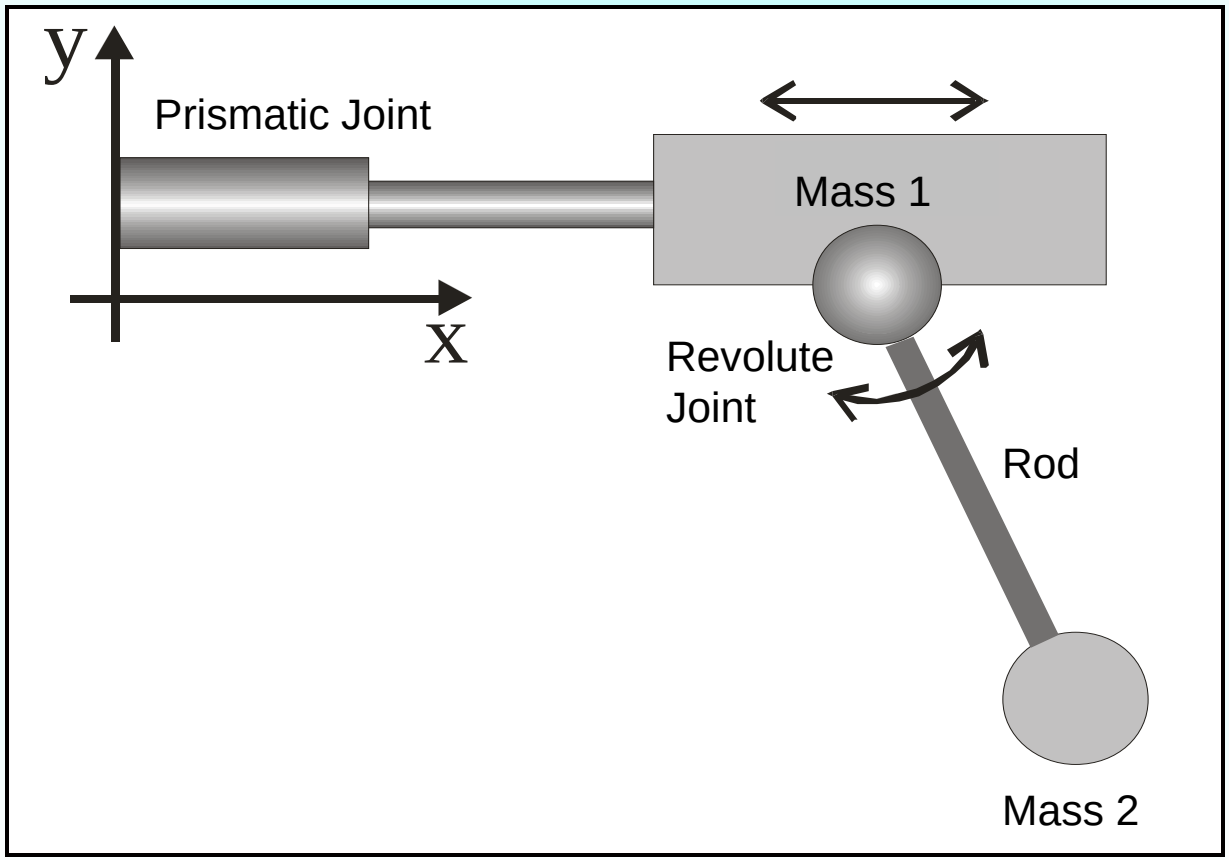
Planar Mechanics

- We shall now look at a first application of multi-bond graphs: ***planar mechanics***.
- We shall notice that a mechanical model composed of multi-bond graphs grows quickly in size and becomes poorly readable.
- For this reason, it is important to wrap multi-bond graph models of mechanical components in a framework that is more suitable to a modular description of mechanical systems.

