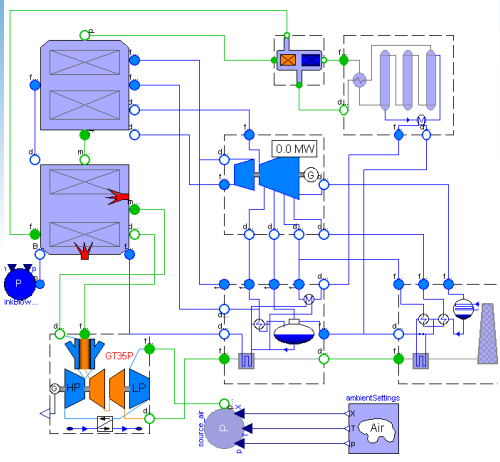




Modeling and Optimization with Optimica and JModelica.org – Languages and Tools for Solving Large-Scale Dynamic Optimization problems



Outline

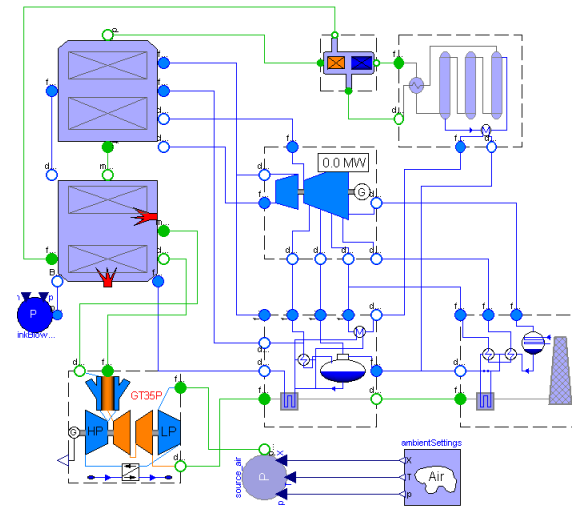
- Modelica
 - Dynamic optimization and Optimica
 - The JModelica.org open source project
 - Applications
 - What's next?
-
- 

Outline

- Modelica
 - Dynamic optimization and Optimica
 - The JModelica.org open source project
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-
- 

What is Modelica?

- A language for modeling of complex heterogeneous physical systems
- Open language
 - Managed and developed by non-profit organization Modelica Association
 - Several tools, commercial and free
 - MapleSim
 - Dymola
 - Simulation X
 - OpenModelica
 - JModelica.org
- Extensive free standard library
 - Electrical, mechanical, thermodynamics, fluid



Modelica history

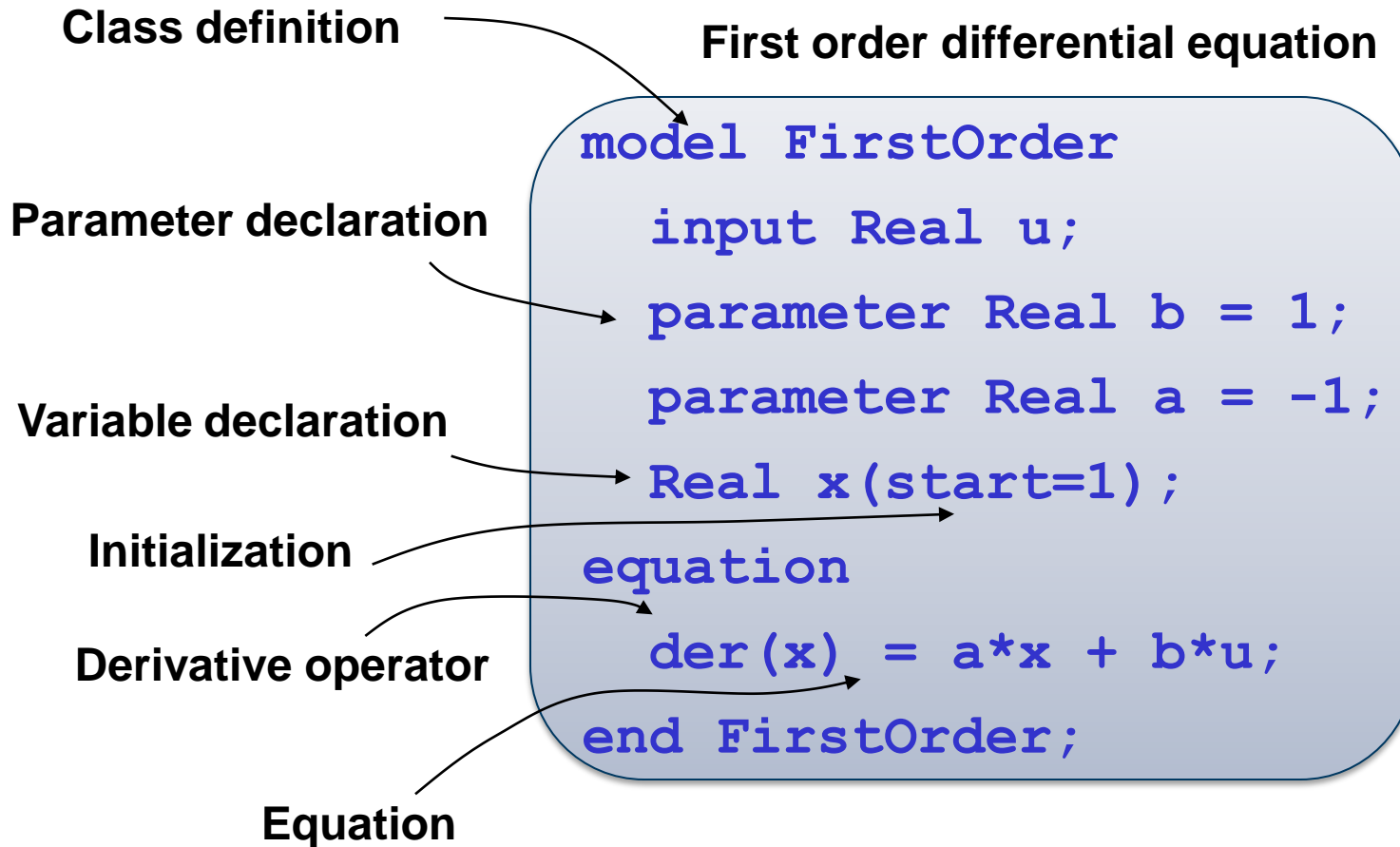
- Evolved from continuous simulation community
 - Simnon
 - Omola/Omsim
 - Bond graphs
- Wide range of applications from start
 - Electronics
 - Mechanics
 - Thermodynamics
- Language development
 - Modelica specification 1.0 in 1997
 - Modelica specification 3.2 in March 2010
- Actively developed by tool vendors and practitioners
 - 65th design meeting in Lund February 2010



