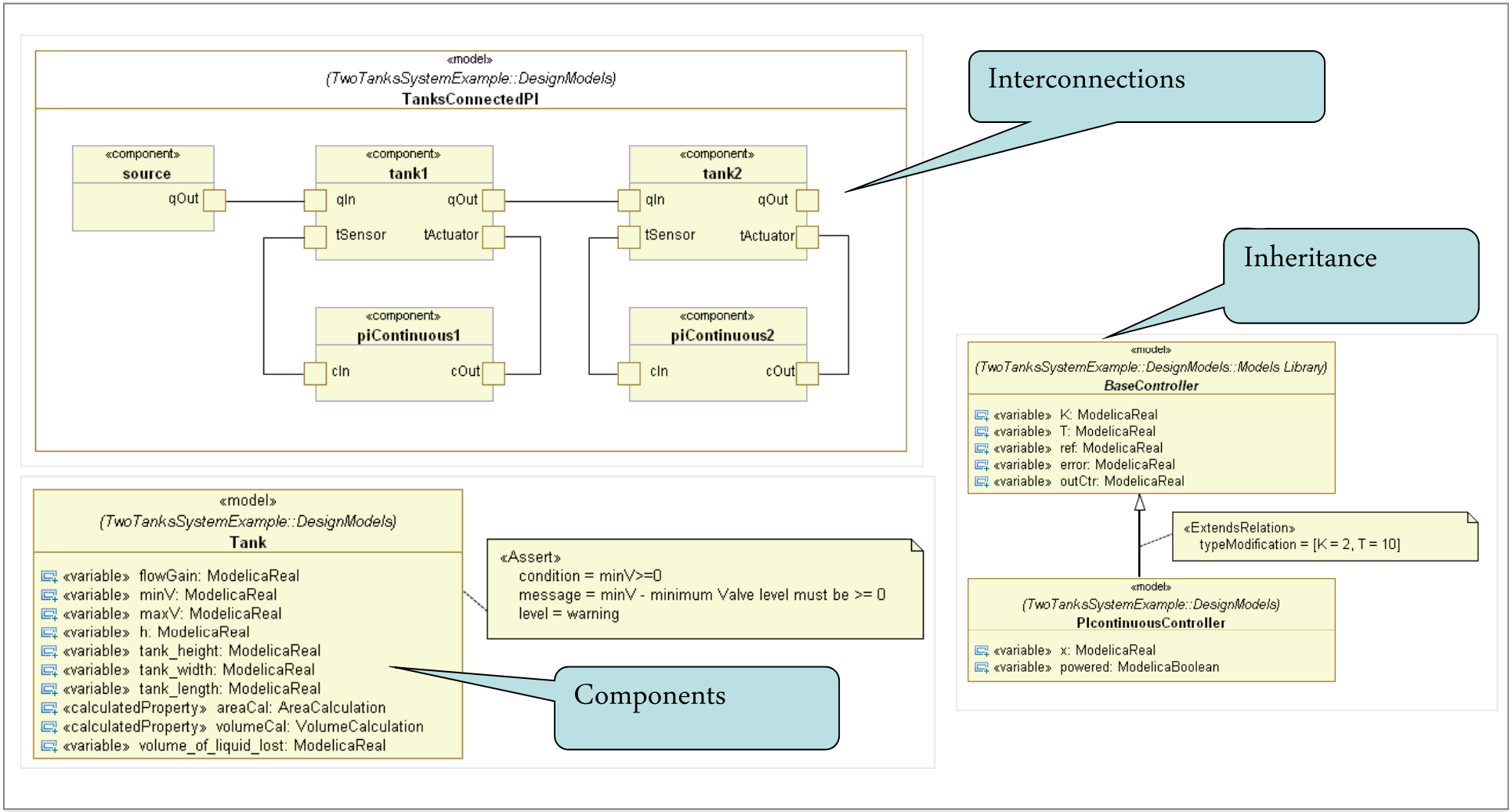
Example: Representation of System Structure



