Enhancing Modelica towards variable structure systems

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SOL

An object-oriented modeling language
for variable structure systems.

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Overview

- Motivation
- Modeling concept
- Presentation of Sol
  - Fundamentals
  - Model hierarchy and type-system
  - Implementation: Equations and transmissions
- Example 1: Switch of the engine model
- Current state of the implementation and Outlook
- Example 2: Pendulum with a structural change

Motivation I

- Many contemporary models contain structural changes at run time:
  - ideal switching processes.
  - variable number of entities or agents.
  - variable level of detail.
  - user interaction.

- A general modeling language supporting variable structure systems offers a number of important benefits.

- Modelica is very limited in this respect. The limitations originate from technical points of view and from a lack of expressiveness.

- MOSILAB offers a first approach to handling variable structure systems in a more general sense.

Motivation II

- We took a rather fundamental approach and decided to develop a new language: Sol. The motivation behind this project is twofold:

- One, Sol shall offer a platform for the development of corresponding technical solutions. This concerns…
  - dynamic recausalization
  - dynamic treatment of higher index problems
  - etc…

- Two, Sol is a language experiment. We want to explore the full power of a declarative modeling approach and how it can handle potential, future problem fields.

- Sol is not a product! We don’t intend to throw another modeling language or dialect on the market. Sol is primarily a tool to enable principal research on the subject of variable structure systems.

Modeling concepts

- Sol attempts to be a language of minimal complexity
- Sol redefines the fundamental concepts of Modelica on a dynamic basis.
- Sol enables the creation, exchange and destruction of components at simulation time.
- To this end, the modeler describes the system in a constructive way, where the structural changes are expressed by conditionalized declarations. These conditional parts can then get activated and deactivated during run-time.
- The constructive approach avoids an explicit description of modes and transitions and yet proves to be fairly powerful.
- The following slides provide an informal and incomplete introduction to Sol.

Sol: Fundamental entity

- A **model** is the essential language element in Sol. It is of very general use and consists always of three optional parts:
- The **header**: Here you can define constants or specify inheritances or include sub-models.
- The **interface**: parameters and variables that are visible from outside are specified in the interface section.
- The **implementation** describes the actual relations between the variables and introduces the dynamics.

```
model myFirst

define minute as 60;

interface:
  parameter Real tau << 1;
  parameter Real sat << 1;
  static Real x;

implementation:
  static Real v;
  when initial then
    x = 0;
  end
    v = der(x);
    x = (sat-x)*(tau/minute);
end myFirst;
```

Sol: Hierarchy and inheritance

- Sol enables the hierarchic organization of models within models (e.g. **packages**)
- Sol offers means for type-generation like model-extension (**extends**), model-redefinitions (**redefine)** or variable-redeclarations (**redeclare**).
- These mechanisms can be applied to complete packages as well.

