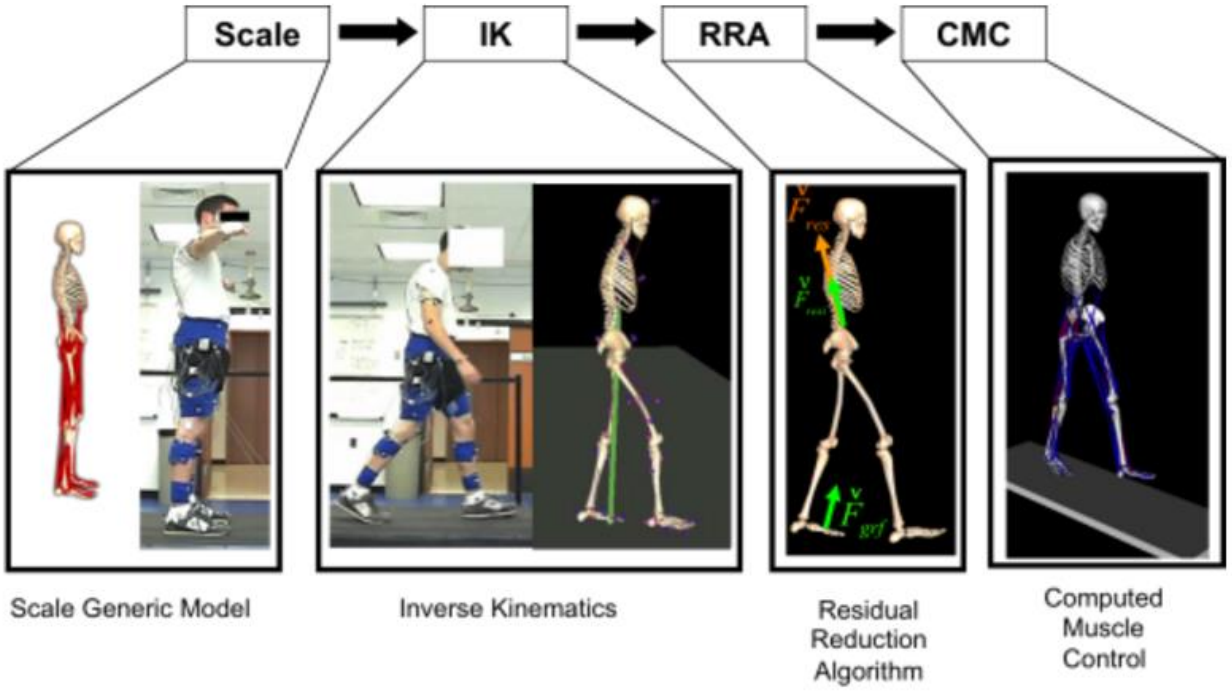
Musculoskeletal modeling

European OpenSim Workshop 2017

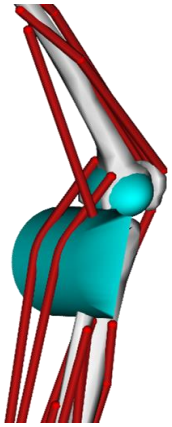
OpenSim workflow

OpenSim enables us to build, exchange, and analyze computer models of the musculoskeletal system and dynamic simulations of movement.

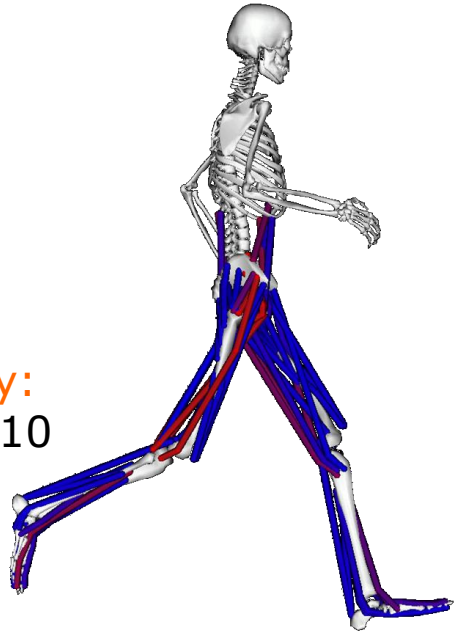


OpenSim model

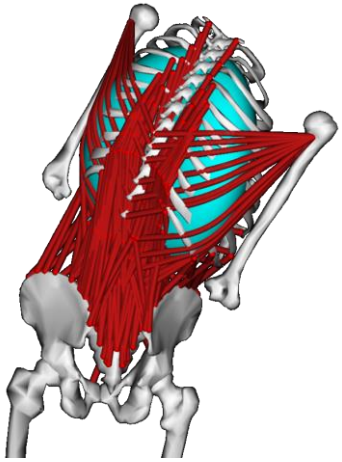
An OpenSim model represents the dynamics of a system of rigid bodies and joints that are acted upon by forces to produce motion.