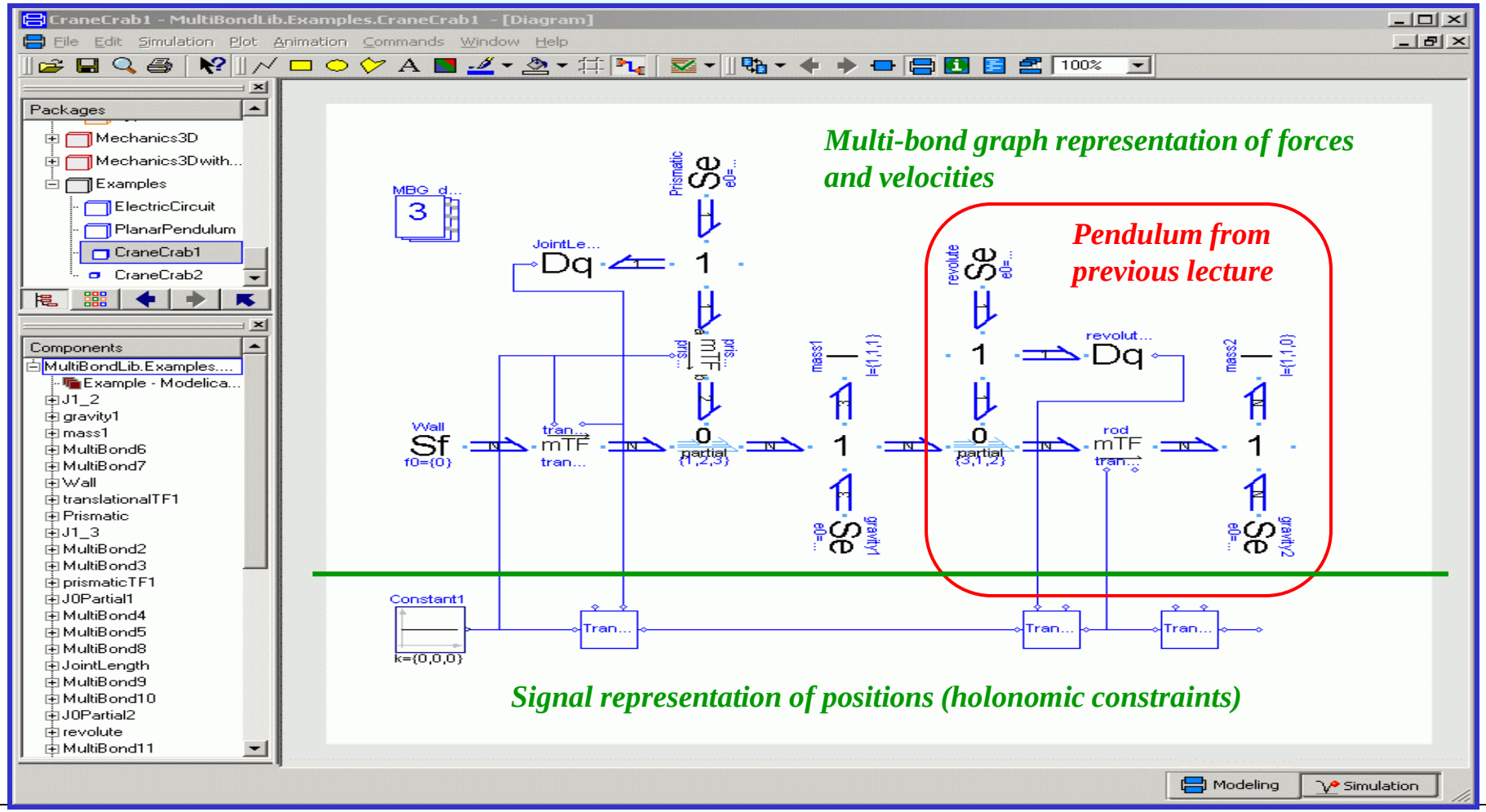
Table of Contents

A Crane Crab

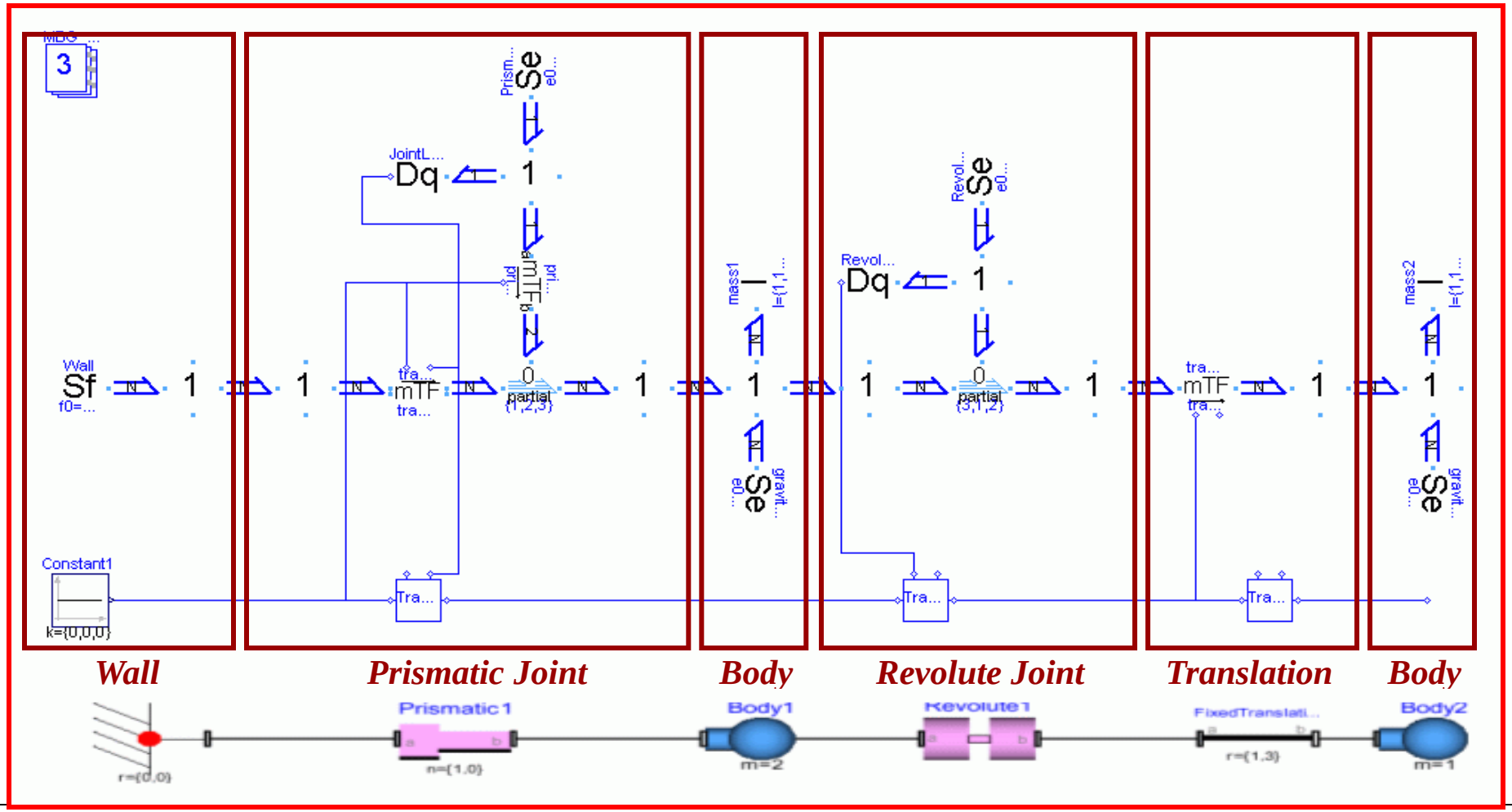
- Let us start by modeling the following crane crab:



