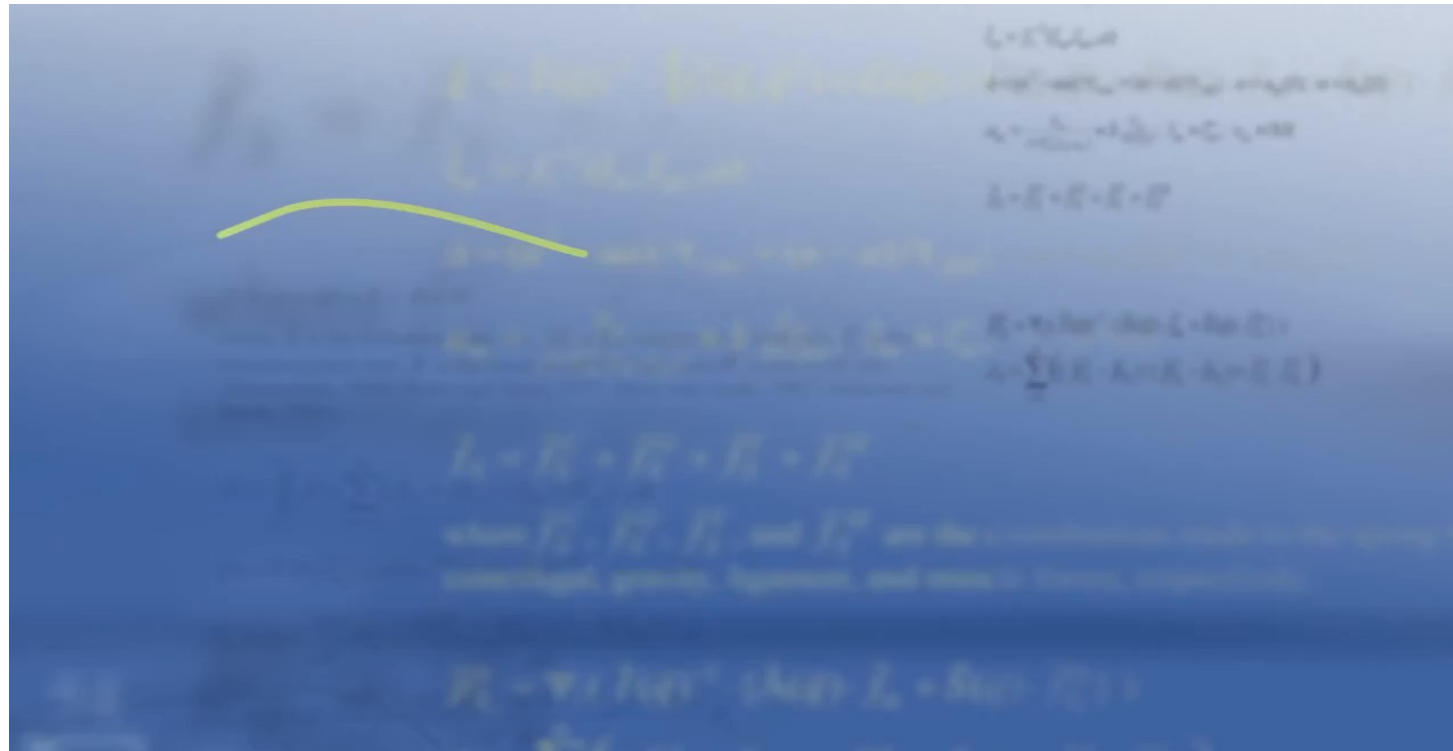


Modeling and Simulation Introduction

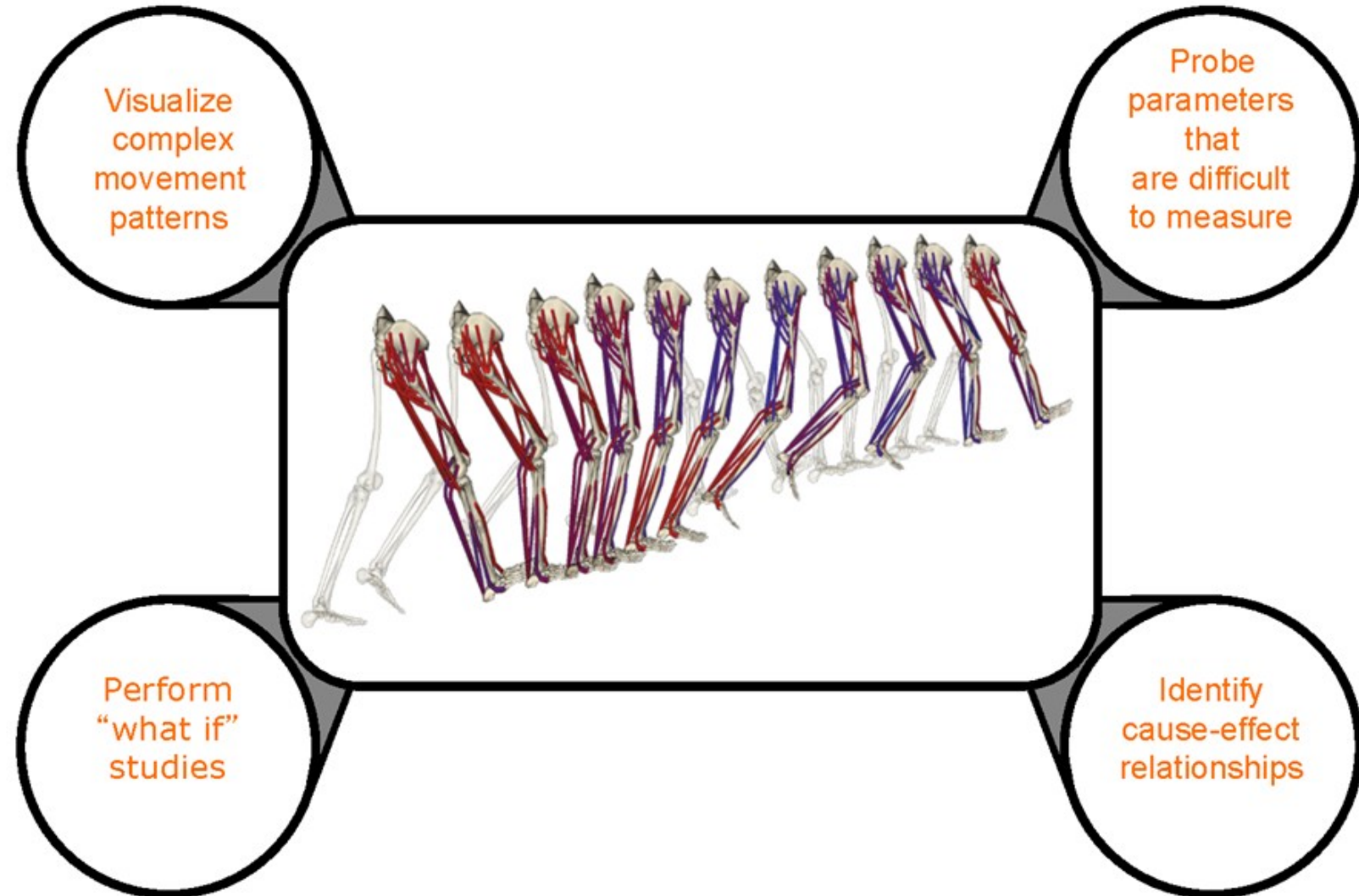
Dimitar Stanev

What is OpenSim?