Key features of Modelica

- Declarative equation-based modeling
 - Text book style equations
 - Multi-domain modeling
 - Heterogeneous modeling
 - Object oriented modeling
 - Inheritance and generics
 - Software component model
 - Instances and (acausal) connections
 - Model libraries
 - Function support
 - Hybrid Differential Algebraic Equation (DAE) formalism
 - Large models (>10.000 equations)
-

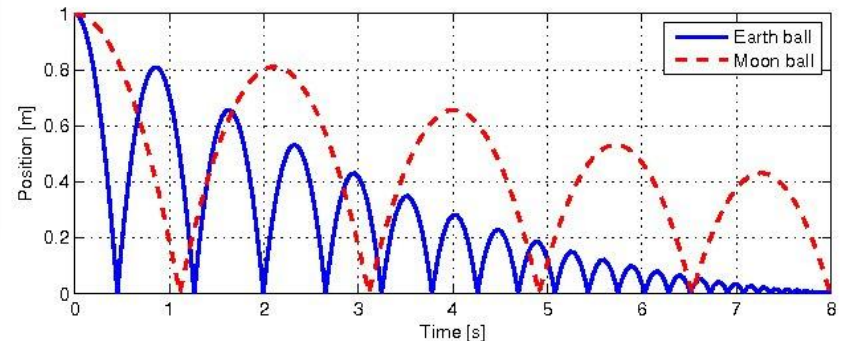
A simple Modelica Model



Hybrid modeling

```
class BouncingBall //A model of a bouncing ball
  parameter Real g = 9.81; //Acceleration due to gravity
  parameter Real e = 0.9; //Elasticity coefficient
  Real pos(start=1); //Position of the ball
  Real vel(start=0); //Velocity of the ball
equation
  der(pos) = vel; // Newtons second law
  der(vel) = -g;
  when pos <=0 then
    reinit(vel, -e*pre(vel));
  end when;
end BouncingBall;
```

```
class BBex
  BouncingBall eBall;
  BouncingBall mBall(g=1.62);
end BBex;
```



Graphical and textual modeling

```
model MotorControl
```

```
Modelica.Mechanics.Rotational.Inertia inertia;
```

```
Modelica.Mechanics.Rotational.Sensors.SpeedSensor speedSensor;
```

```
Modelica.Electrical.Machines.BasicMachines.DCMachines.DC_PermanentMagnet DCPM;
```

```
Modelica.Electrical.Analog.Basic.Ground ground;
```

```
Modelica.Electrical.Analog.Sources.SignalVoltage signalVoltage;
```

```
Modelica.Blocks.Math.Feedback feedback;
```

```
Modelica.Blocks.Sources.Ramp ramp(height=100, startTime=1);
```

```
Modelica.Blocks.Continuous.PI PI(k=-2);
```

```
equation
```

```
connect(inertia.flange_b, speedSensor.flange_a);
```

```
connect(DCPM.flange_a, inertia.flange_a);
```

```
connect(speedSensor.w, feedback.u2);
```

```
connect(ramp.y, feedback.u1);
```

```
connect(signalVoltage.n, DCPM.pin_ap);
```