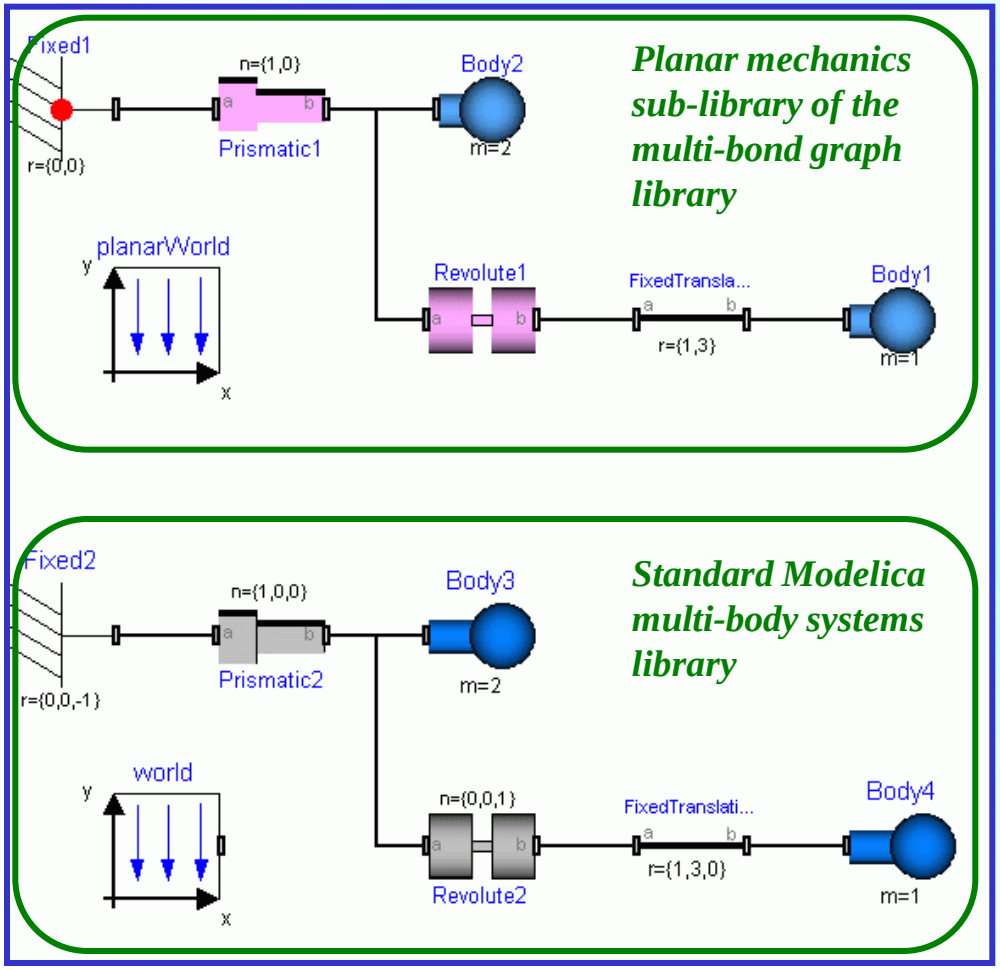
A Crane Crab II



A Crane Crab III



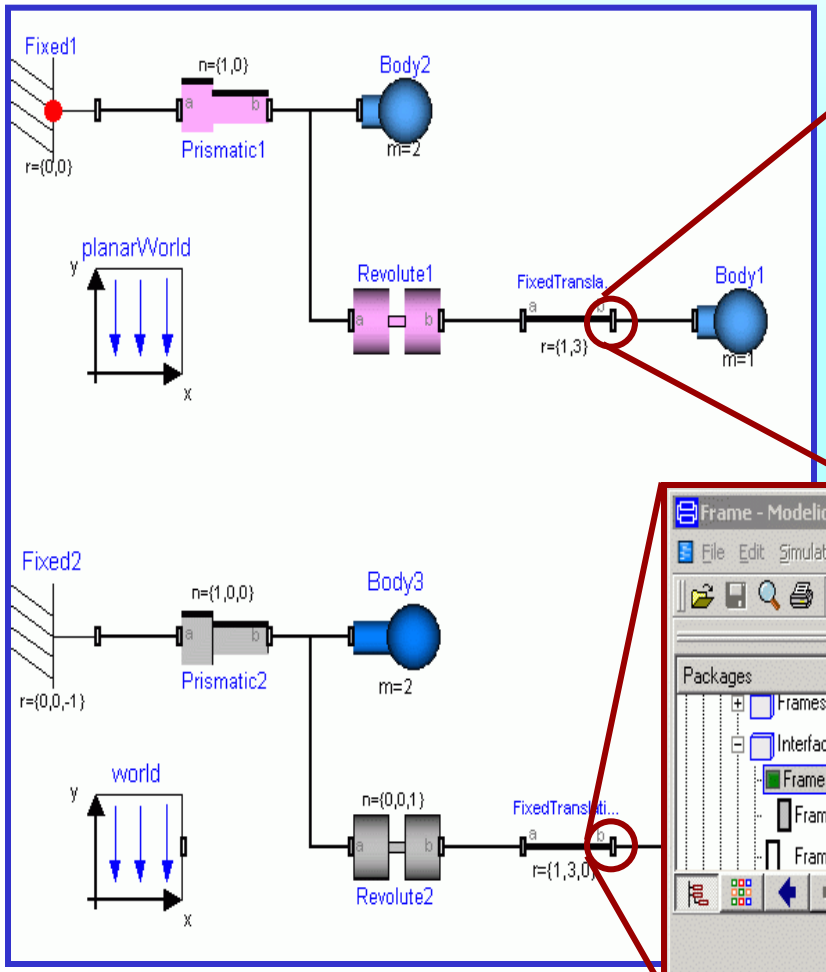
A Crane Crab IV

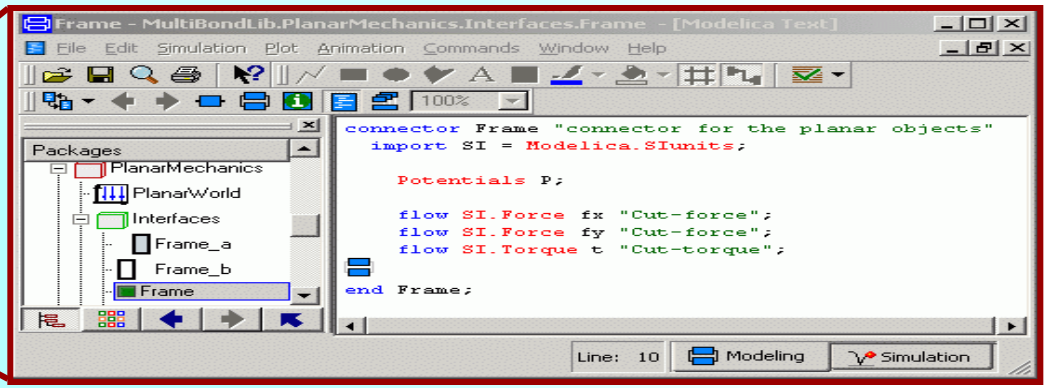


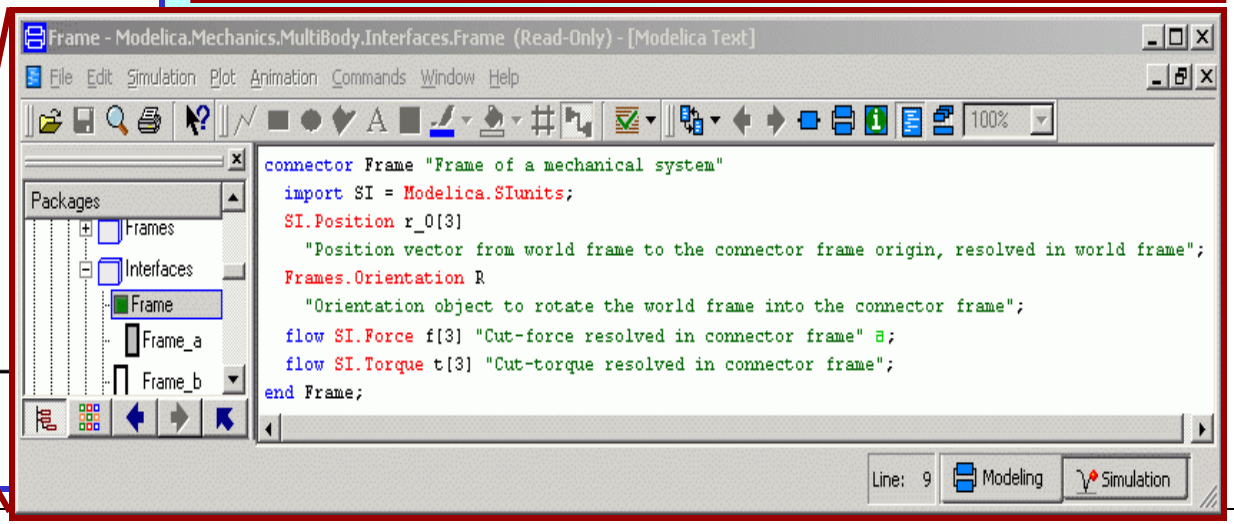
- The standard Modelica multi-body systems library is a general-purpose 3D mechanics library. No separate support for planar mechanics is currently being offered.
- The multi-bond graph library contains separate sub-libraries for planar mechanics and 3D mechanics, as well as for modeling hard collisions between mechanical bodies and for modeling gravitational pools (celestial mechanics).

Mechanical Connectors (Frames)

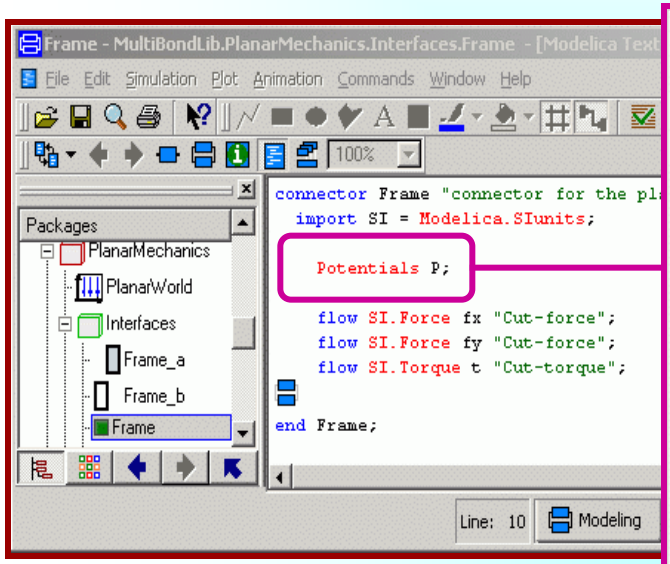
Although the connectors look the same, they are not compatible.