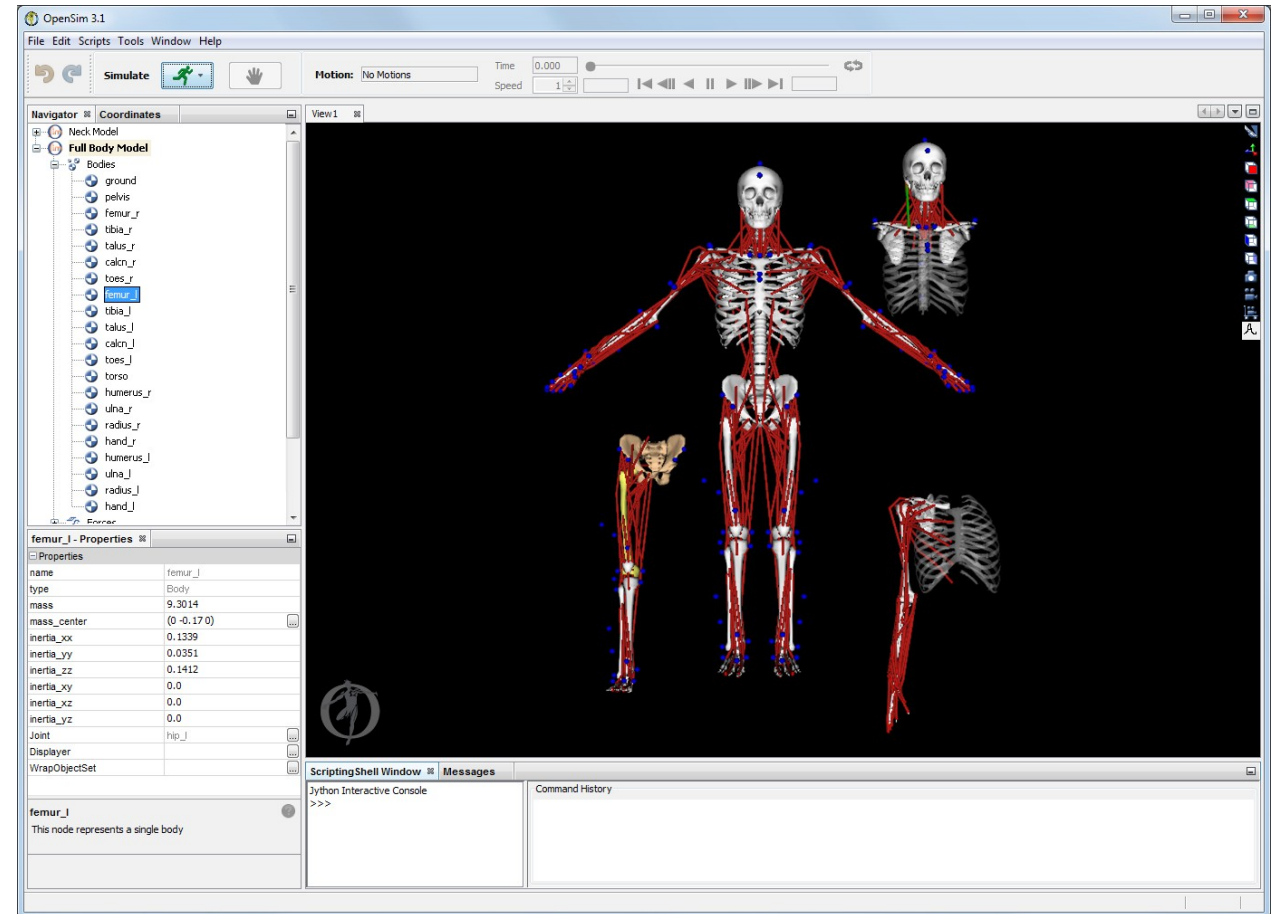
OpenSim Framework

- Open-source
- Extensible
- Widely available
- General purpose
- Standard format for exchanging models
- Reproduce results
- Reusability
- Free

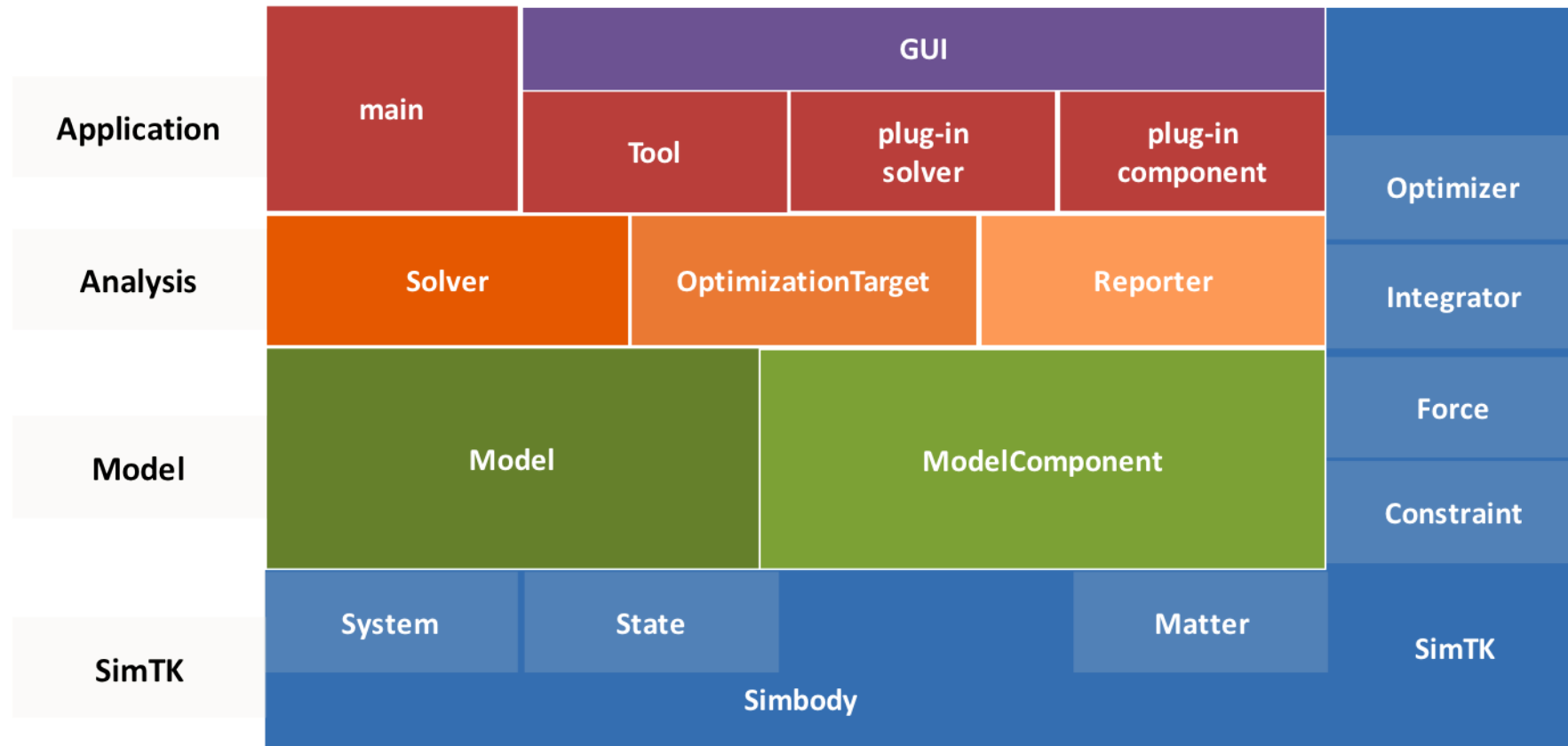


GUI

- Model editing
- Visualization of recorded and simulated data
- Analysis and simulation tools

