# Modelica Overview

by Martin Otter

Abstract:
This slide set gives an overview about the Modelica language, including users view, libraries and a sketch of the language elements.

**Revisions:**

| | |
|---|---|
| 2009-07-17 | Martin Otter (DLR-RM and Chairman of Modelica Association):<br>First version, based on material from courses given at Technical University of Munich. |
| 2013-08-28 | Dietmar Winkler( Telemark University College)<br>Updated information on MSL and MA |
| | |
| | |

# Contents

1. Modelica Introduction
2. Modelica Users View
3. Modelica Libraries
4. Modelica Language Elements

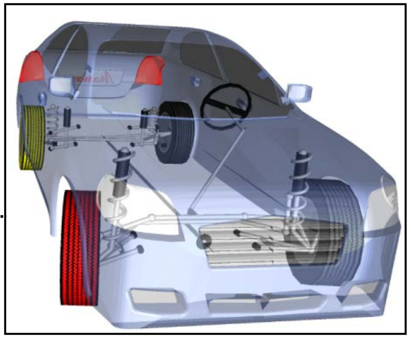
# 1. Modelica Introduction

Goal of **Modelica**:

- 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 is used in industry since year 2000.

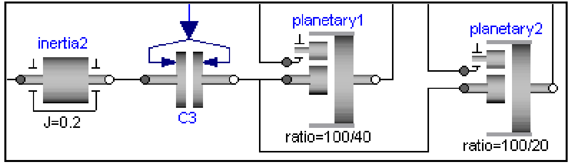
# Example: **detailed vehicle model**

- **Vehicle dynamics** (3-dim. mechanics)

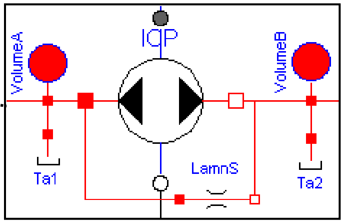


courtesy: Modelon AB

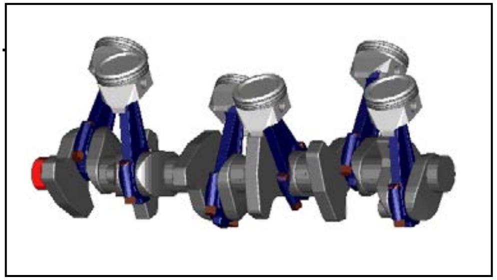
- **Drive trains** (1-dim. mechanics)



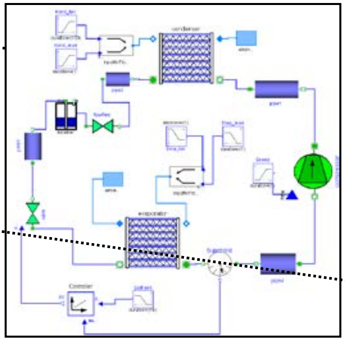
- **Hydraulics**



- **Combustion**

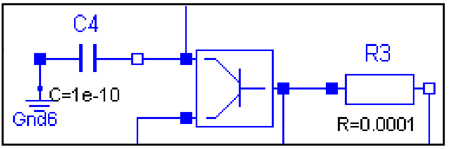


- **Air Conditioning** (Thermofluid systems)

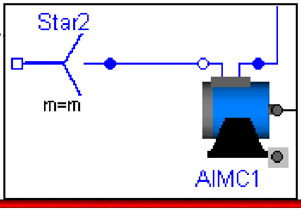


courtesy Modelon AB

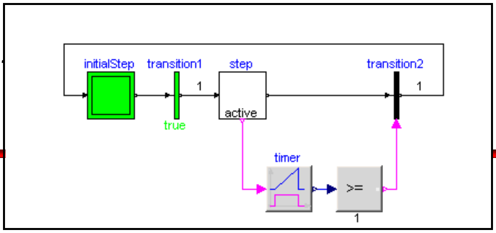
- **Electrical/electronic systems**



- **Electrical machines**



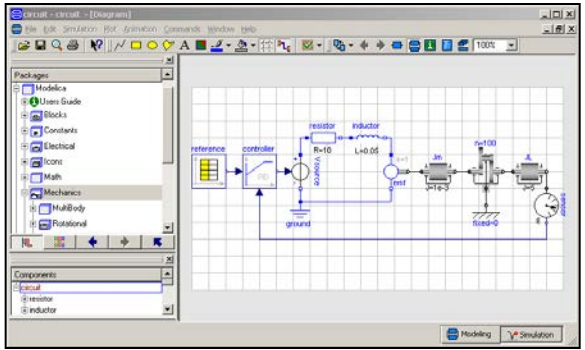
- **Hierarchical state machines**



- **Control** (Input/output blocks, ...)

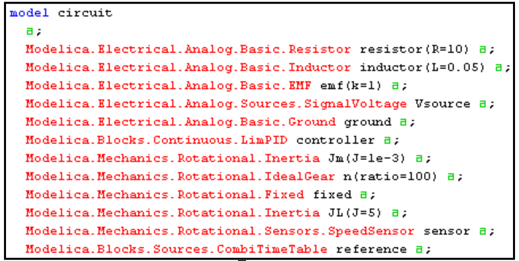
# Modelica Language und Simulation-Environments

**Graphical editor**
for Modelica models



Modelica simulation
environment
(free or commercial)