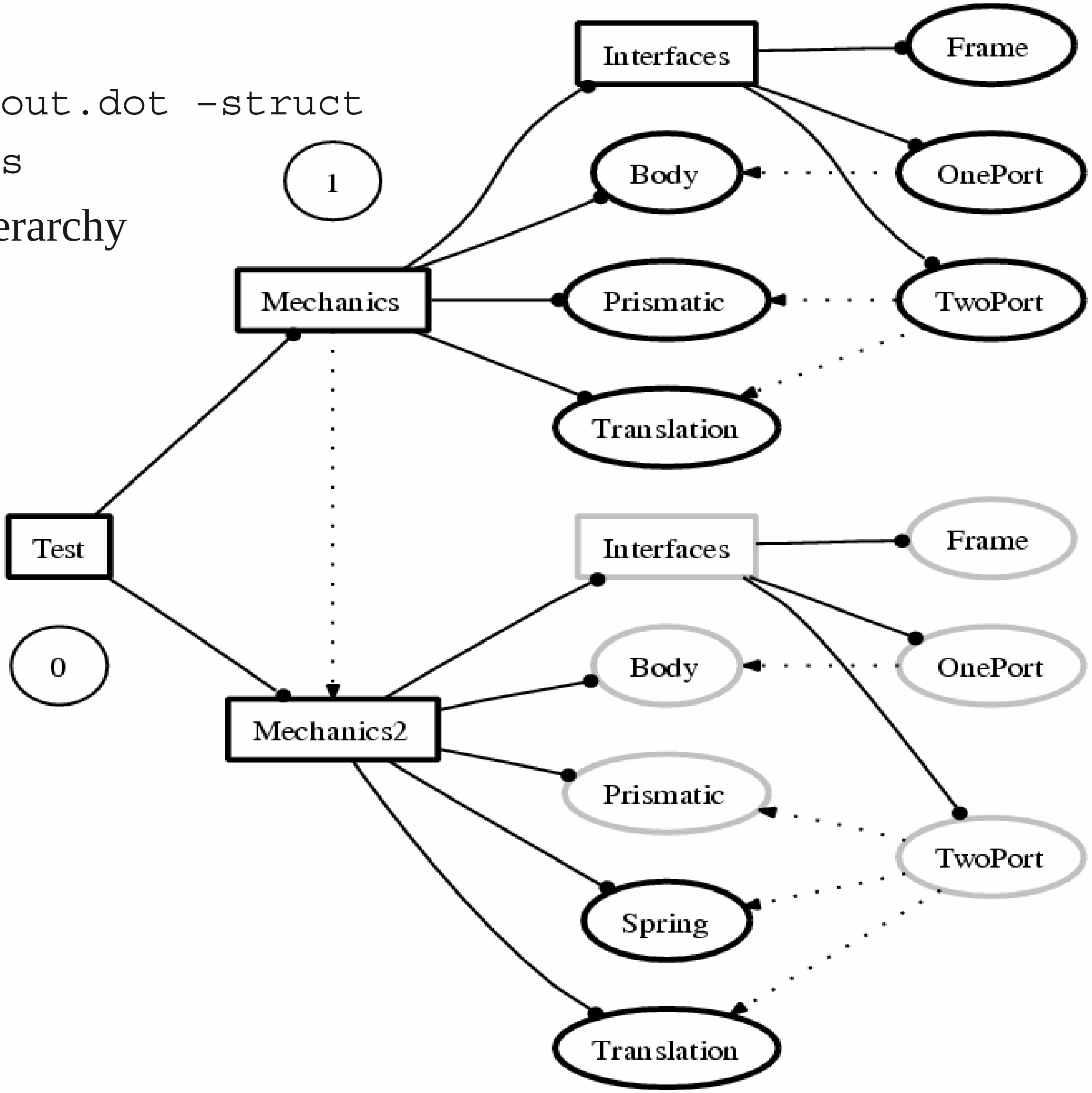
```
package Mechanics

     package Interfaces

          connector Frame
          interface:
            static potential Real x;
            static flow Real f;
          end Frame;

          model OnePort
          interface:
            static Frame f;
          end OnePort;

          model TwoPort
          interface:
            static Frame fa;
            static Frame fb;
          end TwoPort;

     end Interfaces;

     model Body extends Interfaces.OnePort;
     interface:
       parameter Real m;
     end Body;

     model Prismatic extends Interfaces.TwoPort;
     interface:
       parameter Real s;
     …
…
```

Sol: Hierarchy and inheritance

Executing…

```
solsim TestStruct.sol -o out.dot -struct
dot -Tps out.dot -o out.ps
```

produces a graph of the model hierarchy



Sol: Type-system

- Like Modelica, Sol features a structural type system. Thus, separate lines of implementation can be compatible.
- The type is defined in the interface-section (except for the extensions).
- Redeclarations or redefinitions must provide sub-types of their original representation.