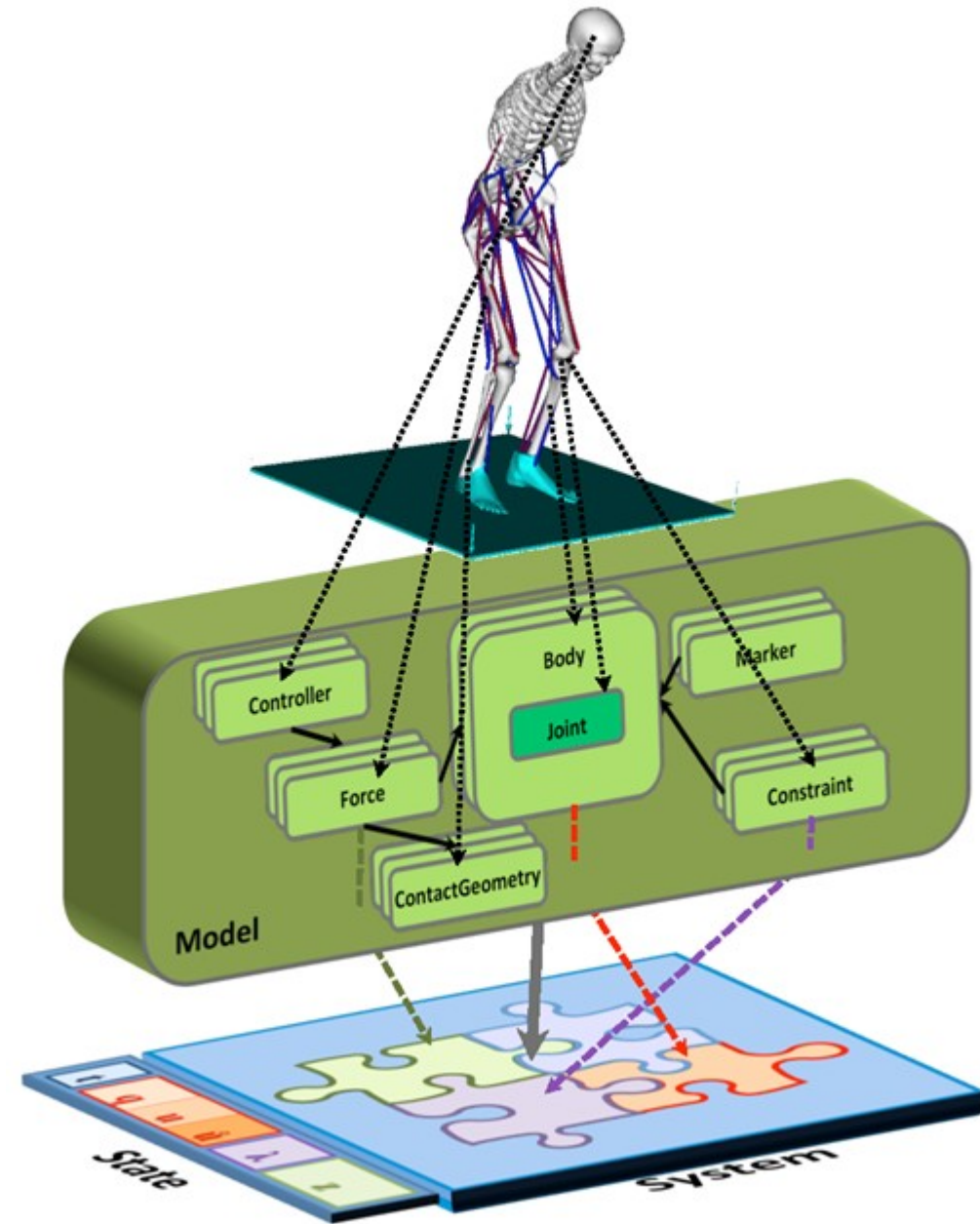


OpenSim API

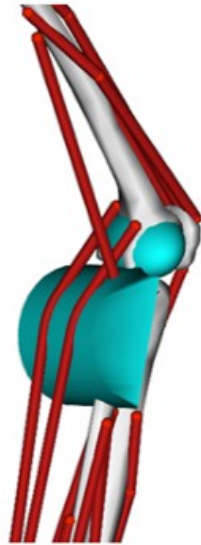


Model Representation

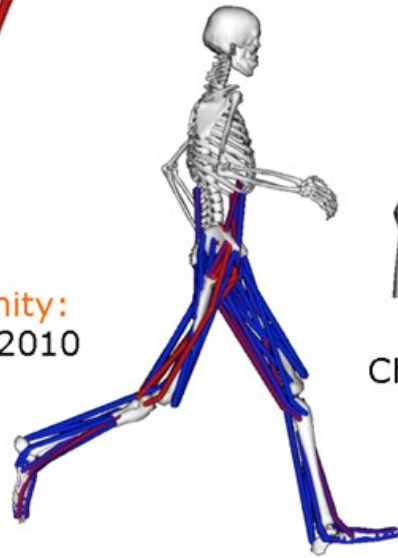
```
1  <?xml version="1.0" encoding="UTF-8" ?>
2  <OpenSimDocument Version="20303">
3    <Model name="arm26">
4      <!--See the credits section below for information about this model's authors, data sources, intended uses, and more. See the publications
5       section for the paper(s) you should cite when using this model. Do not remove either section if you modify or add to this model.
6       If you are this model's author(s), add or update the credits and publications sections before distributing your model.-->
7      <credits> The OpenSim Development Team (Reinbolt, J; Seth, A; Habib, A; Hamner, S) adapted from a model originally created by Kate
14     <publications> Holzbaur, K.R.S., Murray, W.M., Delp, S.L. A Model of the Upper Extremity for Simulating Musculoskeletal Surgery and
15     Annals of Biomedical Engineering, vol 33, pp 829-840, 2005
16     </publications>
17     <length_units>meters</length_units>
18     <force_units>N</force_units>
19     <!--Acceleration due to gravity.-->
20     <gravity> 0 -9.8066 0</gravity>
21     <!--Bodies in the model.-->
22     <BodySet>
1007    <!--Constraints in the model.-->
1008    <ConstraintSet>
1012    <!--Forces in the model.-->
1013    <ForceSet>
1564    <!--Markers in the model.-->
1565    <MarkerSet>
1594    <!--ContactGeometries in the model.-->
1595    <ContactGeometrySet>
1599    <!--Controllers in the model.-->
1600    <ControllerSet name="Controllers">
1604    <!--Probes in the model.-->
1605    <ProbeSet>
1609    <!--Additional components in the model.-->
1610    <ComponentSet name="MiscComponents">
1614    </Model>
1615  </OpenSimDocument>
```



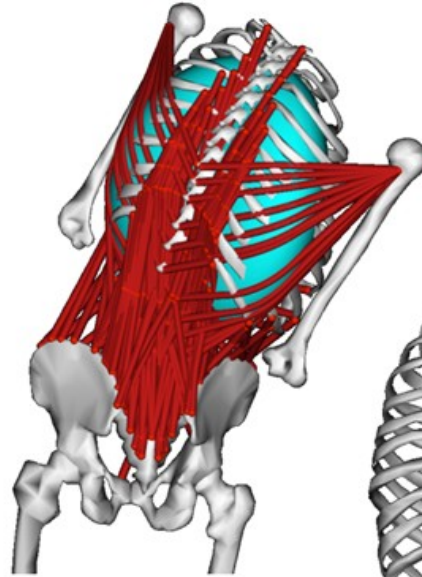
Repository of Models



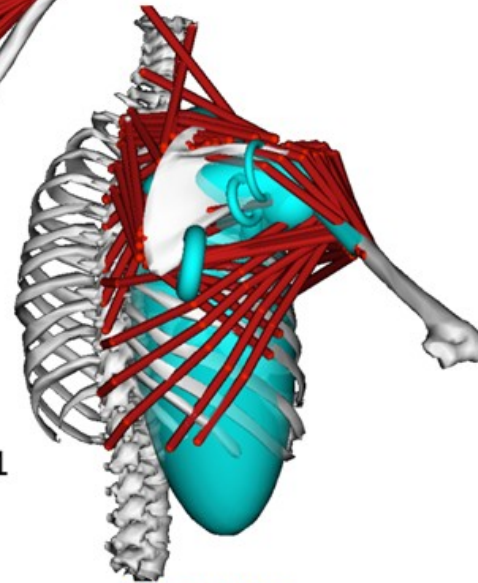
Lower-extremity:
Arnold et al, 2010



Running: Hamner et al, 2010

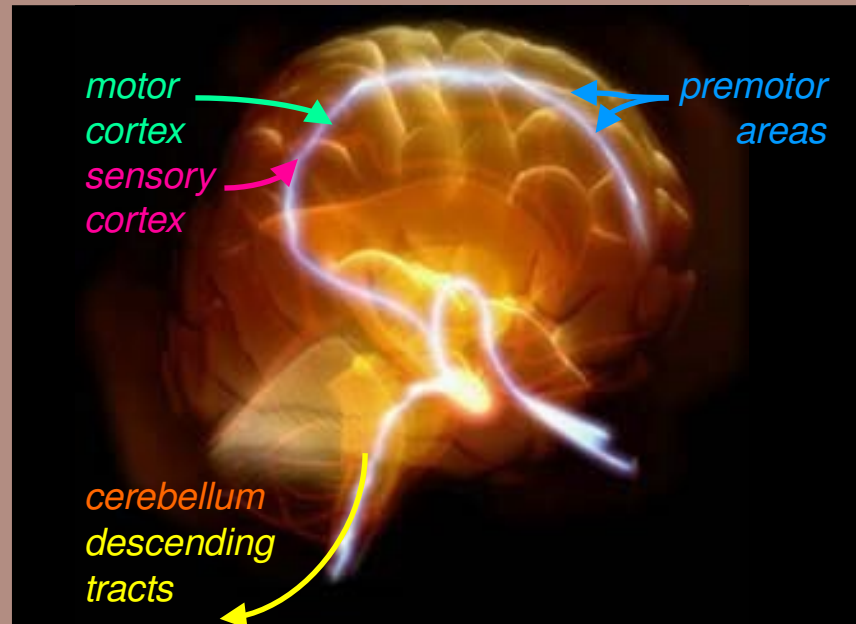
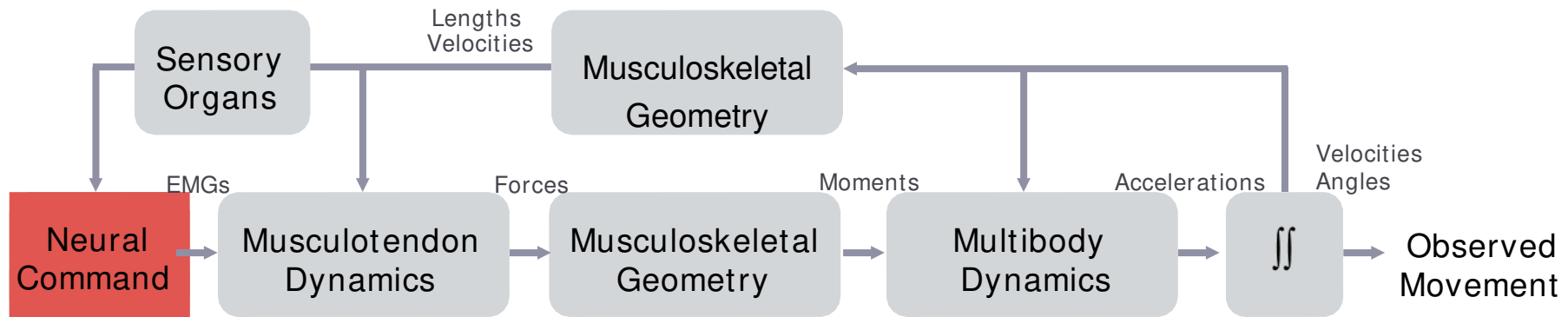