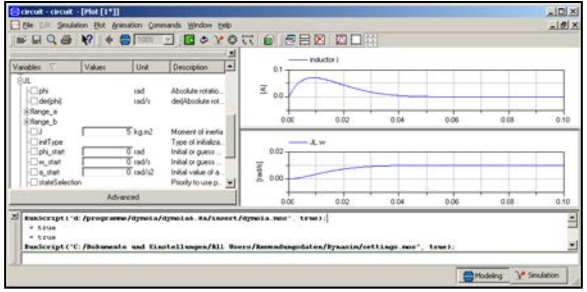
**Textual description**
on file (equations,
"schematic", animation)



```
model circuit
  a;
  Modelica.Electrical.Analog.Basic.Resistor resistor(R=10) a;
  Modelica.Electrical.Analog.Basic.Inductor inductor(L=0.05) a;
  Modelica.Electrical.Analog.Basic.EMF emf(k=1) a;
  Modelica.Electrical.Analog.Sources.SignalVoltage Vsource a;
  Modelica.Electrical.Analog.Basic.Ground ground a;
  Modelica.Blocks.Continuous.LimPID controller a;
  Modelica.Mechanics.Rotational.Inertia Jm(J=1e-3) a;
  Modelica.Mechanics.Rotational.IdealGear n(ratio=100) a;
  Modelica.Mechanics.Rotational.Fixed fixed a;
  Modelica.Mechanics.Rotational.Inertia JL(J=5) a;
  Modelica.Mechanics.Rotational.Sensors.SpeedSensor sensor a;
  Modelica.Blocks.Sources.CombiTimeTable reference a;
```

Free Modelica language

**Translation** of Modelica
models in C-Code,
**Simulation**, and
interactive **scripting**
(plot, freq. resp., ...)



```
RunScript("d:/programme/dymola/dymola4.8a/insert/dymola.mos", true);
 = true
 = true
RunScript("C:/Dokumente und Einstellungen/All Users/Anwendungsdaten/Dynasim/settings.mos", true);
```

Modelica Simulation-
environment
(free or commercial)

## Commercial Modelica Simulation Environments (alphabetical list)

- **CATIA Systems** from Dassault Systèmes
(based on Dymola kernel with PLM integration)
- **CyModelica** from CyDesign
- **Dymola** from Dynasim AB, Sweden
(Dynasim was acquired by Dassault Systèmes in 2006).
- **LMS Imagine.Lab AMESim** from LMS International
- **MapleSim** from MapleSoft, Canada.
- **MathModelica** from Wolfram Research, Sweden.
- **SimulationX** from ITI GmbH, Dresden, Germany.

## Free Modelica Simulation Environments (alphabetical list)

- **JModelica.org** from Lund University and Modelon AB, Sweden
(under development; subset of Modelica is available).
- **OpenModelica** from Linköping University, Sweden
(under development; subset of Modelica is available)

An up-to-date list of Modelica tools is available from www.modelica.org/tools

# Modelica Association

- **Modelica** is a **free language** and is developed by the (non-profit) Modelica Association since 1996:

  2000: First applications

  ...

  2005: **Modelica 2.2**

  2007: **Modelica 3.0**

  ...

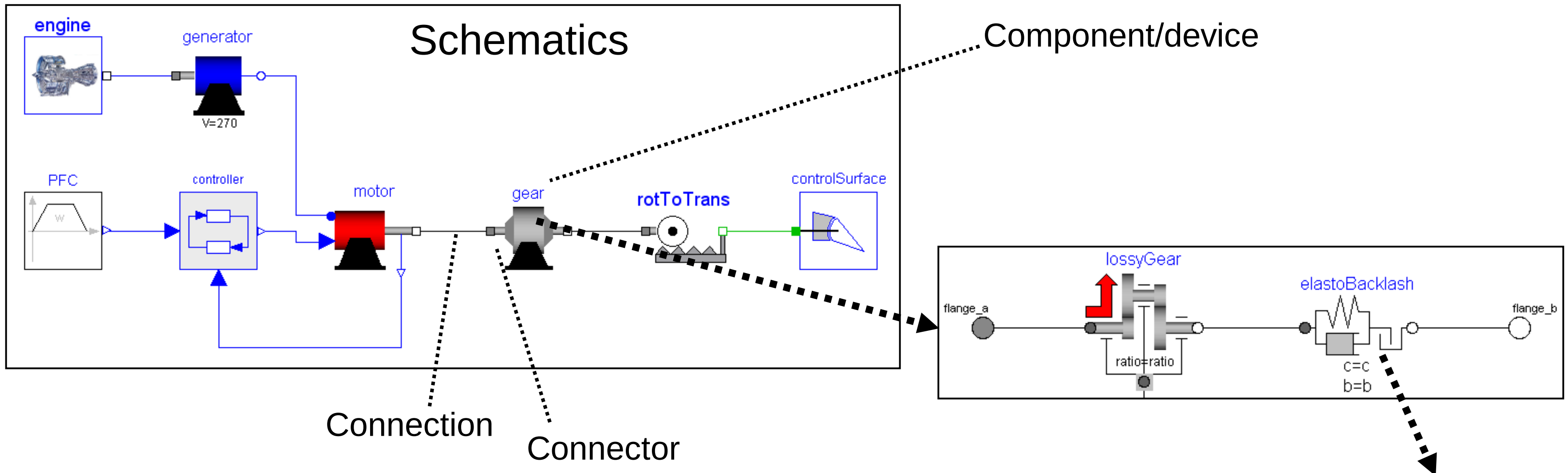
  2012: **Modelica 3.3** (current)

MODELICA
3.2
Language Version 3.2 Released
Hamburg - Harburg, March 24th, 2010

66th Design Meeting in Hamburg, March 2010
(after release of Modelica 3.2)

- Develops also the largest, free library for multi-domain models (**Modelica Standard Library**)
- 112 "individual" and 16 "organizational members"
  (interested in "active" individual members; Therefore requirement: participation at 2 Modelica Design Meetings in the last 12 months).
- 9 International Modelica Conferences (Modelica'2012 with 400 participants)
- All infos under **http://www.modelica.org**
  (Specification, simulation environments, free libraries, 400 papers, ...)