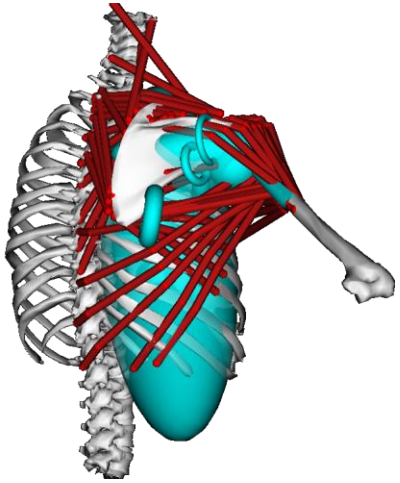
Lower-extremity:
Arnold et al, 2010



Running: Hamner et al, 2010

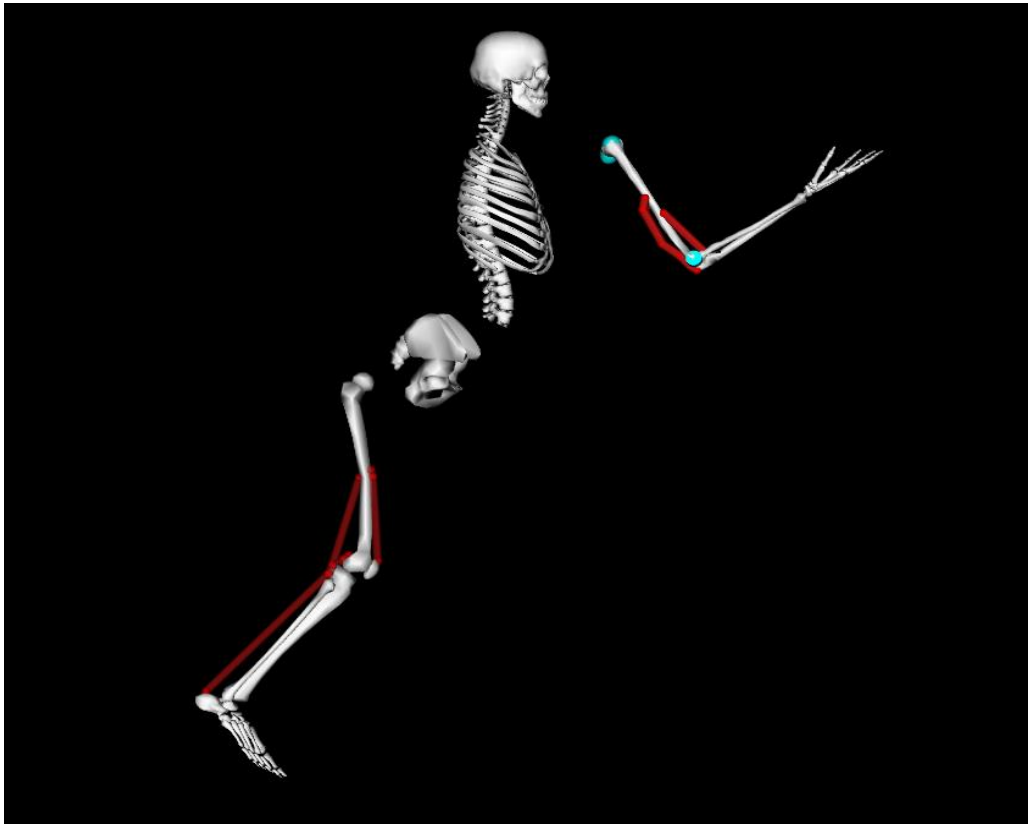


Lumbar-spine:
Christophy et al, 2011



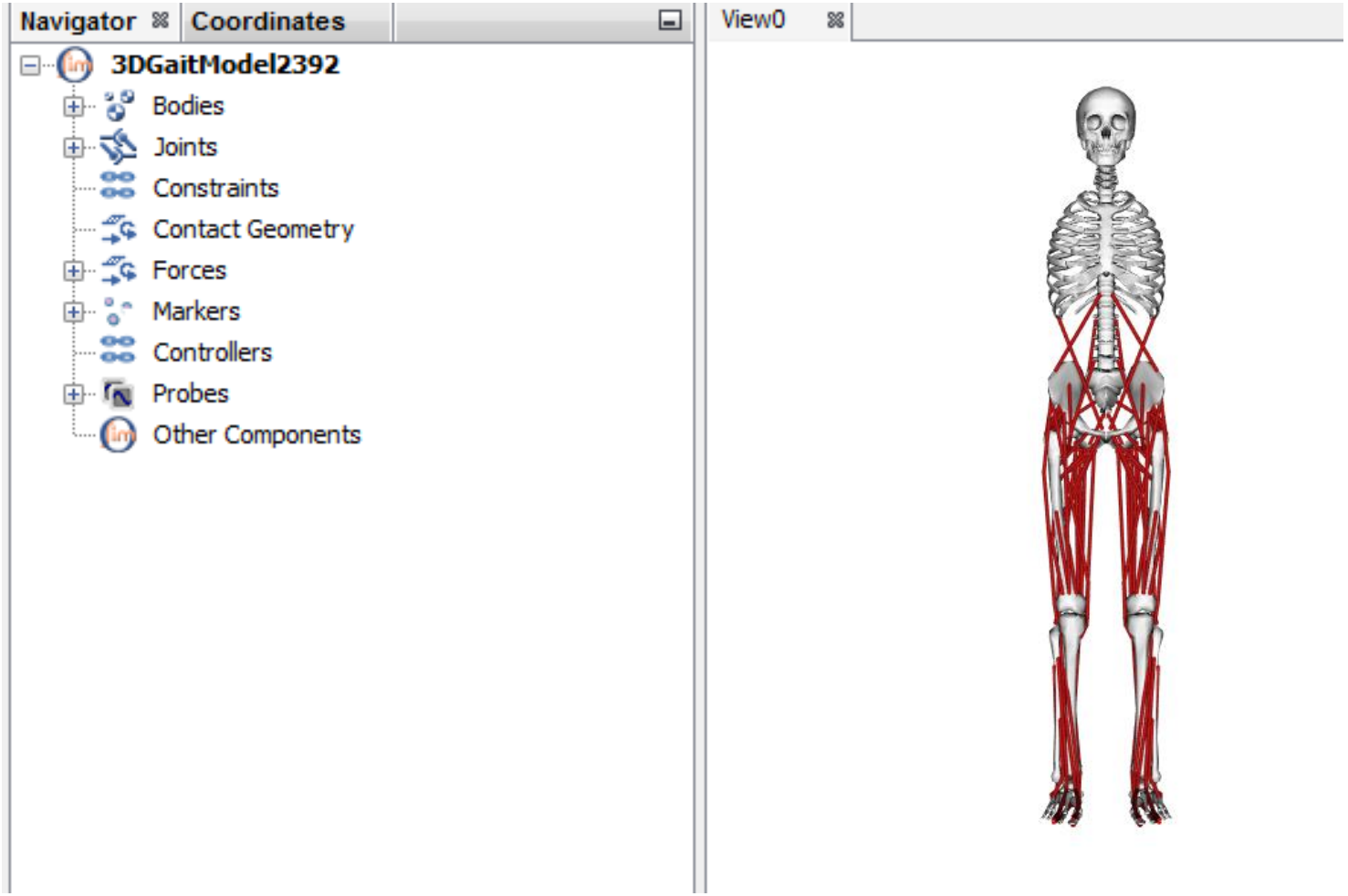
Shoulder:
Matias et al, 2016

Components of an OpenSim Model



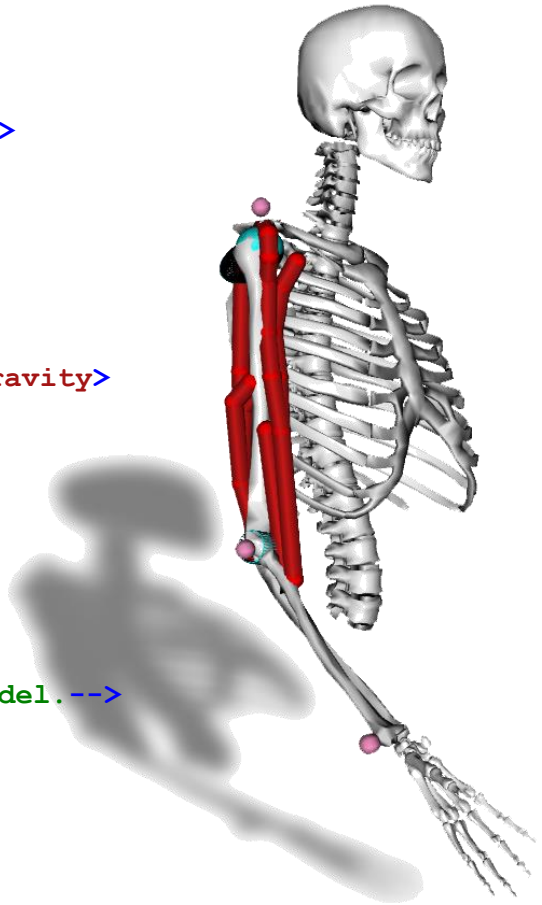
Bodies, joints, constraints, contact geometry, forces, markers, and controllers

Components of an OpenSim Model



OpenSim Model File (.osim)

```
<Model name="Arm26">
   <!—Default values for properties that are not specified.-->
   <defaults> ...
   <credits> Model authors names..
   <publications> ...
   <length_units> m </length_units>
   <force_units> N </force_units>
   <!--Acceleration due to gravity.-->
   <gravity> 0.00000000      -9.80650000       0.00000000 </gravity>
   <!--Bodies in the model.-->
   <BodySet name=""> ...
   <!--Constraints in the model.-->
   <ConstraintSet name=""> ...
   <!—All the force elements in the model.-->
   <ForceSet name=""> ...
   <!—Kinematic markers on the model.-->
   <MarkerSet name=""> ...
   <!—Surface meshes used by contact force elements in the model.-->
   <ContactGeometrySet name=""> ...
</Model>
```

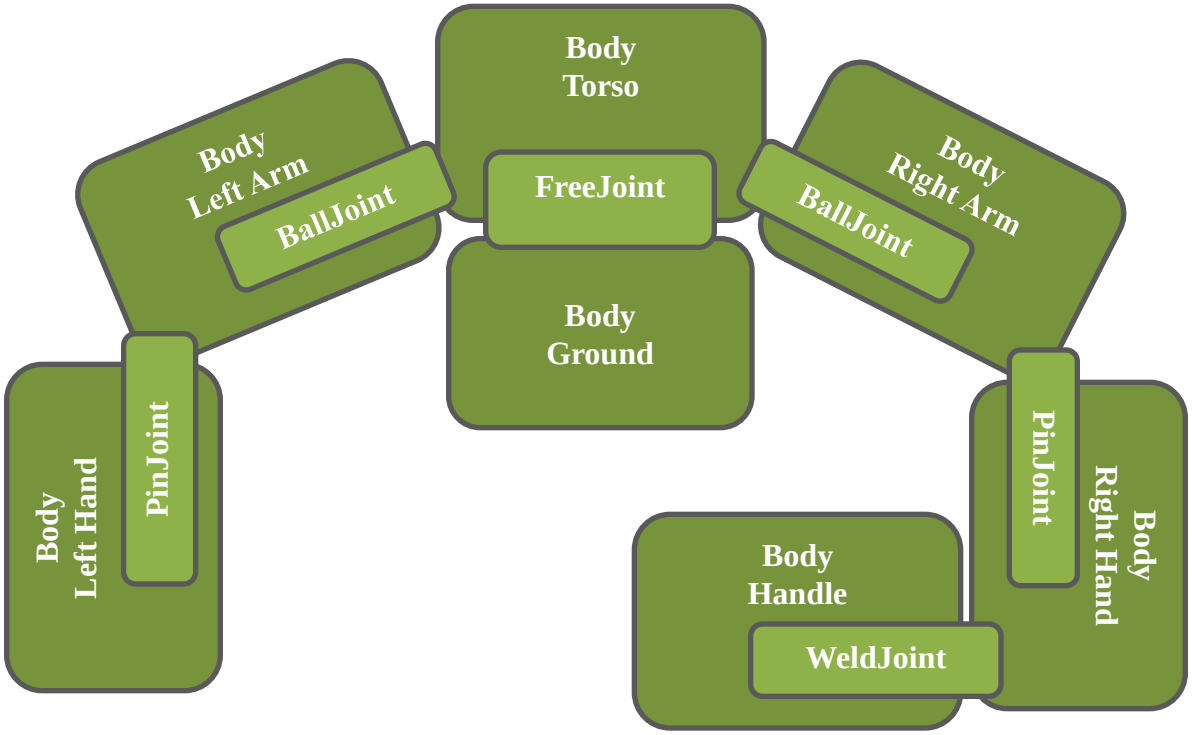


Hint

Use NotePad++, open the '.osim' file and select xml as a language. The ALT+# ,e.g. ALT+4 key combination will allow you to fold the xml tags and explore the model easily.