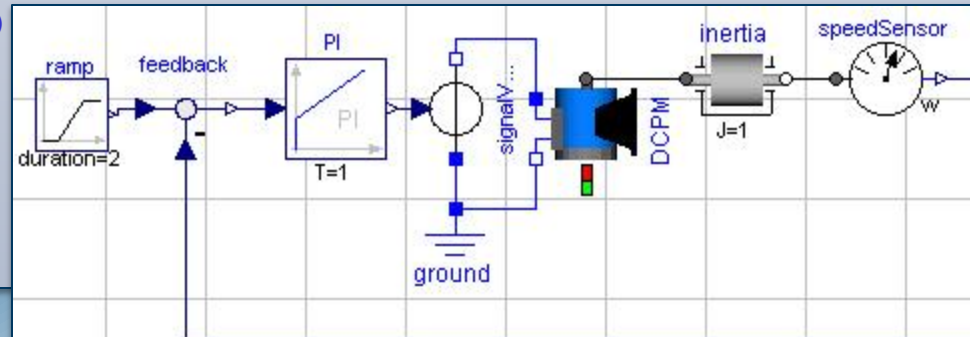
```
connect(signalVoltage.p, ground.p)
```

```
connect(ground.p, DCPM.pin_an);
```

```
connect(feedback.y, PI.u);
```

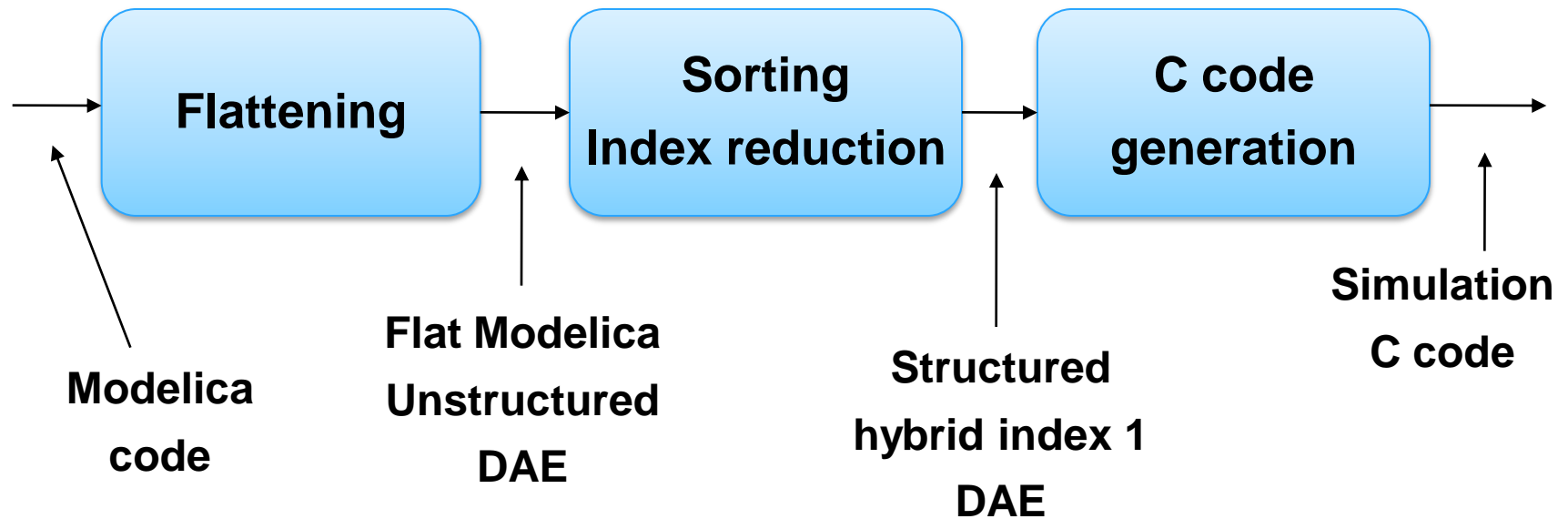
```
connect(PI.y, signalVoltage.v);
```

```
end MotorControl;
```




Translation of Modelica models

- Generation of a mathematical model description from Modelica code



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- Modelica
 - Dynamic optimization and Optimica
 - The JModelica.org open source project
 - Applications
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-
- 

