Articulated bodies

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Abstract

This document explains the principles of the different types of articulated bodies implemented in SOFA . For each kind of articulated body, it first explains quickly the concepts of the method, then shows how to use it in a scene, and finally deals with the implementation.

Contents

1 Soft Articulations

1.1 Concepts

The objective of this method is to use stiff forces to simulate joint articulations, instead of classical constraints.

To do this, a joint is modeled by a 6 degrees of freedom spring. By the way, the user specify a stiffness on each translation and rotation.

- A null stiffness defines a free movement.
- A huge stiffness defines a forbidden movement.
- All nuances are possible to define semi constrained movements.

2 main advantages can be extracted from this method :

- A better stability. As we don't try to statisfy constraints but only apply forces, there is always a solution to resolve the system.
- more possibilities to model articulations are allowed. As the stiffnesses define the degrees of freedom of the articulations, a better accuracy is posssible to simulate free movements as forbidden movements, i.e. an articulation axis is not inevitably totally free or totally fixed.

1.2 Realization

To define physically an articulated body, we first have a set of rigids (the bones). *cf fig. 1*

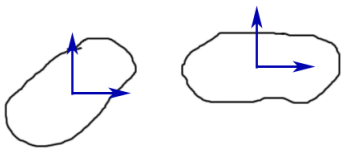


Figure 1: two bones

Each of these bones contains several articulations points, also defined by rigids to have orientation information. *cf fig. 2*

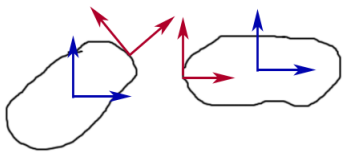


Figure 2: two bones (blue) with their articulation frames (red)

As seen previously, a joint between 2 bones is modeled by a 6-DOF spring. These springs are attached on the articulations points. *cf fig. 3*

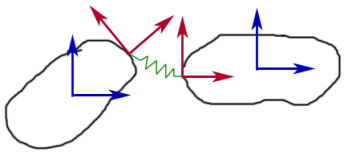
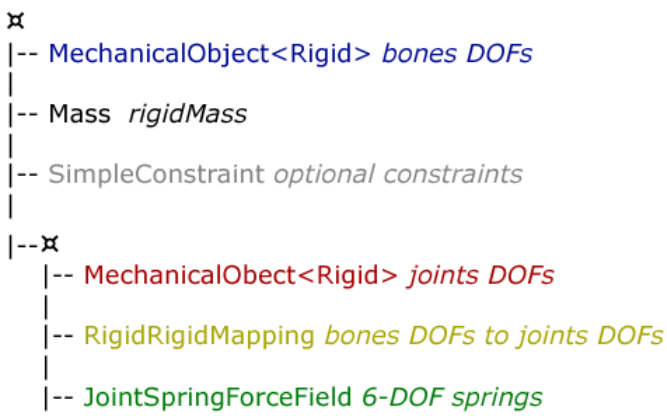


Figure 3: two bones linked by a joint-spring

1.3 Sofa implementation

To simulate these components in Sofa, we first need 2 mechanical objects : one for the bones (independent DOFs), and an other for the articulation points (mapped DOFs). Each of them contains a list of rigid DOFs (respectively all the bones and all the articulations of the articulated body). A mapping performs the link between the two lists, to know which articulations belong to which bones.