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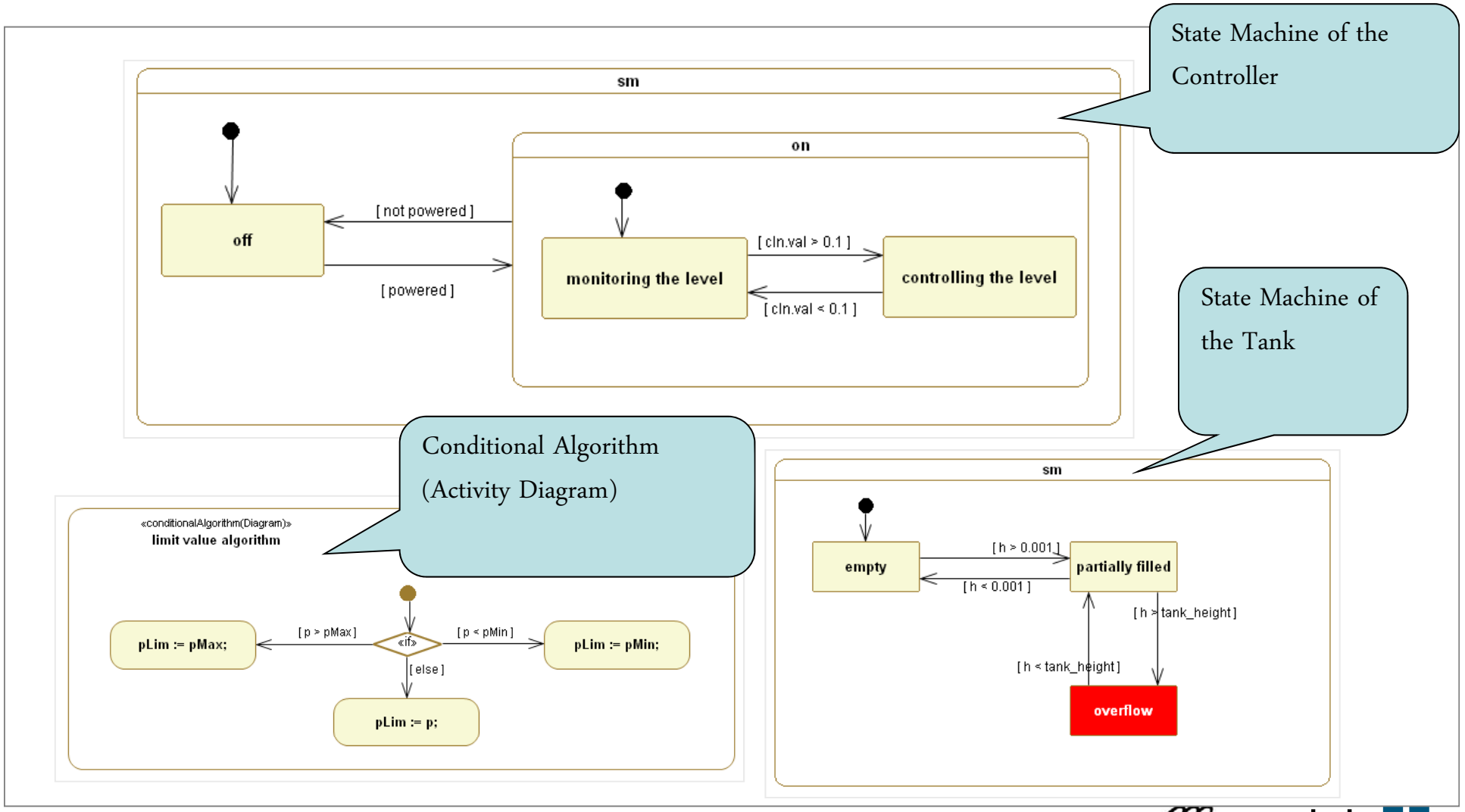
Example: Representation of System Behavior



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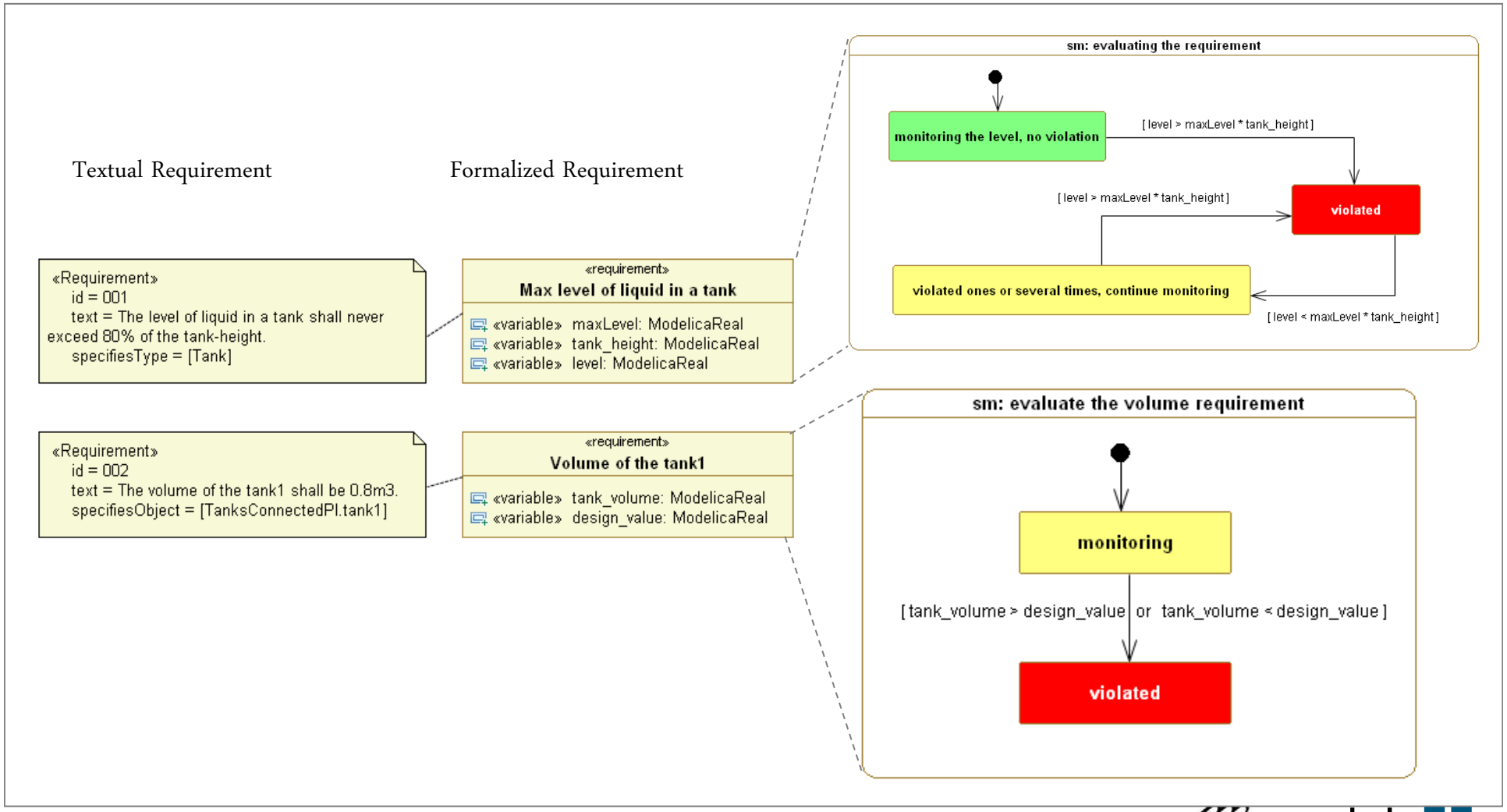
Example: Representation of System Requirements