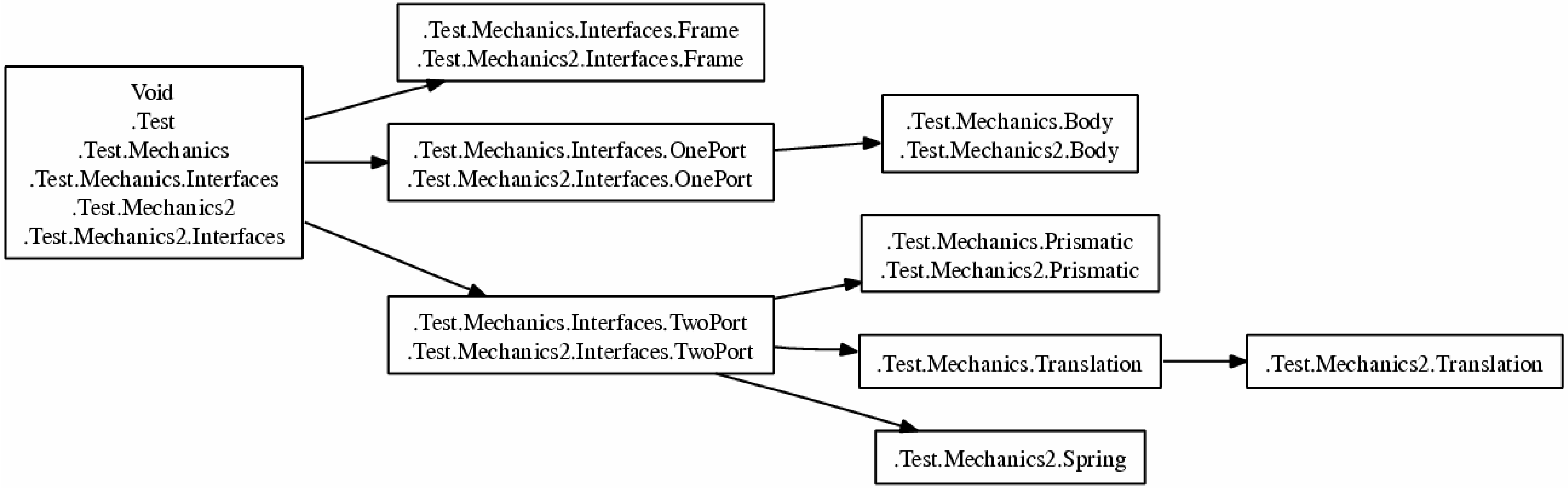
```
package Mechanics

     package Interfaces

          connector Frame
          interface:
            static potential Real x;
            static flow Real f;
          end Frame;

          model OnePort
          interface:
            static Frame f;
          end OnePort;

          model TwoPort
          interface:
            static Frame fa;
            static Frame fb;
          end TwoPort;

     end Interfaces;

     model Body extends Interfaces.OnePort;
     interface:
       parameter Real m;
     end Body;

     model Prismatic extends Interfaces.TwoPort;
     interface:
       parameter Real s;
     …
…
```

Sol: Type-system

Executing…

```
solsim TestStruct.sol -o out.dot -types
dot -Tps out.dot -o out.ps
```

produces a graph of the type hierarchy



Sol: Model-Implementation

- The implementation consists of a block.
- A block may contain…
  - declarations of variables or model-instances
  - equations or transmissions
  - nested (conditional) blocks

Sol: Member-access

- At the declarations the identifier is linked either statically or dynamically to its model-instance.
- Members of an instance can be accessed through
  - The . operator
  - A connection statement
  - The ( ) operator
- Instances can be anonymously declared.

```
     model Sinus
     interface:
       static Real x;
       static out Real y;
     implementation:
       …
     end Sinus;

implementation:
  static Sinus s;

  //1st variant
  s.x = u;
  s.y = v;
  //2nd variant (silly here)
  connection(s.x,u);
  connection(s.y,v);
  //3rd variant
  v = s(x=u);
```

```
 v = Sinus(x=u);
```

Sol: Statements

- Sol provides 3 operators for setting up relations
  - equation (=)
  - causal copy-transmission (<<)
  - causal move-transmission (<-)
- The transmission operators can be applied to model-instances.
- Dynamic instances can be created by transmitting anonymous declarations to a dynamically-linked identifier. Moving to the trash deletes instances.

```
parameter Real R;
static Real u;
static Real i;

u = R*i;
```

```
static Boolean open;
open << false;
```

```
dynamic Resistor currentR;
currentR <- HeatResistor{R<<100};

trash <- currentR;
```

Sol: Branches

- Sol features **if-else**-branches and **when-else**-branches.
- If-branches are evaluated during an update-step.
- When branches are evaluated at the end of an update-procedure and their contents gets activated for the next update procedure.
- There are no syntactical restrictions on the content of the branches.

```
model Gain

interface:
  parameter Real gf;
  static out Real g_out;
  static Real g_in;

implementation:
  static Real h ;
  h << gf * g_in;

  if h < 0.5 then
    g_out << Gain(g_in << h);
  else then
    g_out << h;
  end;

end Gain;
```