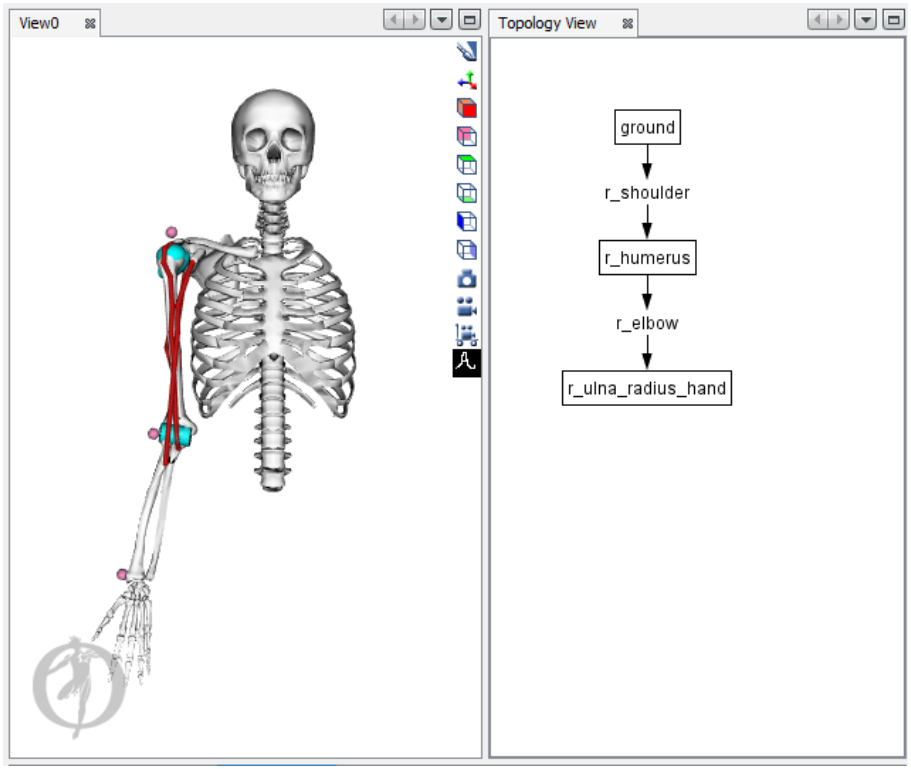
Tree Topology of Multibody Models

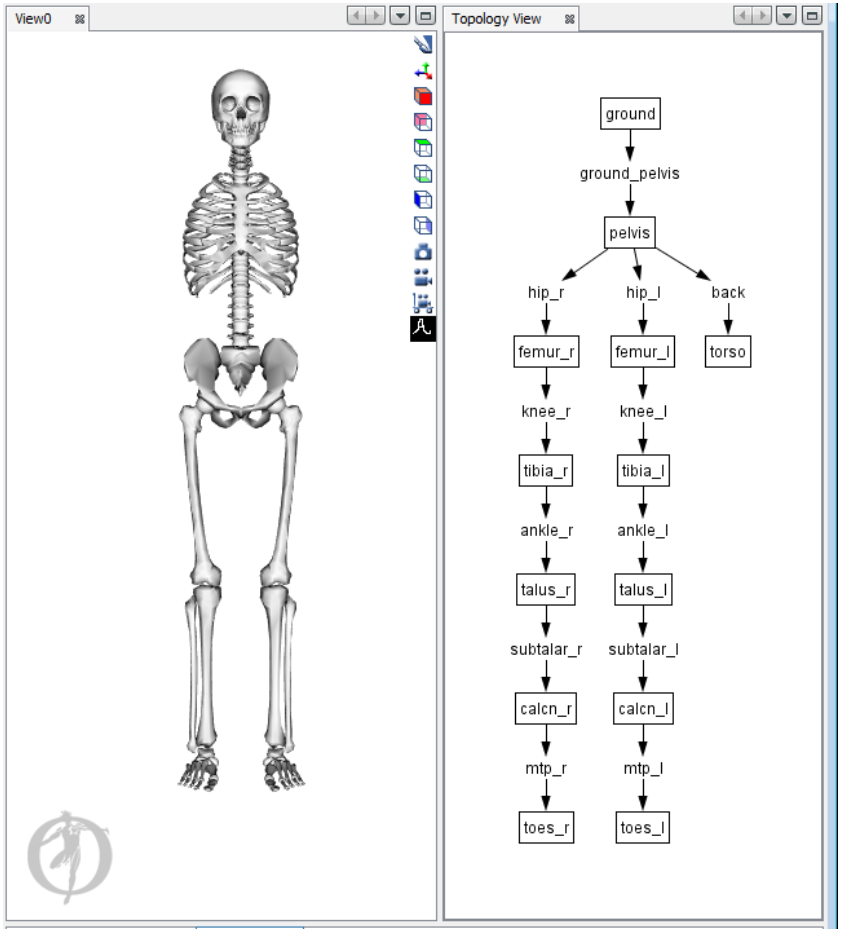
- Each body is connected to its parent body by ONE joint to create a chain or open tree structure.



Tree Topology of Multibody Models

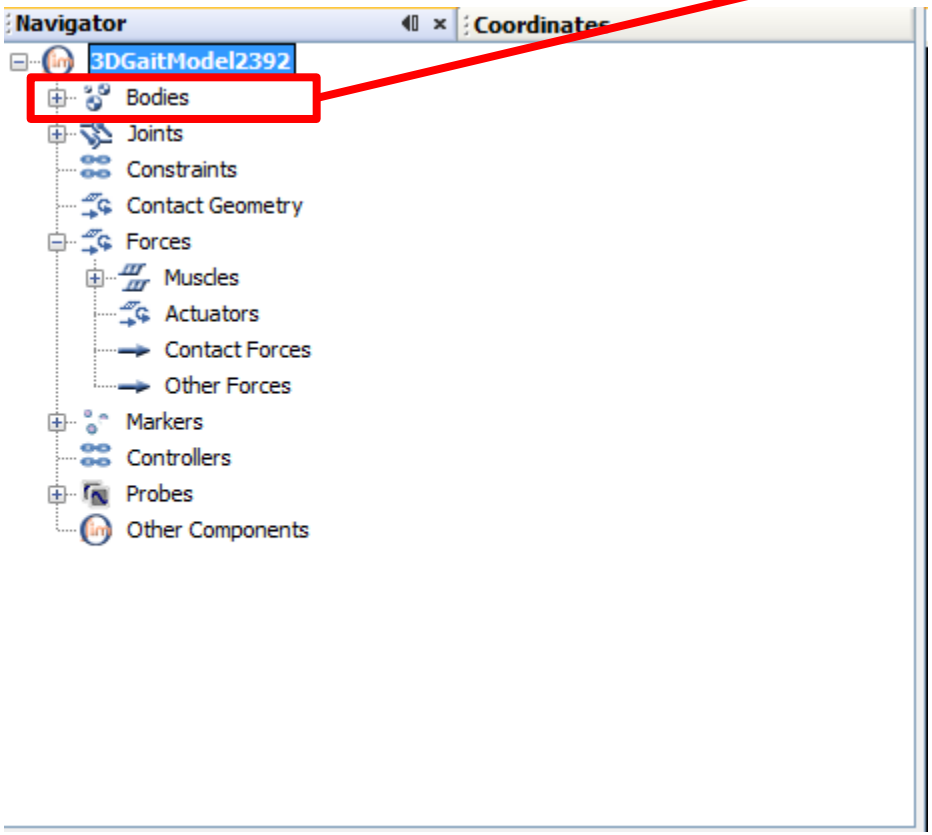
- You can view the topology of your model (Window>topology view).

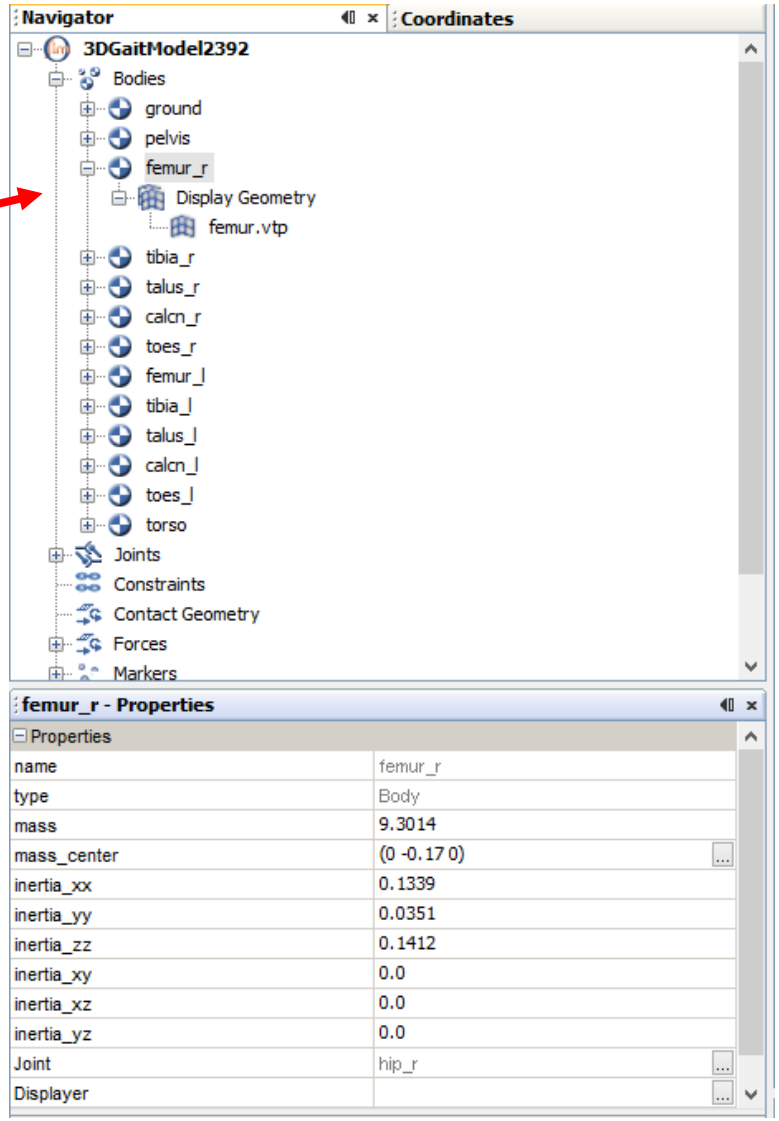




Bodies of the musculoskeletal model

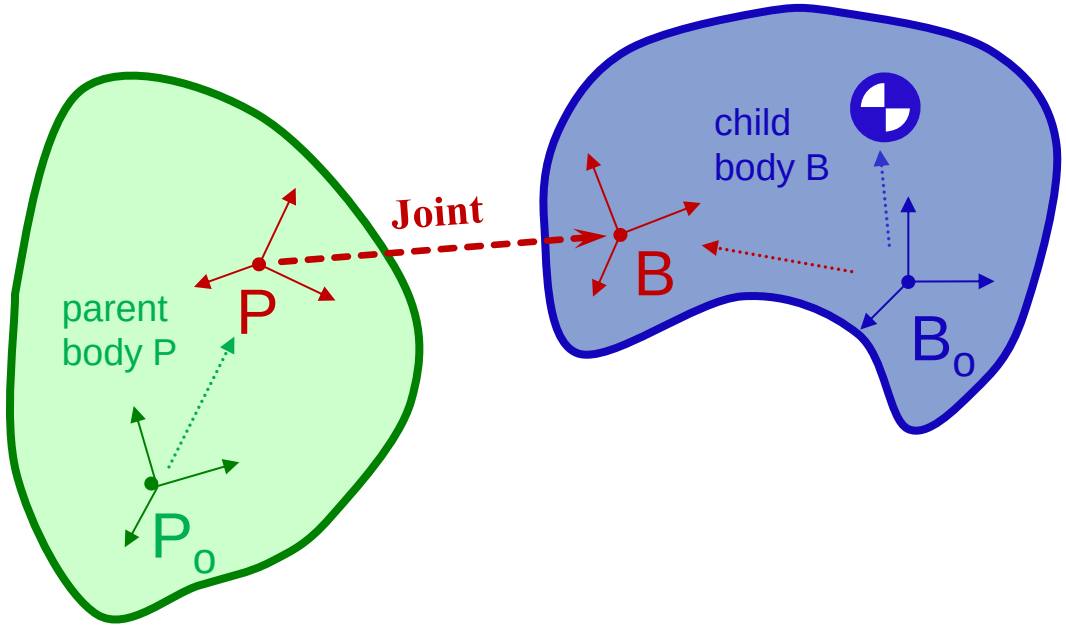
- Inertial properties
- Geometry file(s)