Lumbar-spine:
Christophy et al, 2011

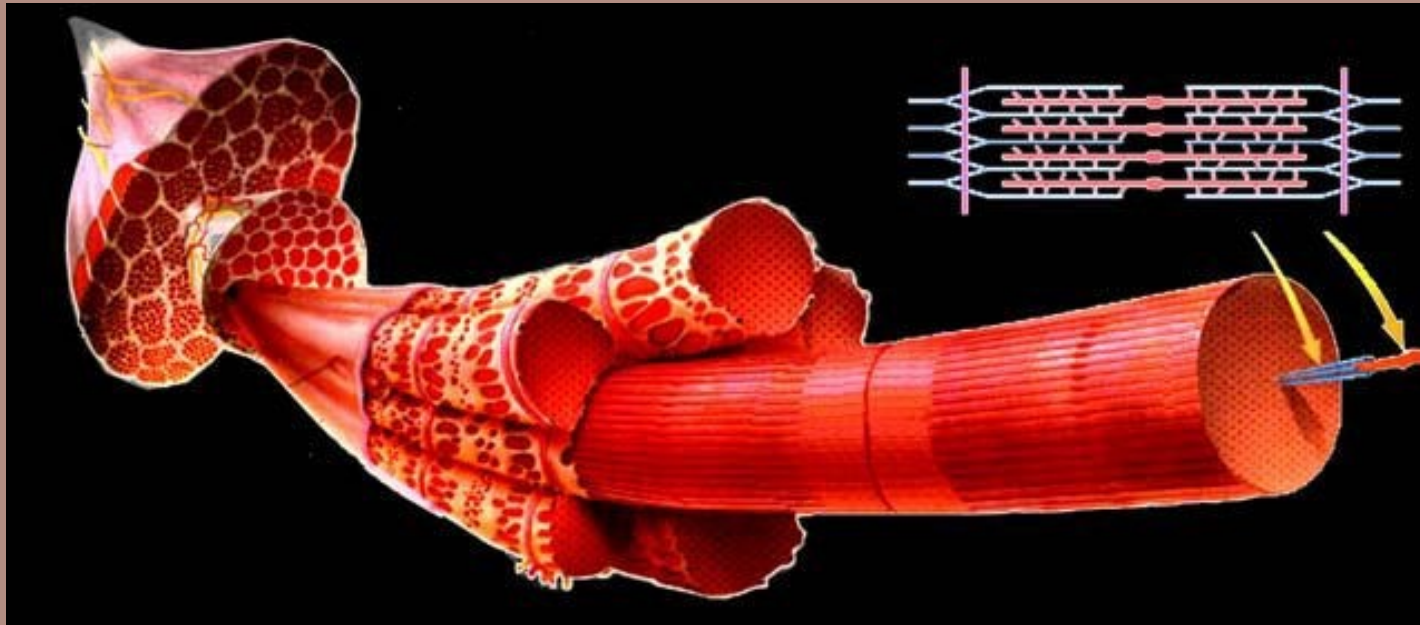
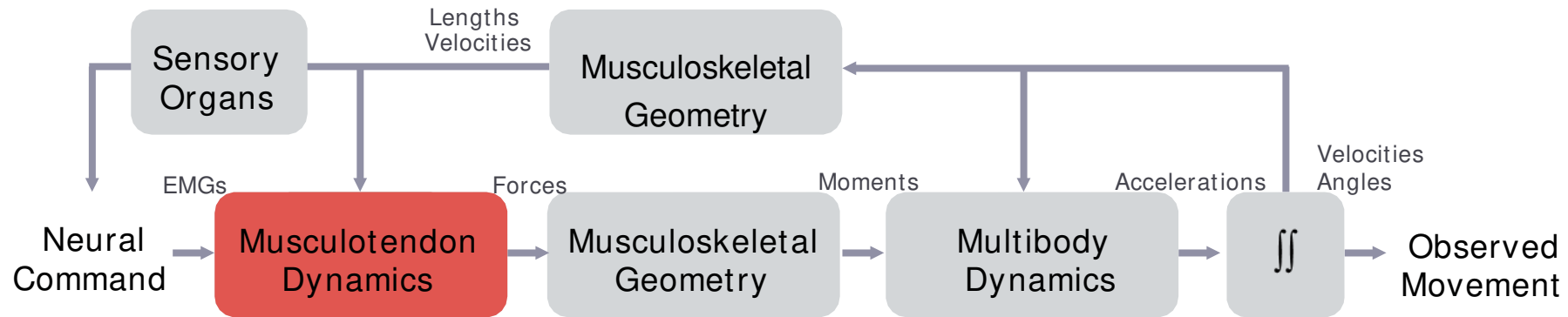


Shoulder:
Matias et al, in prep.

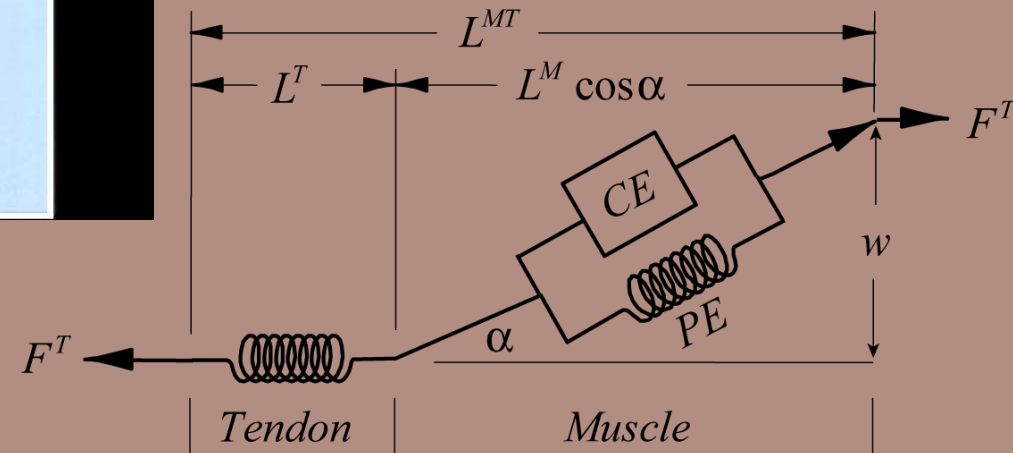
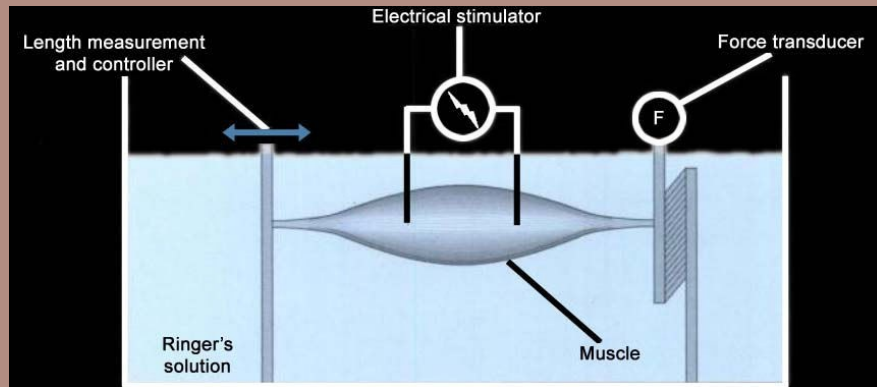
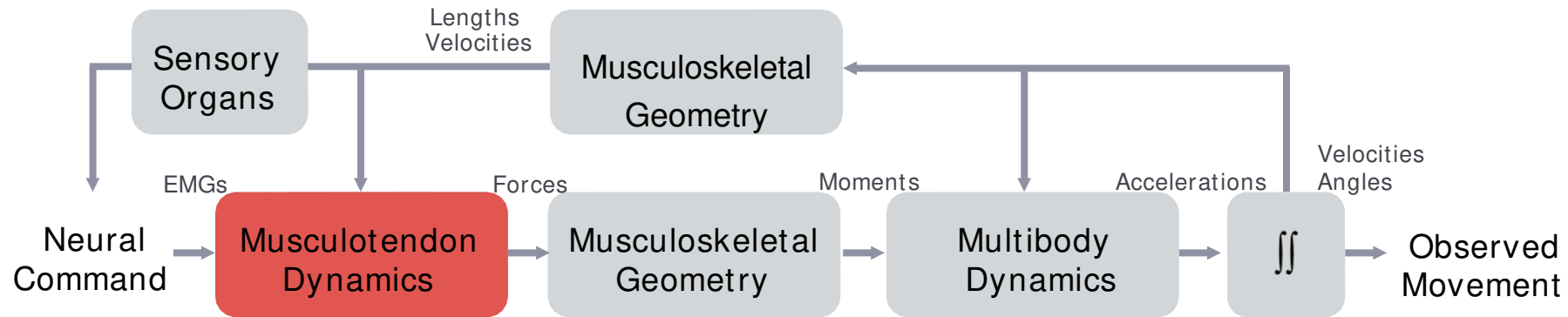
The Cause of Movement



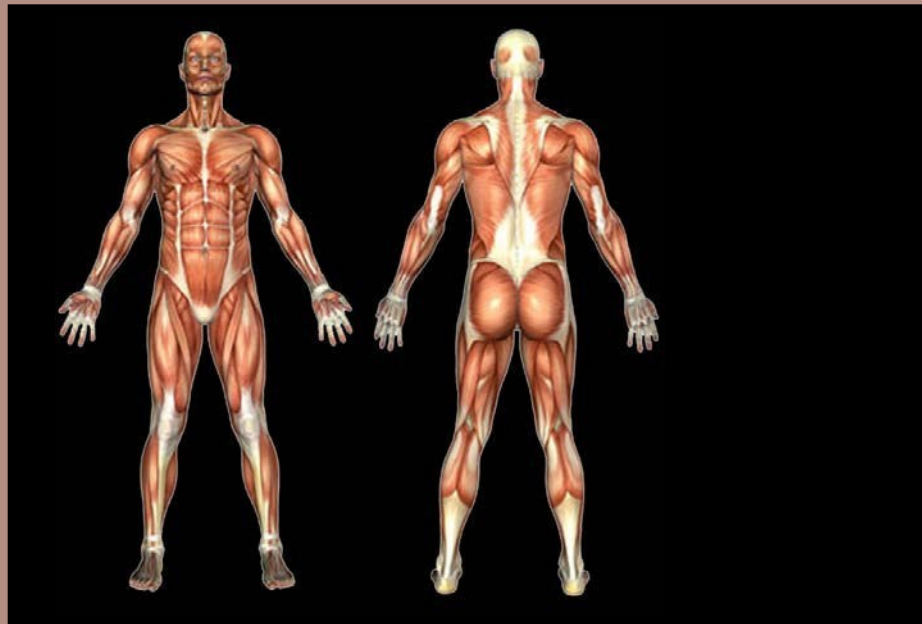
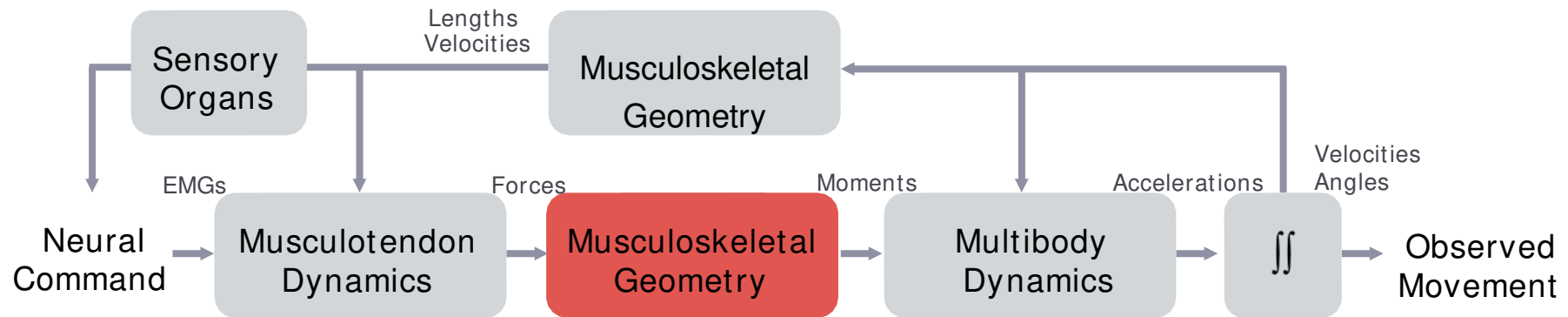
Muscle Excitation and Force