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Example: Simulation and Requirements Evaluation

«model»
(TwoTanksSystemExample::SystemSimulations)
TankSystemSimulation

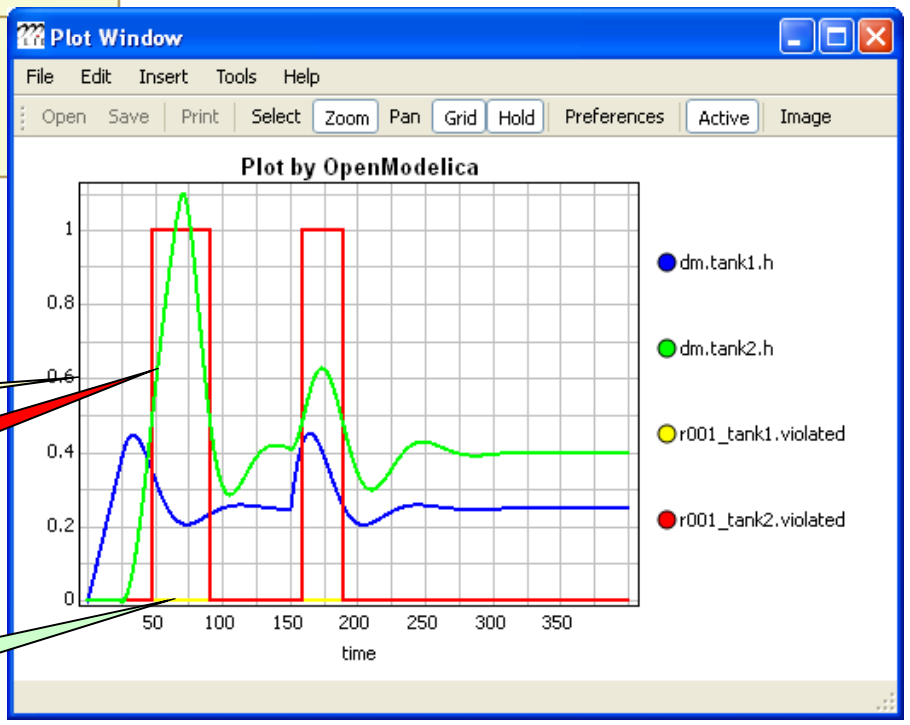
«component» dm: TanksConnectedPI
«requirementInstance» r001_tank1: Max level of liquid in a tank
«requirementInstance» r001_tank2: Max level of liquid in a tank
«requirementInstance» r002_tank1: Volume of the tank1

Req. 001 is instantiated 2 times (there are 2 tanks in the system)

tank-height is 0.6m

Req. 001 for the tank2 is violated

Req. 001 for the tank1 is not violated



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Parallel Execution Compilation to MultiCore