Body and Joint Reference Frames

A joint (in red) defines the kinematic relationship between two frames (B and P) each affixed to a rigid-body (the parent, Po, and the body being added, Bo)



B specified by joint **`location`** and **`orientation`**

P specified by joint **`locationInParent`** and **`orientationInParent`**

Joint coordinates specify the kinematics of B relative to P

Joints in an OpenSim model

WeldJoint: no coordinates (fuses bodies together)

PinJoint: one coordinate about the common Z-axis of parent and child joint frames

SliderJoint: one coordinate along common X-axis of parent and child joint frames

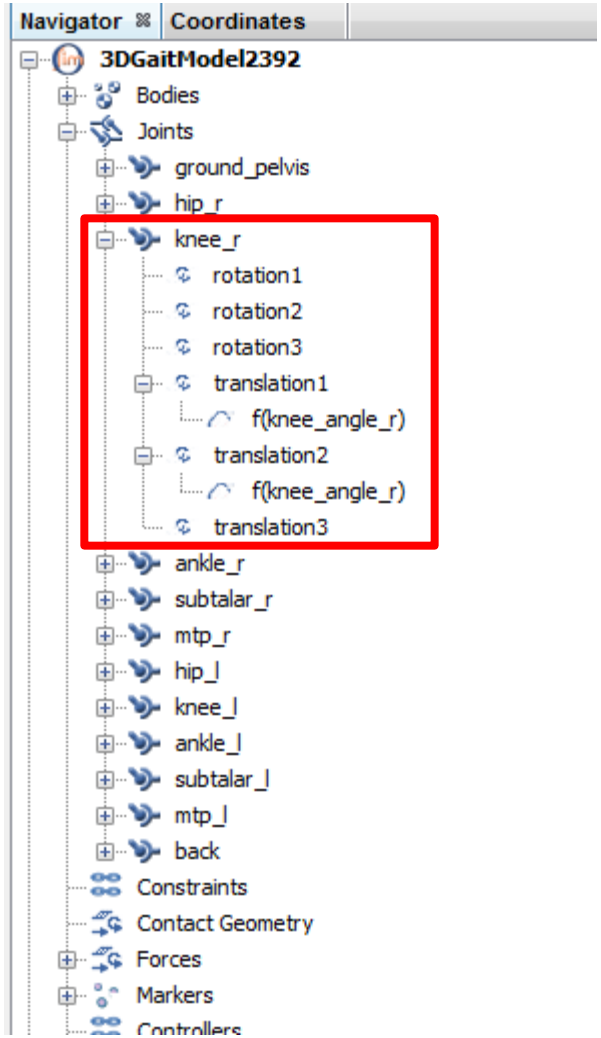
BallJoint: three rotational coordinates that are about X, Y, Z of B in P

EllipsoidJoint: three rotational coordinates that are about X, Y, Z of B in P with coupled translations such that B traces an ellipsoid

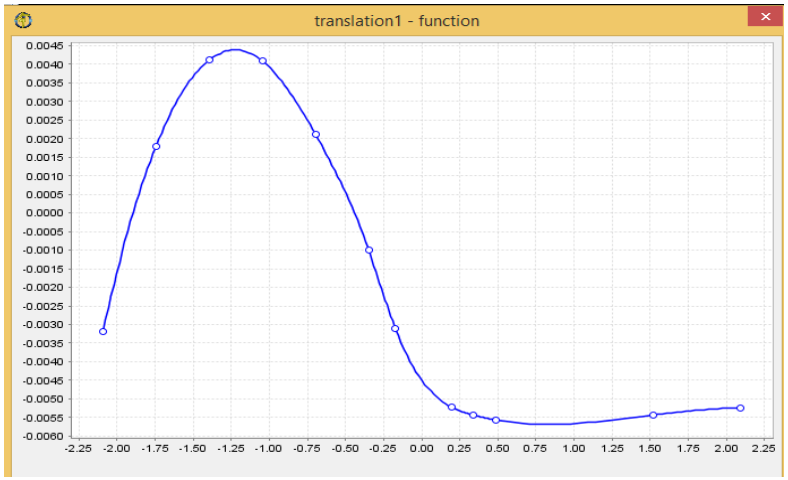
FreeJoint: six coordinates with 3 rotations and 3 translations of B in P

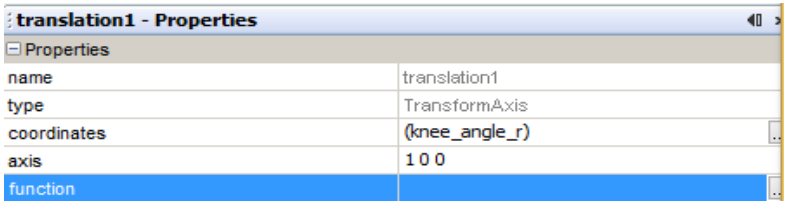
CustomJoint: user specified 1-6 coordinates and user defined spatial transform to locate B with respect to P

Joints in an OpenSim model



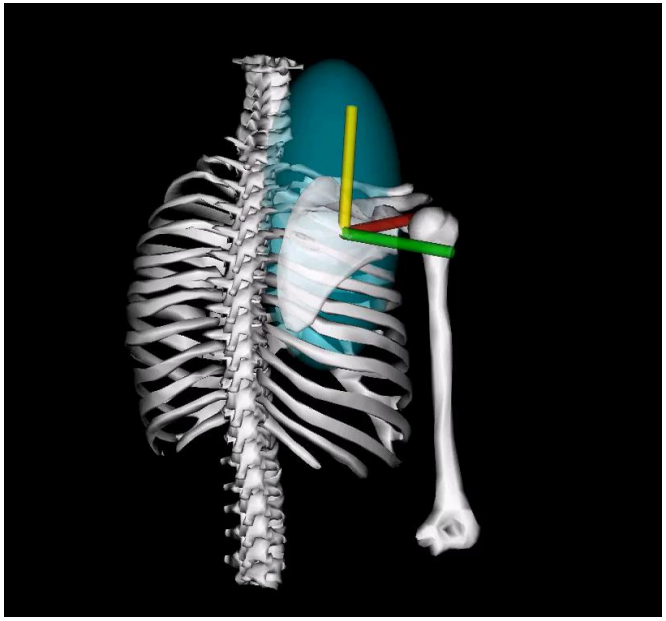
$$\begin{cases} x_{trans} = f(knee\_angle) \\ y_{trans} = f(knee\_angle) \end{cases}$$



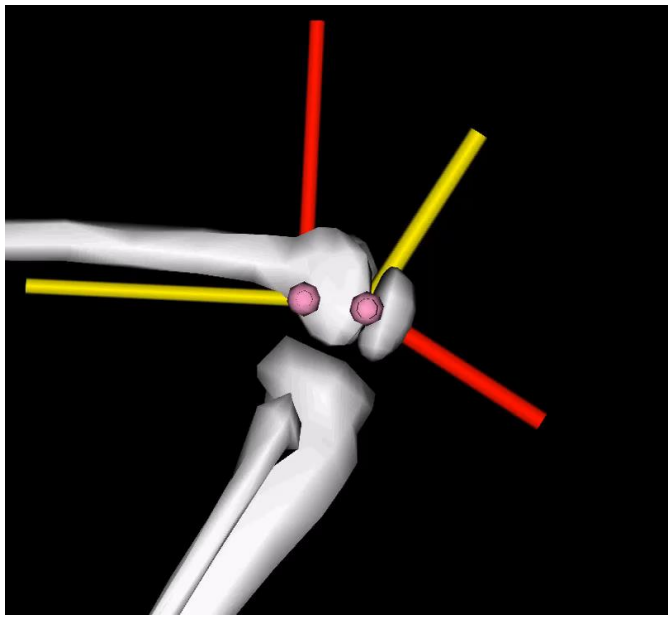


Biological joints in Opensim

- **Shoulder model** uses an ellipsoid joint to describe how the scapula slides on the thorax surface
- **Knee model** uses splines to describe the translation of the tibia w.r.t. femur as a function of knee flexion