Optimization and Modelica

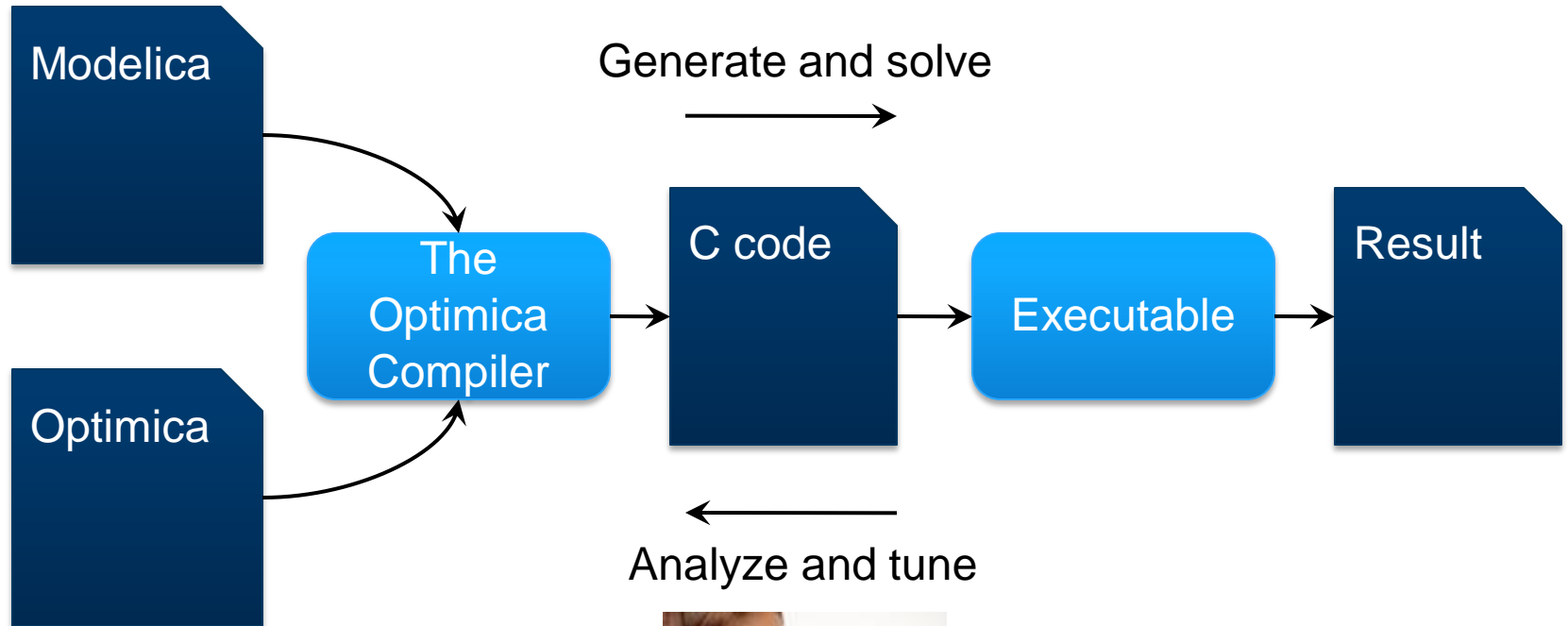
- Modelica increasingly used in industry
 - Expert knowledge
 - Capital investments
 - Mainly simulation... ...but new areas emerge
 - Model reduction
 - Parameter identification
 - Dynamic optimization
 - Model predictive control
 - Usages reported so far
 - Cope with simulation-oriented interfaces
 - Treat model essentially as a black box
 - Fast algorithms explores model structure
 - Real-time optimization
-

Dynamic optimization

- Many algorithms
 - Applicability highly model-dependent (ODE, DAE, PDE, hybrid)
 - Calculus of variations
 - Direct single/multiple shooting
 - Direct collocation methods
 - Simulation-based methods (GA, simulated annealing)
- Analogy with different simulation algorithms
 - Heavy burden to used numerical algorithms
 - Fortran, C, (AMPL)
- Engineering need for high-level descriptions
 - Shift focus from *encoding*
 - to *formulation* of optimization problem



Typical workcycle



Dynamic optimization

$$\min_{u(t), p} \Psi(\bar{z}, p)$$

subject to the dynamic system

$$F(\dot{x}(t), x(t), y(t), u(t), p, t) = 0, \quad t \in [t_0, t_f]$$

and the constraints

$$c_{ineq}(x(t), y(t), u(t), p) \leq 0, \quad t \in [t_0, t_f]$$

$$c_{eq}(x(t), y(t), u(t), p) = 0, \quad t \in [t_0, t_f]$$

$$c_{ineq}^p(\bar{z}, p) \leq 0$$

$$c_{eq}^p(\bar{z}, p) = 0$$

where

$$\bar{z} = [x(t_1), \dots, x(t_{N_p}), y(t_1), \dots, y(t_{N_p}), u(t_1), \dots, u(t_{N_p})]^T, \quad t_i \in [t_0, t_f]$$