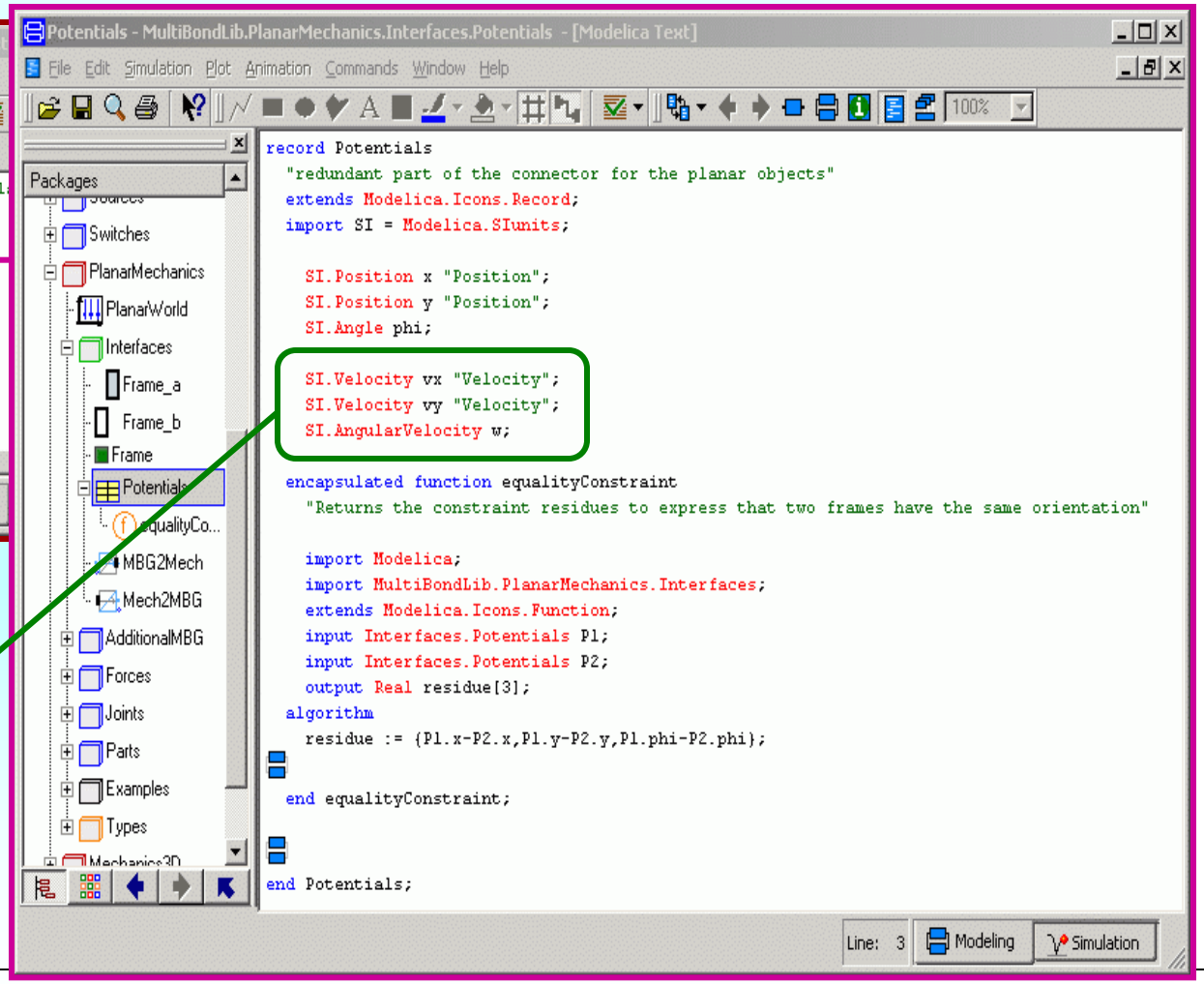






Mechanical Connectors (Frames) II

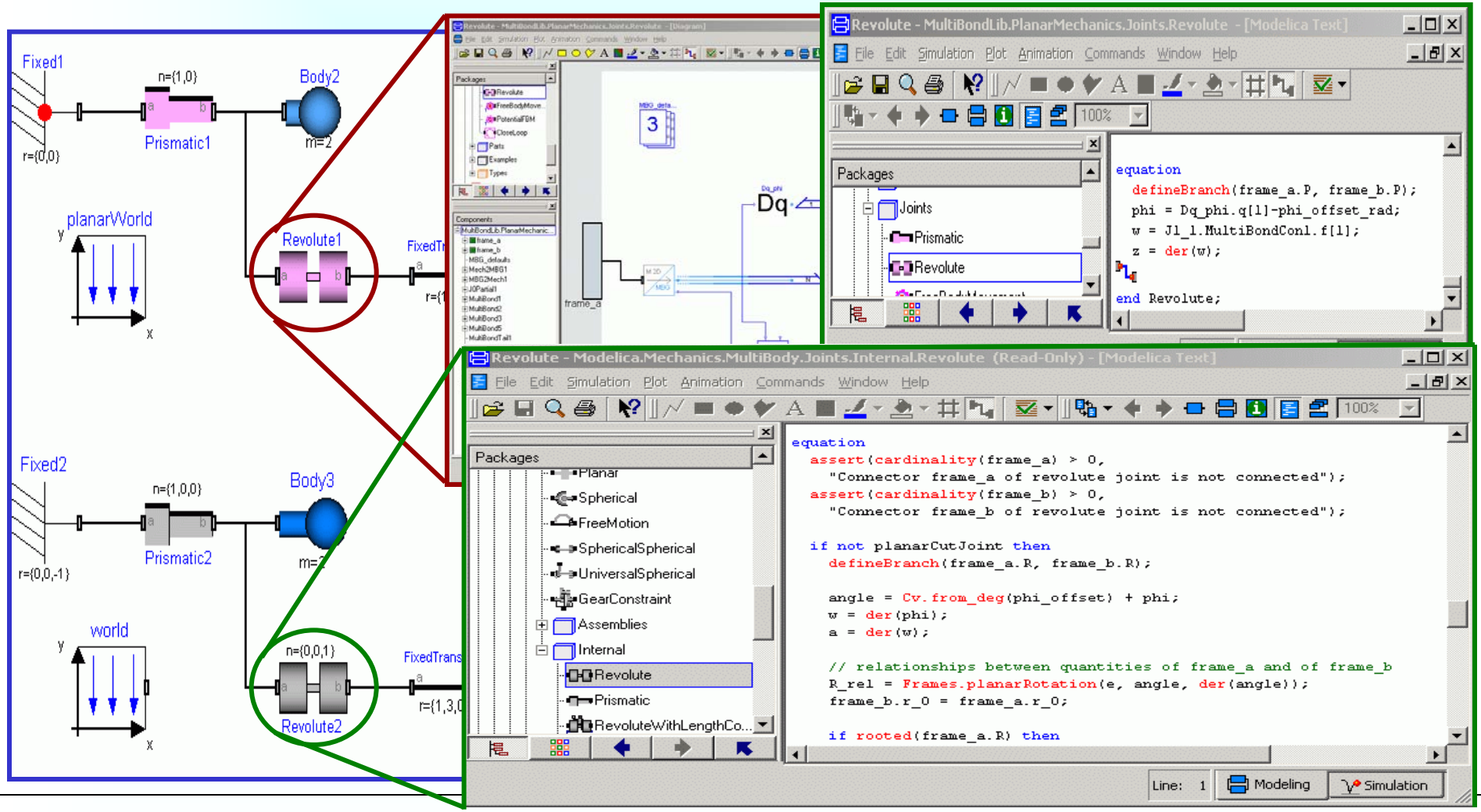




Redundant connections needed because of the bond graph approach.

The component models of the standard multi-body systems library and the wrapped multi-bond graph library cannot be mixed.

Revolute Joints



Revolute Joints II

- Using the multi-bond graph library, almost the entire model of the revolute joint has been coded graphically. There are only very few equations to be coded in the equation window. (There is still quite a bit of code there, because the object is being animated, and ***Dymola*** doesn't offer graphical support yet for coding animation models.)
- Using the multi-body library of the standard ***Modelica*** library, the entire revolute joint had to be coded by means of equations, leading to a fairly large equation model that is difficult to understand and even harder to maintain.

Rationale for Multi-bond Graphs

- It is important to keep the distance between the lowermost graphical layer and the equation layer small, such that as few equations as possible need to be maintained in alphanumerical form.
- ***Bond graphs and multi-bond graphs provide the most primitive graphical interface that is still fully object-oriented.*** Hence, when using bond graphs, the distance between the lowermost graphical layer (the bond graph layer) and the equation layer is minimized.