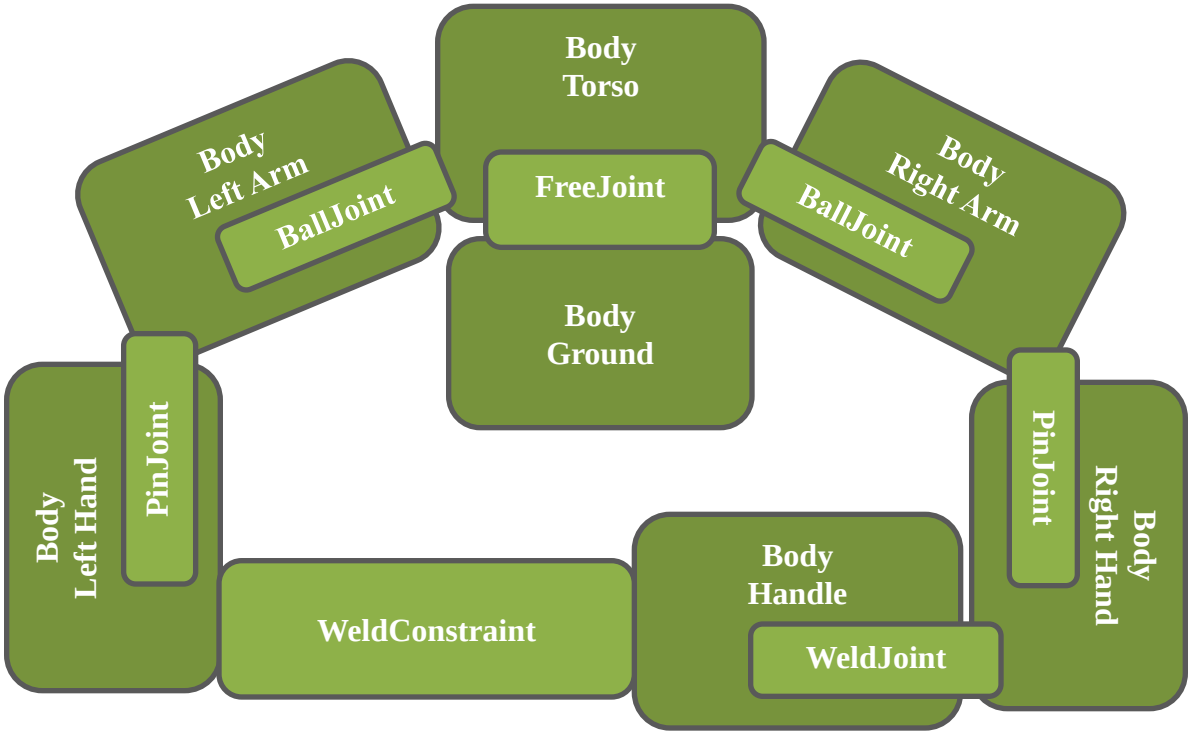
Seth et al, 2016



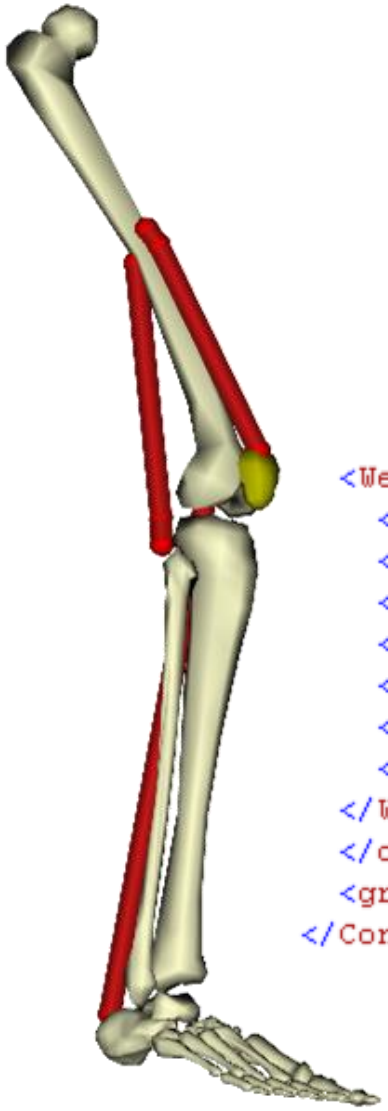
Yamaguchi et al., 1989

Tree Topology of Multibody Models

- A constraint is required to form a closed loop



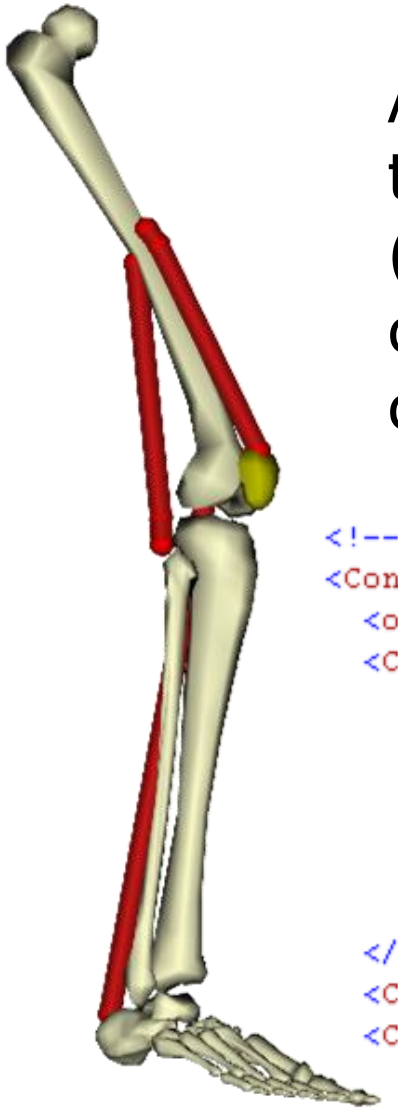
Kinematic Constraints



A **weld constraint** fixes the relative location and orientation of two bodies (i.e., no translations or rotations).

```
<WeldConstraint name="">
  <isDisabled> false </isDisabled>
  <body_1> ground </body_1>
  <body_2> calcn_r </body_2>
  <location_body_1>        0.0000000000       0.0000000000       0.0840000000
  <orientation_body_1>        0.0000000000       0.0000000000       0.00000000
  <location_body_2>        0.0000000000       0.0000000000       0.0000000000
  <orientation_body_2>        0.0000000000       0.0000000000       0.00000000
</WeldConstraint>
</objects>
<groups/>
</ConstraintSet>
```

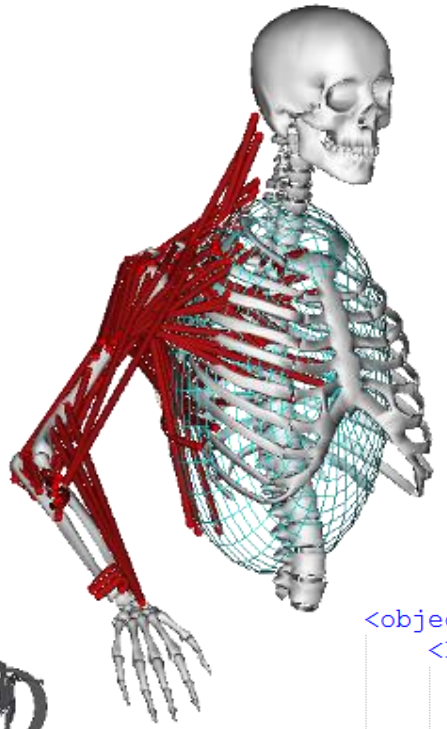
Kinematic Constraints



A **coordinate coupler constraint** relates the generalized coordinate of a given joint (the dependent coordinate) to any other coordinates in the model (independent coordinates).

```
<!--Constraints in the model.-->
<ConstraintSet name="">
  <objects>
  <CoordinateCouplerConstraint name="pat_tx_r">
    <isDisabled> false </isDisabled>
    <coupled_coordinates_function>
      <natCubicSpline name="">...
    </coupled_coordinates_function>
    <independent_coordinate_names> knee_angle_r </independent_coordinate_names>
    <dependent_coordinate_name> pat_tx_r </dependent_coordinate_name>
  </CoordinateCouplerConstraint>
  <CoordinateCouplerConstraint name="pat_ty_r">...
  <CoordinateCouplerConstraint name="pat_angle_r">...
```

Kinematic Constraints

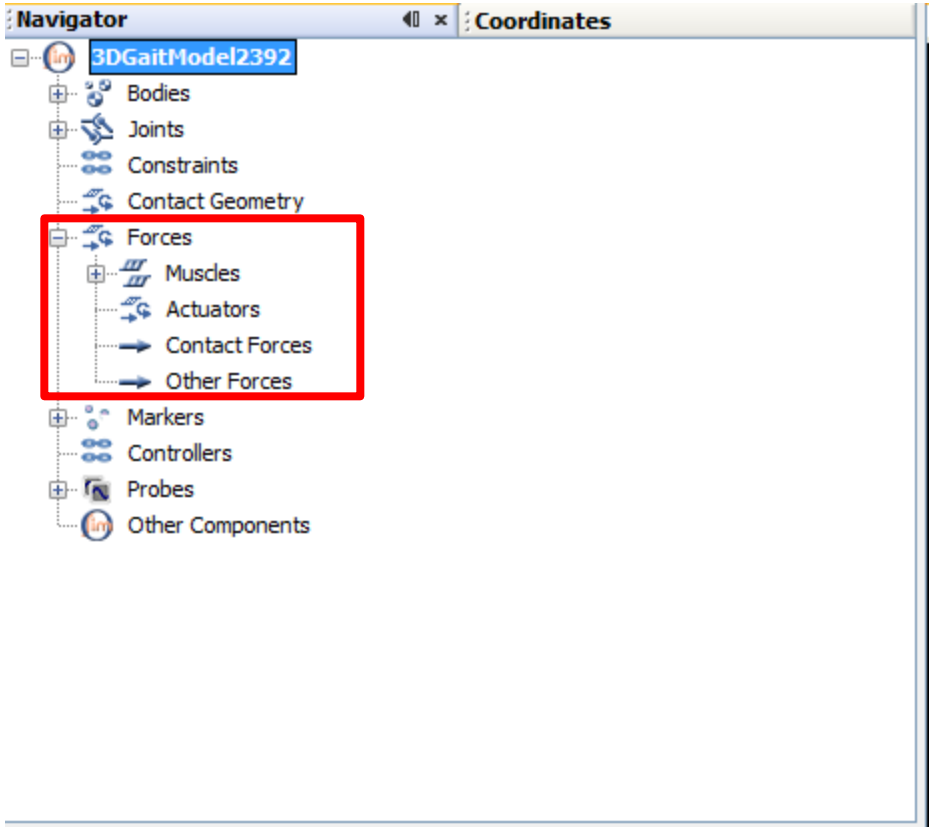


A **point constraint** fixes a point defined with respect to two bodies (i.e., no relative translations).

