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Introduction to MODELICA

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April 10th, 2012

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SIMUREX 2012

Cargèse, France - April 10-14, 2012

Overview

- Modelica – where to get Information
- Main features
- Building Modelica models
- Some programming details
- Structuring – reuse

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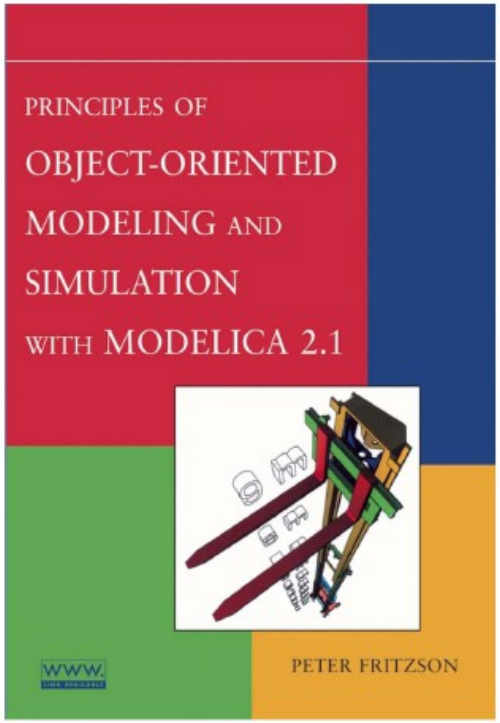
More information...

- Modelica Association: www.modelica.org
- OpenModelica: www.openmodelica.org
- “The” book:
  - Peter Fritzson,
    Principles of Object Oriented
    Modeling and Simulation
    with Modelica 2.1,
    Wiley-IEEE Press, 2004



Credits for this tutorial – Thanks to ...

- A lot of very good, detailed, topic specific tutorials are available, see: http://modelica.org/

- Among them:
  - Peter Fritzson, *Introduction to Object-Oriented Modeling and Simulation with OpenModelica*, (2006)
  - Mohsen Torabzadeh-Tari (Linköping University), *Introduction to Object-Oriented Modeling, Simulation and Control with Modelica*, (May 2011).
  - Martin Otter (DLR-RM and Chairman of Modelica Association), *Modelica Overview*, 2009
  - Sébastien FURIC, R&D Engineer, LMS (INSA Lyon, 2007)

Modelica - status

- Free, open language
- Specification available at: www.modelica.org
- Developed since 1997 (1.0), V 3.2 released March 2010
- Modelica Association established 2000 in Linköping
  Open, non-profit organization
  Industry and Academia

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Modelica – main goals

- Modeling the dynamic behavior of technical systems consisting of components from, e.g., mechanical, electrical, thermal, hydraulic, pneumatic, fluid, control and other domains in a convenient way.
- Models are described by differential, algebraic, and discrete equations.
- No description by partial differential equations, i.e., no FEM (finite element method) and no CFD (computational fluid dynamics), but using results of, e.g., FEM programs.

Modelica – main features (1)

