# Increasing programmability with domain-specific languages

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PELAB

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pelab



# PELAB at a Glance

- Programming environments laboratory, founded in 1981
- Staff: 5 professors, 4 assistant professors, 11 phd students, 4 engineers
- Current topics:
  - Compiler technology
  - Software composition
  - Parallel computing
  - Design and implementation of programming and modeling languages and systems
  - Equation-based object-oriented modeling and simulation languages
  - Large-scale software engineering
  - Requirements engineering
  - Software testing and debugging





# Problem

• Productivity and Quality of human-made software







# Modelica – A Cyber-Physical Modeling Language for Systems Engineering and the OpenModelica Environment



#### September 25, 2014

#### STEW Workshop

#### Peter Fritzson

Professor at Linköping University, Sweden Vice Chairman of Modelica Association Director of Open Source Modelica Consortium Senior Member, IEEE

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## What is Modelica?

A language for modeling of complex cyber-physical systems

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







## What is Special about Modelica?





### What is Special about Modelica?



## **Graphical and Textual View**

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





## 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 too



Courtesy of Martin Otter, DLR, Oberphaffe Germany



### 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
- Slunits 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



## The OpenModelica Open Source Environment www.openmodelica.org

- Advanced Interactive Modelica compiler (OMC)
  - Supports most of the Modelica Language ٠
  - Modelica and Python scripting
- Basic environment for creating models ۲
  - **OMShell** an interactive command handler

OHShell - OpenHodelica She

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OpenModelica 1.4.3

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press enter.

true

true

record

end record

>> plot(h)

true

- **OMNotebook** a literate programming notebook ٠
- **MDT** an advanced textual environment in Eclipse ٠



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

toot...



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## OSMC – International Consortium for Open Source Model-based Development Tools, 46 members Mar 2014

#### 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**

#### /trunk: Lines of Code



#### Industrial members

- Bosch Rexroth AG, Germany
- •Siemens PLM, California, USA
- •Siemens Turbo, Sweden
- CDAC Centre, Kerala, India
- Creative Connections, Prague
- DHI, Aarhus, Denmark
- EDF, Paris, France
- Equa Simulation AB, Sweden
- Fraunhofer IWES, Bremerhaven
- Frontway AB, Sweden
- IFP, Paris, France

#### University members

- Austrian Inst. of Tech, Austria
- Linköping University, Sweden
- UC Berkeley, USA
- •TU Berlin, Insti UEBB, Germany
- FH Bielefeld, Bielefeld, Germany
- •TU Braunschweig, Germany
- Univ Calabria, Italy
- Danish Technical Univ, Denmark
- •TU Dortmund, Germany
- •TU Dresden, Germany
- Université Laval, Canada
- Georgia Inst. Technology, USA

- GTI, USA
- ISID Dentsu, Tokyo, Japan
- ITI, Dresden, Germany
- Maplesoft, Canada
- Ricardo Inc., USA
- STEAG, Dehli, India
- •TLK Thermo, Germany
- •Sozhou Tongyuan, China
- VTI, Linköping, Sweden
- VTT, Finland
- Wolfram MathCore, Sweden
- Ghent University, Belgium
- Halmstad University, Sweden
- Heidelberg University, Germany
- TU Hamburg/Harburg Germany
- KTH, Stockholm, Sweden
- Univ of Maryland, Syst Eng USA
- Univ of Maryland, CEEE, USA
- Politecnico di Milano, Italy
- Ecoles des Mines, CEP, France
- Mälardalen University, Sweden
- Univ Pisa, Italy
- •Telemark Univ College, Norway



## OpenModelica MDT Eclipse Plug-in with OpenModelica Algorithmic Code Debugger

Debug - HelloWorld/SimulationModel.mo - Eclipse SDK				- D X
<u>File Edit Navigate Search Project Run Window Help</u>				
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Simulation Model [Modelica Developement Tooling (MDT) GDB] C:\Users\adeas31\workspaceMDT\H	lelloWorld\SimulationModel	l.exe		
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## General Tool Interoperability & Model Exchange Functional Mock-up Interface (FMI)

The FMI development a result 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, standardized by Modelica Association
- 14 automotive use cases for evaluation
- > 40 tool vendors are supporting it





#### Simulation and Requirements Checking Tank system example





#### ParModelica – Modelica Parallel Algorithmic Programming Execution on GPUs and CPUs via portable OPENCL code generation





## **Get More Information, Download Software**



Peter Fritzson Principles of Object Oriented Modeling and Simulation with Modelica 3.3 A Cyber-Physical Approach

Wiley-IEEE Press, 2014 1250 pages

## OpenModelica

- www.openmodelica.org
- Modelica Association

www.modelica.org





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**Christoph Kessler** 

Linköping University Sweden

\*This research is funded by EU FP7 projects PEPPHER and EXCESS, and by SeRC







# The Computer Engineer's Solution Today Heterogeneous Multicore

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# The Application Programmer's Nightmar Heterogeneous Multicore

- ☺ Distributed Memory or Non-coherent Shared Memory
- Oifferent Programming Models
- ⊗ Low Abstraction Level
- Require Architecturespecific Optimization





# **Common: GPU-Based Systems**

 ② Distributed Memory
 ③ Different Programming Models
 ③ Low Abstraction Level
 ③ Require Architecturespecific Optimization





# **Common: GPU-Based Systems**





# Programming of GPU-based Systems ... with OpenCL™ (?)

- Code portability ©



- Programmability (low level)
- Performance portability 😣 (requires reoptimization)



## **Skeleton Programming**



- A **skeleton** is a pre-defined generic software component that
  - Models a common computation / dependence pattern
    - $\rightarrow$  well-defined semantics; metadata implicit
  - Can be customized with sequential user code
  - Provides a *sequential* interface
  - Encapsulates all platform-specific implementation details (parallelism, heterogeneity, memory management, ...)

## SkePU www.ida.liu.se/~chrke/skepu



- C++ template library targeting GPU-based systems
- 6 dataparallel skeletons
  - Map, Reduce, Scan, MapReduce, MapArray, MapOverlap (stencil)
- 1 task-parallel skeleton: farm
- STL-based containers wrapping operand data
  - Smart containers Vector<...>, Matrix<...> optimizing data transfers and memory management at runtime
- Generation of platform-specific variants for user functions
- Multiple back-ends: C, OpenMP, OpenCL, CUDA, StarPU, (MPI)
  - Hybrid CPU-GPU execution (with StarPU backend)
  - Multi-GPU support
- Low overhead
- Auto-tunable [Dastgeer *et al.* IWMSE'11, MULTIPROG'12, APPT'13; PhD'14]
- Open-source





- Domain-specific languages
  - High level of abstraction
  - Automatic code generation
- Model-based development of Cyber-Physical Systems
  - OpenModelica open-source environment
- Skeleton programming
  - Parallelism, heterogeneity, communication managed internally
  - Performance, portability and automatic optimizations for free!