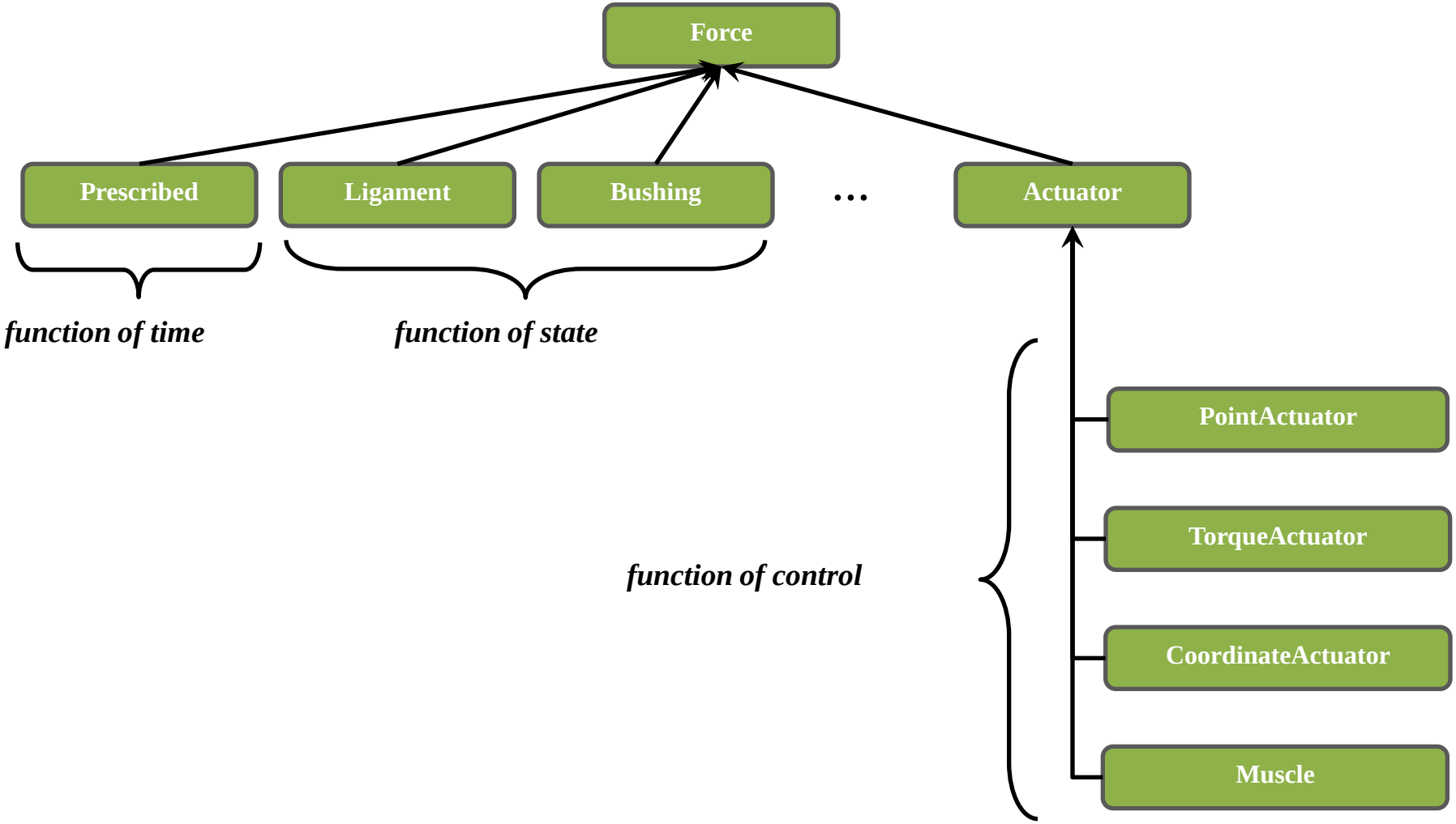
```
<objects>
    <PointConstraint name="acromio-clavicular">
        <!--Flag indicating whether the constraint is disabled or not. Disabled means that t
        <isDisabled>false</isDisabled>
        <!--Specify first of two bodies connected together by the constraint.-->
        <body_1>clavicle_r</body_1>
        <!--Specify second of two bodies connected together by the constraint.-->
        <body_2>scapula_r</body_2>
        <!--Location of the point in first body specified in body1 reference frame.-->
        <location_body_1>0.1909 0.0086 0.0003</location_body_1>
        <!--Location of the point in second body specified in body2 reference frame.-->
        <location_body_2>0 0 0</location_body_2>
    </PointConstraint>
</objects>
```

Forces in a OpenSim model

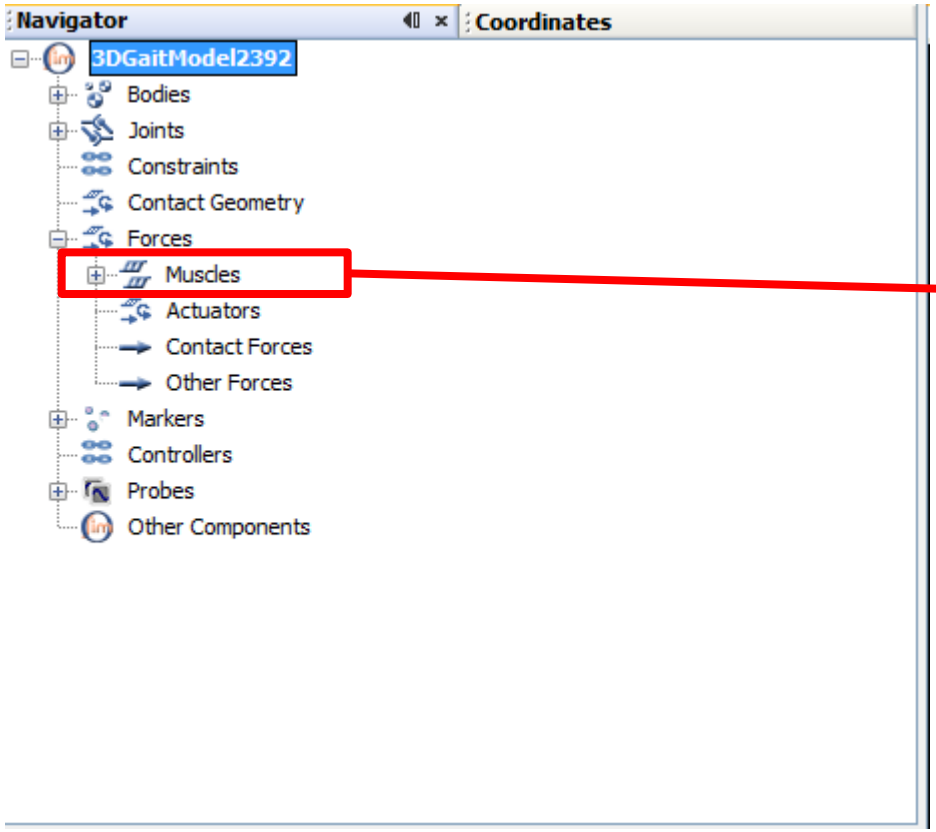
Forces

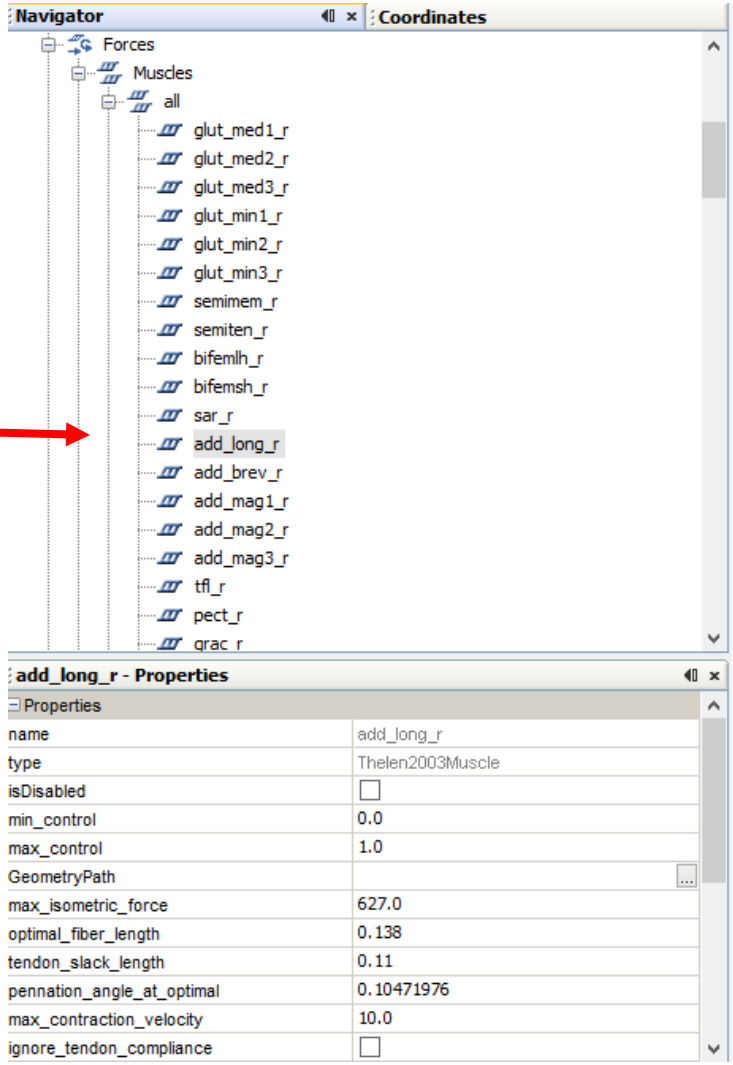


Types of Forces in OpenSim

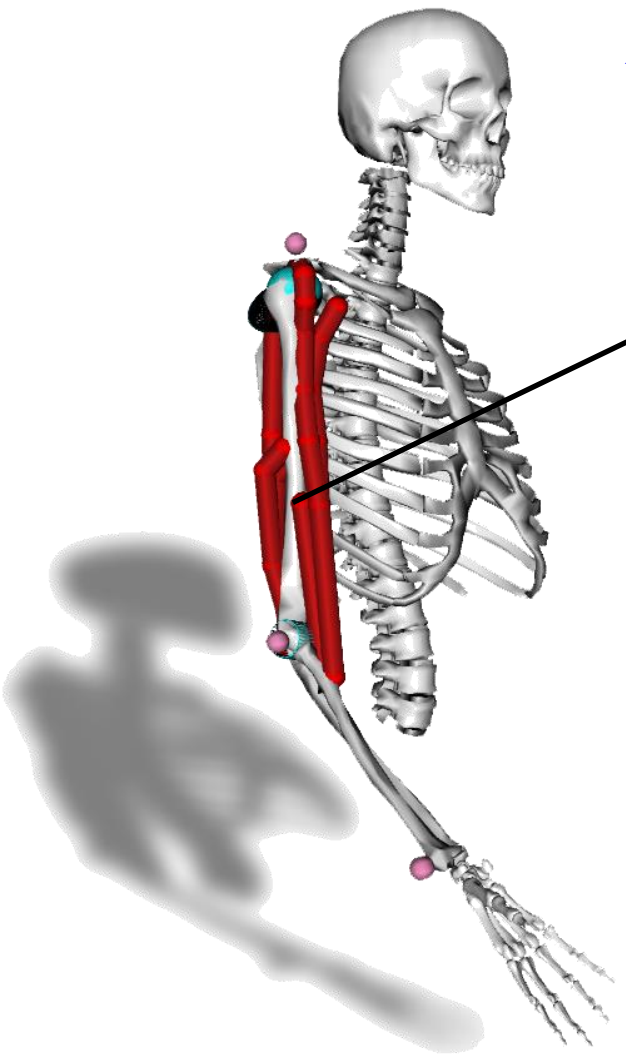


Muscle Actuator Example (GUI)