Example 1

- Let us model a simple machine, consisting of an engine that drives a fly-wheel.
- Two models are provided for the engine:
  - The first model “Engine1” applies a constant torque on the flange.
  - In the second model “Engine2”, the torque is dependent on the positional state similar to a piston-engine.
- The machine-model connects the engine and the fly-wheel. It contains a structural change that is reflected by a substitution of the engine-models.
- Initially, the fly-wheel is at rest, and the more complex engine model is used. When the speed exceeds a certain threshold, it seems appropriate to average the torque. Thus, the simpler engine-model is used instead.
- The example in the paper (shown in the next slides) had to be adapted to the current state of implementation.

Example 1

```
connector Flange
interface:
  static potential Real phi;
  static flow Real t;
end flange;

partial model Engine
interface:
  parameter Real meanTorque<<1;
  static Flange f;
end Engine;

model Engine1 extends Engine;
implementation:
  f.t = meanTorque;
end Engine1;

model Engine2 extends Engine;
implementation:
  static Real transm;
  transm = 1+sin(f.phi);
  f.t = meanTorque*transm;
end Engine2;
```

```
model FlyWheel
interface:
  parameter Real inertia << 1;
  static Flange f;
  static Real w;
implementation:
  static Real z;
  w = der(f.phi);
  z = der(w);
  f.t = inertia*z;
  when initial then w=0; f.phi=0; end;
end FlyWheel;

model Machine
implementation:
  static FlyWheel Wheel1{inertia<<10};
  static Boolean fast;
  if fast then
    static Engine1 E{meanTorque<<100};
    connection(E.f,Wheel1.f);
  else then
    static Engine2 E{meanTorque<<100};
    connection(E.f,Wheel1.f);
  end;
  when initial then fast<<false; end;
  when Wheel1.w > 50 then fast<<true; end;
end Machine;
```

Example 1

- The previous model contained a separate branch for each mode. The transitions are modeled by when-statements.
- Here we present a second variant, where the model-instance is dynamically linked to the identifier.
- The corresponding update of the connection statement is treated automatically by the system.