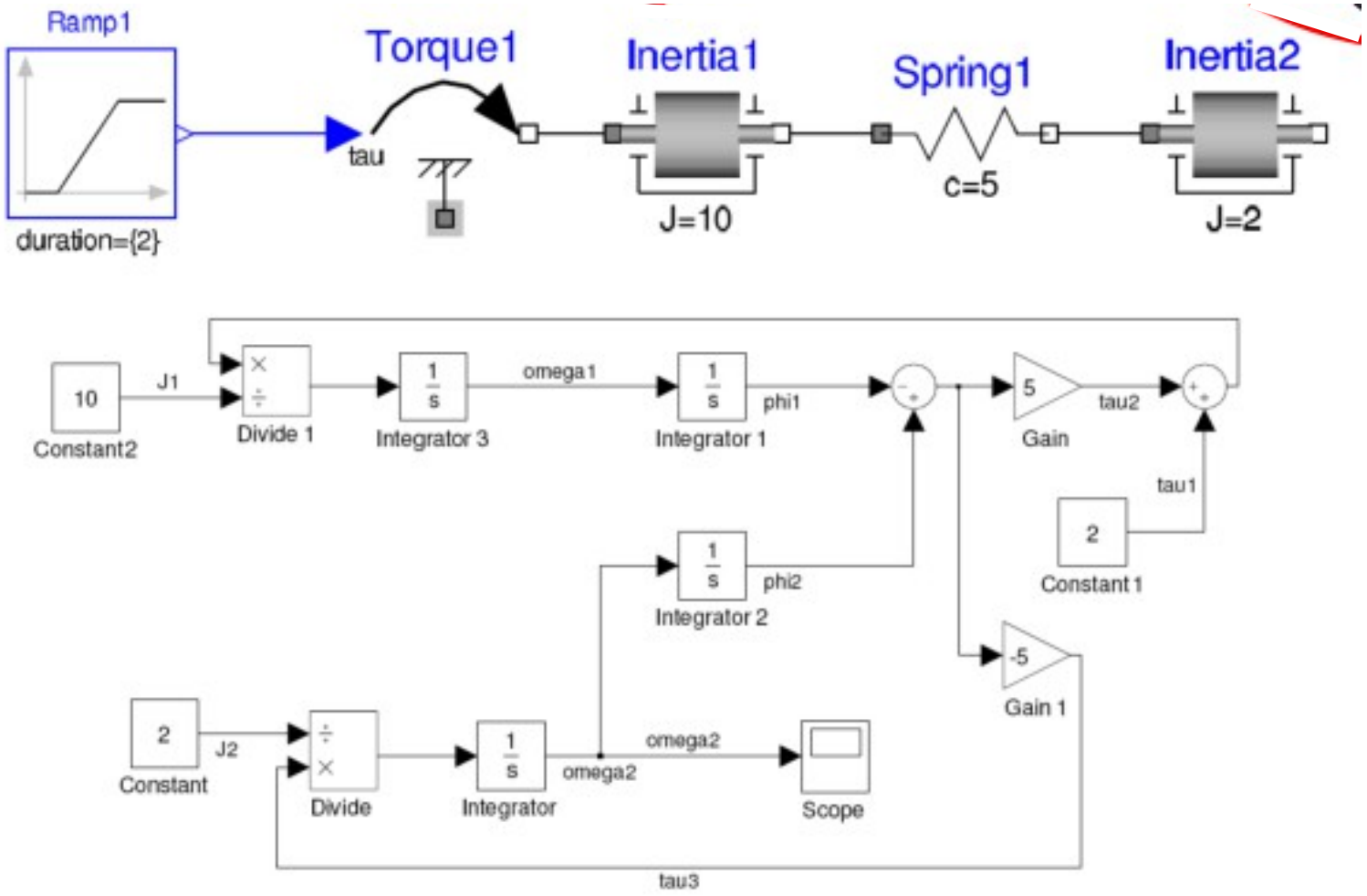
- Declarative language (acausal)
  - Equations and mathematical functions allow acausal modelling (high level specification, increased correctness)
- A single modelling framework
- Multi-domain modeling
  - electrical, mechanical, thermodynamic, hydraulic, biological, control, event, real-time, etc... domains
- Hybrid modeling: continuous-time + discrete-time
- Modular programming! Components; connections
  - Hierarchical system architecture capabilities

Modelica – main features (2)

- Several basic constructs (model, block, record, …) but technically,
- Everything is a class *(warning : not a OO language!)*
  - Strongly typed object-oriented language with a general class concept, Java & MATLAB-like syntax
- Efficient, non-proprietary
  - Efficiency comparable to C; advanced equation compilation,
  - e.g. 300 000 equations, ~150 000 lines on standard PC
- Several environments for Visual component programming