Muscle Actuator Example (OSIM file)

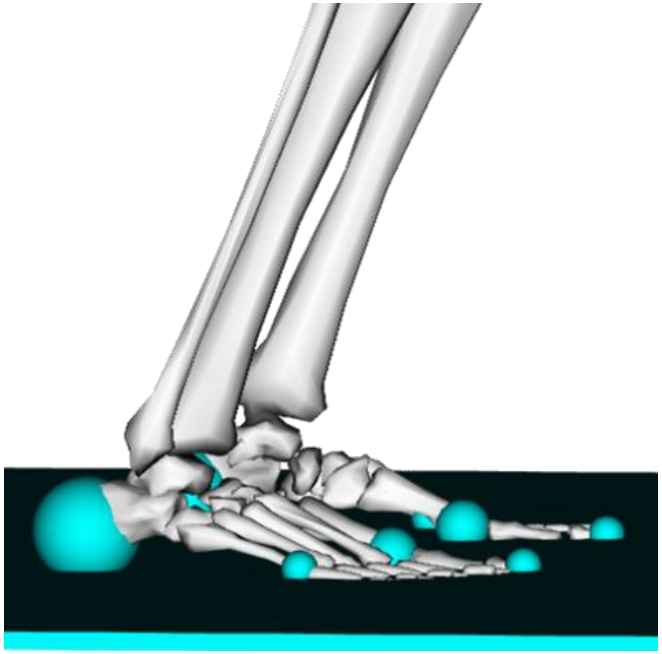


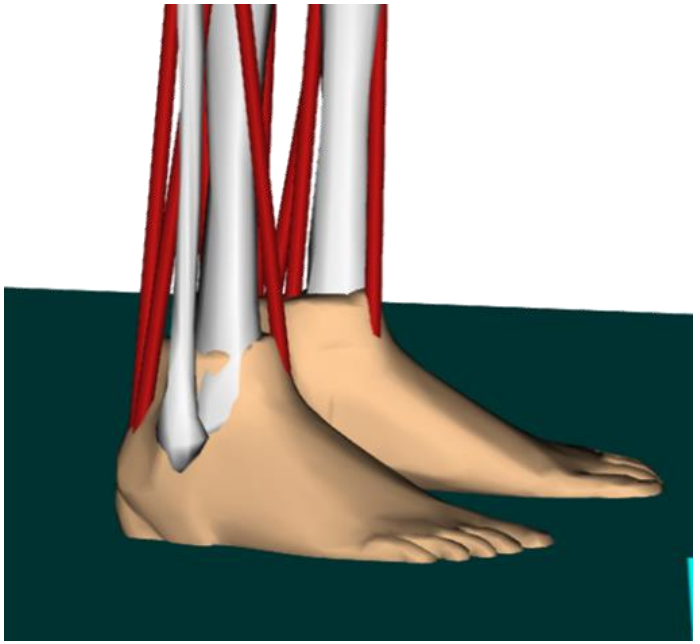
```
<Thelen2003Muscle name="brachialis_r">
   <GeometryPath name="">
      <!—- points on bodies that define the path of the muscle -->
      <PathPointSet name="">
         <objects>
            <PathPoint name="brachialis_r-P1">
               <location> -0.00240000 -0.15330000 0.00710000 </location>
               <body> humerus_r </body>
            </PathPoint>
            <PathPoint name="brachialis_r-P2">
               <location> 0.00000000  0.03100000 -0.00530000 </location>
               <body> r_ulna_radius_hand </body>
            </PathPoint>
         </objects>
         <groups/>
      </PathPointSet>
      <PathWrapSet name=""> ...
   </GeometryPath>
   <!--maximum isometric force of the muscle fibers-->
   <max_isometric_force> 972.00000000 </max_isometric_force>
   <!--optimal length of the muscle fibers-->
   <optimal_fiber_length> 0.08580000 </optimal_fiber_length>
   <!--resting length of the tendon-->
   <tendon_slack_length> 0.05300000 </tendon_slack_length>
   <!--angle between tendon and fibers at optimal fiber length-->
   <pennation_angle> 0.00000 </pennation_angle>
   <!--time constant for ramping up of muscle activation-->
   <activation_time_constant> 0.01000000 </activation_time_constant>
   <!--time constant for ramping down of muscle activation-->
   <deactivation_time_constant> 0.04000000 </deactivation_time_constant>
   <!--maximum contraction velocity at full activation (fiber length/s)-->
   <Vmax> 10.00000000 </Vmax>
   ...
</Thelen2003Muscle>
```

Contact modeling in Opensim

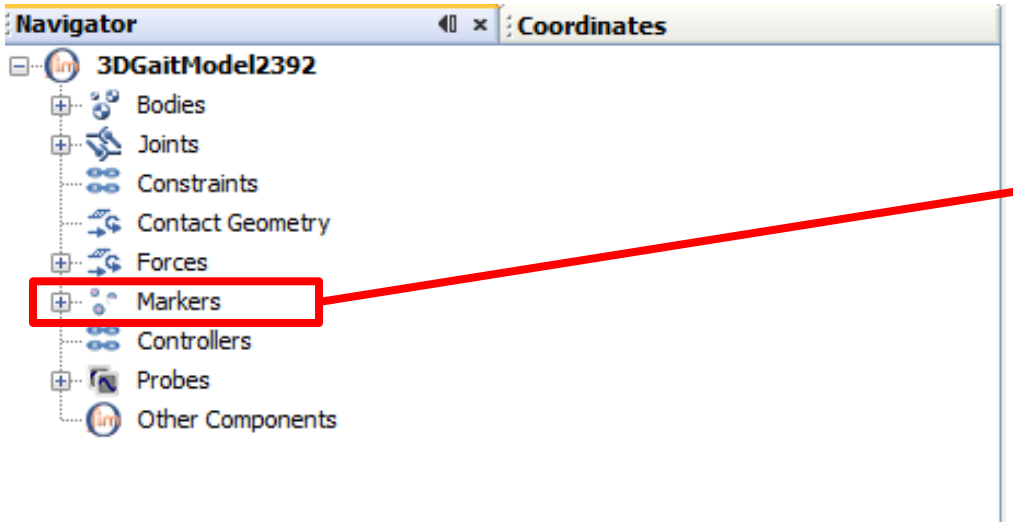
Deformation-Based Contact Forces

- Hunt-Crossley for analytical shapes
- Elastic foundation for an arbitrary mesh





Markers in an OpenSim model

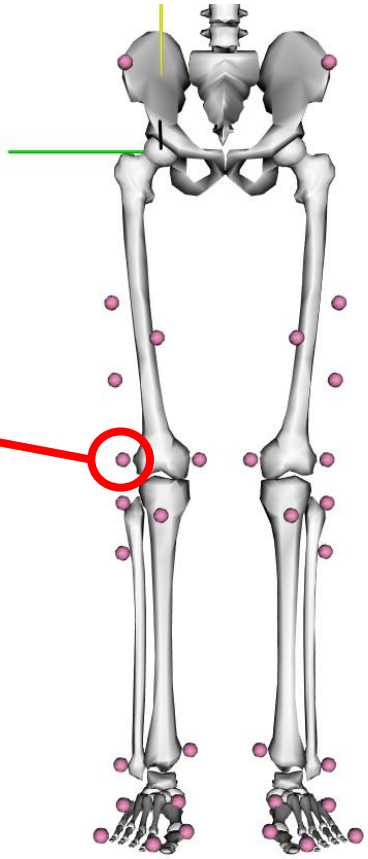


- Referred to as **virtual markers** as opposed to the experimental markers

Markers

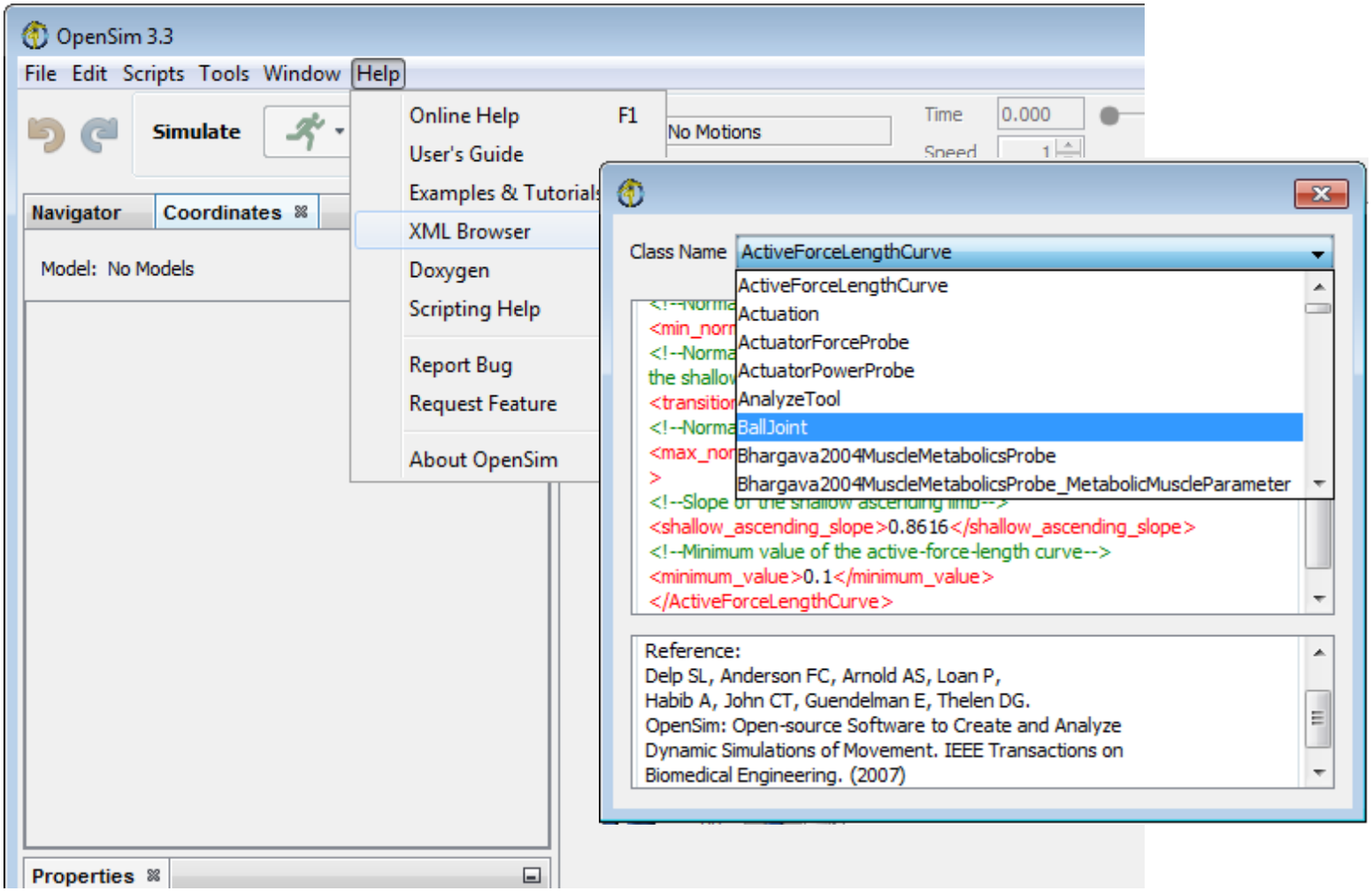
- Rigidly connected to bodies
- Location expressed in local coordinates

```
<Marker name="R.Knee.Lat">
    <!--Body segment in the model on which the marker resides.-->
    <body>femur_r</body>
    <!--Location of a marker on the body segment.-->
    <location> -0.0034701 -0.426099 0.0613926</location>
    <!--Flag (true or false) specifying whether or not a marker should be kept f
    <fixed>false</fixed>
</Marker>
<Marker name="R.Knee.Med">
    <!--Body segment in the model on which the marker resides.-->
    <body>femur_r</body>
    <!--Location of a marker on the body segment.-->
    <location> 0.000330306 -0.443005 -0.0596931</location>
    <!--Flag (true or false) specifying whether or not a marker should be kept f
    <fixed>false</fixed>
</Marker>
```