Optimization with Modelica

- Strong support for modeling of dynamic systems
- Missing elements
 - Cost function
 - Constraints
 - What to optimize
 - Initial guesses
- Optimica
 - Small extension of Modelica
 - Enable high-level formulation of optimization problems

Optimica – an example

$$\min_{u(t)} \int_{t_0}^{t_f} 1 dt$$

subject to the dynamic constraint

$$\dot{x}_1(t) = (1 - x_2(t)^2)x_1(t) - x_2(t) + u(t), \quad x_1(0) = 0$$

$$\dot{x}_2(t) = x_1(t), \quad x_2(0) = 1$$

and

$$x_1(t_f) = 0$$

$$x_2(t_f) = 0$$

$$-1 \leq u(t) \leq 1$$

A Modelica model

```
model VDP
  Real x1(start=0);
  Real x2(start=1);
  input Real u;
equation
  der(x1) = (1-x2^2)*x1 - x2 + u;
  der(x2) = x1;
end VDP;
```

An Optimica model

```
optimization VDP_Opt(objective=cost(finalTime),
                    startTime=0,
                    finalTime(free=true, initialGuess=1))
VDP vdp(u(free=true, initialGuess=0.0));
Real cost (start=0);
equation
    der(cost) = 1;
constraint
    vdp.x1(finalTime) = 0;
    vdp.x2(finalTime) = 0;
    vdp.u >= -1; vdp.u <= 1;
end VDP_Opt;
```

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- **The JModelica.org open source project**
- Applications
- What's next?

The JModelica.org open source project

What?

JModelica.org is an extensible Modelica-based open source platform for optimization, simulation and analysis of complex dynamic systems.

Our mission:

To offer a community-based, free, open source, accessible, user and application oriented Modelica environment for optimization and simulation of complex dynamic systems, built on well-recognized technology and supporting major platforms

Origin:

JModelica.org is the result of research at the Department of Automatic control, Lund University, and is now maintained and developed by Modelon AB in cooperation with academia.

JModelica.org is open source

- Source code is freely available
 - Open Source Initiative approved licenses
 - GPL (CPL)
- Infrastructure supporting a community
 - Transparency of development
 - Interactive web site
 - User forums



Community

JModelica.org

Login | Preferences | Help/Guide | About Trac

Wiki | **Timeline** | Roadmap | Browse Source | View Tickets | Search
← Previous Period | Next Period →

Timeline

09/11/09: Yesterday

- 16:05 Ticket #348 (PySUNDIALS required to run tests) closed by tove
fixed: Resolved in r950. Test suite now runs ok on my computer (which doesn't ...)
- 16:03 Changeset [950] by tove
Fix so that test suite can be run without cvodes and openopt, #348.
- 16:00 Ticket #348 (PySUNDIALS required to run tests) reopened by tove
Replying to jens_rantil: > I now consider this ticket fixed ...
- 15:50 Ticket #310 (Generate Python exception of compilation of generated code fails) closed by tove
fixed: These tests should be fixed in r949.
- 15:49 Changeset [949] by tove
Fixed tests that were broken due to changeset:910, see #310.
- 09:00 Milestone w0937 completed
- 08:58 Milestone 1.0b1 completed
- 08:58 Ticket #370 (Restructure README file in Python package) updated by jakesson
milestone changed
- 08:55 Ticket #370 (Restructure README file in Python package) created by jakesson
The README file in the /trunk/Python directory is partially obsolete. The ...
- 00:37 Ticket #293 (Sundials CVode(s)ReInit(...)) should be called when resimulating updated by
status, type, summary changed
Problem: Currently new memory is allocated every time a simulation ...
- 00:31 Ticket #369 (Cleanup SundialsODESimulator.run()) closed by jens_rantil
fixed: I consider this resolved for now.
- 00:26 Changeset [948] by magnus
Version 1.0 beta 1 for Modelica conference dress rehearsal.

View changes from 09/11/09
and 30 days back.