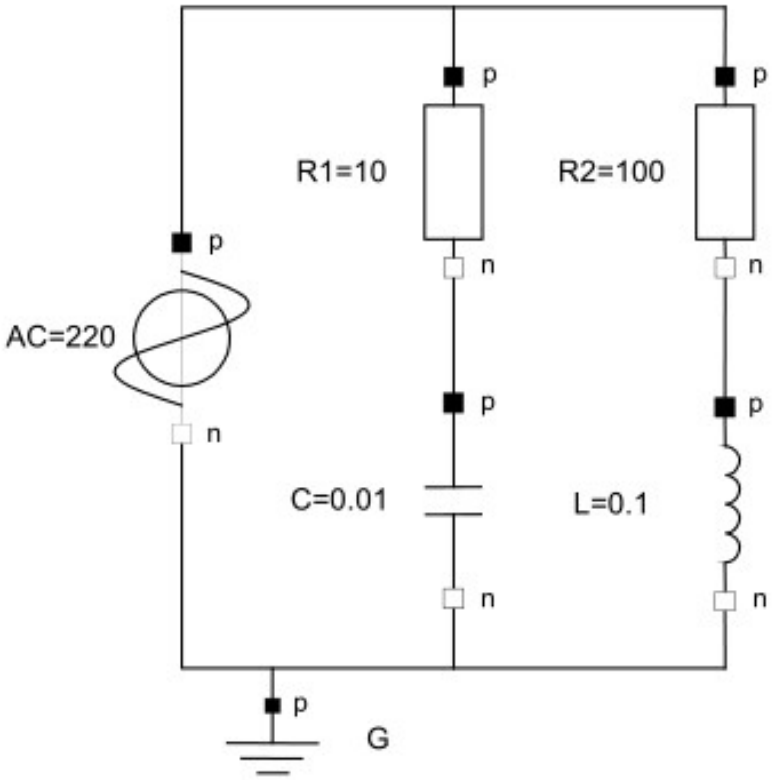
Acausal versus causal modeling

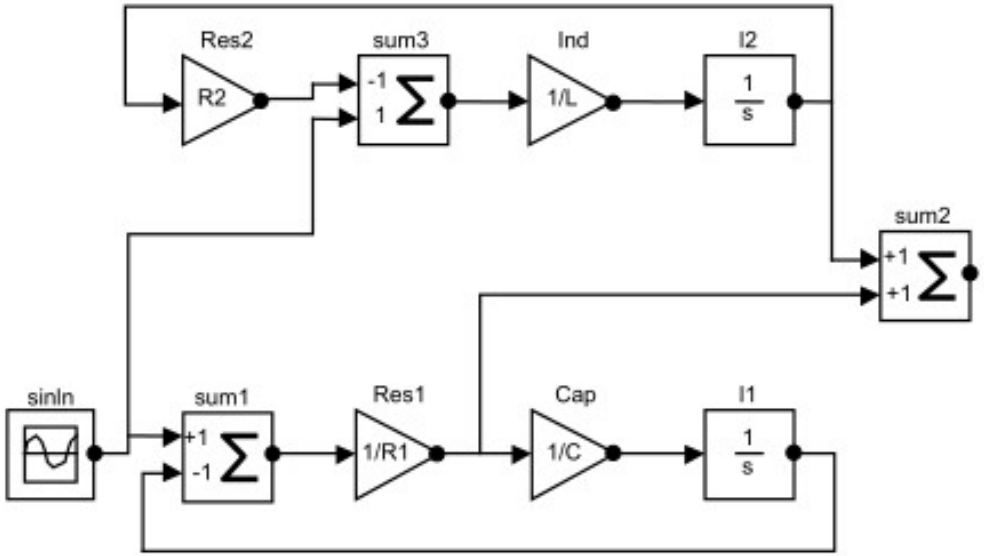
- Acausal model (Modelica)



- Causal block-based model (Simulink)

Modelica vs Simulink Block Oriented Modeling





- Modelica: Physical system Simulink: Signal-flow model

Equations versus assignment

- Equation clauses are not sequences of statements! (in particular, there is no notion of assignment, nor evaluation order)
- It is however possible to describe how to compute a result by means of sequences of assignments, loops, etc. in Modelica, but not using equations!

semantics

- The semantics of the Modelica language is specified by means of a set of rules for translating any class described in the Modelica language to a flat Modelica structure. A class must have additional properties in order that its flat Modelica structure can be further transformed into a set of differential, algebraic and discrete equations (= flat hybrid DAE). Such classes are called simulation models.