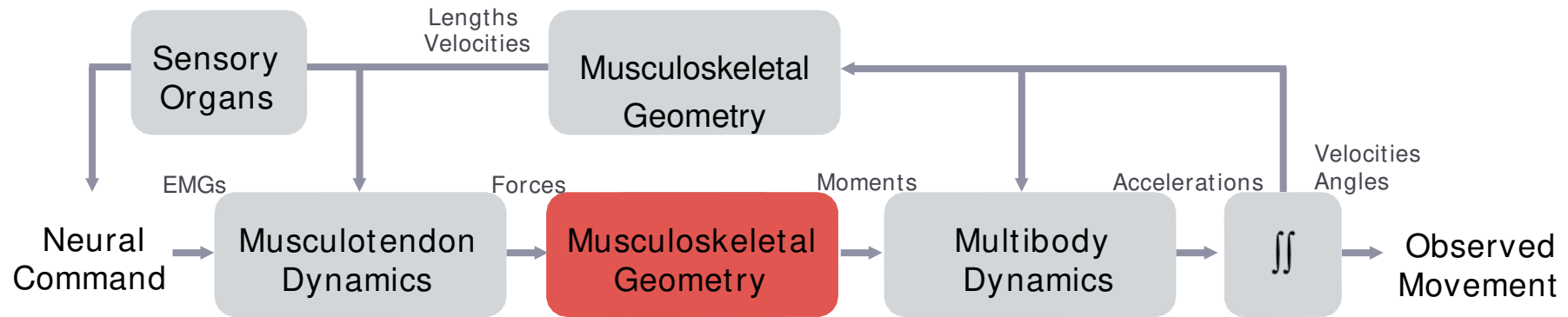
Muscle Excitation and Force



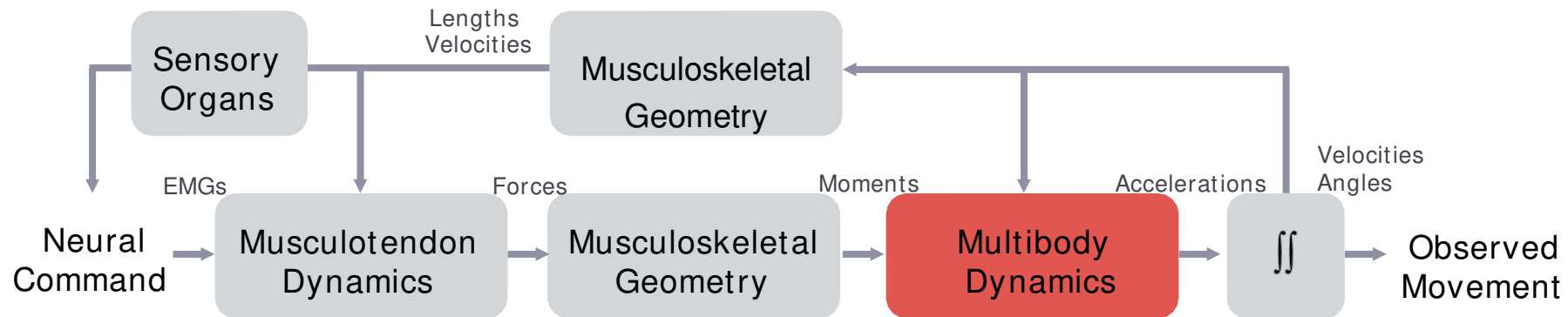
Muscle Routing



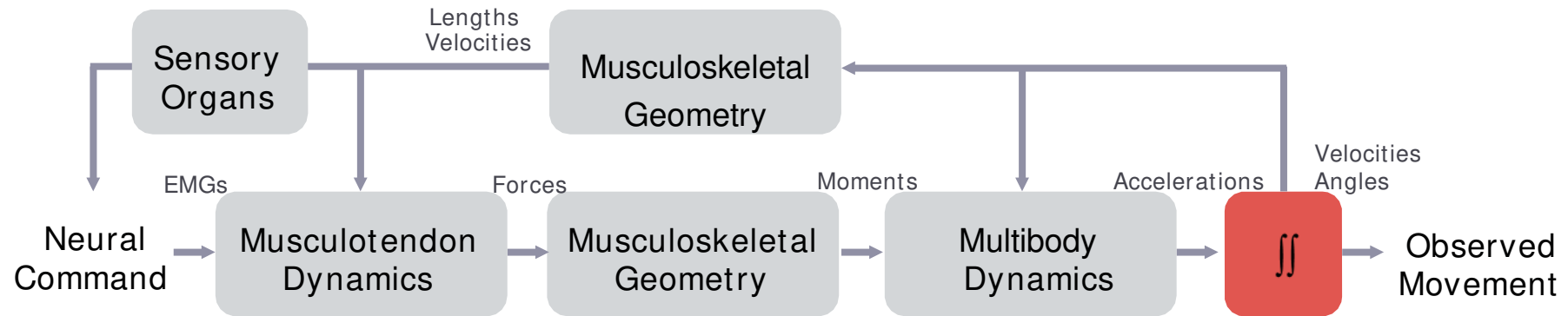
Muscle Routing



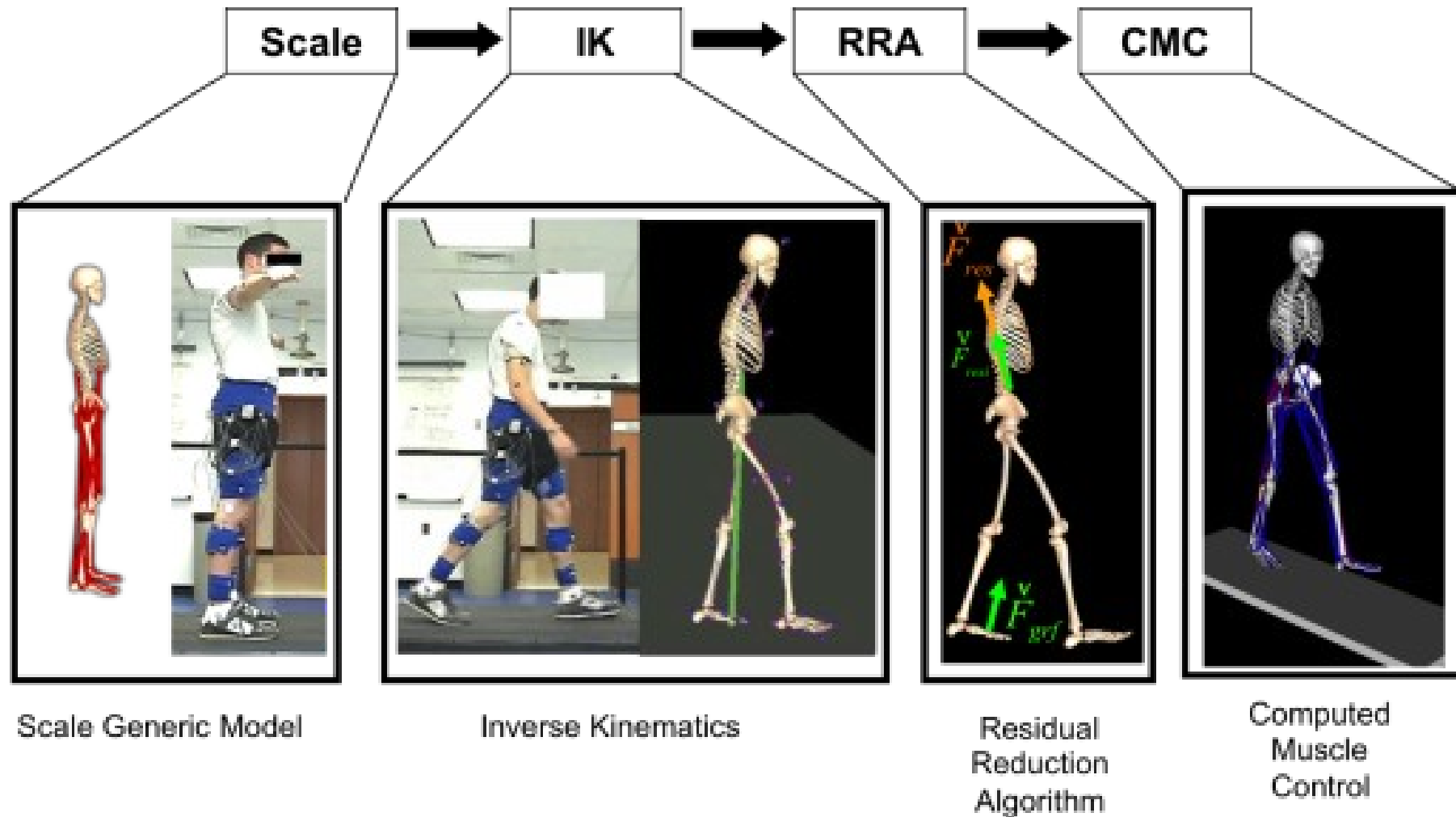
Multibody Dynamics



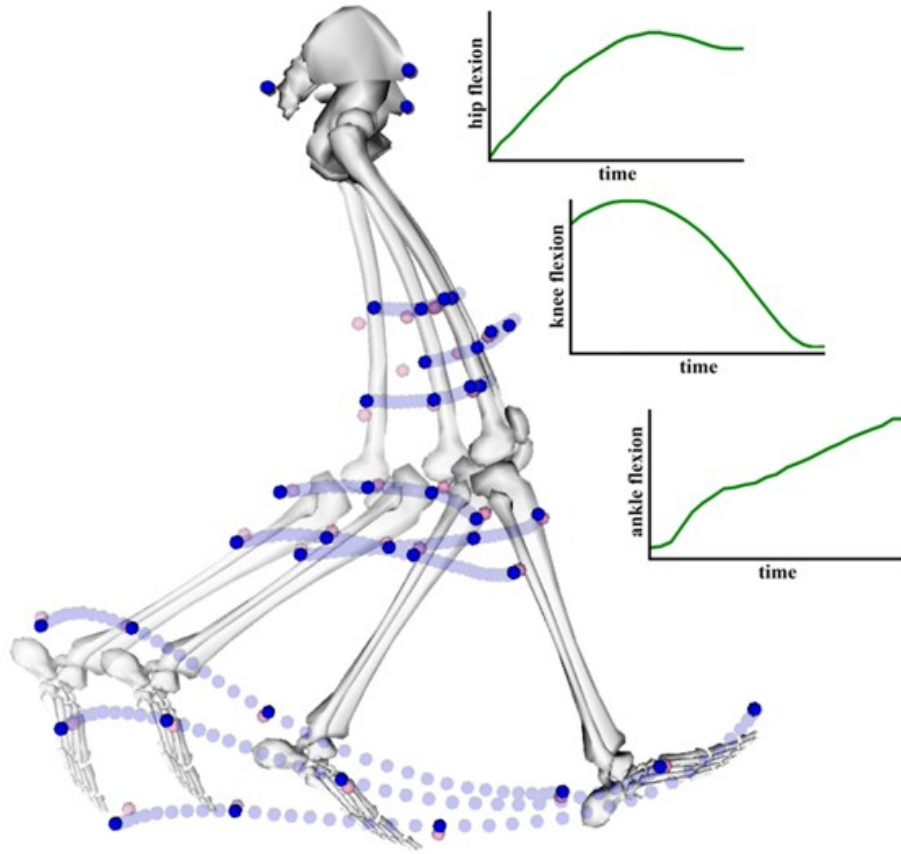
Numerical Integration



Inverse Simulation



Inverse Kinematics

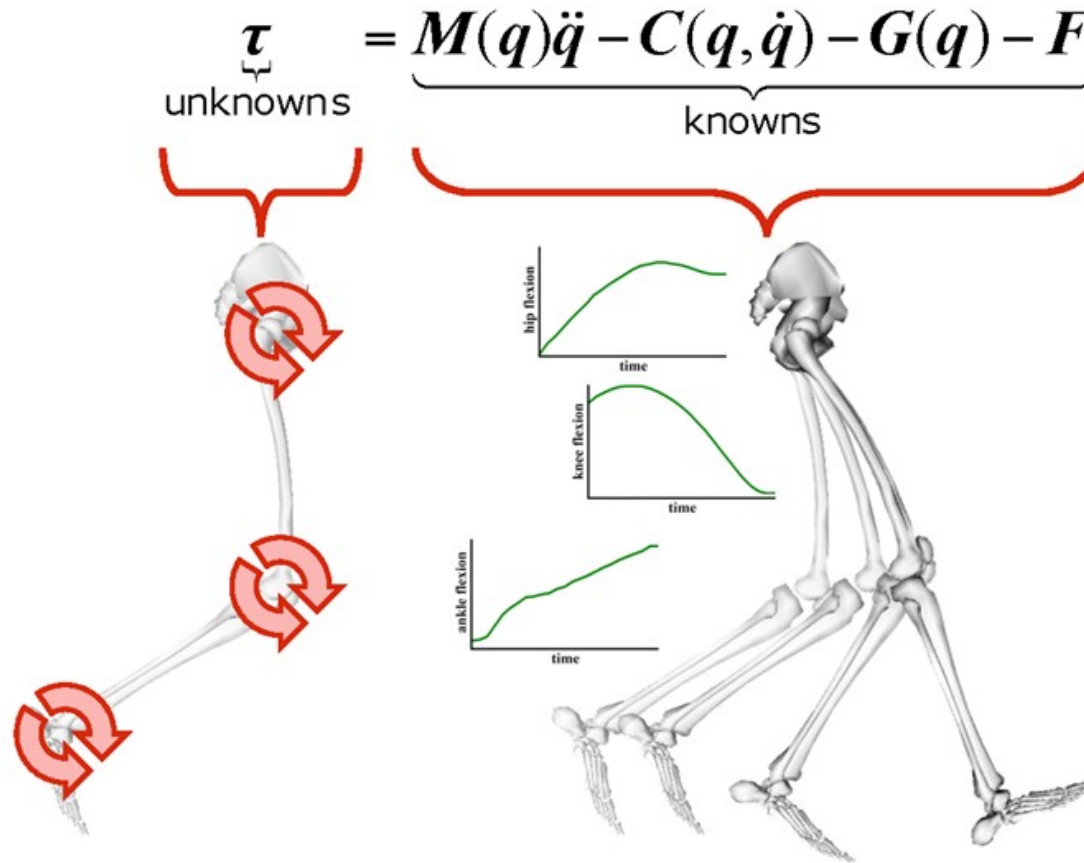


$$\min_q \left[\underbrace{\sum_{m=1}^{\# \text{ markers}} w_m \left\| \mathbf{x}_m^{\text{exp}} - \mathbf{x}_m(q) \right\|^2}_{\text{Marker Error}} + \underbrace{\sum_{c=1}^{\# \text{ coordinates}} \omega_c (q_c^{\text{exp}} - q_c)^2}_{\text{Coordinate Error}} \right]$$

The equation is divided into two parts by red brackets. The first part, labeled 'Marker Error', represents the sum of squared distances between experimental marker positions and model marker positions, weighted by w_m . The second part, labeled 'Coordinate Error', represents the sum of squared differences between experimental joint angles and model joint angles, weighted by ω_c . A plus sign is placed between the two parts.

The diagram below the equation illustrates the two error components. On the left, a skeletal model is shown with blue dots representing markers. A red bracket connects this model to the 'Marker Error' term in the equation. On the right, a skeletal model is shown with red arrows indicating joint angles. A red bracket connects this model to the 'Coordinate Error' term in the equation. The angles shown are 22°, -1°, and 9°.

Inverse Dynamics



Static Optimization

$$M_j = \sum \text{muscle moments} + \sum \text{moments due to other structures}$$

number
of flexors

number of
extensors

$$M_j = \underbrace{\sum_{f=1}^{n_f} F_f r_f}_{\text{flexion moment}} - \underbrace{\sum_{e=1}^{n_e} F_e r_e}_{\text{extension moment}}$$