# 2. Modelica Users View

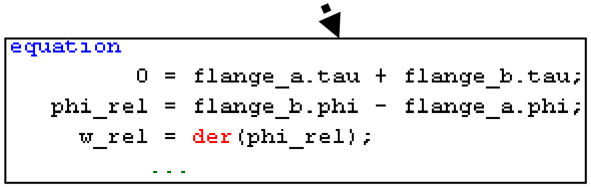


Schematics

Component/device

Connection

Connector



```
equation
      0 = flange_a.tau + flange_b.tau;
  phi_rel = flange_b.phi - flange_a.phi;
    w_rel = der(phi_rel);
         ...
```

- Each **Icon** represents a **physical component**.
  (electrical resistance, mechanical device, pump, ...)

- A **connection line** represents the actual physical

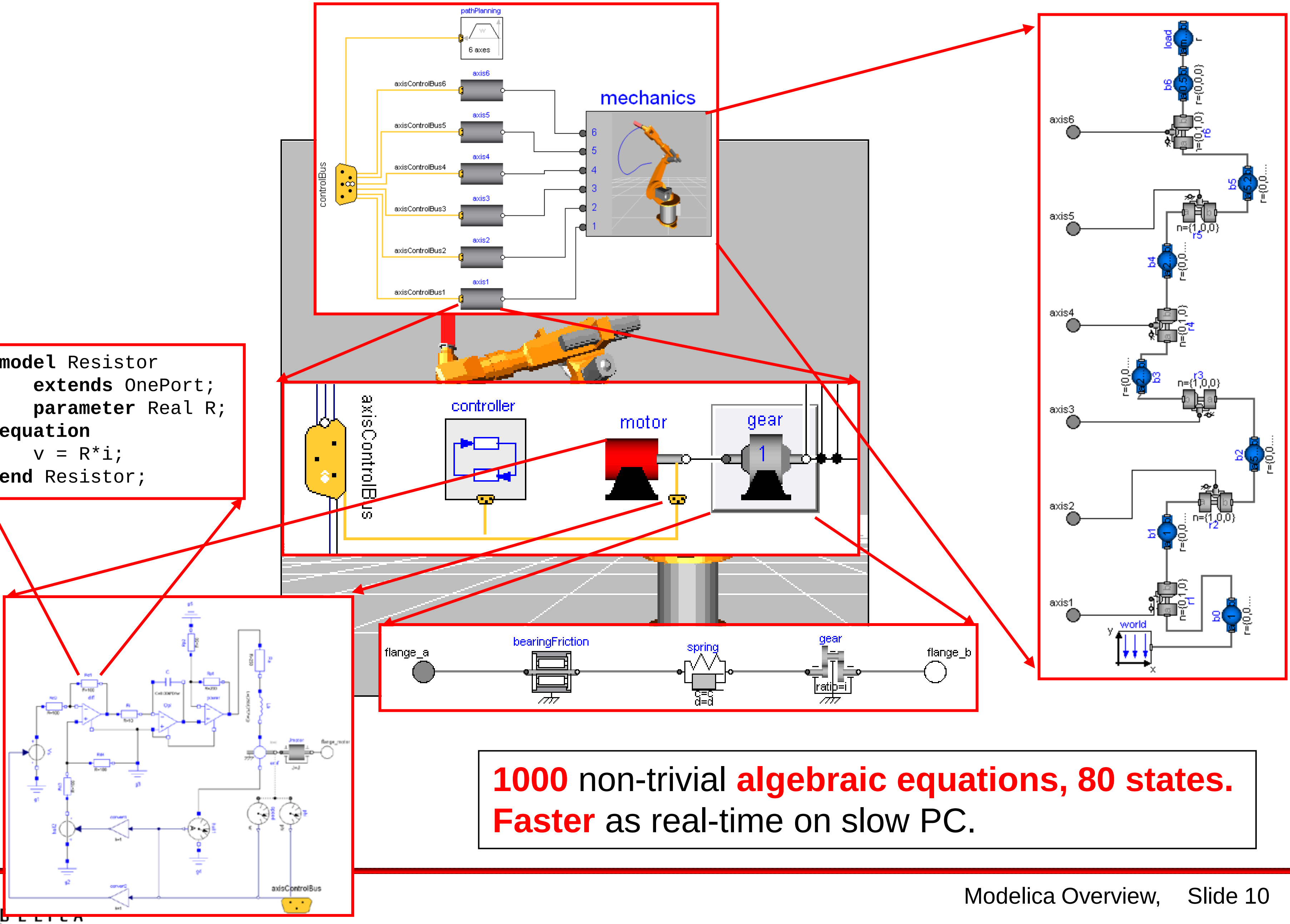
  **coupling** (wire, fluid flow, heat flow, ...)

- A component consists of **connected** sub-components
  (= hierarchical structure) and/or is described by **equations**.