- Opened and closed tickets
- Ticket updates
- Repository checkins
- Milestones
- Wiki changes

Update

- Transparency
- Track activity
- Releases

JModelica.org

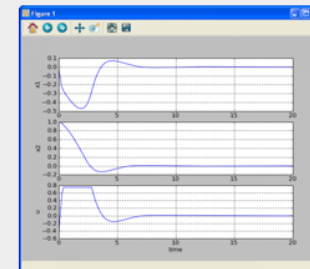
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About JModelica.org

JModelica.org is an *extensible Modelica-based open source platform for optimization, simulation and analysis of complex dynamic systems*. The main objective of the project is to create an industrially viable open source platform for optimization of Modelica models, while offering a flexible platform serving as a virtual lab for algorithm development and research. As such, JModelica.org is intended to provide a platform for technology transfer where industrially relevant problems can inspire new research and where state of the art algorithms can be propagated from academia into industrial use. JModelica.org is a result of research at the Department of Automatic Control, Lund University, and is now maintained and developed by Modelon AB.

```
Python
# 2.349098e+002 7.18e-011 1.0e-007 11.0 1.31e-001 2.00e+000 1.00e+000 1
# 2.349098e+002 4.48e-011 7.8e-007 11.0 8.25e-001 2.00e+000 1.00e+000 1
# 2.349098e+002 4.48e-011 7.8e-007 11.0 8.25e-001 2.00e+000 1.00e+000 1
# 2.349098e+002 2.75e-011 4.9e-007 11.0 3.18e-001 2.00e+000 1.00e+000 1
# 2.349098e+002 2.75e-011 4.9e-007 11.0 3.18e-001 2.00e+000 1.00e+000 1
Number of iterations..... 43
Objective..... (scaled)..... (unscaled)
Dual Infeasibility..... 1.346008611009029e+003 7.346008611009029e+003
Constraint Violation..... 1.5130196224264e-011 1.5130196224264e-011
Optimal NLP error..... 1.0000000000000e-11 1.0000000000000e-11
Optimal NLP error..... 8.152888627749624e-009 8.152888627749624e-009
Number of objective function evaluations ..... 284
Number of objective gradient evaluations ..... 24
Number of equality constraint evaluations ..... 284
Number of inequality constraint evaluations ..... 24
Number of feasibility constraint evaluations ..... 44
Number of Lagrangian multiplier evaluations ..... 0
Total CPU secs for NLP function evaluations ..... 1.367
Total CPU secs for NLP function evaluations ..... 0.466
EXIT: optimal solution found.
```



» Read more

Recent comments

- I am clueless, I have never
2 days 7 hours ago
- I tried it first with 1.0a1,
3 days 10 hours ago
- Never seen it before. I
4 days 51 min ago
- Ok. That's what I
thought. I
4 days 23 hours ago
- The test suite currently
runs
5 days 11 hours ago
- Yes, I think this is a
5 days 11 hours ago
- More background on this
5 days 21 hours ago
- I updated the INSTALL
file in
1 week 3 days ago
- It is possible to specify
1 week 3 days ago
- Using Dymola for
modeling of