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Assembling models

- To get a model of a system:
  - Pick Basic (or complex!) (sub)models
  - Connect these models
- The DAE is derivated from the sub-models and from the equations defined by the connections

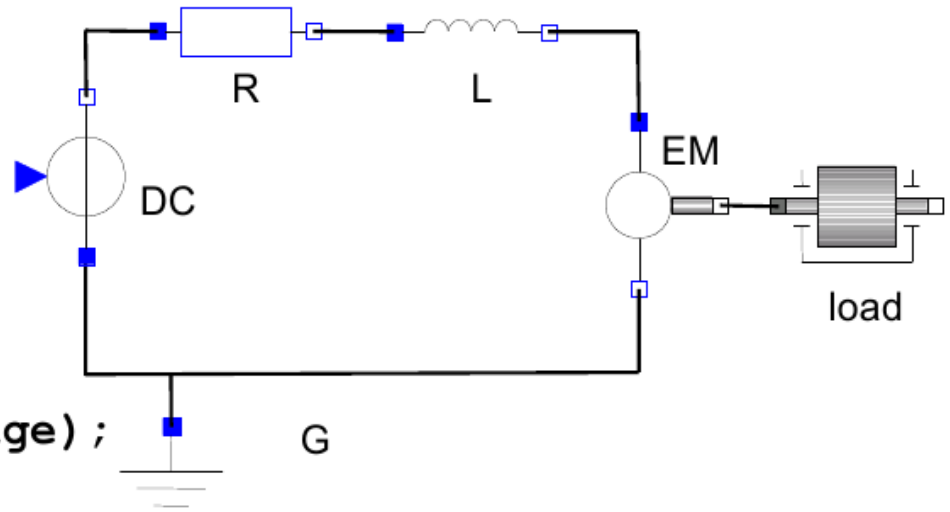
Several elementary constructs

- Model: elementary model or assembly of such models
- Block: construct with defined causality (inputs / outputs)
- Record: data only
- Connector: to define interactions between models
- Function: to define specific computations, behaviors

A DC motor model

- A DC motor can be thought of as an electrical circuit which also contains an electromechanical component (Mohsen Torabzadeh-Tari)

```
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
```