- By **symbolic** algorithms, the high level Modelica description $0 = \mathbf{f}(\dot{\mathbf{x}}(t), \mathbf{x}(t), \mathbf{y}(t), t)$
  is transformed into a set of explicit differential equations: $\dot{\mathbf{x}}(t) = \mathbf{f}(\mathbf{x}(t), t)$

$$\mathbf{y}(t) = \mathbf{f}(\mathbf{x}(t), t)$$

# Example: Industrial Robots (from Modelica.Mechanics.MultiBody.Examples.Systems.RobotR3.fullRobot)



```
model Resistor
   extends OnePort;
   parameter Real R;
equation
   v = R*i;
end Resistor;
```

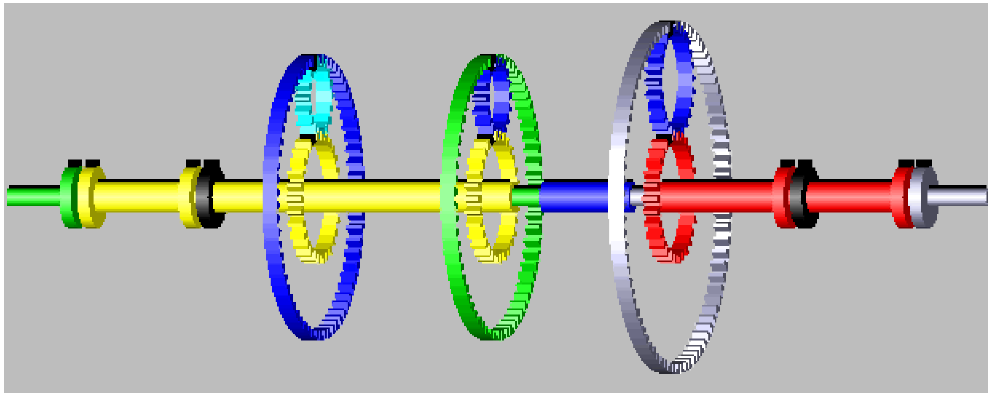
**1000** non-trivial **algebraic equations, 80 states.**
**Faster** as real-time on slow PC.

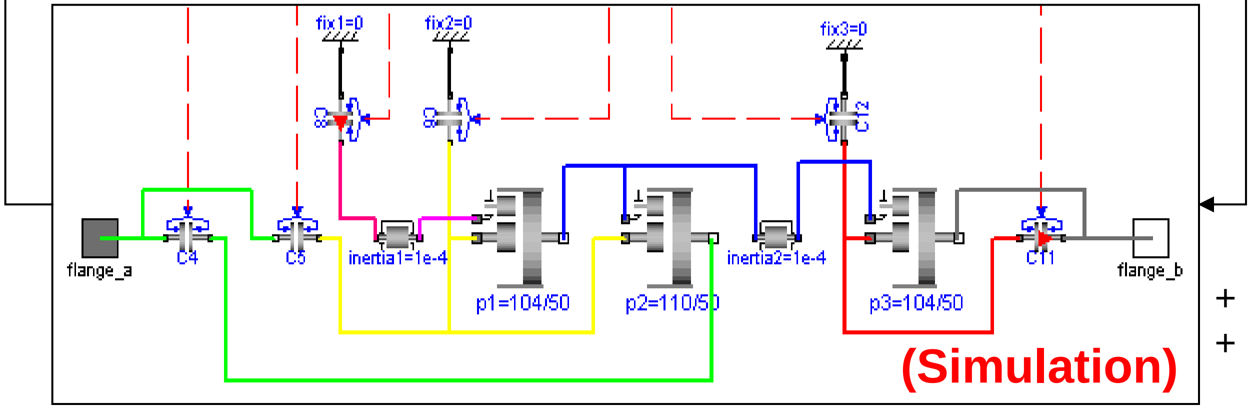
# Example: Hardware-in-the-Loop Simulation of automatic gear boxes

(different vehicle manufacturers)

desired pressure

Electronic Control Unit
**(Hardware)**

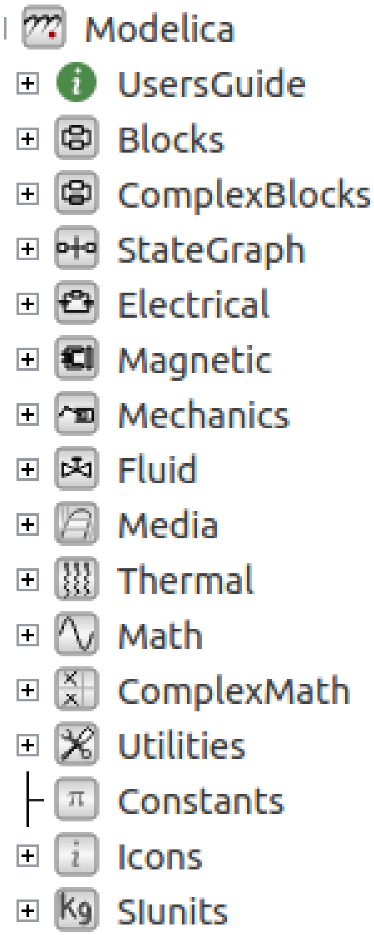




**(Simulation)**

+ driver + engine
+ 1D vehicle dynamics

# 3. Modelica Libraries



Modelica
- UsersGuide
- Blocks
- ComplexBlocks
- StateGraph
- Electrical
- Magnetic
- Mechanics
- Fluid
- Media
- Thermal
- Math
- ComplexMath
- Utilities
- Constants
- Icons
- SIunits

Library „**Modelica**“ is the

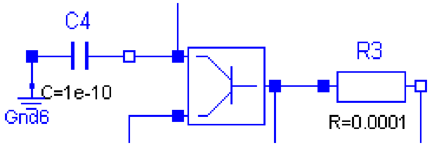
Modelica Standard Library

which is developed from the Modelica Association.
It is freely available in source code and
can be modified and used in commercial programs.