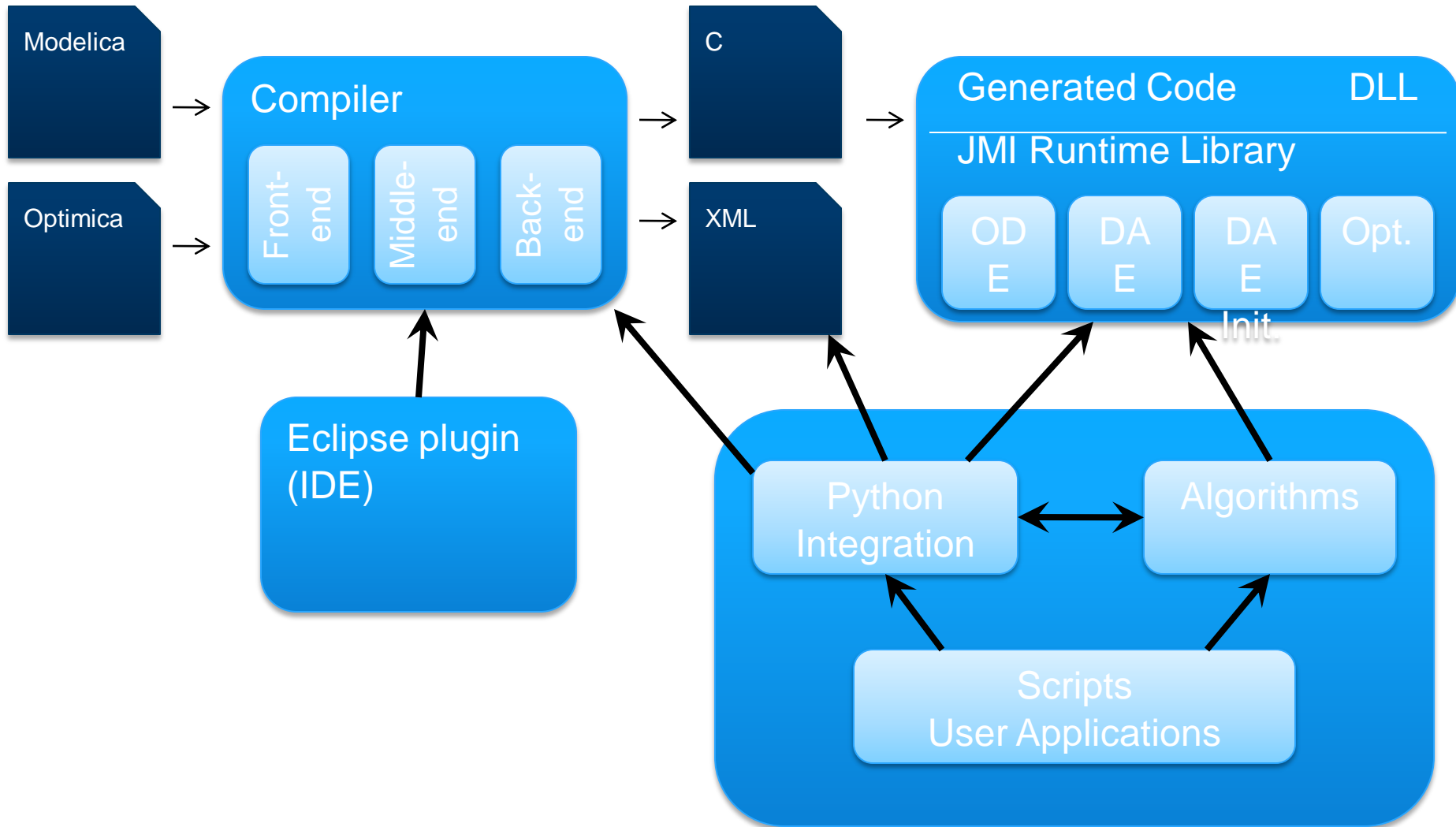
- Documentation
- News
- Forums

Technologies

- Modelica
- JastAdd meta-compiler tool
 - Modelica/Optimica compiler front-ends pure Java
 - Easily embedded jar-files
- Python
 - Scientific computing environment
 - Scripting and visualization
 - Custom application development
- XML
 - Model meta data and equations
- Eclipse
 - Modelica and Optimica IDE
 - Refactoring

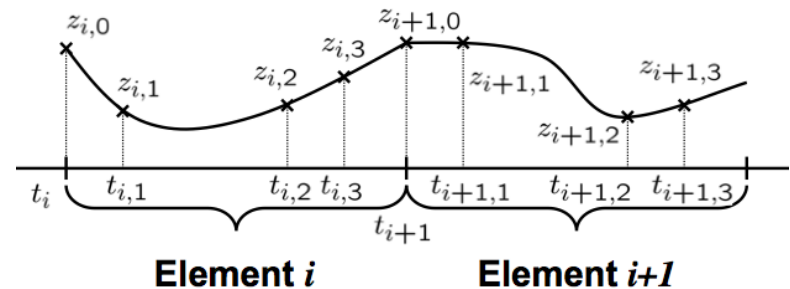


JModelica.org architecture



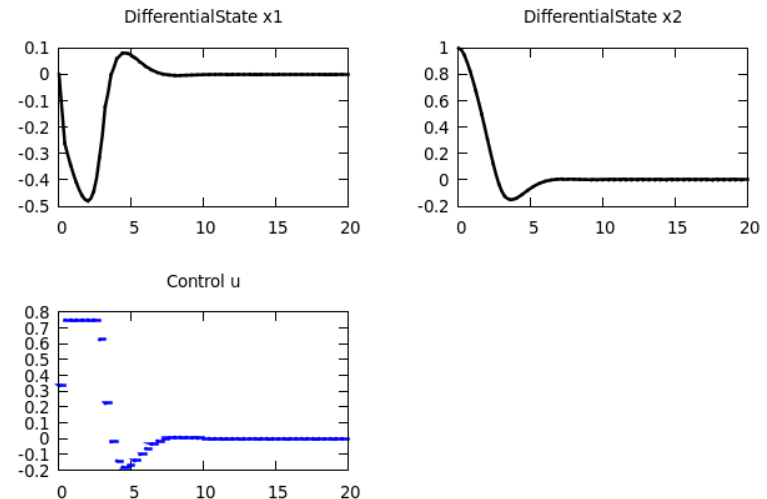
Interface I: C model execution API–JMI

- C functions for evaluation of:
 - DAE residual
 - DAE initialization system
 - Event indicator functions (hybrid systems)
 - Cost function
 - Constraints
- Integrated AD package: CppAD
 - High-accuracy Jacobians
 - Sparsity patterns
- Direct collocation algorithm
 - Approximate controls and states by piecewise polynomials
 - Large but sparse non-linear program
 - NLP solver IPOPT