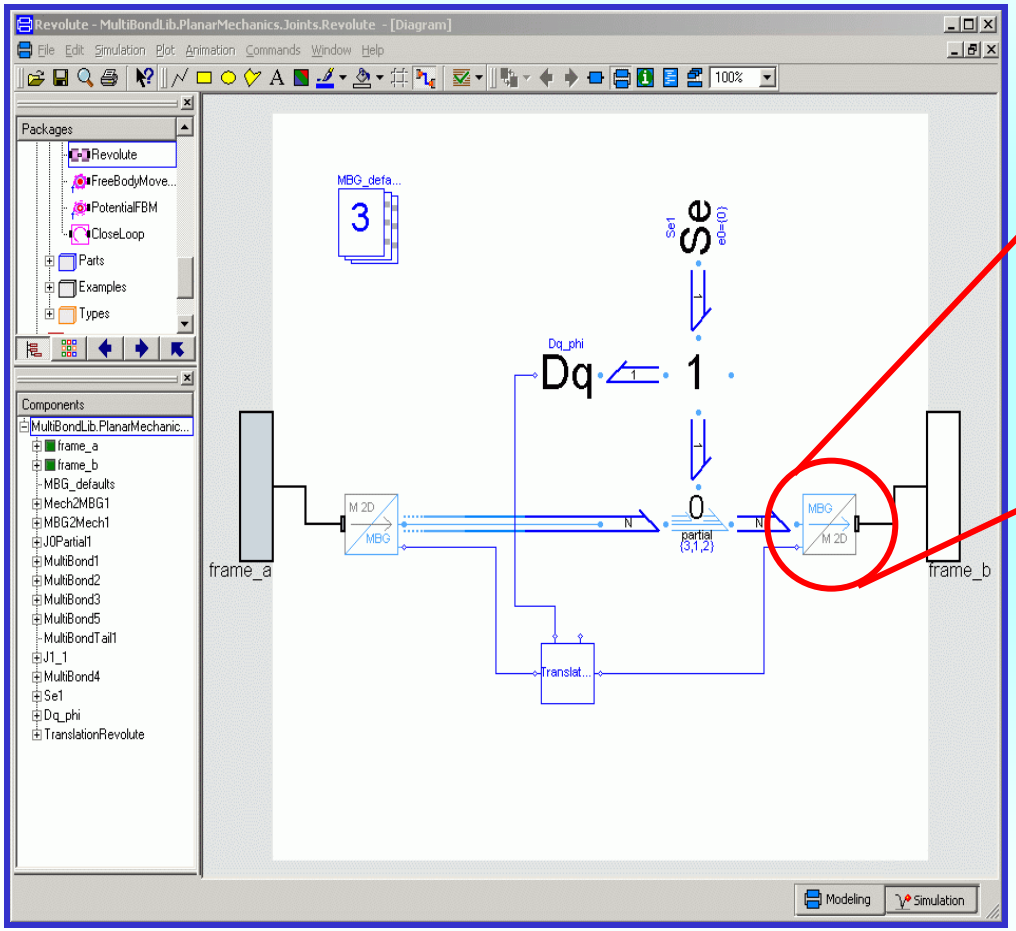
Rationale for Multi-bond Graphs II

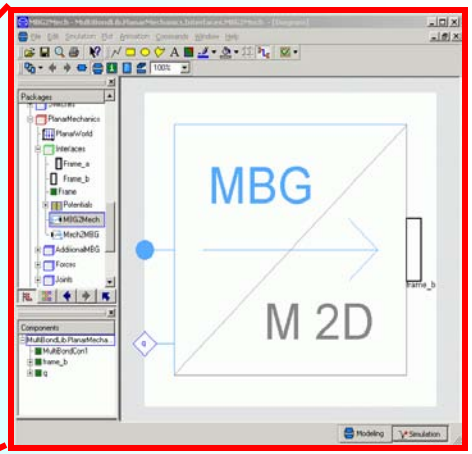
- However, this does not imply that bond graphs offer an optimal user interface. For mechanical systems, this is certainly not the case.
- ***Wrapping bond graphs*** enables the modeler to map *any* graphical object-oriented modeling paradigm onto a lower-level bond graph layer that simplifies the maintenance of the resulting application libraries.

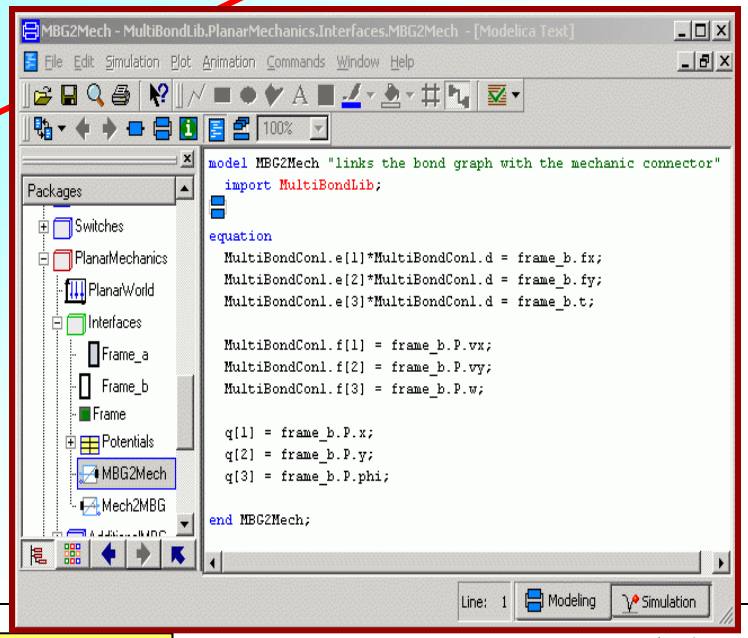
Animation

- In ***Dymola***, mechanical models can be ***automatically animated***. The end user of the models doesn't need to be concerned about this facet of modeling.
- However, individual bonds cannot be animated. The animation must take place at a higher conceptual level, namely that of multi-body system components, such as masses and joints.
- For this reason, a wrapping of multi-bond graphs is ***necessary*** if the resulting models are to be animated.