1.3.1 Corresponding scene graph



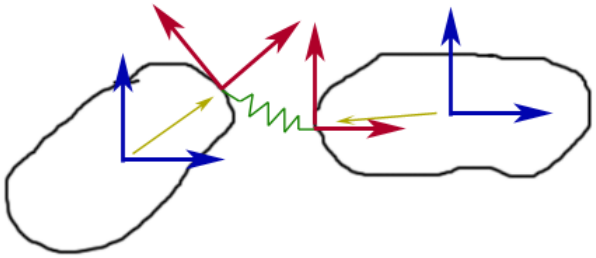


Figure 4: a simple articulated body scene

1.3.2 Example

The example softArticulations.scn shows a basic pendulum :

```
<Node>
  <Object type="BruteForceDetection"/>
  <Object type="DefaultContactManager"/>
  <Object type="DefaultPipeline"/>
```

```
  <Object type="ProximityIntersection"/>

  <Node>
    <Object type="CGImplicitSolver" />
    <Object type="MechanicalObject" template="Rigid" name="bones DOFs"
            position="0 0 0  0 0 0 1
                      1 0 0  0 0 0 1
                      3 0 0  0 0 0 1
                      5 0 0  0 0 0 1
                      7 0 0  0 0 0 1" />
    <Object type="UniformMass" template="Rigid" name="bones mass"
            mass="1 1 [1 0 0,0 1 0,0 0 1]" />
    <Object type="FixedConstraint" template="Rigid" name="fixOrigin"
            indices="0" />

    <Node>
      <Object type="MechanicalObject" template="Rigid" name="articulation points"
              position="0 0 0  0.707914 0 0 0.707914
                       -1 0 0  0.707914 0 0 0.707914
                        1 0 0  0.707914 0 0 0.707914
                       -1 0 0  0.707914 0 0 0.707914
                        1 0 0  0.707914 0 0 0.707914
                       -1 0 0  0.707914 0 0 0.707914
                        1 0 0  0.707914 0 0 0.707914
                       -1 0 0  0.707914 0 0 0.707914
                        1 0 0  0.707914 0 0 0.707914" />
      <Object type="RigidRigidMapping"
              repartition="1 2 2 2 2" />
      <Object type="JointSpringForceField" template="Rigid" name="joint springs"
              spring="0 1   0 0 0 0 1 0   0 30000  0 200000   0  0 0 0  0 0 0 1
                      2 3   0 0 0 0 1 0   0 30000  0 200000   0  0 0 0  0 0 0 1
                      4 5   0 0 0 0 1 0   0 30000  0 200000   0  0 0 0  0 0 0 1
                      6 7   0 0 0 0 1 0   0 30000  0 200000   0  0 0 0  0 0 0 1" />
    </Node>
    <Node>
      <Object type="MechanicalObject" template="Vec3d"
              position="-1 -0.5 -0.5  -1 0.5 -0.5 ..." />
      <Object type="MeshTopology"
              lines="0 1  1 2  ..."
              triangles="3 1 0  3 2 1  ..." />
      <Object type="TriangleModel"/>
      <Object type="LineModel"/>
      <Object type="RigidMapping"
              repartition="0 8 8 8 8" />
    </Node>
  </Node>
</Node>
```

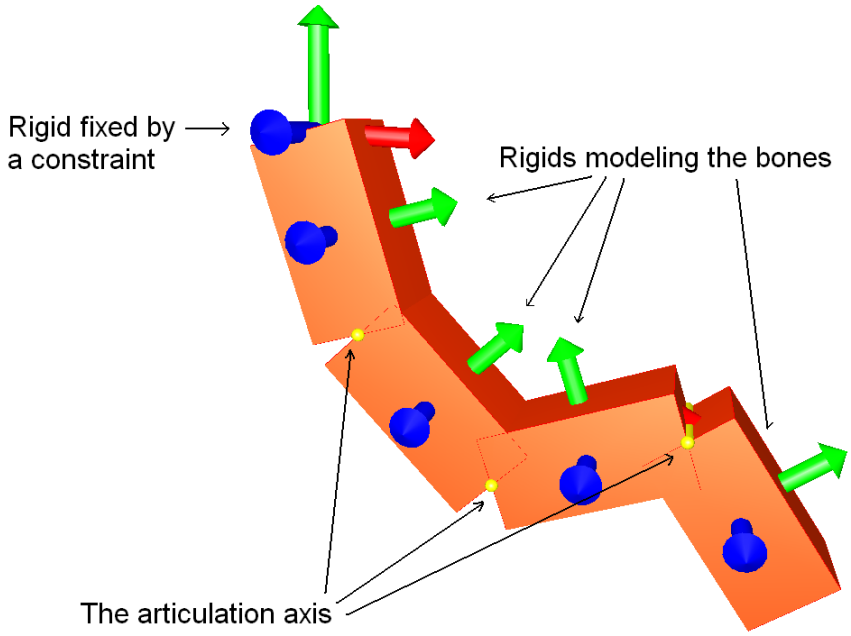


Figure 5: The pendulum is composed by 4 rigids linked one by one by articulations

In this example, we have under the first node the components to manage collisions, as usual. Under the second node, we have :

- the solver,
- the mechanical object modeling the independent rigid DOFs (5 rigids here),
- the rigid mass,
- a constraint, to fix the first rigid.