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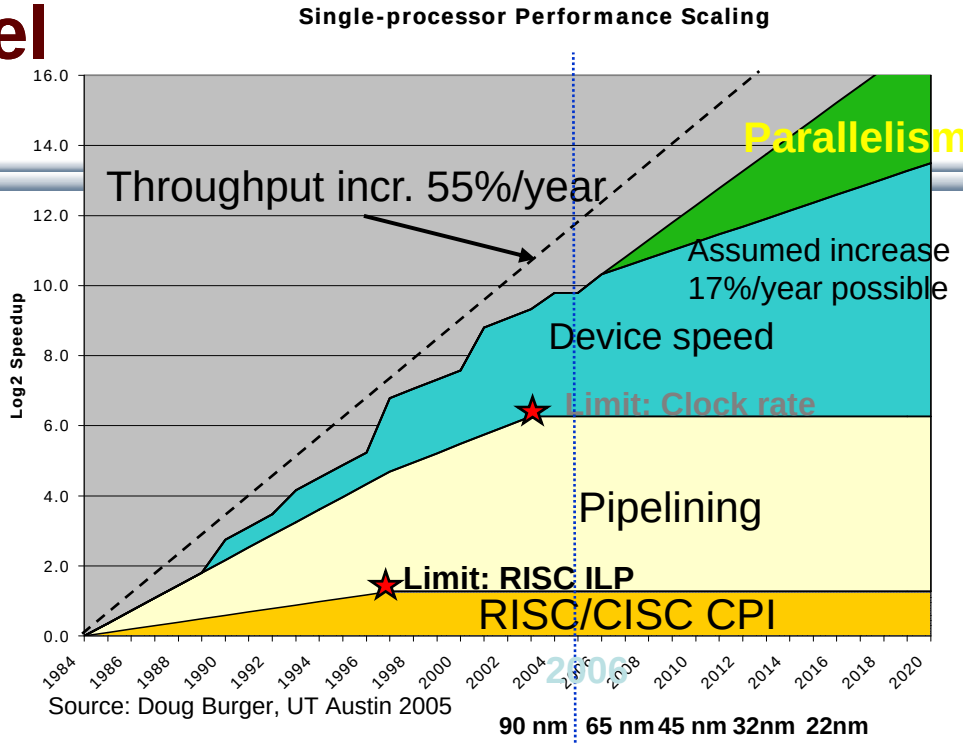
Towards High-Level Parallel Modeling and Simulation



Source: Doug Burger, UT Austin 2005

- Simulations are time-consuming
- Moore's "Law": (since 1965)
  - #devices per chip area doubles every 18 months
  - CPU clock rate also doubled every 18 months – until 2003,
    then: heat and power issues, limited ILP, ...
    → superscalar technology has reached its limits,
    only (thread-level) parallelism can increase throughput substantially
- The consequence:
  Chip multiprocessors (+ clusters)
  - Multi-core, PIM, ... (for general-purpose computing)
- Need parallel programming/modeling/parallelization
  - Automatic parallelization
  - Explicit parallel modeling and parallel programming

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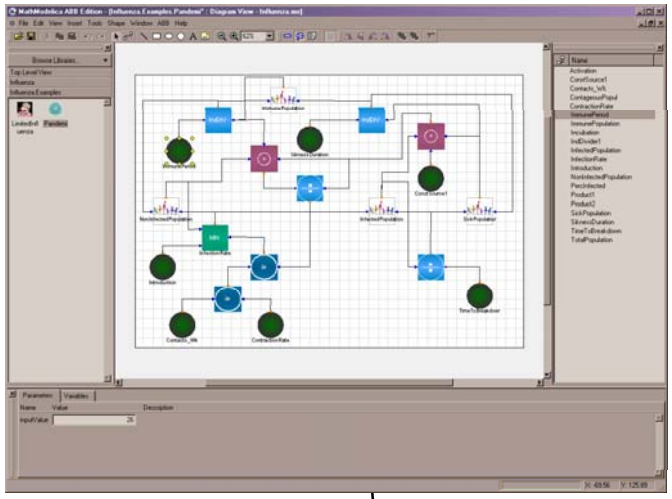
Towards Easy-to-Use Modeling & Simulation using Parallel Computers



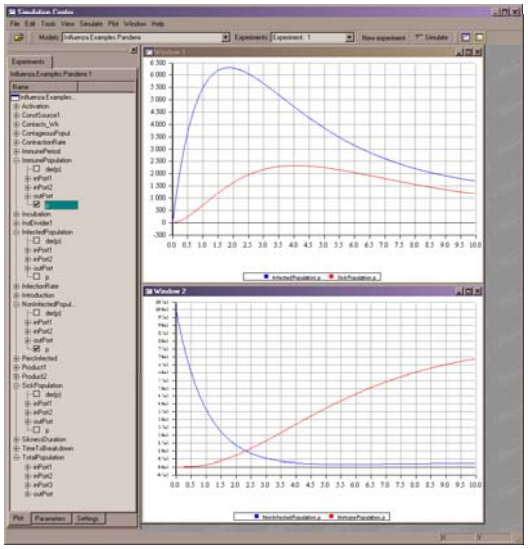
Modeling using drag'n'drop

Translation

Parallel Simulation Code

Parallel Execution

Visualization



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Integrating Parallelism and Mathematical Models Three Approaches

- **Automatic Parallelization of Mathematical Models (ModPar)**
  - 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.
    - NestStepModelica

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Modelica Simulations – Parallelization Approach

- Simulation = solution of (hybrid) DAEs from models

$$g(\dot{X}, X, Y, t) = 0$$

$$h(X, Y, t) = 0$$

- In each step of numerical solver:
  - Calculate $\dot{X}$ in g (and Y in h)
- Parallelization approach: perform the **calculation** of $\dot{X}$ in **parallel**
  - Called *parallelization over the system*.
- Drawback: Numeric solver might become bottle-neck