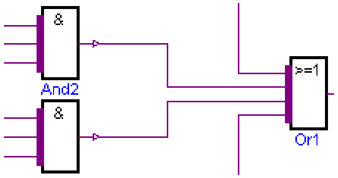
Continuous development since 1998.
Newest version 3.2.1 from August 2013:

1340 generic models
1000 functions
1450 packages (mostly media definitions)

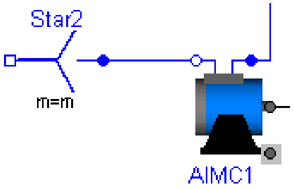
# Library Modelica: Electrical and Thermal Libraries



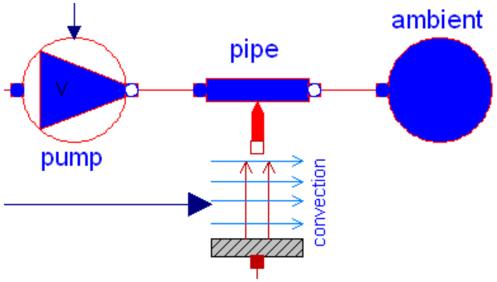
**Analog electric** and electronic components, such as resistor, capacitor, transformers, diodes, transistors, transmission lines, switches, sources, sensors.



**Digital electrical** components based on the VHDL standard, like basic logic blocks with 9-valued logic, delays, gates, sources, converters between 2-, 3-, 4-, and 9-valued logic.



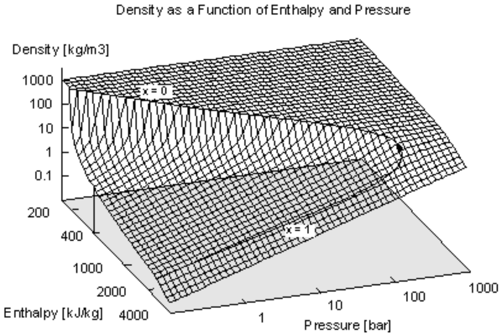
**Electrical machines**
(uncontrolled asynchronous-, synchronous-, DC-machines)



**Simple thermo-fluid pipe flow**, especially to model cooling of machines with air or water (pipes, pumps, valves, ambient, sensors, sources) and

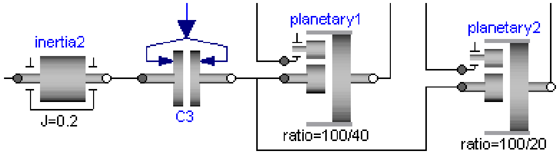
**lumped heat transfer** with heat capacitors, thermal conductors, convection, body radiation, sources and sensors.

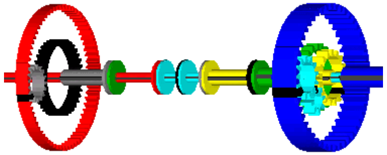
# Library Modelica: Media and Mechanical Libraries



density as function of pressure and enthalpy for water

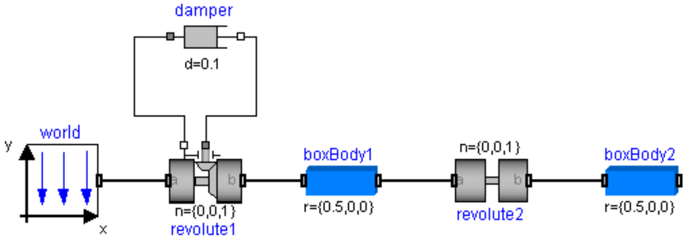
**Large media library** with
- 1240 gases and mixtures between these gases.
- table based media (h = h(T), etc.)
- high precision model for water (IF97)
- moist air.

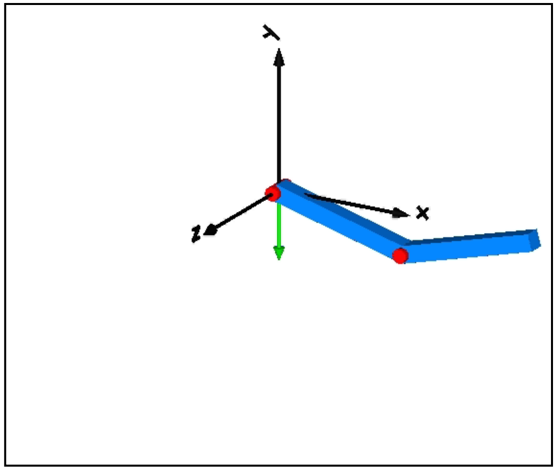


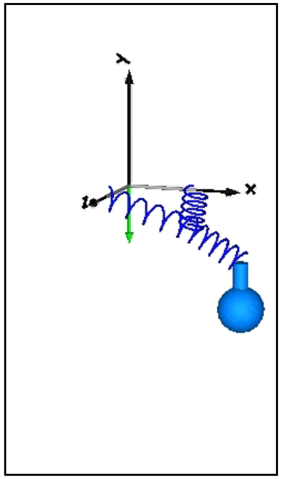


**1-dim. mechanical systems**, e.g., drive trains, planetary gears, convenient definition of speed/torque dependent friction (clutches, brakes, bearings, ..)

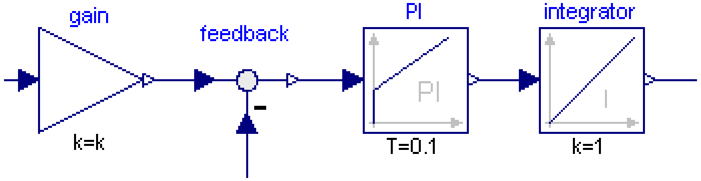
**3-dim. mechanical systems** consisting of joints, bodies, force and sensor elements. Joints can be driven by drive trains defined by 1-dim. mechanical system library.