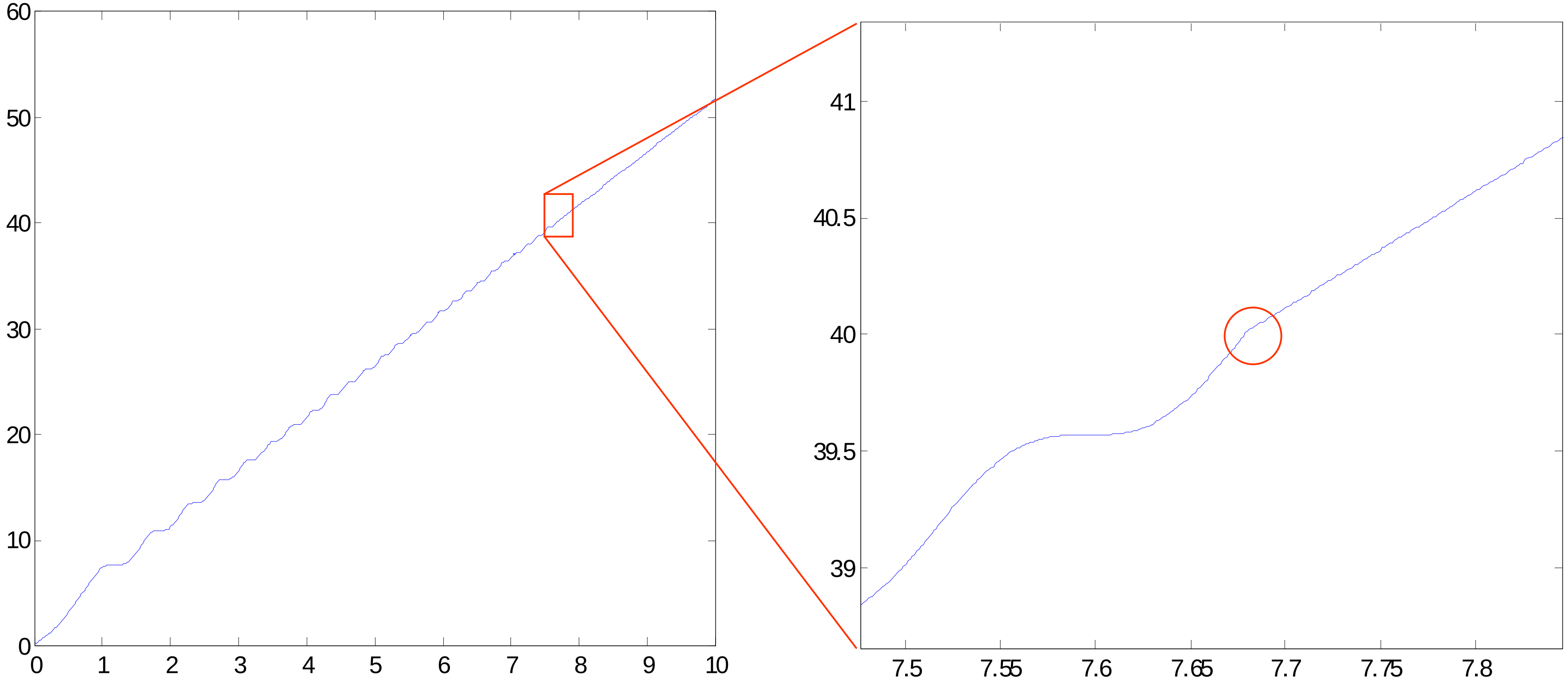
```
model Machine

implementation:
  static FlyWheel Wheel1{inertia<<10};
  dynamic Engine E;
  connection(E.f,Wheel1.f);

  when initial then
    E <- Engine2{meanTorque << 100};
  end;
  when Wheel1.w > 50 then
    E <- Engine1{meanTorque << 100};
  end;

end Machine;
```

Example 1: Results

Executing…

```
solsim TestEngine.sol -o out.dat -sim 10 0.001
pgnuplot results.gnu
```

simulates through 10’000 Euler steps and draws a plot of the angular velocity



Current Implementation

The program solsim is an interpreter

1. The model-textfile is parsed and mapped on the internal data-structures.
2. The type generation is processed (extensions, redefinitions..).
3. The relevant model-instances are created.
4. The corresponding transmissions (and equations) are dynamically flattened and ordered.
5. The dynamically flattened system is then evaluated.
6. The evaluation of branch-statements may lead to further instantiations or to the deletion of existing instances.
7. Thus, a structural change leads to an update (not rebuild) of the dynamically flattened system.
8. The evaluation continues until the end of the simulation.

Outlook

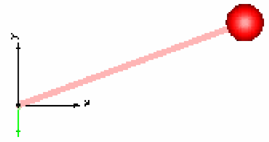
The current implementation is still in an early stage and represents only an intermediate solution. Our future work will focus on…

- The dynamic causalization processes
- The dynamic handling of higher-index problems
- The inclusion of arrays
- Well-specified handling of discrete events
- Strict and formal presentation of the language
- Development of optimization schemes.

Obviously we have now a large playground for our research.

2nd Example

- Let us model a pendulum. The mass is constrained in its movement by a non-elastic, mass-less wire.
- In general this model is highly non-linear. The video on the right hand side displays a stiff but continuous approximation of the model. It was modeled and simulated in Dymola.
- We present now two conceptual solutions in Sol where the system is modeled in an ideal way by a structural change.
- The structural change is modeled at different levels of abstraction.



