Modelling of Energy Systems with OpenModelica

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Outline

• Recent relevant achievements of OpenModelica

• Coverage of libraries for energy system simulation

• Research & development activities based on OMC (also in partnership with Dynamica srl)

• Conclusions and recommendations for 2015
Recent relevant achievements of OpenModelica

- First-class front-end
  - Almost 100% flattening
  - Some issues with lookup in corner cases
  - Some issues remaining with package constants (Modelica.Media)
  - Some issues with lost start attributes set in medium models
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• Huge progress in the back-end
  – Initial equations handled with full symbolic processing
  – Nonlinear equation tearing
  – Rudimentary support of homotopy() operator
  – Wide choice of integration algorithms
  – Reliable CSE not yet available
  – Some issues with nonlinear solver convergence
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• OMEdit begins being really usable
  – Vastly improved look&feel of graphical editing
  – Transformational debugger available
  – Full control of compiler options
  – Replaceable classes not handled (medium & heat transfer models)
  – Indentation and formatting not preserved by editor (RCSs support is severely impaired)
Basic building block #1: Modelica.Media

- Most challenging part of the MSL w.r.t. efficient compiler support
  - Complex extends/redeclare involving packages and functions
  - Package constants used throughout
  - Arrays, records, arrays and records within arrays
  - Inline/LateInline/CSE required for proper operation

- 100% Modelica.Media coverage achieved!!

- Essential for the modelling of energy systems based on thermo-hydraulic processes (Rankine and Brayton cycles)
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• Essential for the modelling of energy systems based on thermo-hydraulic processes (Rankine and Brayton cycles)

• Issues with package constants
  – Incorrect evaluation of package constants for gas mixtures when using iterators in expressions
  – Inefficient handling of package constants determined by functions (re-evaluated every time instead of just once)

• Medium-defined start attributes sometime lost in translation
  – Essential for reliable initialization of nonlinear solver
Basic building block #2: ExternalMedia

- Medium library interfacing Modelica models with external codes for fluid property computation
- Under development since 2007 using Dymola
- Relies on external functions (not external objects!)
- 100% compatible with Modelica.Media.Interfaces
- Used for thermodynamic cycles with evaporating fluids other than water
  - Refrigeration system
  - Heat pumps
  - Organic Rankine Cycle systems
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- 100% Coverage achieved in Windows and Linux!
  - FluidProp (TU Delft)
  - RefProp (US NIST)
  - CoolProp (Université Liege, open source!)
- Package constants are still not evaluated once and for all
Basic building block #3: ThermoPower

- Developed @ Politecnico since 2002, mainly using Dymola
- Dynamic modelling of power production systems based on thermodynamic processes
- Aimed at control system studies

- Progress since the 2014 Annual Meeting (testsuite logs)
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• Main open issues
  – Full support of CSE to avoid repeated function calls to heavy medium property functions
  – Convergence problems with nonlinear solver
  – Lost start attributes break initialization
  – Proper support of homotopy() strategic for reliable initialization of complex systems
Value of the testsuites for the OSMC

• Large and diverse collections of test cases are essential to develop a strong Modelica compiler

• The testsuite is one of the most valuable assets of the OSMC!

• Great job with automated testing

• One example: tuning the nonlinear solver
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More and more diversified libraries in the testsuite
More feedback for the developers
Automatically generated synthetic reports available @ each commit
APPLICATIONS OF OMC TO ENERGY SYSTEM STUDIES @ POLITECNICO DI MILANO
SIMULATION OF BOILERS
AND STEAM GENERATORS
Modelling of industrial boilers with Modelica / OMC
Requirements

• Use of Modelica for full customization to customer's needs

• Robust & dependable numerical back-end
  – Smooth initialization
  – Efficient and error-free simulation

• Low-cost simulation infrastructure
  – Open source OMC
  – Open source ThermoPower
  – Value-added customer library

• Complete and easy-to-use GUI
Status

- Two industrial projects (hopefully...) starting Q1 2015
- OMC already viable solution
- Improvements in back-end welcome
  - Full support of homotopy() for initialization
  - More efficient simulation
- Improvements in OMEdit welcome
  - Support of replaceable classes
  - Graphical editing of hierarchical models (nested modifiers)
- Industrial use-cases for OMC testing and advertising
POWER PLANT SIMULATION

POLITECNICO

Dynamica
Modelling, Optimization & Control

TU Delft
Power Plant Simulation
Requirements

• Efficient handling of large systems (200+ states) with heavy use of IF97 water medium