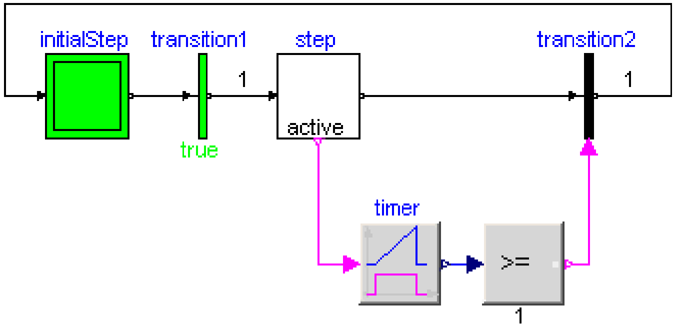




# Library Modelica: Control and Script Libraries



**Continuous** and **discrete input/output blocks**, e.g., PI, PID, transfer function, state space, filter, logical, non-linear, routing, table source blocks



**Hierarchical state machines** with same modeling power as Statecharts. Modelica is used as synchronous action language, i.e. deterministic behavior is guaranteed (not the case for Statecharts)

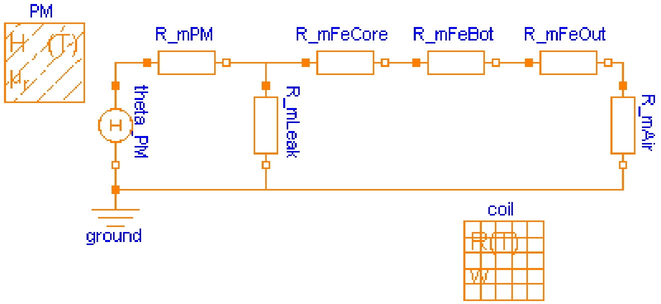
**Logical blocks** such as "and, or, edge, timer, ", ...

```
A = [1,2,3;
       3,4,5;
       2,1,4];
b = {10,22,12};
x = Matrices.solve(A,b);
Matrices.eigenValues(A);
```

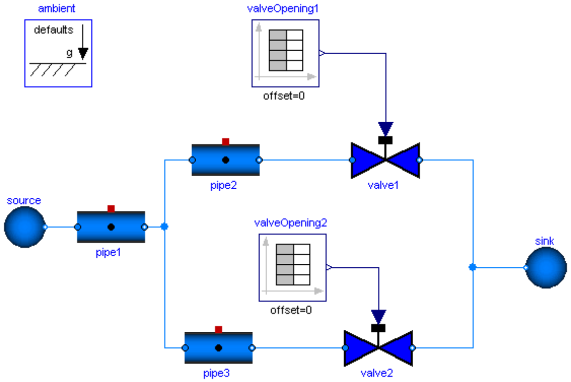
**Functions** on **matrices**, such as for solving linear systems, eigen and singular values etc.,

and **functions** operating on strings, streams, files, e.g., to copy and remove a file or sort a vector of strings.

# Library Modelica: Sublibraries that were added in 3.1



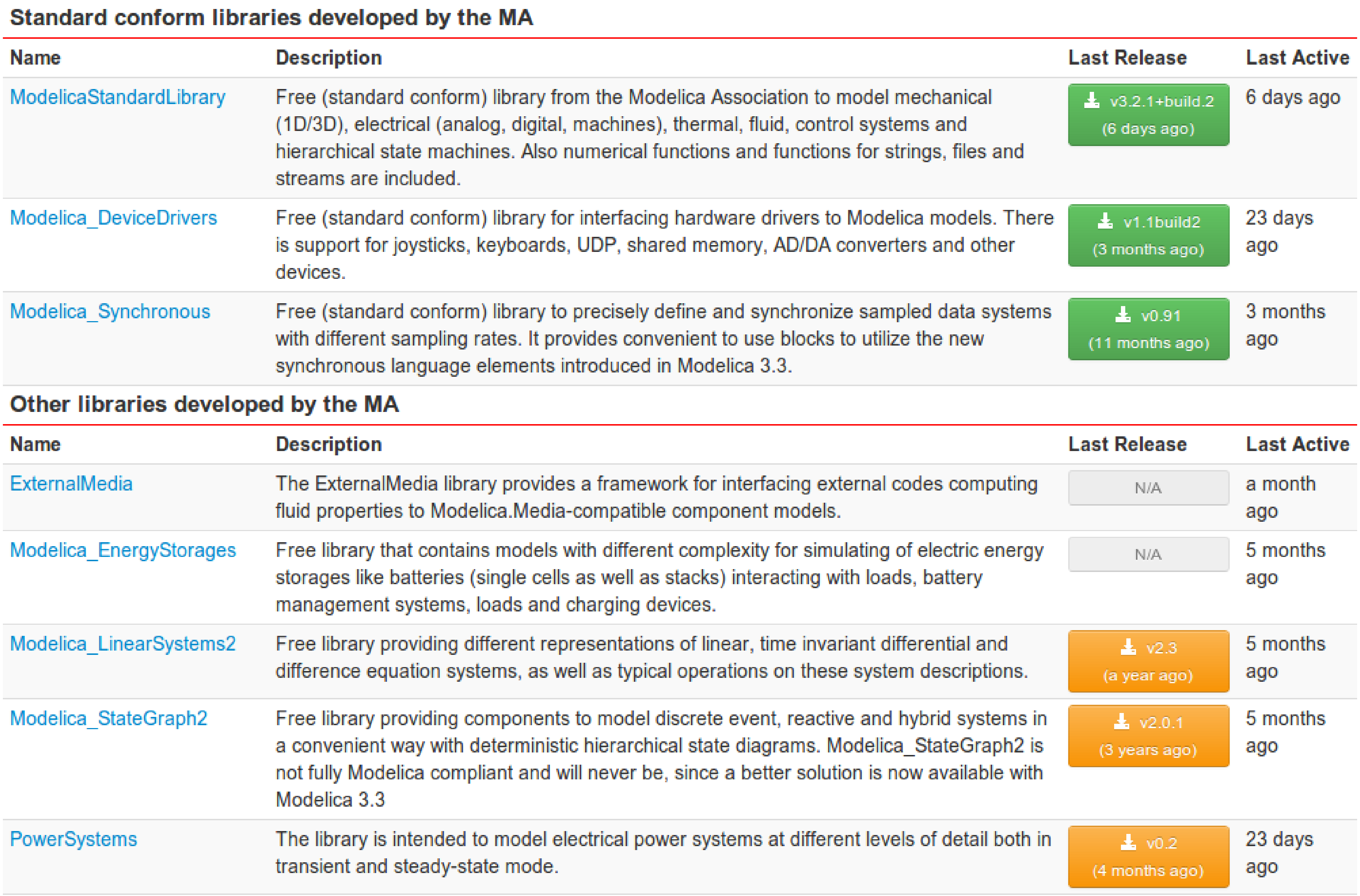
**Electro-magnetic** devices with lumped magnetic networks. E.g. flux tubes, magnetic sources and sensors, magnetic materials.