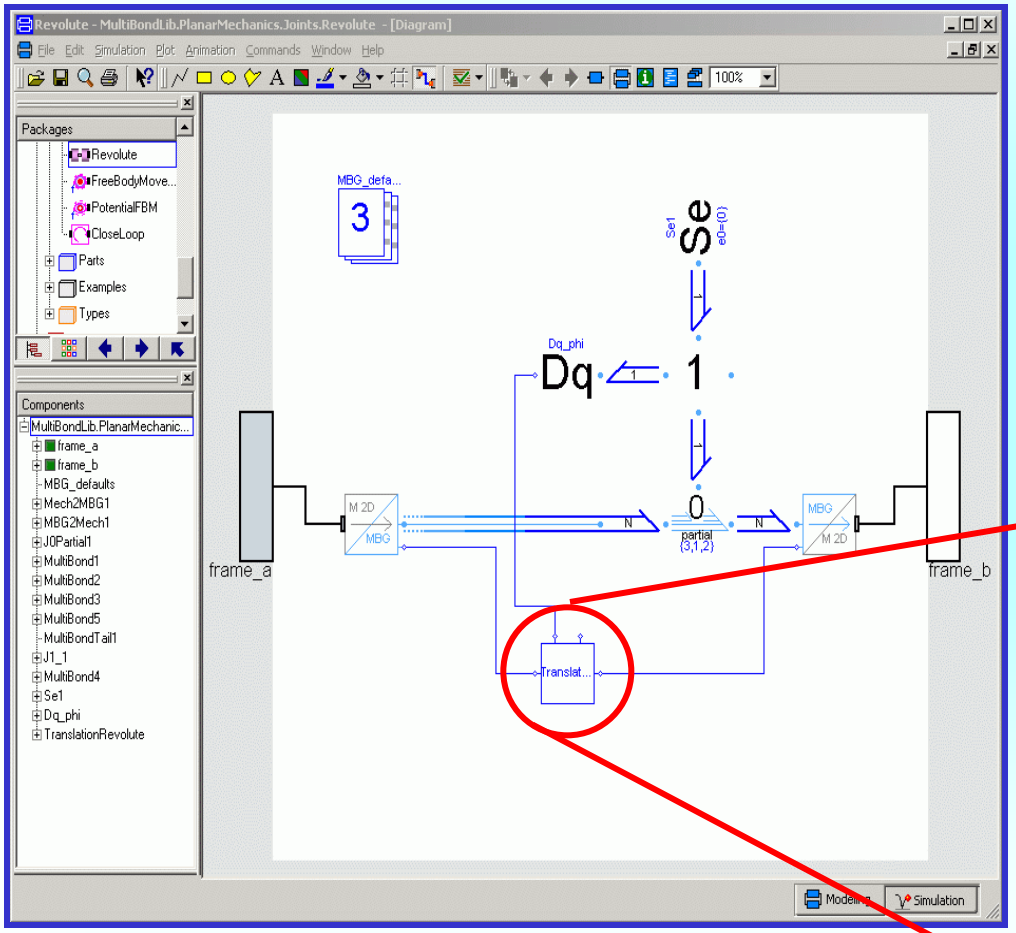
The Wrapper Models

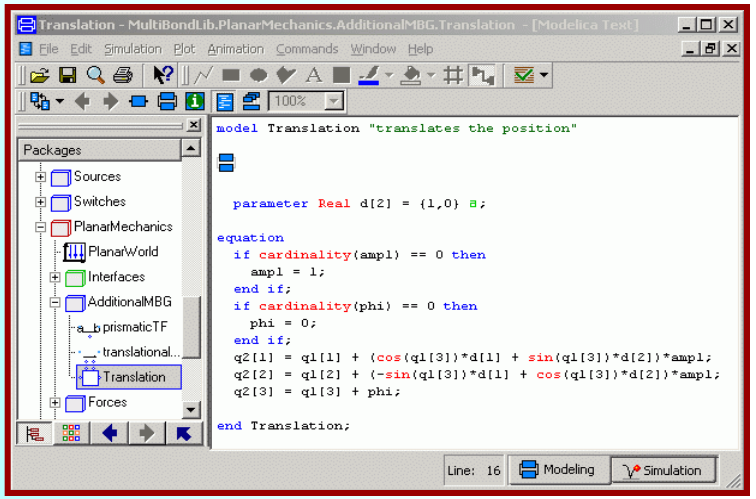


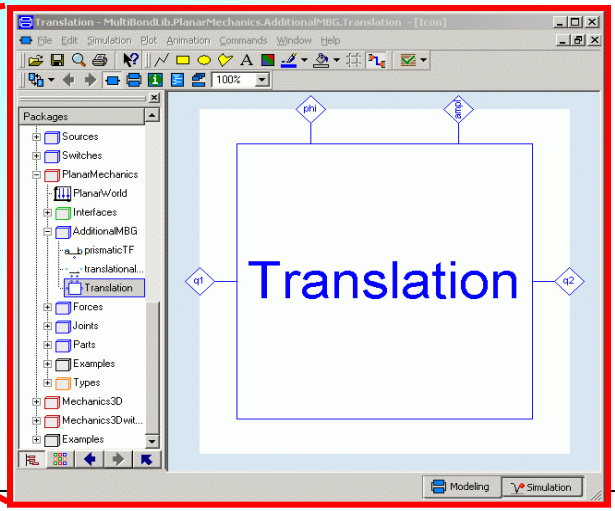




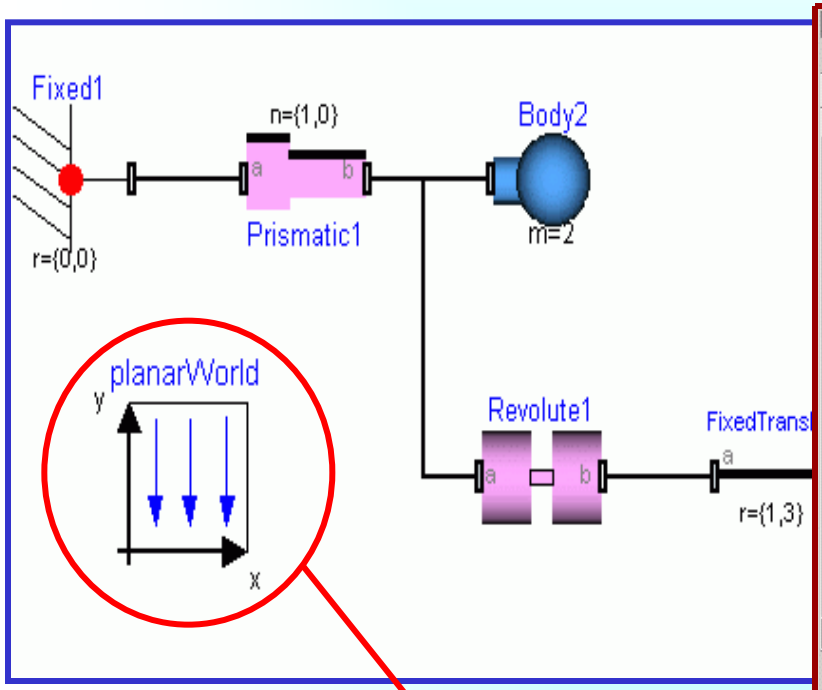
The Position Translation Model

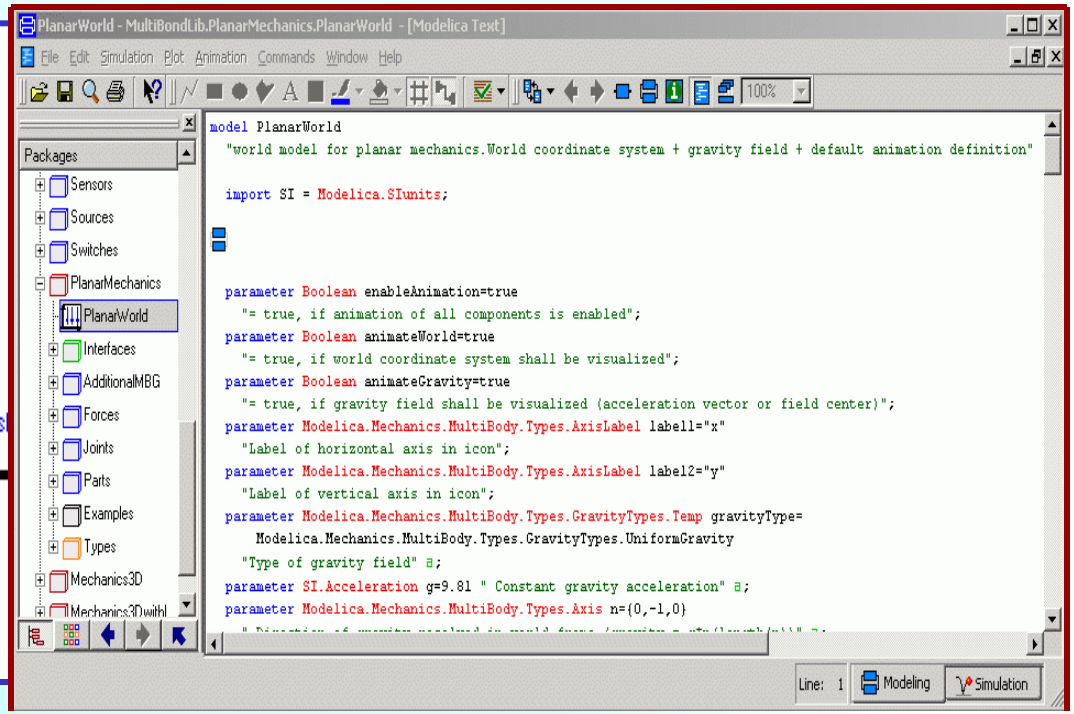






The Planar World Model

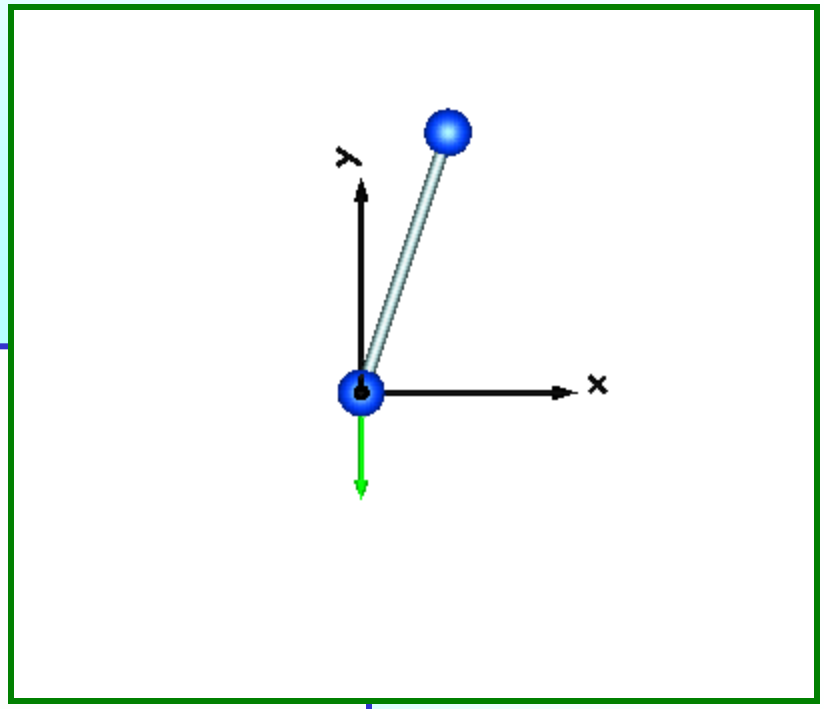


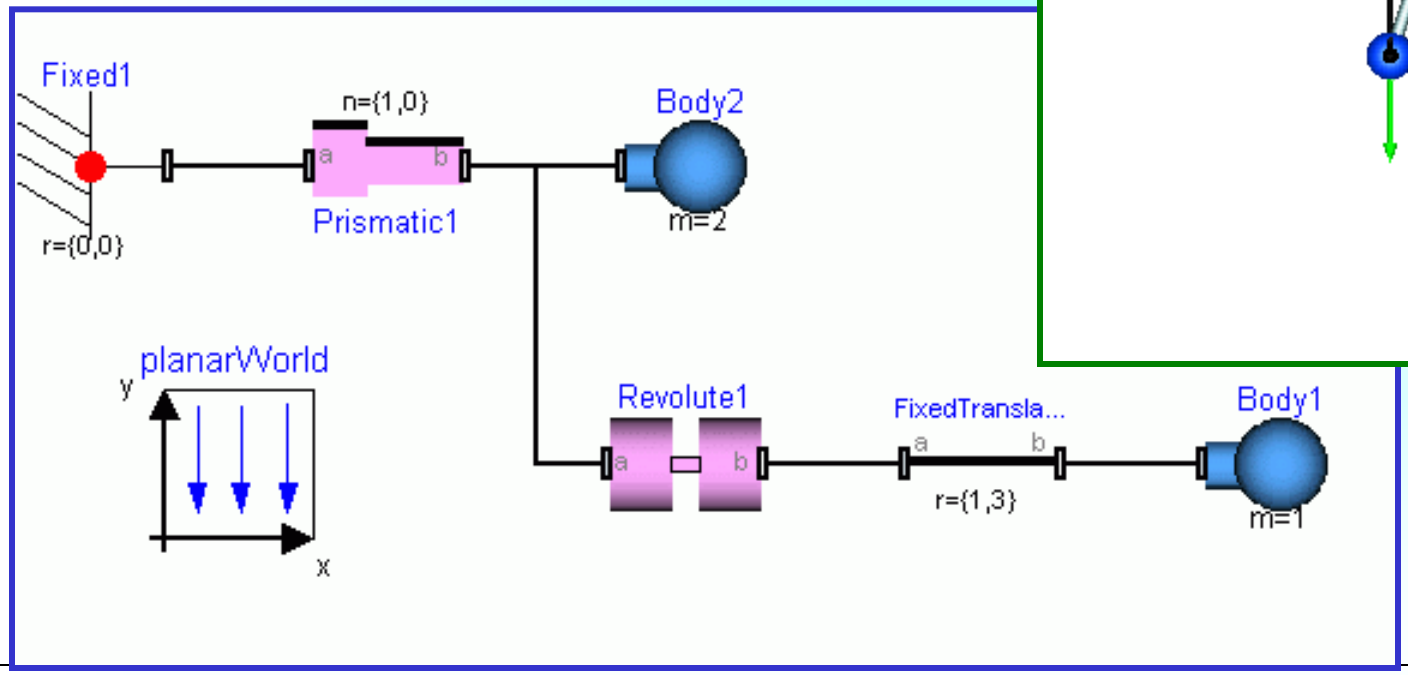


Every planar mechanical model must invoke the "planarWorld" model.

The primary purpose of the world model is to set up the animation.

Crane Crab Simulation Results

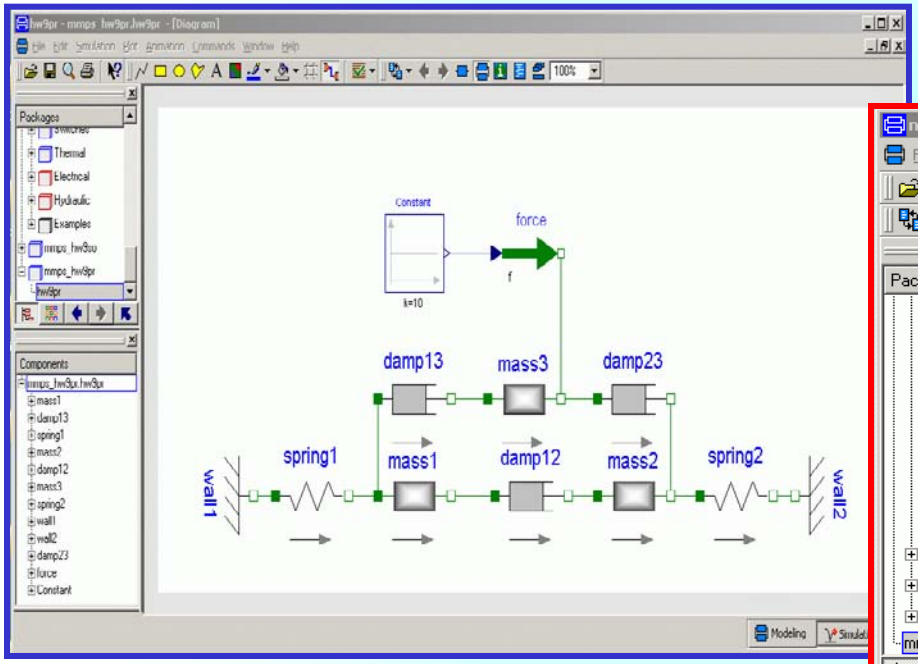


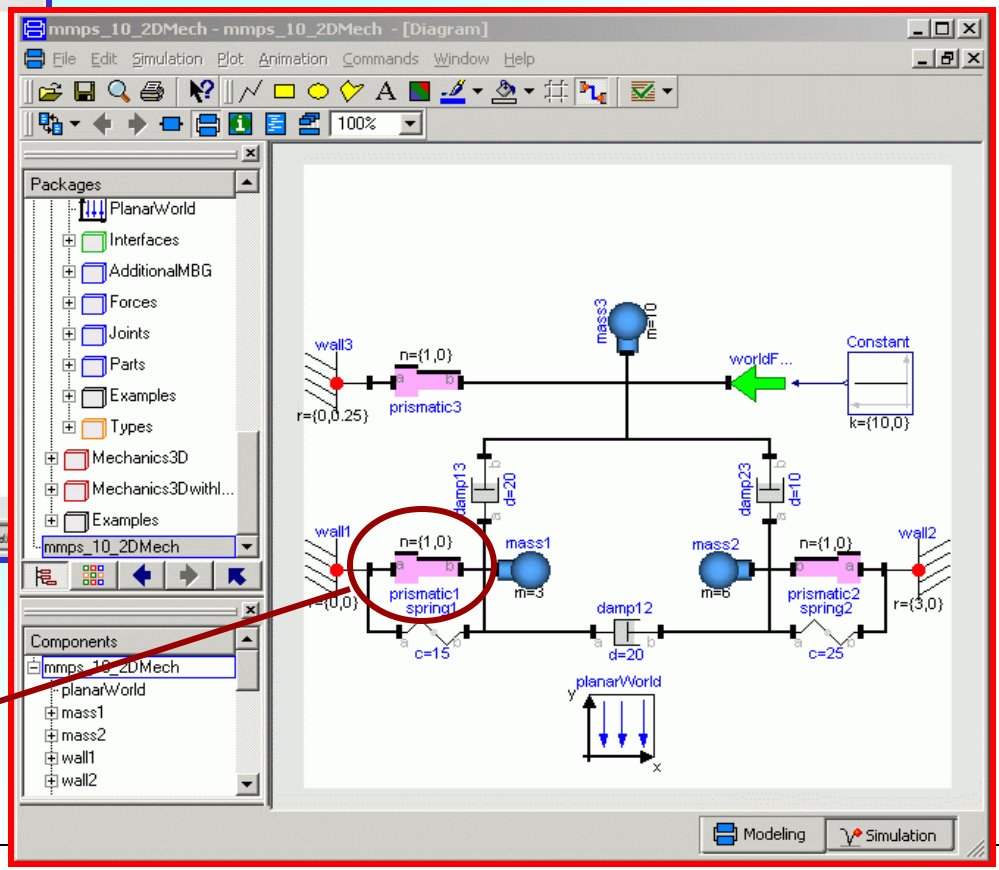


2D Simulation of 1D Models

- It is of course always possible to make use of the planar library also for the simulation of 1D models.
- Let us investigate, what the overhead of such an approach would be.
- To this end, we shall simulate the sliding mass model now using the planar mechanics library.

2D Simulation of 1D Models II





Prismatic joints need to accompany the masses in order to limit their degrees of freedom to one.

Translation Logs

Wrapped 1D mechanical bond graph model

Messages - Dymola

Syntax Error | Translation | Dialog Error | Simulation