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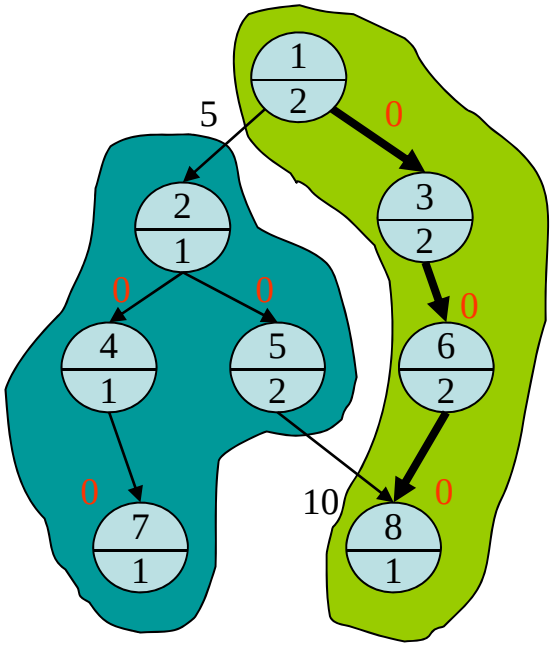
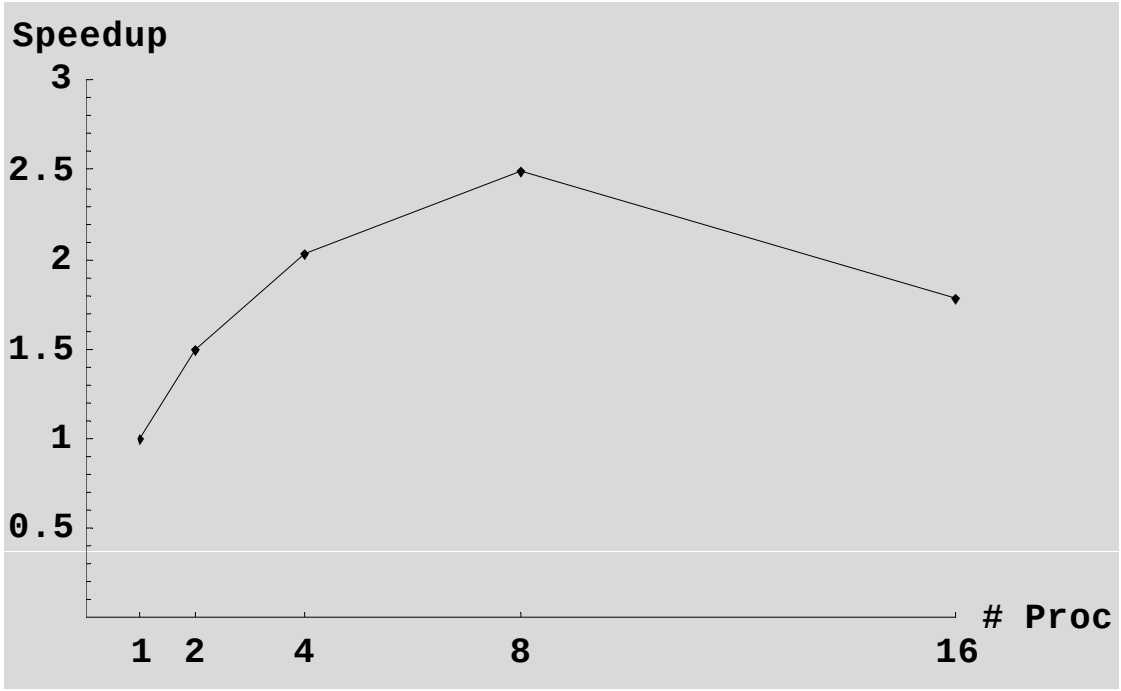
Example – Task Graphs and Parallelized Application



Clustered Task Graph



Thermofluid Pipe Application

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Modified Approach – Inlining and Pipelining

- Try to keep **communication as close** as possible
- Only **communicate in one direction** inside a time step.
- **Solver Inlining** – distribute the solver across all the processors
- Some **parallelism** across the **method** – parallel evaluation of Runge-Kutta step