General library for **fluid pipe flow** for all media of Modelica.Media

- **one** and **multiple substances**
- **one** and **multiple** (homogenous) **phases**
- **incompressible** and **compressible**

# More free libraries under www.Modelica.org/libraries



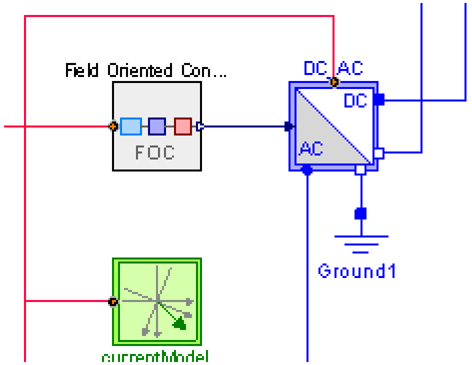
## Standard conform libraries developed by the MA

| Name | Description | Last Release | Last Active |
|---|---|---|---|
| ModelicaStandardLibrary | Free (standard conform) library from the Modelica Association to model mechanical (1D/3D), electrical (analog, digital, machines), thermal, fluid, control systems and hierarchical state machines. Also numerical functions and functions for strings, files and streams are included. | v3.2.1+build.2<br>(6 days ago) | 6 days ago |
| Modelica_DeviceDrivers | Free (standard conform) library for interfacing hardware drivers to Modelica models. There is support for joysticks, keyboards, UDP, shared memory, AD/DA converters and other devices. | v1.1build2<br>(3 months ago) | 23 days ago |
| Modelica_Synchronous | Free (standard conform) library to precisely define and synchronize sampled data systems with different sampling rates. It provides convenient to use blocks to utilize the new synchronous language elements introduced in Modelica 3.3. | v0.91<br>(11 months ago) | 3 months ago |

## Other libraries developed by the MA

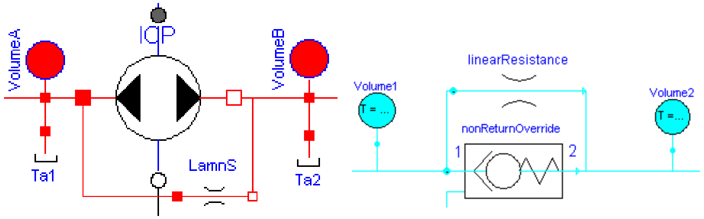
| Name | Description | Last Release | Last Active |
|---|---|---|---|
| ExternalMedia | The ExternalMedia library provides a framework for interfacing external codes computing fluid properties to Modelica.Media-compatible component models. | N/A | a month ago |
| Modelica_EnergyStorages | Free library that contains models with different complexity for simulating of electric energy storages like batteries (single cells as well as stacks) interacting with loads, battery management systems, loads and charging devices. | N/A | 5 months ago |
| Modelica_LinearSystems2 | Free library providing different representations of linear, time invariant differential and difference equation systems, as well as typical operations on these system descriptions. | v2.3<br>(a year ago) | 5 months ago |
| Modelica_StateGraph2 | Free library providing components to model discrete event, reactive and hybrid systems in a convenient way with deterministic hierarchical state diagrams. Modelica_StateGraph2 is not fully Modelica compliant and will never be, since a better solution is now available with Modelica 3.3 | v2.0.1<br>(3 years ago) | 5 months ago |
| PowerSystems | The library is intended to model electrical power systems at different levels of detail both in transient and steady-state mode. | v0.2<br>(4 months ago) | 23 days ago |

# Quickly growing number of commercial libraries. Small selection:



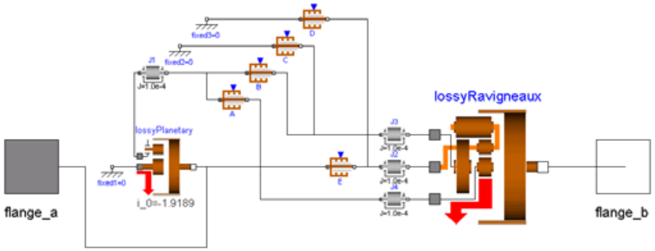
## SmartElectricDrives (ATI, Austria)

Controlled electrical machines with quasi-stationary and transient models, e.g.,
controllers (voltage/frequency, field-oriented, speed/position),
power electronics (AD/DC, DC/AC, DC/DC converters, PWM),
energy storages (batteries, supercaps, fuel cells), ...