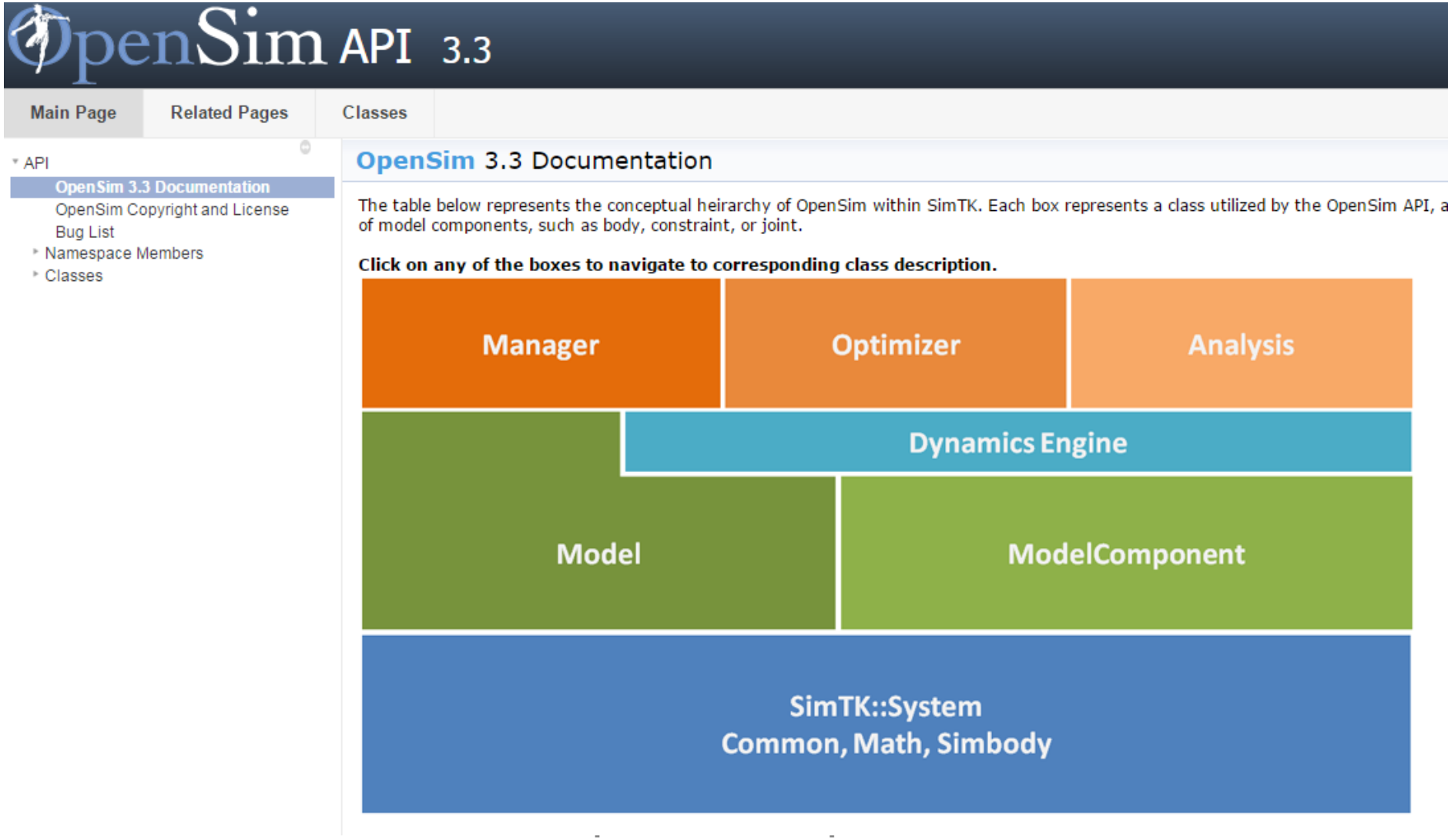
How to find what you need (1)

- Help>XML Browser



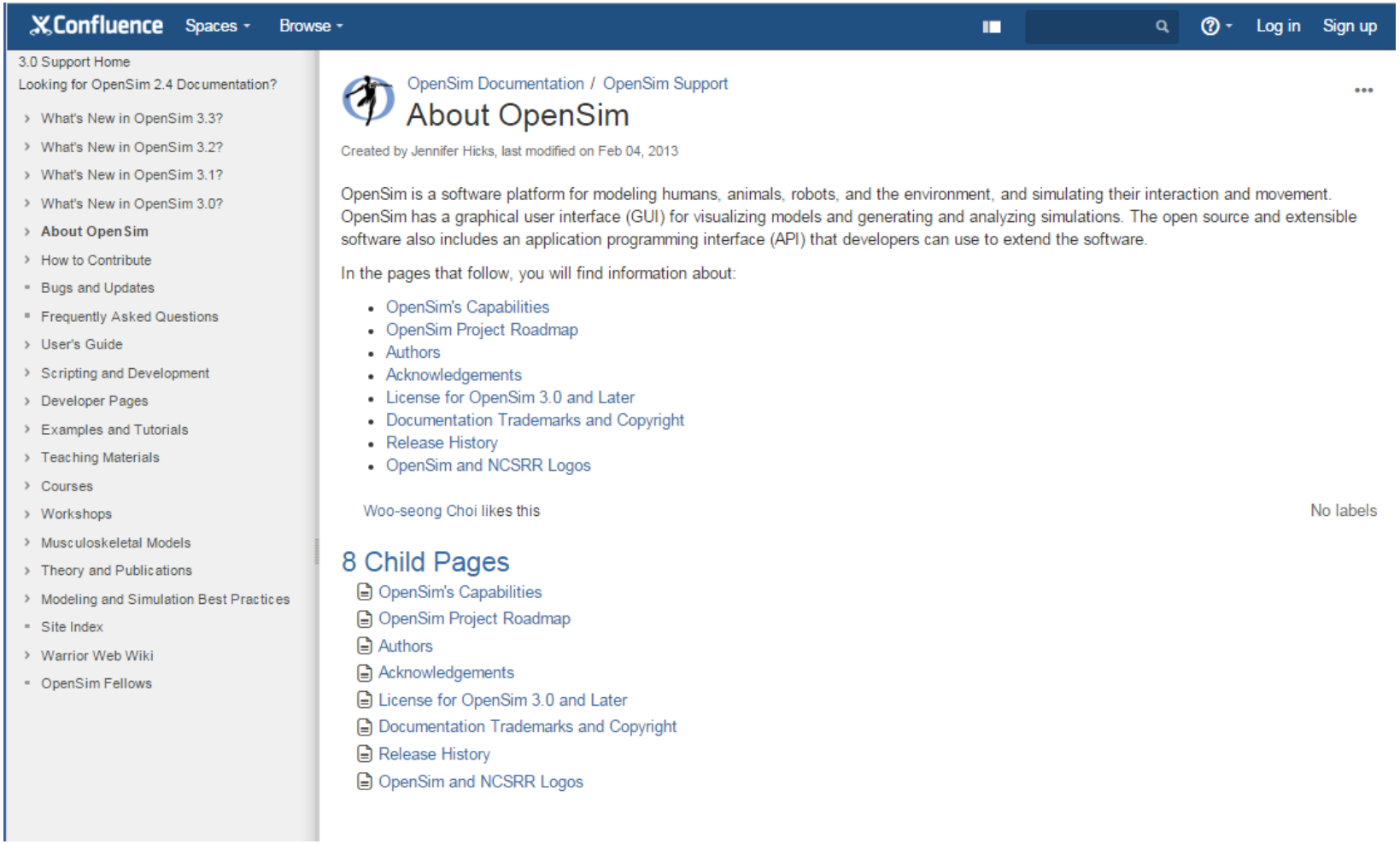
How to find what you need (2)

- OpenSim_DIR\sdk\doc\OpenSimAPI.html



How to find what you need (3)

- Confluence website



http://simtk-confluence.stanford.edu:8080/display/OpenSim/OpenSim+Support