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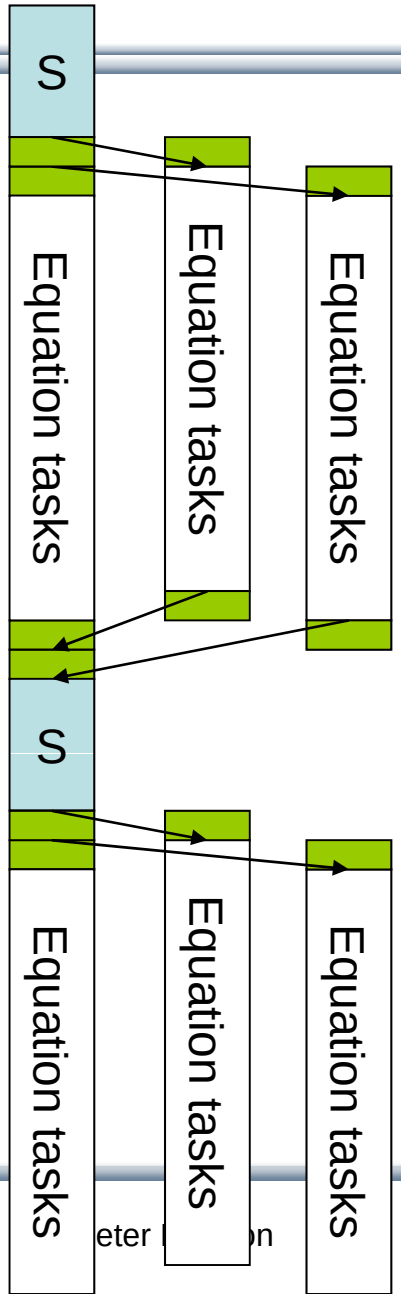
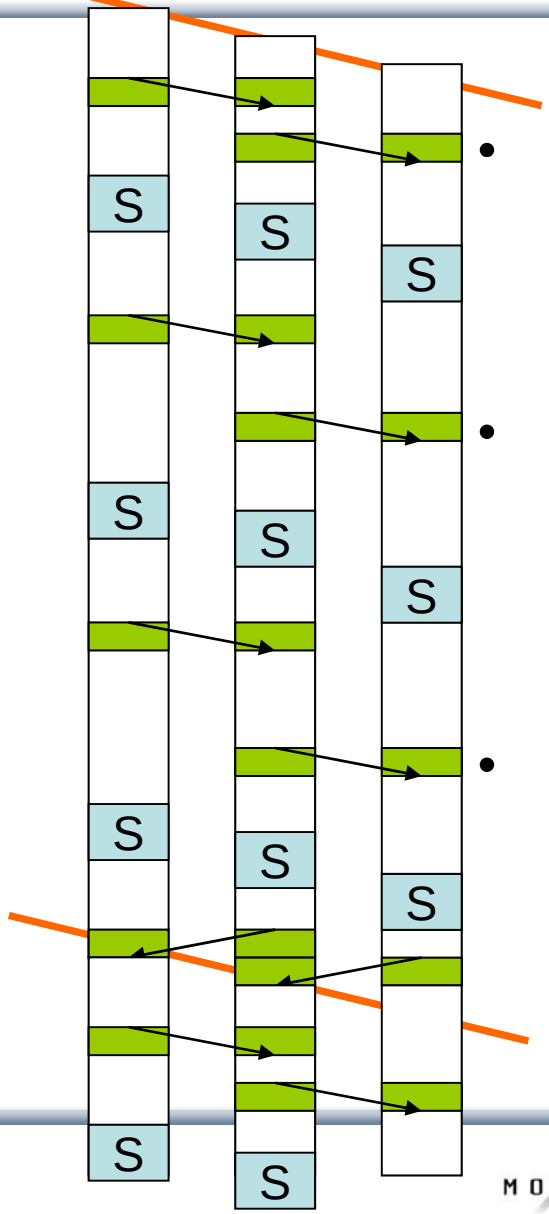
Task Merging vs Approach with Pipelining/Inlining



Use a graph rewriting system to merge tasks into larger tasks, based on latency and bandwidth.

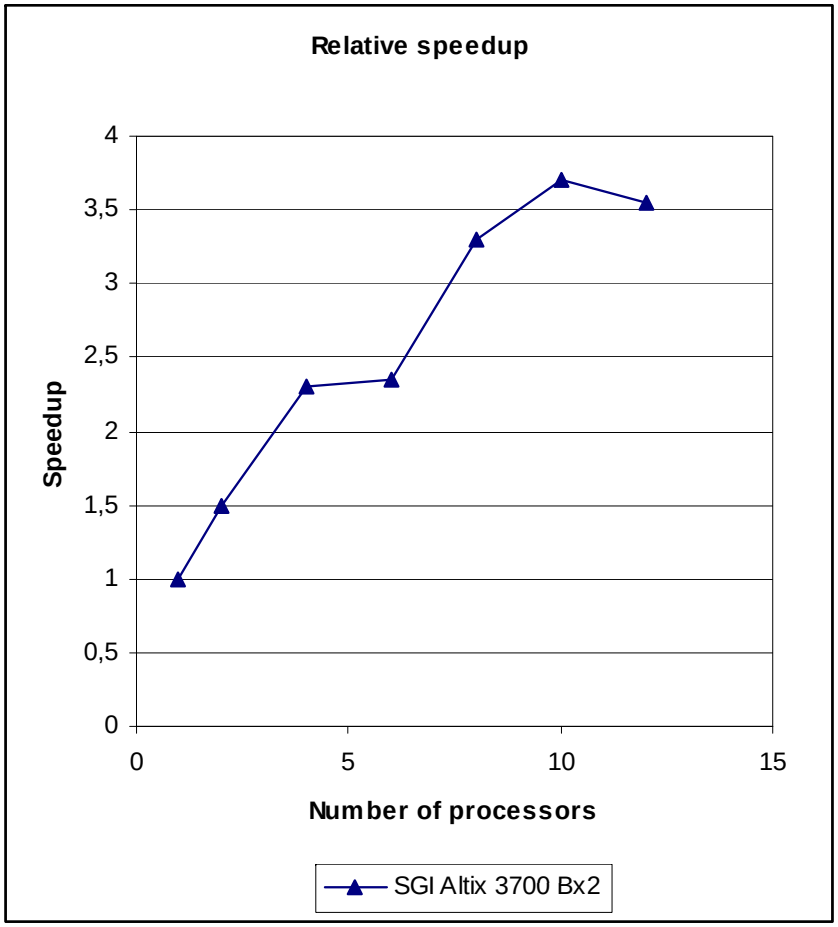
Some tasks are duplicated to avoid communication within a step