Translation of mmps_hw9so.Mechanical.Translation.Examples.SlidingMasses:
DAE having 685 scalar unknowns and 685 scalar equations.

STATISTICS

Original Model
 Number of components: 105
 Variables: 706
  Constants: 0
  Parameters: 59 (59 scalars)
  Unknowns: 647 (685 scalars)
  Differentiated variables: 6 scalars
 Equations: 491
  Nontrivial : 250

Translated Model
 Constants: 185 scalars
 Free parameters: 40 scalars
 Parameter depending: 19 scalars
 Inputs: 0
 Outputs: 0
 Continuous time states: 6 scalars
 Time-varying variables: 36 scalars
 Alias variables: 464 scalars
 Assumed default initial conditions: 3
  LogDefaultInitialConditions=true; gives more information
 Number of mixed real/discrete systems of equations: 0
 Sizes of linear systems of equations: { }
 Sizes after manipulation of the linear systems: { }
 Sizes of nonlinear systems of equations: { }
 Sizes after manipulation of the nonlinear systems: { }
 Number of numerical Jacobians: 0

Finished
// experiment StopTime=10
Finished

Wrapped 2D mechanical bond graph model

Messages - Dymola

Syntax Error | Translation | Dialog Error | Simulation

Translation of mmps_10_2DMech:
DAE having 3705 scalar unknowns and 3705 scalar equations.