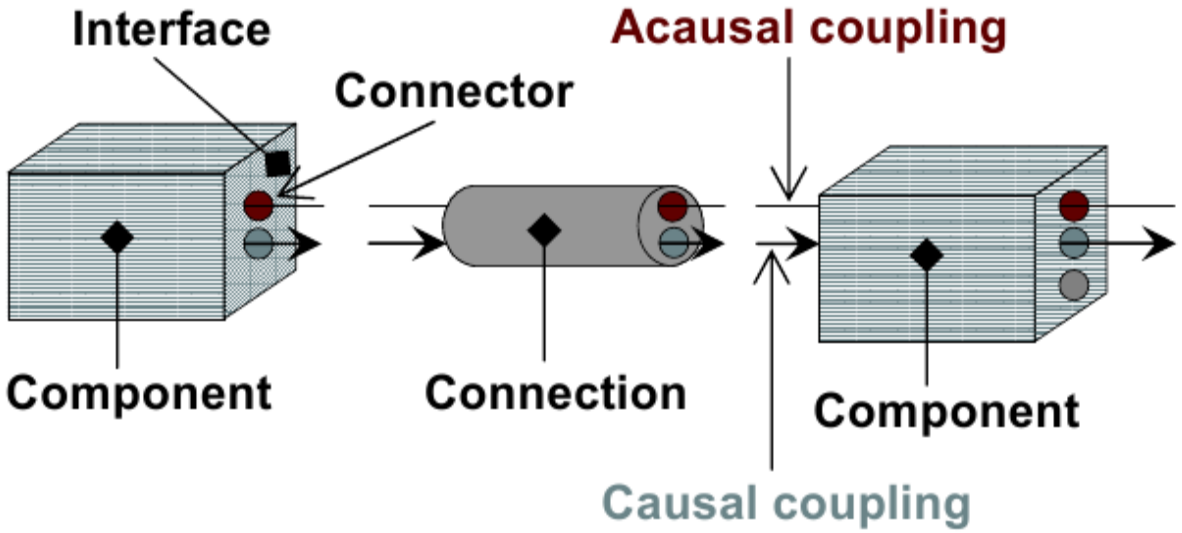
Derived system of equations

```
0 == DC.p.i + R.n.i
DC.p.v == R.n.v

0 == R.p.i + L.n.i
R.p.v == L.n.v

0 == L.p.i + EM.n.i
L.p.v == EM.n.v

0 == EM.p.i + DC.n.i
EM.p.v == DC.n.v

0 == DC.n.i + G.p.i
DC.n.v == G.p.v

EM.u == EM.p.v - EM.n.v
0 == EM.p.i + EM.n.i
EM.i == EM.p.i
EM.u == EM.k * EM.ω
EM.i == EM.M / EM.k
EM.J * EM.ω == EM.M - EM.b * EM.ω

DC.u == DC.p.v - DC.n.v
0 == DC.p.i + DC.n.i
DC.i == DC.p.i
DC.u == DC.Amp * Sin[2 π DC.f * t]

R.u == R.p.v - R.n.v
0 == R.p.i + R.n.i
R.i == R.p.i
R.u == R.R * R.i

L.u == L.p.v - L.n.v
0 == L.p.i + L.n.i
L.i == L.p.i
L.u == L.L * L.i'
```

(`load` component not included)

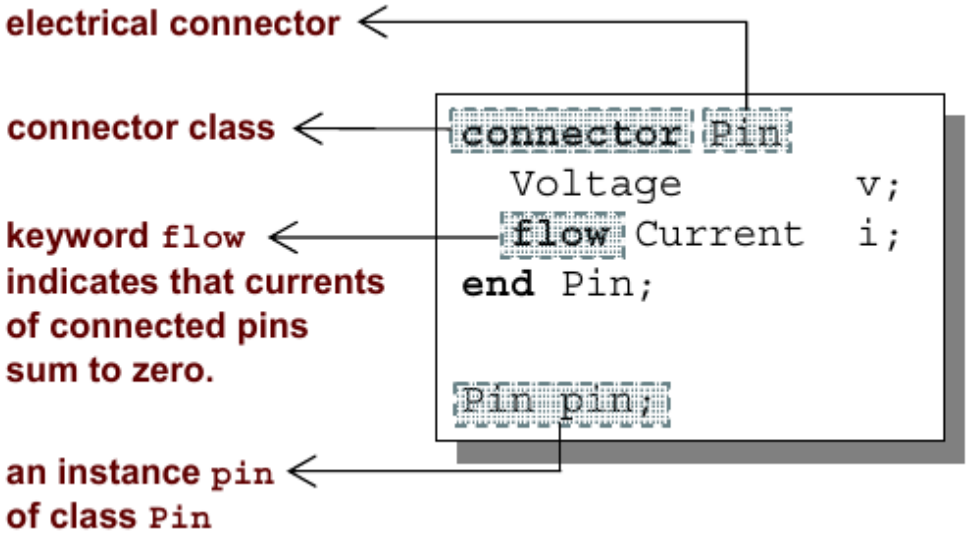
- Automatically derived by a Modelica tool for simulation

