### Agenda: January 27th

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 – 9:00</td>
<td>Verify your Opensim installation</td>
</tr>
<tr>
<td>9:00 – 9:30</td>
<td>Introducing faculty and participants</td>
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<tr>
<td></td>
<td><em>Ilse Jonkers &amp; Friedl De Groote</em></td>
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<tr>
<td>9:30 – 10:00</td>
<td>Musculoskeletal modeling in Opensim - Use and application</td>
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<tr>
<td></td>
<td><em>Ilse Jonkers</em></td>
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<tr>
<td>10:00 – 10:30</td>
<td>Data import, marker set definition, and scaling</td>
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<td></td>
<td><em>Marjolein van der Krogt</em></td>
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<tr>
<td>10:30 – 11:00</td>
<td>Coffee</td>
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<tr>
<td>11:00 – 13:00</td>
<td>Work on your own project</td>
</tr>
<tr>
<td>13:00 – 14:00</td>
<td>Lunch</td>
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<tr>
<td>14:00 – 14:30</td>
<td>Inverse Kinematics</td>
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<td></td>
<td><em>Friedl De Groote</em></td>
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<td>14:30 – 16:00</td>
<td>Work on your own project</td>
</tr>
<tr>
<td>16:00-16:30</td>
<td>Coffee</td>
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<td>16:30-17:00</td>
<td>Inverse Dynamics</td>
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<td><em>Giordano Valente</em></td>
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<tr>
<td>17:00-18.00</td>
<td>Work on your own project</td>
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OpenSim is a repository of models

Running: Hamner et al, 2010

Lower-extremity: Arnold et al, 2010

Lumbar-spine: Christophy et al, 2011

Shoulder: Matias et al, in prep.
Components of an OpenSim Model
What is a musculoskeletal model?

1. **Skeleton:**
   - Bones are rigid bodies
   - Joints permit motion between bodies
   - Constraints limit motion

2. **Muscles:**
   - Specialized forces

3. **Other forces:**
   - PrescribedForce
   - BushingForce
   - CoordinateActuator
   - Contact
What is a musculoskeletal model?

Model
<Model name="Arm26">
  <!-- Default values for properties that are not specified.-->
  <defaults>
    <credits> Model authors names..
    <publications> ...
    <length_units> m
    <force_units> N
    <!-- Acceleration due to gravity. -->
    <gravity> 0.00000000
    <!-- Bodies -->
    <BodySet name="">
    <!-- Constraints -->
    <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="">
  </defaults>
</Model>
Tree Topology of Multibody Models

Each body is connected by ONE joint to create a chain or open tree structure.
Bodies of the musculoskeletal model

Bodies
Defining a Body and its Joint

```xml
<Body name="block">
  <mass> 5.00 </mass>
  <mass_center>0.0 0.0 0.0 </mass_center>
  <inertia_xx> 0.1 </inertia_xx>
  ...
  <inertia_yz> 0.0 </inertia_yz>
</Body>

<!--Joint connects the block to ground. -->

<Joint>
```
Biological joints in Opensim

- define novel joint types (e.g. Ellipsoid)
- customizable “spline” joints (e.g. Knee)
Joints in a musculoskeletal model

Joint
Joints in a musculoskeletal model

Joint
Body and Joint Reference Frames

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

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

Joint coordinates specify the kinematics of B relative to P
Defining a Body and its Joint

```xml
<Joint>
  <SliderJoint name="">
    <parent_body>ground</parent_body>
    <location_in_parent>0.0 0.0 0.0</location_in_parent>
    <!-- 45 degrees in the horizontal plane -->
    <orientation_in_parent>0.0 0.7853981633974483 0.0</orientation_in_parent>
    <location>0.0 -0.1 0.0</location>
    <orientation>0.0 0.7853981633974483 0.0</orientation>
    <!-- Generalized coordinates parameterizing this joint. -->
    <CoordinateSet name="">
      <objects>
        <Coordinate name="block_trans">
          <!-- Coordinate can describe rotational, translational, or coupled. -->
          <motion_type>translational</motion_type>
          <default_value>0.00000000</default_value>
          <range>-10 10</range>
          <locked>false</locked>
        </Coordinate>
      </objects>
    </CoordinateSet>
  </SliderJoint>
</Joint>
```