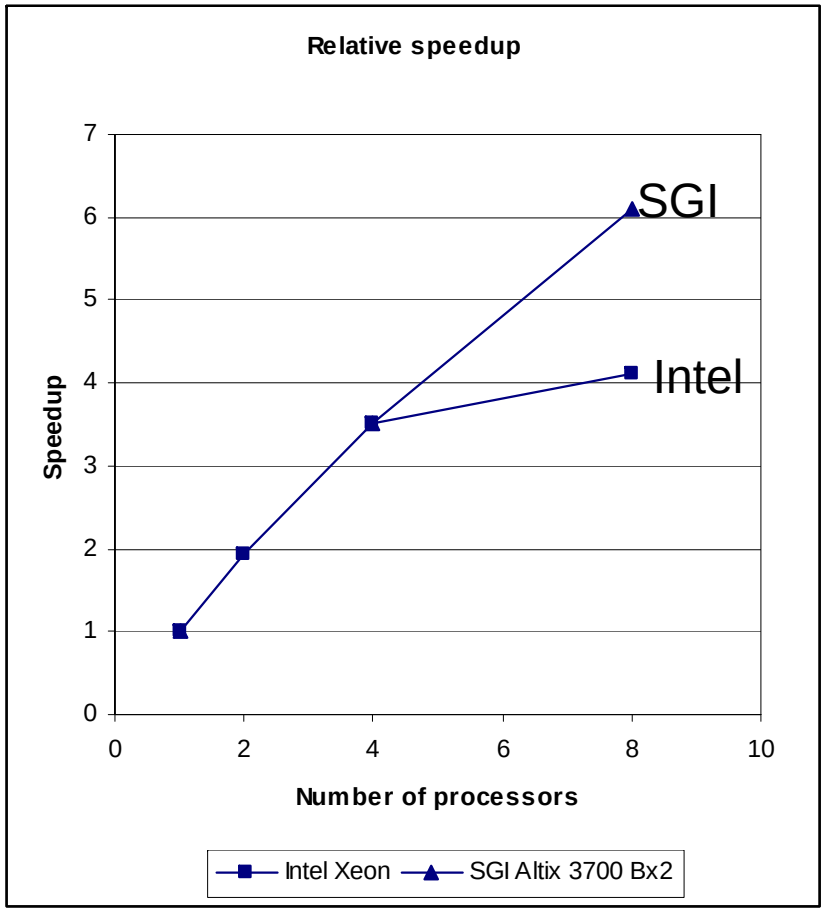
- Try to keep communication as close as possible
- Only communicate in one direction inside a time step.
- Solver Inlining – distribute the solver across all the processors

Measurements Pipelined (100000 steps Flexible Shaft Model, Fall 2008)

Task-merging, MPI, SGI Altix

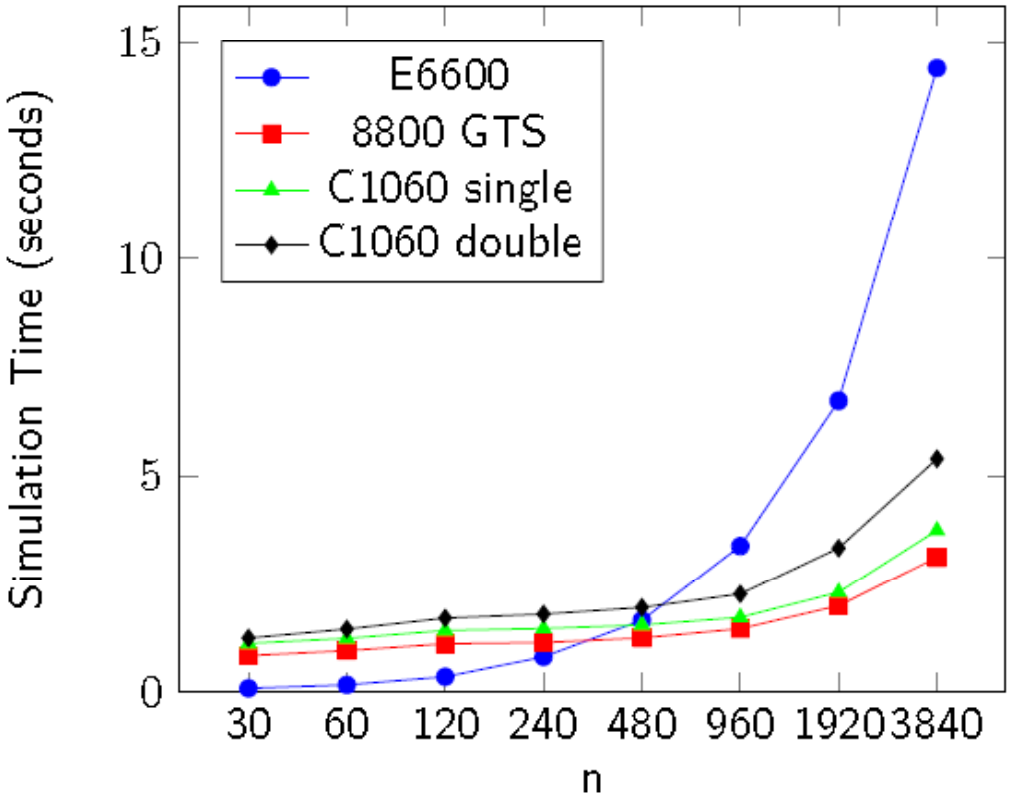


Pipelined, Pthreads, SGI, Intel Xeon



Speedup Measurements on NVIDIA (nov 2009)