moment arm

1 equation with
 $n_f + n_e$ unknowns

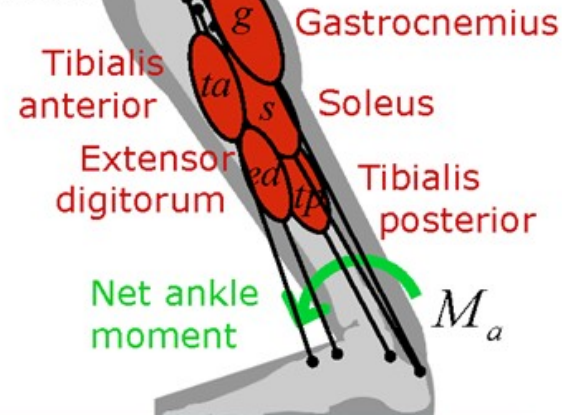
Ankle example

$$M_a = (F_{ta} r_{ta} + F_{ed} r_{ed}) - (F_g r_g + F_s r_s + F_{tp} r_{tp})$$

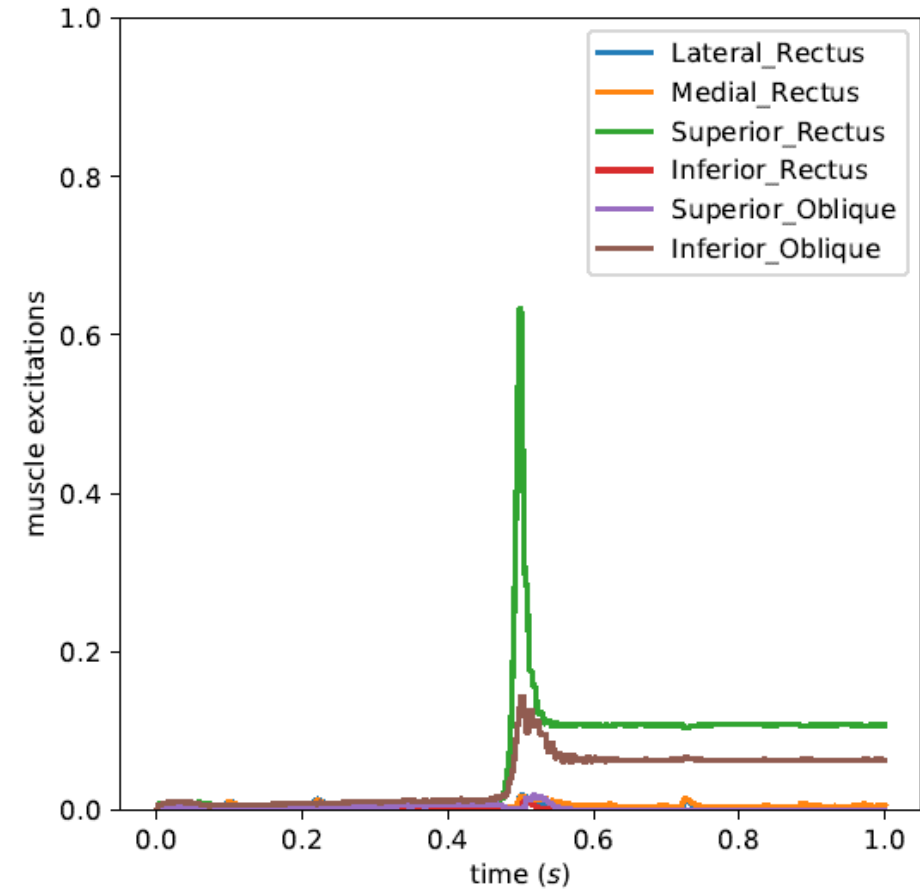
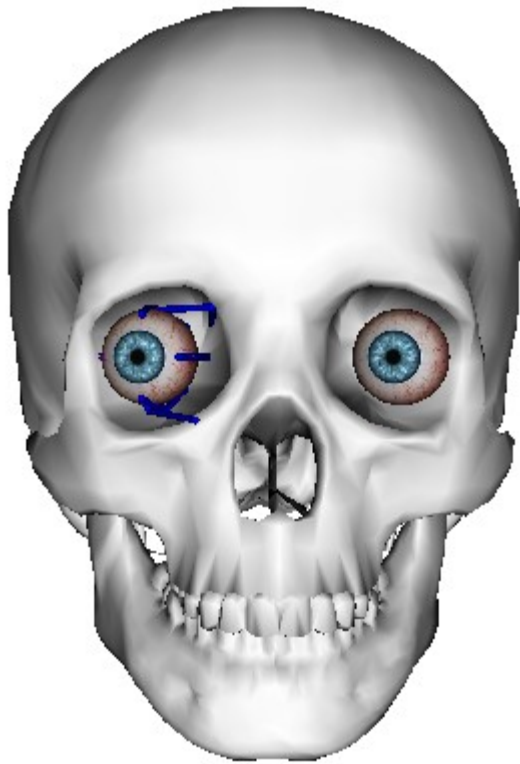
How can we solve this?

Major flexors

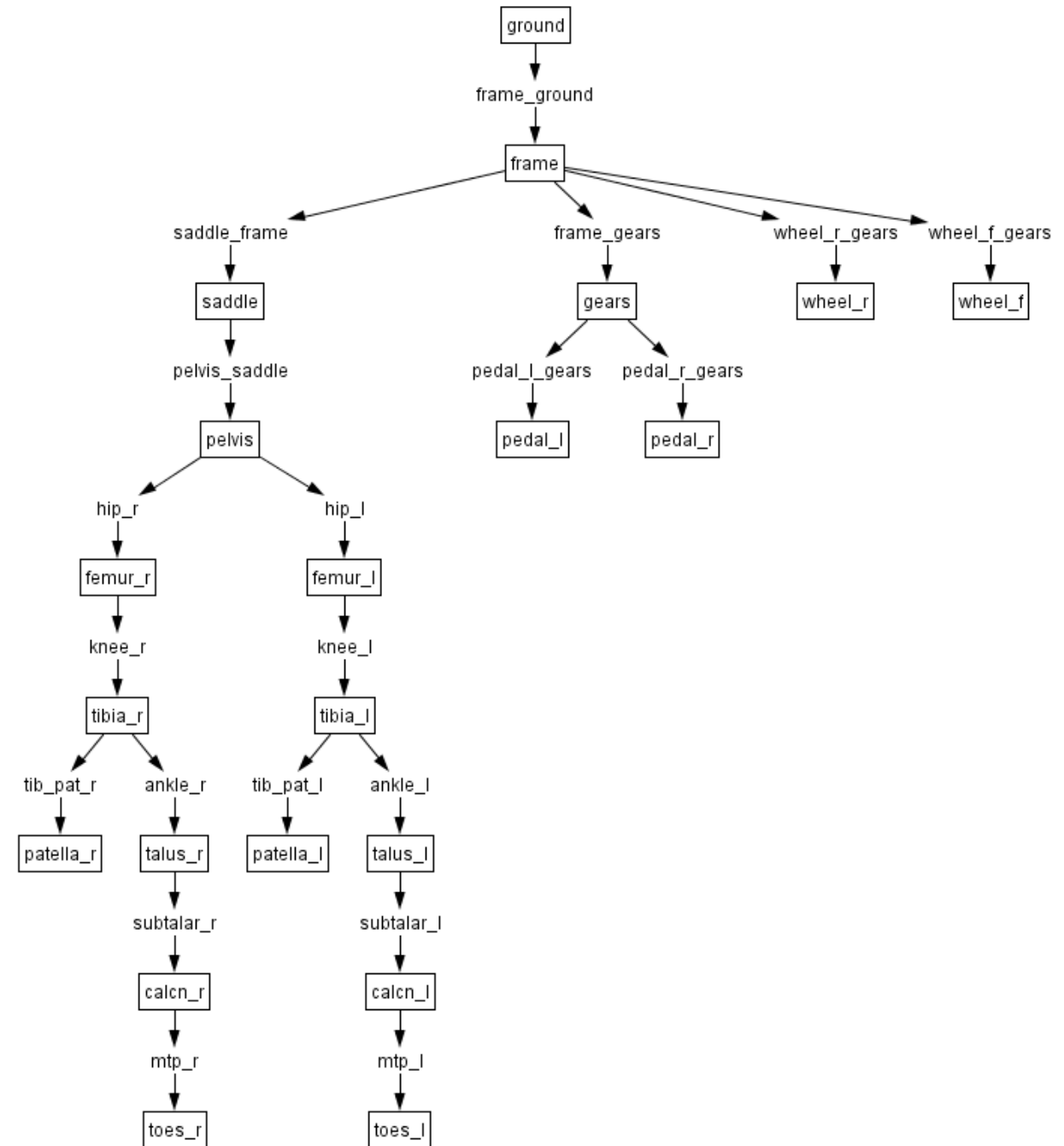
Major extensors



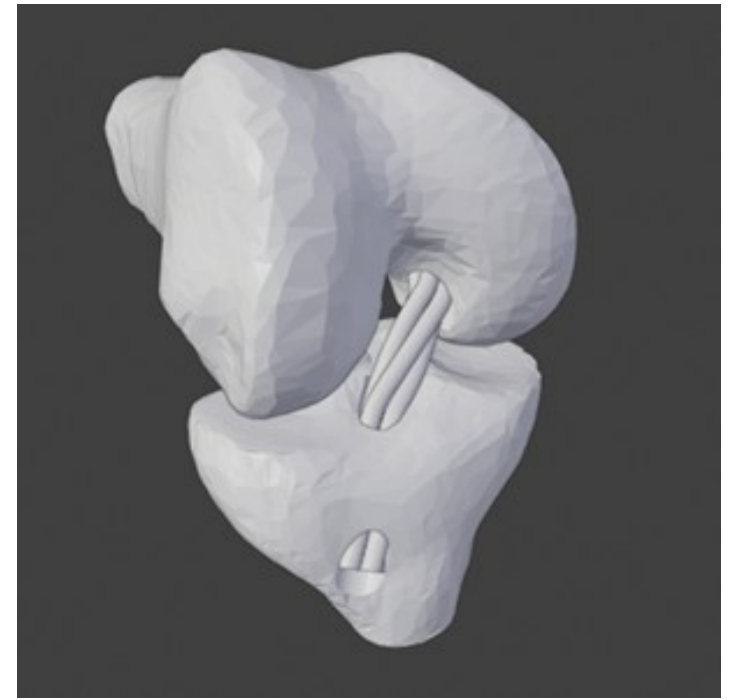
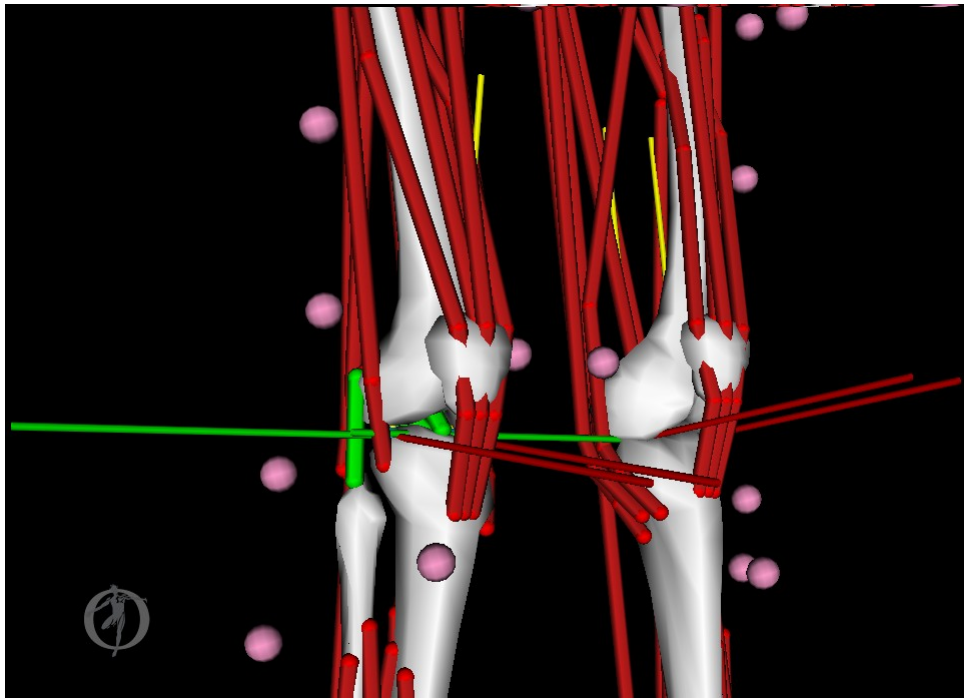
An Open-Source Eye Model