"VisbleObject name="" ...
Kinematic Constraints

<!--Constraints in the model-->
<ConstraintSet name="">
<objects>
<CoordinateCouplerConstraint name="pat_tx_r">
  <isDisabled> false </isDisabled>
  <coupled_coordinates_function>
    <natCubicSpline name="">
      ...
    </natCubicSpline>
  </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>
<CoordinateCouplerConstraint name="pat_angle_r">
  ...
</CoordinateCouplerConstraint>
<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 </location_body_1>
  <orientation_body_1> 0.0000000000 0.0000000000 0.0000000000 </orientation_body_1>
  <location_body_2> 0.0000000000 0.0000000000 0.0000000000 </location_body_2>
  <orientation_body_2> 0.0000000000 0.0000000000 0.0000000000 </orientation_body_2>
</WeldConstraint>
</objects>
</ConstraintSet>
Available Joints and Constraints

<WeldJoint>: No $q$’s, adds body frame to parent

<PinJoint>: One $q$, rotation about common Z

<SliderJoint>: One $q$, translation along common X

<BallJoint>: Three $q$’s, rotation about body-fixed X, Y, Z

<FreeJoint>: Six $q$’s, rotations like Ball and 3 translations

<CustomJoint>: User-defined SpatialTransform, 1 to 6 $q$’s

<WeldConstraint>: frames on two bodies are fixed

<PointConstraint>: points on two bodies are fixed

<CoordinateCouplerConstraint>: $q_{dep} = F(q_{ind})$
Tree Topology of Multibody Models

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

Constraint is required to form a closed loop.
Forces in a musculoskeletal model

Forces
Types of Forces in OpenSim

- Prescribed
- Ligament
- Bushing
- Actuator
  - PointActuator
  - TorqueActuator
  - CoordinateActuator
  - Muscle

*function of time*
*function of state*
*function of control*
Muscle Actuator Example

```xml
<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>
    </PathPointSet>
  </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>0.000000</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>
```
Muscle Actuator Example

OpenSim Workshop
Contact modeling in Opensim

Deformation-Based Contact Forces

- Hunt-Crossley for analytical shapes
- Elastic foundation for an arbitrary mesh
Markers in a musculoskeletal model

Markers
- Sternum
- R.Acromion
- L.Acromion
- Top.Head
- R.ASIS
- L.ASIS
- V.Sacral
- R.Thigh.Upper
- R.Thigh.Front
- R.Thigh.Rear
- R.Knee.Lat
- R.Knee.Med
- R.Shank.Upper
- R.Shank.Front
- R.Shank.Rear
- R.Ankle.Lat
- R.Ankle.Med
- R.Heel
- R.Midfoot.Sup
- R.Midfoot.Lat
- R.Toe.Lat
Markers

<MarkerSet>
  <objects>
    <Marker name="CLAV">
      <!-- Body segment in the model on which the marker resides. -->
      <body>torso</body>
      <!-- Location of a marker on the body segment. -->
      <location> 0.02 0.39 0</location>
      <!-- Flag (true or false) specifying whether or not a marker should be kept fixed in the marker placement step. i.e. If false, the marker is allowed to move. -->
      <fixed>false</fixed>
    </Marker>
    <Marker name="RSHO">
      <!-- Body segment in the model on which the marker resides. -->
      <body>torso</body>
      <!-- Location of a marker on the body segment. -->
      <location> -0.040383 0.388169 0.193032</location>
      <!-- Flag (true or false) specifying whether or not a marker should be kept fixed in the marker placement step. i.e. If false, the marker is allowed to move. -->
      <fixed>false</fixed>
    </Marker>
  </objects>
</MarkerSet>