Modelica Model, Generated Code, Function of Problem Size



- **New Platform NVIDIA Fermi 2050 2 Teraflop peak**
- **In Use from January 2011**

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New Scalable OpenModelica Parallel Code Generator

- Work in Progress
- Both **task** parallelism and **data** parallelism
- Handling non-expanded **arrays** efficiently
- Planned use of TLM-partitioning for more parallelism

- Generating **OpenCL** code for platform independence
- **Template** based code generator

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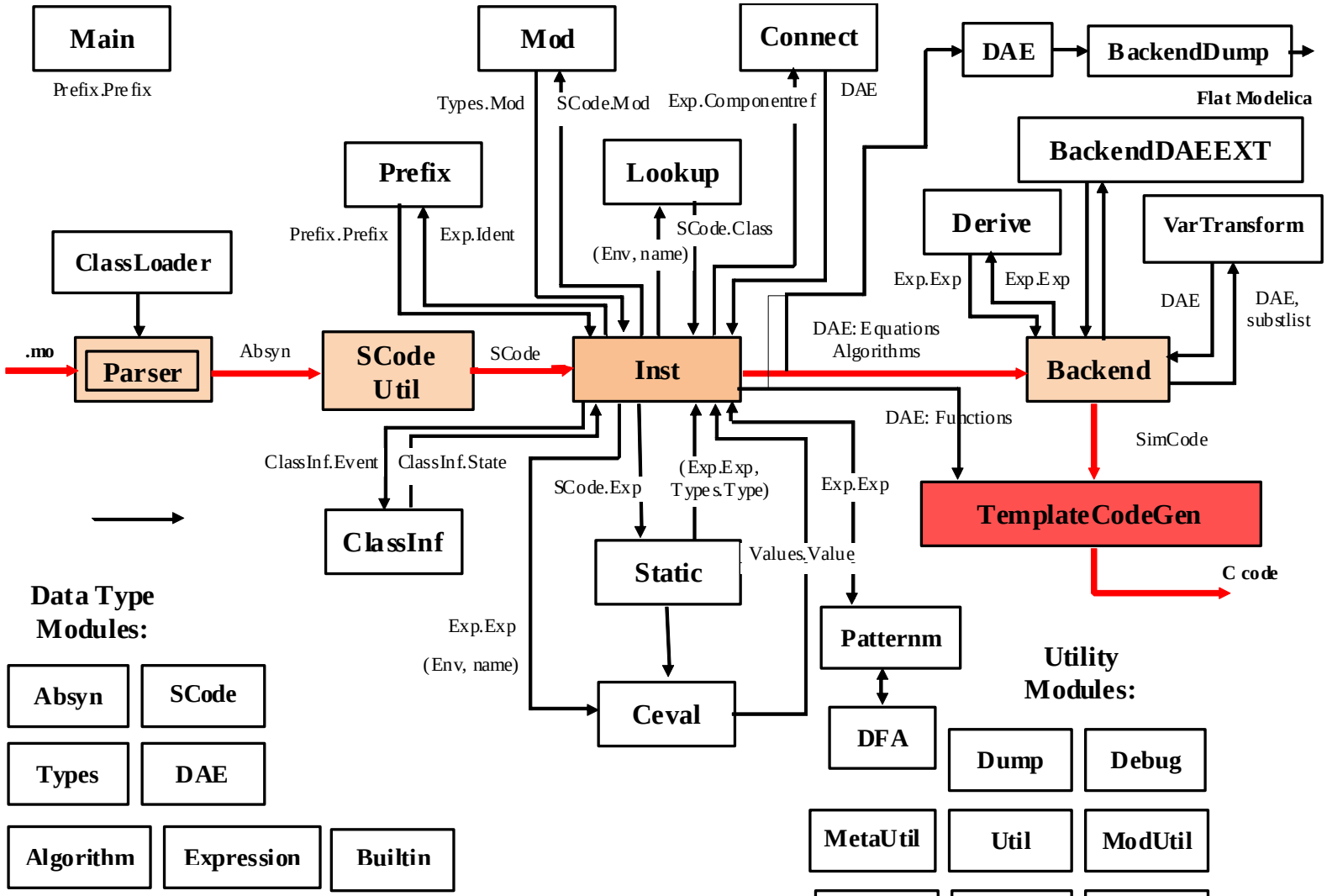
The OpenModelica Compiler

Implemented mainly in MetaModelica and C/C++; 114 packages



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Summary of MODPROD Research in PELAB

- Modeling language design (semantics, type systems, meta-modeling, extensibility)
- Modelica-SysML integration
- Requirements traceability
- Compilation to multi-core platforms
- Compilation and performance measurements for real-time simulation

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