## Hydraulic/Pneumatic Libraries (Modelon AB, Sweden)

Libraries to model pipe networks for oil and air. Contain all important standard components like pumps, valves, volumes, lines, sensors



## PowerTrain (DLR-RM, Germany)

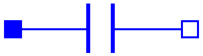
Library to model vehicle power trains and all type of planetary gearboxes. E.g. standard and planetary gears with losses, clutches with friction, flexible driveline models, automatic gearboxes,
optional 3D effects (mounting on vehicle)

# 4. Modelica Language Elements

## Example: Definition of Capacitor

```
connector Pin
  Voltage      v;   // identical at connection
  flow Current i;   // sums to zero at connection
end Pin;
          partial model TwoPin
            Pin p, n;   Voltage v;
          equation
            v = p.v - n.v;
            0 = p.i + n.i;
          end TwoPin;

                   model Capacitor
                     extends TwoPin;
                     parameter Capacitance C;
                   equation
                     C*der(v) = p.i;
                   end Capacitor;
```



$$\frac{dv}{dt}$$

# Example: Hierarchical Modelica Model

textual representation

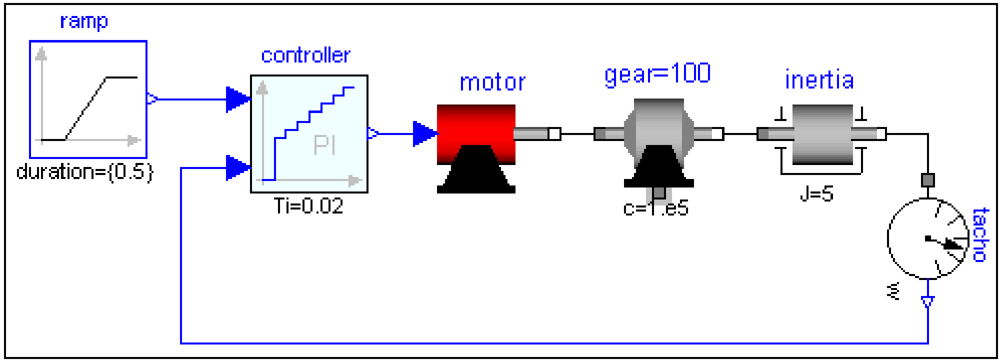
```
model MotorDrive
  PI          controller;
  Ramp        ramp;
  Motor       motor;
  Gearbox     gear(ratio = 100);
  Inertia     inertia(J = 10);
  SpeedSensor tacho;
equation
  connect(controller.y    , motor.i_ref);
  connect(motor.flange    , gearbox.flange_a);
  connect(gearbox.flange_b, inertia.flange_a);
  connect(inertia.flange_b, tacho.flange);
  connect(tacho.w         , controller.u_m);
  connect(ramp.y          , controller.u_r);
end MotorDrive;
```

Class name

Modifier

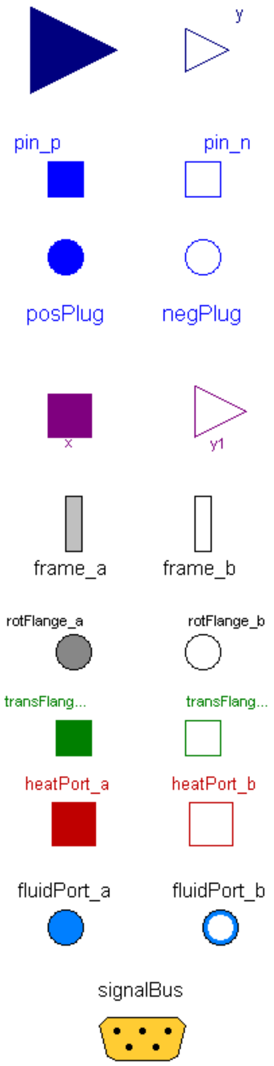
Instance name

Connector



graphical representation

# **Many pre-defined connectors**, e.g.:



input/output signals

electrical pins

electrical plugs (multi-phase networks)

VHDL digital input/output signals

3-dim. mechanical frame

1-dim. rotational mechanical flange

1-dim. translational mechanical flange

1-dim. heat transfer

fluid port (for all media from Modelica.Media)

signal bus

# Different types of variables in a connector definition

| *Category* | *Example* | *Explanation* |
|---|---|---|
| **input/output** variable | **input** Real u | Connected variables are identical;<br>block diagram connection restrictions |
| **potential** variable | Real v; | Connected variables are identical |
| **flow** variable | **flow** Real i; | Sum of the connected variables is zero |
| **stream** variable | **stream** Real h; | Describes bi-directional flow of matter<br>(more complicated definition) |
| **overdetermined** variable set | | Redundant set of variables with constraint equations, e.g., orientation matrix,<br>dq0 transformation (more complicated def.) |
| **signal bus** | **explandable**<br>**connector** Bus<br>**end** Bus; | Content defined by signals connected to the connector. |

# Other Language Elements

- Mathematical notation for **matrices** and **arrays**
- **Arrays** not only from numbers but also **from models** (e.g. arrays of resistors).
- **Replaceable submodels**, e.g., to change quickly between different versions of a transmission in a vehicle system model.
- Language elements to define conveniently **discontinuous** and **variable structure** systems, e.g., to model friction or ideal switches.
- Mathematical **functions** with varying number of input/output arguments. The procedural part of Modelica is used as scripting language.
- Convenient calling of **C, Fortran**, and **Java** functions within Modelica.
- **Powerful library concept** (Modelica tool has enough information to find model in the file system automatically, version handling, transformations between versions, ...).