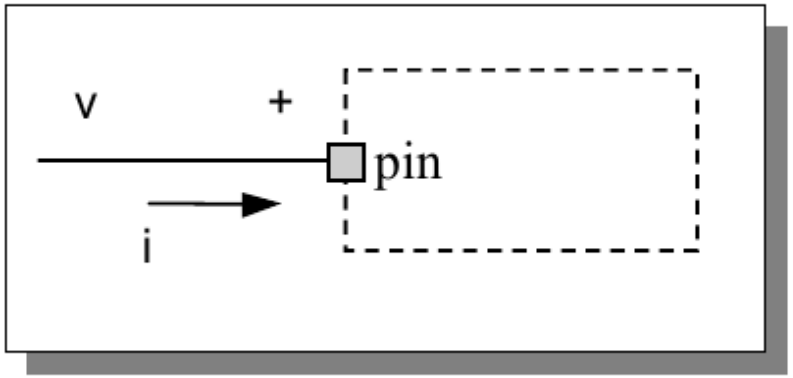
Connectors



- Connect(A.x, B.y):
  - Acausal coupling: x = y
  - Causal coupling: x and y are declared **`flow`**: A.x + B.y = 0

Connector classes





- Connectors are specific classes with two kinds of variables:
  - Standard: potential or energy level => Equality
  - Flow: some kind of flow => Sum to zero

Domain	Potential	Flow	Carrier	Modelica Lib.
Hydraulic	Pressure	Volume flow	Volume	HyLibLight
Heat	Temp.	Heat Flow	Heat	HeatFlowID

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Algorithms

- Sequence of statements
- Classical programming constructs:
  - Assignments
  - If – then - elseif – else
  - Loops : for, while
- Event driven statements (see “events”):
  - When

Event based modeling

- Events are distinguished time instants
- Time instants defined through:
  - Explicit time
  - Change of variable value : False to True or change of boolean: (x >= 2.4) (**`edge`**, **`change`**)
- **`Initial`** and **`terminal`** events
- Repeated events (**`sample`**)
- Event based behavior:

  `when cond then equation end when`

Functions (1)

- Definition of a function:
  - Eventually, some structural parameters used to denote array dimensions
  - Formal parameters
  - Eventually, some internal variables
  - Executable statements (or call to foreign function, written in C for instance)
  - Executable statements include assignments, "while" loops, "for" loops and return

```
function myFunction
   input Real u1, u2;
   output Real y1, y2;
protected
   Real x1, x2;
algorithm
   x1 := u1 + u2;
   x2 := u1 - u2;
   y1 := x1 * x2;
   y2 := x1 / x2;
end myFunction;
```

Functions (2)

- Declarative Mathematical semantics: always returns the same result given the same input argument values
- Positional and named arguments
- Multiple results
- External functions (C or FORTRAN code)

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Managing complex systems modeling

- Models: Composition and Hierarchy
- Packages: set of Modelica entities
- Libraries: structured sets of packages
- REUSE !

Packages

- A package is
  - A name space (model definition, programming)
  - A hierarchical set of Modelica classes and constant components
- Packages may be stored:
  - As nested Modelica classes, in a single file
  - In the host file system, as a tree of directories and files

Libraries

- A library is a hierarchy of packages, structured by the application domain or by the provided programming or technical functionalities

- A library usually provides several subpackages containing:
  - The public types used in the library
  - Eventually, some useful functions
  - The connectors used to build classes
  - Interfaces of classes
  - Instantiable classes
  - Some test models

And now ..