• Robust initialization: support of homotopy() is strategic

• Open source infrastructure strategic for attracting public funding

• Support of non-conventional media for the study of future concepts
  – Supercritical CO2 cycles
  – CO2-capture
  – Integration of thermal storage systems
Status

• Currently updating ThermoPower.PowerPlants to run in OMC
• Evaluation and profiling of OMC on full scale models soon possible
• H2020 PowerPlants 2020+ project under review
  – Flexible operation of present and future fossil-fired power plants
  – Coal-fired, combined-cycle, and future CO2 cycle concepts
  – Integration with thermal storage
  – Integrated, open-source modelling and simulation platform based on Modelica and open source tools (→ OMC!)
  – Passed stage 1 evaluation, stage 2 proposal now being prepared
INTEGRATED DESIGN & OPTIMIZATION OF ORC SYSTEMS
Modelica-based cycle and component design
Modelica-based dynamic simulation
Requirements

• Equation-based declarative modelling and design rules
• Modelica-based tool for integrated
  – Cycle design
  – Equipment design
  – Dynamic simulation
  – Design optimization (including dynamic behaviour!)
• Open-source infrastructure
  – No royalties, only added value
  – Better framework for public funding
• Very strong nonlinear solver
• Optimization capabilities
  – Derivative-free (via GenOpt)
  – Derivative-based (via Optimica, OMC/Jmodelica?)
• Easy access to exotic organic fluid models
Status

• Dynamic simulation
  – Small library based on ThermoPower available
  – Validated vs. experimental data
  – Works in Dymola

• Equation-based design
  – Prototype currently being developed and tested with Dymola
  – Derivative-free optimization with GenOpt (LLBL, USA)

• Testing with OMC will start next week
SIMULATION OF CRYOGENIC COOLING SYSTEMS FOR SUPERCONDUCTING MAGNETS IN TOKAMAKS
Modelling of SCM cooling systems
The 4C code

Mithrandir (Fortran code)

Cryogenics (Modelica code)
Validation of Cryogenics on the Helios experiment
Requirements

- Open-source infrastructure
- Closed-source competitors
  - Proprietary high-performance Russian Fortran codes
  - Object-Oriented models for EcoSimPro
- Flexible code generation from same model
  - Stand-alone, variable step-size simulators
  - Fixed-step size simulators for co-simulation
  - Widest choice of implicit integration algorithms
- Robust steady-state initialization of highly nonlinear models
  - Support of homotopy() strategic
- State of the art, Helium models
  - RefProp via FluidProp / ExternalMedia
  - Table-based interpolations of RefProp via CoolProp / ExternalMedia
  - 100% native RefProp implementation via HelmholtzMedia
- Extensible to also handle the cryogenic fluid generation circuit
Status

• Helium models via ExternalMedia now supported by OMC
• Helium models from HelmholtzMedia library now supported by OMC
• Simple components (pump, valve, helium bath) work fine
• FEM pipe models (from ThermoPower)
  – Back-end issues finally solved one week ago
  – Test results still doesn't match exactly the Dymola results
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- Aim at getting 100% coverage by end of February
- Potential Trojan horse to the world of nuclear fusion reactors
  - Full scale studies of cooling systems including cryoplant for ITER
  - Studies of the coupling between Tokamak and steam turbine (DEMO)
  - Access to EURATOM funding
Conclusions and Recommendations

• OpenModelica has vastly improved during 2014

• We can state that models of conventional and innovative energy systems can be handled by OpenModelica

• Feedback from the developers is very effective and very fast (often better than with commercial software)

• The availability of an open-source infrastructure is crucial for both commercial applications and publicly funded research
Conclusions and Recommendations

• Some key improvements are still necessary for satisfactory performance (and could be carried out within the year 2015)

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  – Avoid losing Media-set start attributes during flattening
  – Fix remaining issues with medium package constants
  – Faster compilation of models using Modelica.Media
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  – Full homotopy() support, including structural simplifications at $\lambda = 0$
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• OMEdit (with help from Front-end)
  – Support of replaceable classes
  – Hierarchical editing of models (nested modifiers)
  – Comment- and formatting-preserving parsing and saving
Thank you for your support!

Adeel Asghar
Willi Braun
Lennart Ochel
Per Östlund
Adrian Pop
Vitalij Ruge
Martin Sjölund
Volker Waurich

Bernhard Bachmann
Peter Fritzson
Thank you for your kind attention!