2nd Example: 1st Version

In the first version, the structural change is modeled at the top level.

```
model WirePendulum

interface
   parameter Real l;
   static Real[2] x;
   static Real[2] v;

implementation:
   static Boolean free;

   if free then
     static Body b{x_start<<x,
                   v_start<<v};
    when dist(a=fa.x, b=fb.x) >= l
    then
       free << false;
       x << b.x;
       v << b.v;
     end;
   …
```

```
   …
   else then
     static Fixed fix{x << [0,0]};
     static Body b{};
     static Revolute{w_start<<f(v),
                     phi_start<<g(x)}
     static Translation{n<<[l,0]}
     connection(fix.f,R.fa);
     connection(R.fb,T.fa);
     connection(T.fb,b.f );

     when (x=T.f*T.r) <= 0 then
        free << true;
        x << b.x;
        v << b.v;
     end;

  end;

  when initial then
      free << true;
       x << 0.4; y << 1.0;
  end;

end WirePendulum
```

2nd Example: 2nd Version

- The first version simply models a transition between two separate models.
- However, this transition is non-physical. The actual force-impulse is not taken into account.
- The second variant (on the right) does not contain a structural change at the top-level. It must be in one of the sub-models.
- Let us examine the sub-models…

```
model WirePendulum2
interface:
  parameter Real l;
  static Real[2] x;

implementation:
  static Fixed f;
  static Revolute r;
  static LimitedPrismatic p;
  static Body b;

  connection(f.f,r.fa);
  connection(r.fb,p.fa);
  connection(p.fb,b.f);
end FreePendulum2
```

2nd Example: 2nd Version

The corresponding sub-models own equations and operations for the handling of mechanical impulses.

```
model Fixed
interface:
   parameter Real m;
   parameter Real I;
   static IFrame f;
implementation:
   static Real[2] v;
   static Real[2] a;
   static Real w;
   static Real z;

   f.x = x;
   f.phi = phi;
   Ve = 0;
   We = 0;
end Fixed;
```

```
model Body
interface:
  parameter Real m;
  parameter Real I;
  static IFrame f;
implementation:
  static Real[2] v;  static Real[2] a;
  static Real w;     static Real z;
  static Real Vpre;  static Real Wpre;

  f = m*a;  t = I*z;
  v = der(f.x); w = der(f.phi);

  f.F = m*(f.Ve-Vpre);
  f.T = I*(f.We-Wpre);

  when f.impulse then
    Vpre << pre(v);
    Wpre << pre(w);
    v << f.Ve;
    w << f.We;
  else then
    a = der(v);
    z = der(w);
  end;

end Body;
```

2nd Example: 2nd Version

```
model LimitedPrismatic
interface:
    parameter Real l;
    parameter Real[2] n;
    static Real s;
    static Real v;
    static Real a;
    static frame fa;
    static frame fb;
implementation:
  static Boolean free;

  static Real[2] r;
  r[1]=n[1]*sin(fa.phi)+n[2]*cos(fa.phi);
  r[2]=n[2]*sin(fa.phi)-n[2]*cos(fa.phi);
  fb.x = fa.x+s*r;
  fa.phi = fb.phi;
  a = der(v);
  fa.t = cross(r*s,fb.f) + fb.t;
  fa.f + fb.f = 0;

  fa.We = fb.Wb;
  fa.Ve = fb.Ve + cross(r*s,fa.We);
  fa.F + fb.F = [0,0]:
  fa.T = cross(r*s,fb.F) + fb.T = 0;
```

```
  if free then
    fa.f*r = 0;
    when dist(a=fa.x, b=fb.x) >= l
    then
      fa.impulse << true;
      fa.impulse << true;
    end;
  else then
    s = l;
    when (fa.f-fb.f)*r*sign(x=s) < 0
    then free << true; end;
  end;

  when fa.impulse then
    free << false;
    (fa.Ve - fb.Ve)*r = 0;
    v = 0;
    fa.impulse << false;
    fa.impulse << false;
  else then
    fa.F*r = 0;
    v = der(s);
  end;

end LimitedPrismatic
```

2nd Example: Conclusions

- In the second version, the structural change was modeled in the limited joint and involves a force-impulse.
- The second version is a truly object-oriented solution. However, it is more demanding with respect to the simulator’s capabilities (dynamic handling of index-changes, etc.).
- Consider the task where you want to extend your model to a double-pendulum of the same kind. The first approach reveals to be a dead-end whereas the second one can easily be extended.
- However, important is that both approaches shall be possible in Sol.

2nd Example: Conclusions

- None of the two variants is per se the better one. The decision between different variants depends on the current task and can only be made by the modeler.

- Thus, a general modeling language shall attempt to refrain from enforcing modeling-decisions. It should only provide the elementary means and let the modeler compose his solution out of them.

The End