STATISTICS

Original Model
 Number of components: 268
 Variables: 2470
  Constants: 0
  Parameters: 623 (715 scalars)
  Unknowns: 1847 (3705 scalars)
  Differentiated variables: 18 scalars
 Equations: 1486
  Nontrivial : 984

Translated Model
 Constants: 1722 scalars
 Free parameters: 83 scalars
 Parameter depending: 577 scalars
 Inputs: 0
 Outputs: 0
 Continuous time states: 6 scalars
 Time-varying variables: 101 scalars
 Alias variables: 2045 scalars
 Number of mixed real/discrete systems of equations: 0
 Sizes of linear systems of equations: {10, 10, 10}
 Sizes after manipulation of the linear systems: {0, 2, 0}
 Sizes of nonlinear systems of equations: { }
 Sizes after manipulation of the nonlinear systems: { }
 Number of numerical Jacobians: 0

Finished
// experiment StopTime=10
Finished

Simulation Logs

Messages - Dymola

Syntax Error | Translation | Dialog Error | Simulation

```
Log-file of program ./dymosim
(generated: Tue Dec 12 18:45:32 2006)

dymosim started
... "dsin.txt" loading (dymosim input file)
... "SlidingMasses.mat" creating (simulation result file)

Integration started at T = 0 using integration method DASSL
(DAE multi-step solver (dassl/dasslrt of Petzold modified by Dynasim))
Integration terminated successfully at T = 10
   CPU-time for integration      : 0.01 seconds
   CPU-time for one GRID interval: 0.02 milli-seconds
   Number of result points       : 501
   Number of GRID   points       : 501
   Number of (successful) steps  : 75
   Number of F-evaluations       : 237
   Number of Jacobian-evaluations: 15
   Number of (model) time events : 0
   Number of (U) time events     : 0
   Number of state    events     : 0
   Number of step     events     : 0
   Minimum integration stepsize  : 2e-005
   Maximum integration stepsize  : 0.253
   Maximum integration order     : 5
Calling terminal section
... "dsfinal.txt" creating (final states)
```

Messages - Dymola

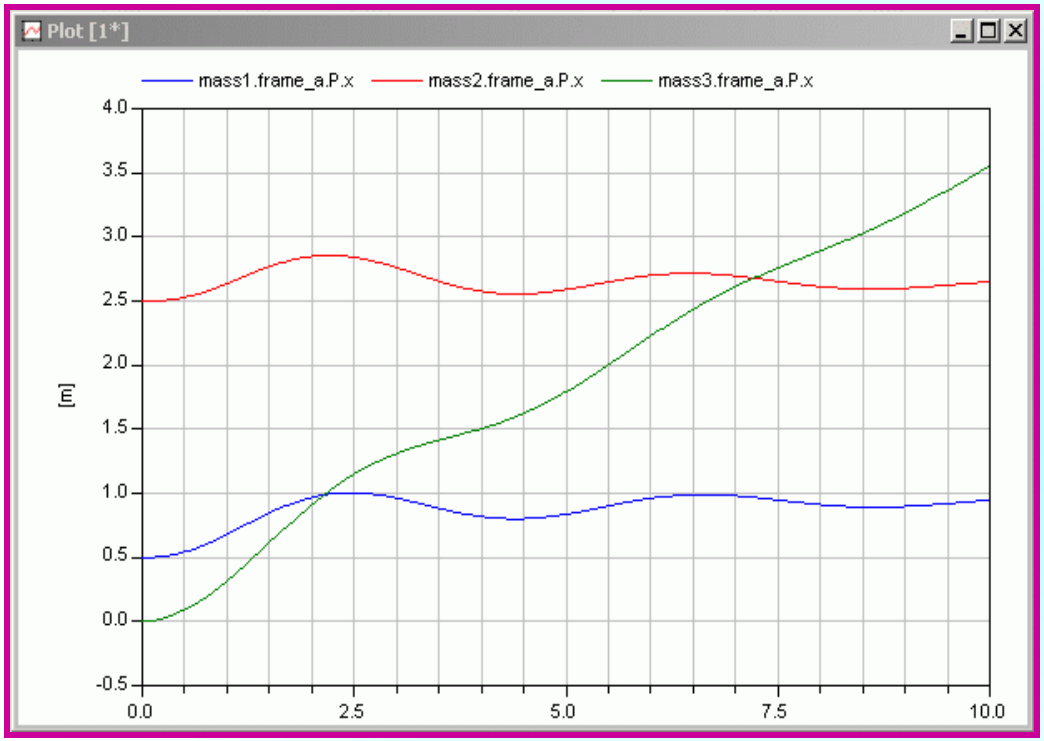
Syntax Error | Translation | Dialog Error | Simulation

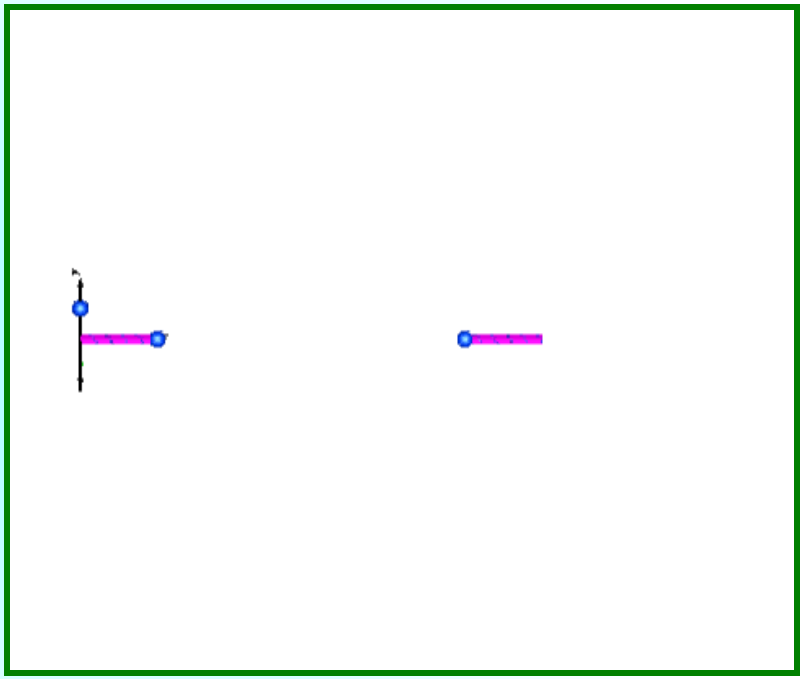
```
Log-file of program ./dymosim
(generated: Thu Dec 14 21:56:27 2006)

dymosim started
... "dsin.txt" loading (dymosim input file)
... "mmps_10_2DMech.mat" creating (simulation result file)

Integration started at T = 0 using integration method DASSL
(DAE multi-step solver (dassl/dasslrt of Petzold modified by Dynasim))
Integration terminated successfully at T = 10
   CPU-time for integration      : 0.02 seconds
   CPU-time for one GRID interval: 0.04 milli-seconds
   Number of result points       : 501
   Number of GRID   points       : 501
   Number of (successful) steps  : 76
   Number of F-evaluations       : 239
   Number of H-evaluations       : 576
   Number of Jacobian-evaluations: 15
   Number of (model) time events : 0
   Number of (U) time events     : 0
   Number of state    events     : 0
   Number of step     events     : 0
   Minimum integration stepsize  : 2e-005
   Maximum integration stepsize  : 0.253
   Maximum integration order     : 5
Calling terminal section
... "dsfinal.txt" creating (final states)
```


Simulation Results





References I

- Zimmer, D. (2006), *A Modelica Library for MultiBond Graphs and its Application in 3D-Mechanics*, MS Thesis, Dept. of Computer Science, ETH Zurich.

- Zimmer, D. and F.E. Cellier (2006), "The Modelica Multi-bond Graph Library," *Proc. 5th Intl. Modelica Conference*, Vienna, Austria, Vol.2, pp. 559-568.

References II

- Cellier, F.E. and D. Zimmer (2006), "Wrapping Multi-bond Graphs: A Structured Approach to Modeling Complex Multi-body Dynamics," *Proc. 20th European Conference on Modeling and Simulation*, Bonn, Germany, pp. 7-13.