- Modelica – where to get Information
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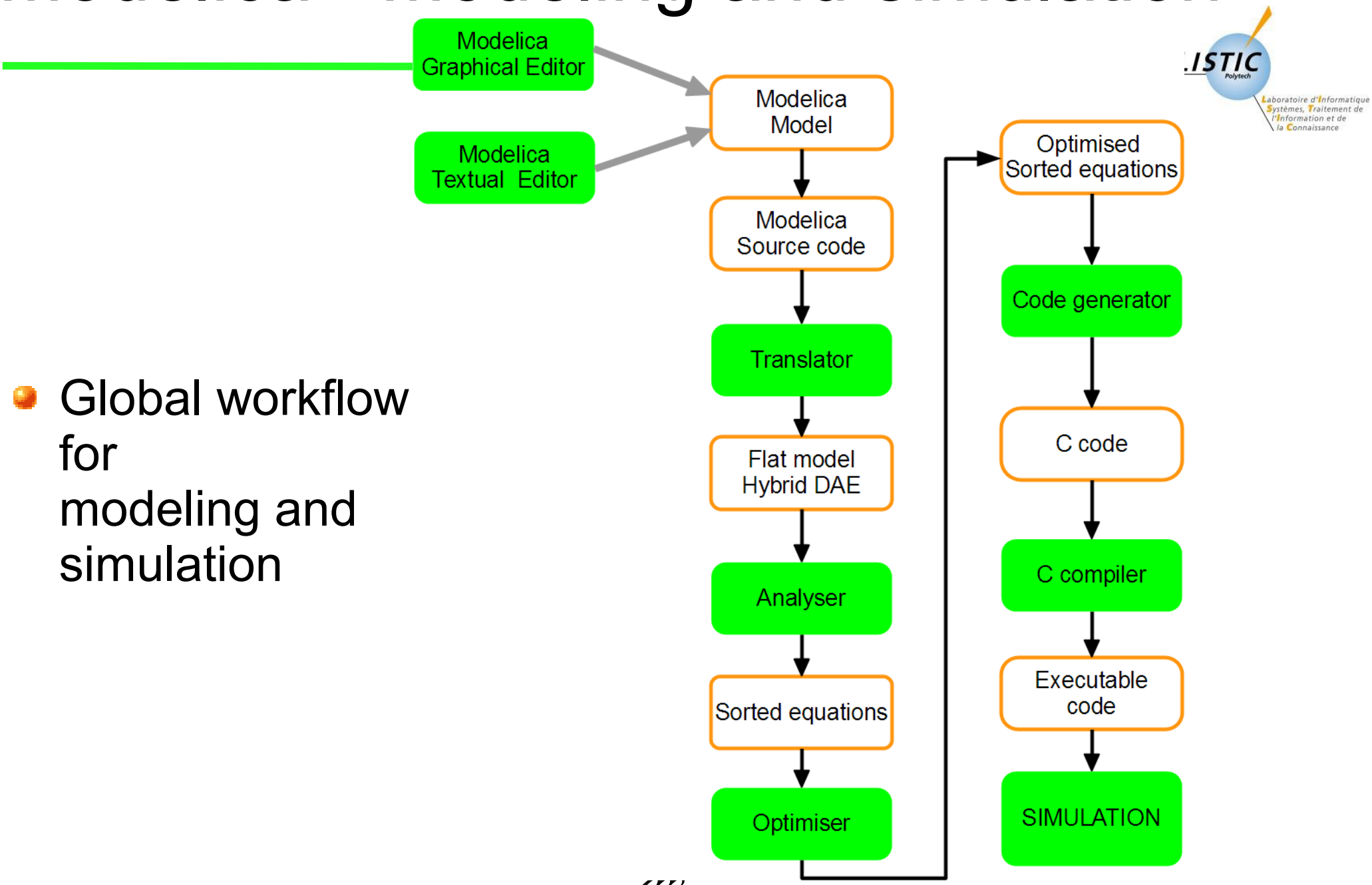
- Run the simulation !!!

Modelica - Modeling and simulation

- Global workflow for modeling and simulation



Free and commercial Modelica tools

- Usually provide Modeling AND simulations facilities
- Should provide tool-independent models
- Open source:
  - OpenModelica from OSMC
- Commercial
  - MathModelica by MathCore
  - Dymola by Dassault systems / Dynasim
  - SimulationX by ITI
  - MapleSim by MapleSoft
- ...

Thank you

Enjoy modeling/simulation with Modelica !

Questions ?