Interface II: XML export

- Standardized format for DAE model exchange
- Neutral w.r.t. model usage
 - Simulation, optimization, LFTs, model reduction
- (Not yet quite) neutral w.r.t. modeling language
- Model meta data
 - Variable names
 - Parameter values
- Model equations
 - DAE
 - Initialization system
 - Functions and algorithms
 - Optimization
- XML import to ACADO



MSc project by Roberto Parrotto in collaboration with Joel Andersson, KU Leuven

Outline

- Modelica
 - Dynamic optimization and Optimica
 - The JModelica.org open source project
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 - What's next?
-
- 

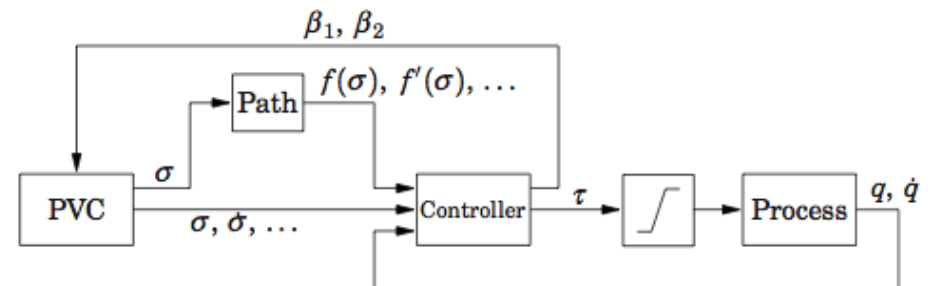
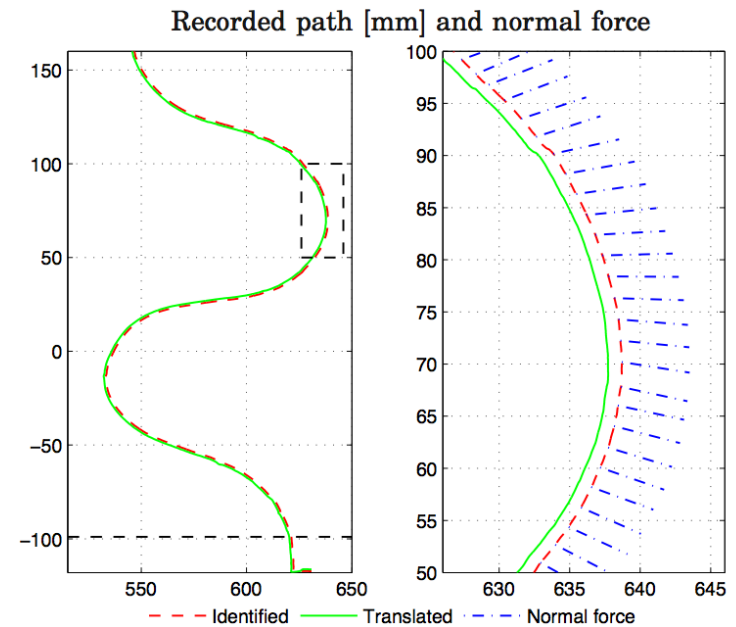
Grade change optimization

- Collaboration with plastics manufacturer Borealis
- Polyethylene production
- Tree reactors in series
 - Pre-loop
 - Loop
 - Gas phase
- Decision support
 - Flexible production
 - Raw material prices vary
 - Minimize off-spec
- JModelica.org for optimization
 - Grade changes and parameter estimation
- PhD student project: Per-Ola Larsson and Niklas Andersson




Time optimal robot control

- Track specified paths in 3D
- Record path
- Generate splines
- Optimize
- Implement



Master's theses by Marin Hast, Björn Olofsson and Henrik Nilsson

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- 

What's next?

- Improved Modelica compliance
 - Generics
 - Fluid modeling support
- Simulation
 - SUNDIALS
 - Hybrid systems
- Continued work on Python interface
 - Feedback appreciated
- Algorithm integration
- Application-driven development



JModelica.org in research

- Continued work on Optimica language extension
 - Execution of Model Predictive Controllers
 - PIC-LU (Process Industrial Center at Lund University)
 - Grade change optimization at Borealis
 - Poly-ethane process
 - Robust optimization
 - Parallelization of optimization algorithms (Texas A&M)
 - Explore the power of multi and many core
 - Decomposition schemes for interior point methods
 - Safe refactoring
 - Modelica source code transformations
 - Exploit research related to JastAdd
 - Adapt and extend framework developed for Java
-

Join the community

- Use in industrial applications
- Education
- Interfacing your algorithms
- Research
- Develop