The third node (a child of the previous one) contains the components relative to the articulations :

- the mechanical object modeling articulation points. Positions and orientations are relative to their parents.
- the mapping to link the two mechanical objects, as explained before. To know which articulations belong to which bones, a repartition vector is used. Several cases for this vector are possible :
  - no value specified : every articulations belong to the first bone (classic rigid mapping).
  - one value specified (ex: repartition="2") : each bone has the same number of articulations.
  - number of bones values (like here, repartition="1 2 2 2 2") : the number of articulations is specified for each bone. For instance, here the first bone has 1 articulation, the next has 2 articulations, the next 2, Etc.
- the JointSpringForceField containing the springs (4 springs here). Each spring is defined by a list of parameters. For instance for the first spring we have "0 1 0 0 0 0 1 0 0 30000 0 200000 0 0 0 0 0 0 0 1".

- "0 1" are the indices of the two articulations the spring is attached to
- "0 0 0 0 1 0" design the free axis for the movements. "0 0 0" mean that the 3 translation axis are constrained, and "0 1 0" mean that only the Y rotation axis is free.
- "0 30000 0 2000000" are the stiffnesses for each kind of movement: "0 30000" are respectively for free translation and for constrained translation", and "0 2000000" are respectively for free rotation and for constrained rotation.
- "0" is the damping factor
- "0 0 0" is to specify the initial translation
- "0 0 0 1" is to specify the initial rotation (quaternion)

The last node contains the collision model. Nothing special here.

1.4 Skinning

The articulated body described previously models the skeleton of an object. To have the external model (for the visual model or the collision model), which follows correctly the skeleton movements, it has to be mapped with the skeleton. A skinning mapping allows us to do this link. The external model is from this moment to deform itself smoothly, i.e. without breaking points around the articulations.

The influence of the bones on each point of the external model is given by skinning weights. 2 ways are possible to set the skinning weights to the mapping :

- Either the user gives directly the weights list to the mapping. It is useful if good weights have been pre computed previsouly, like in Maya for instance.
- Else, the user defines a number of references n that will be used for mapped points. Then, each external model point will search its n nearest bones (mechanical DOFs), and then compute the skinning weights from the relation :

$$W = \frac{1}{d^2}$$

with d : the distance between the external point and the rigid DOF.

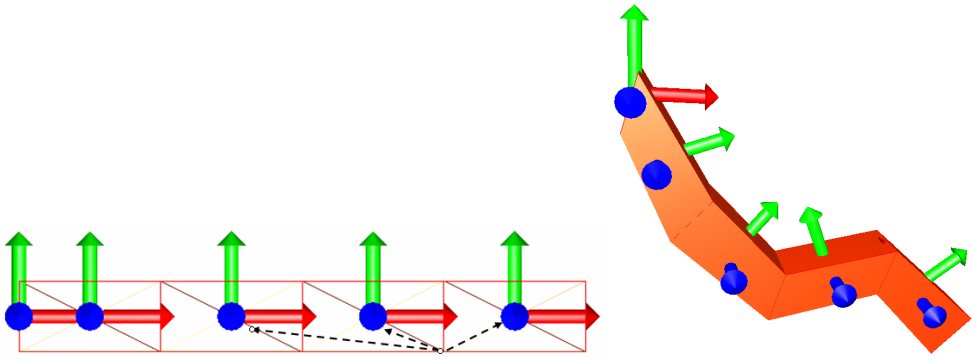


Figure 6: In the example "softArticulationsSkinned.scn" the external points compute their skinning weights from the 3 nearest DOFs