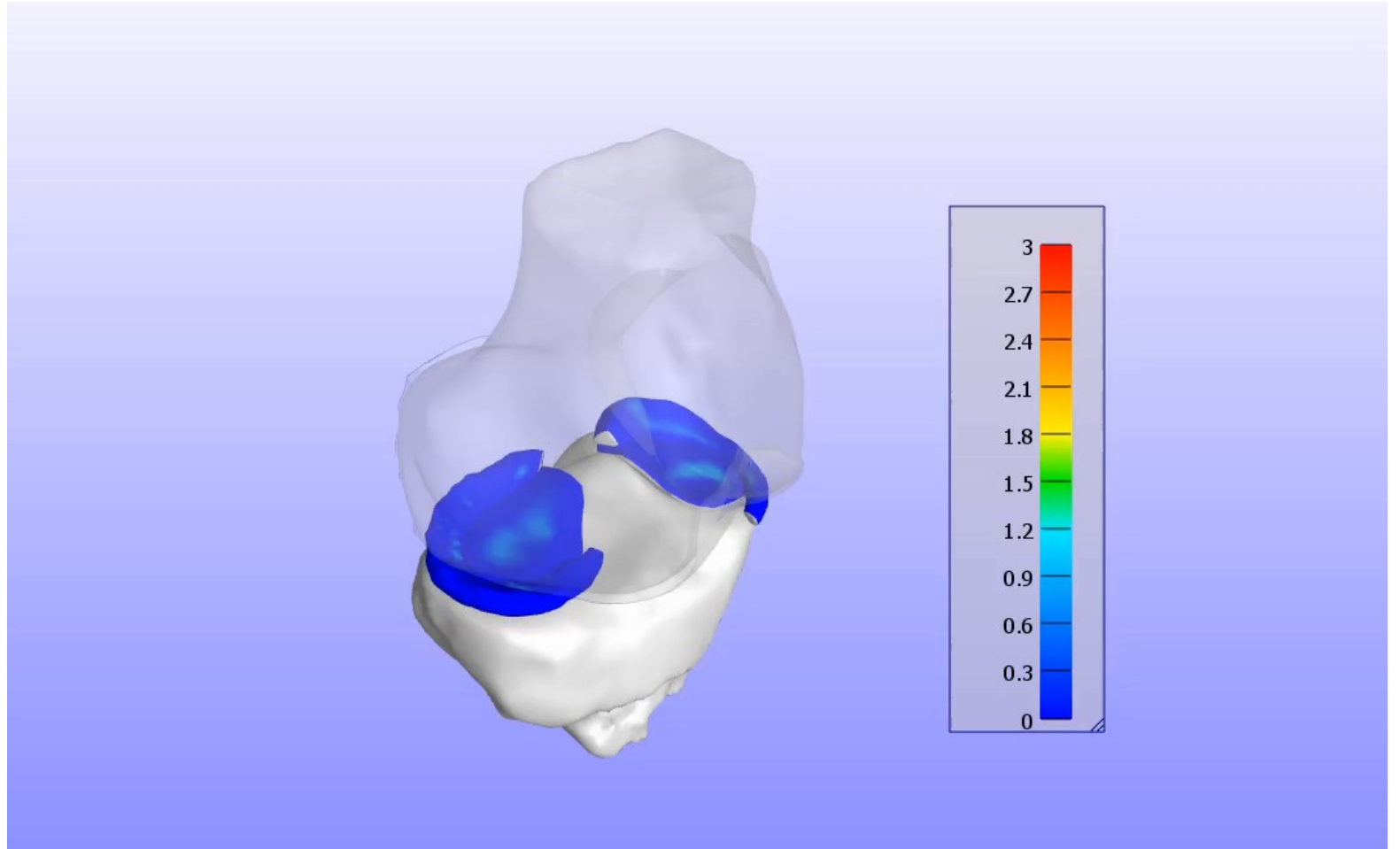
Cycling Model



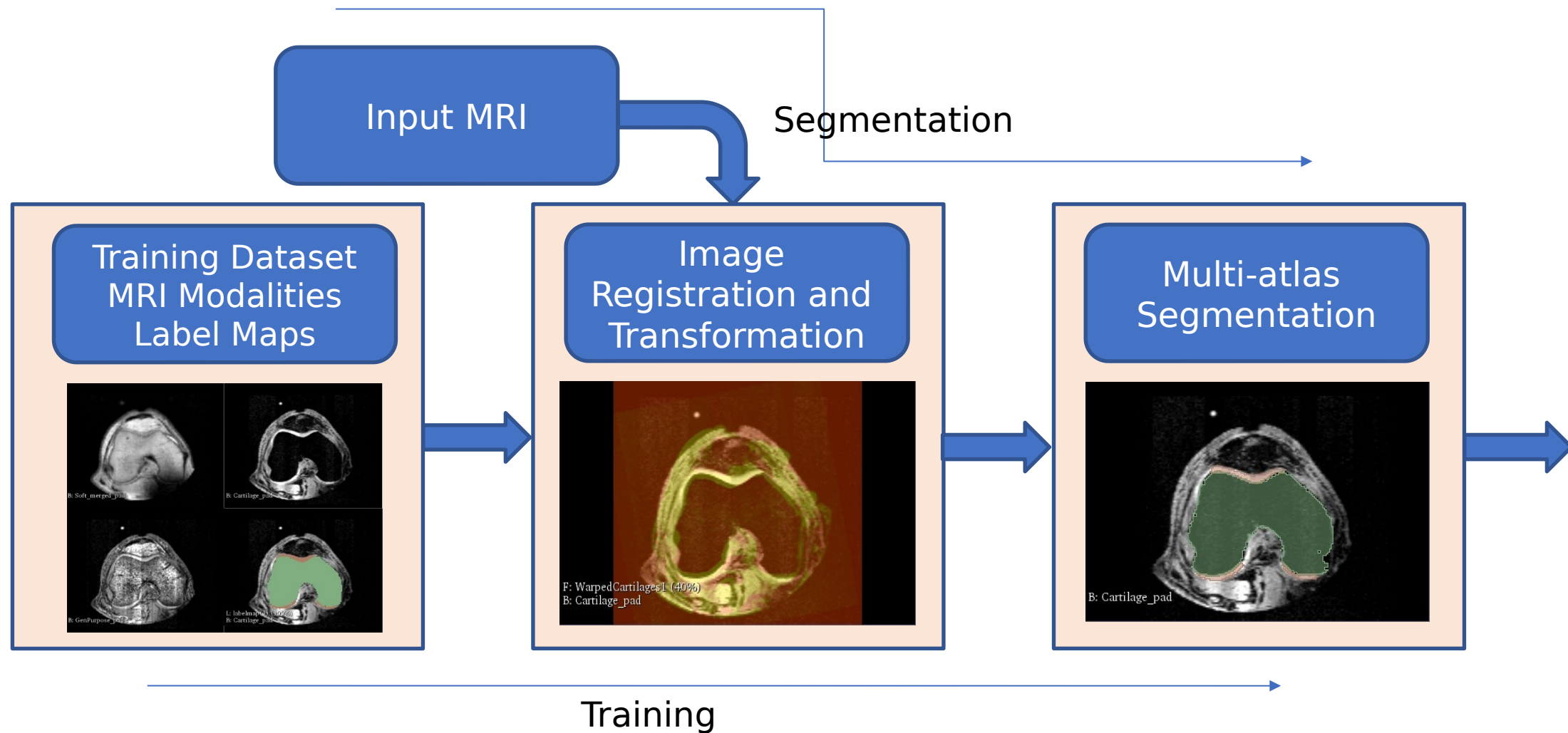
Knee Modeling and Simulation



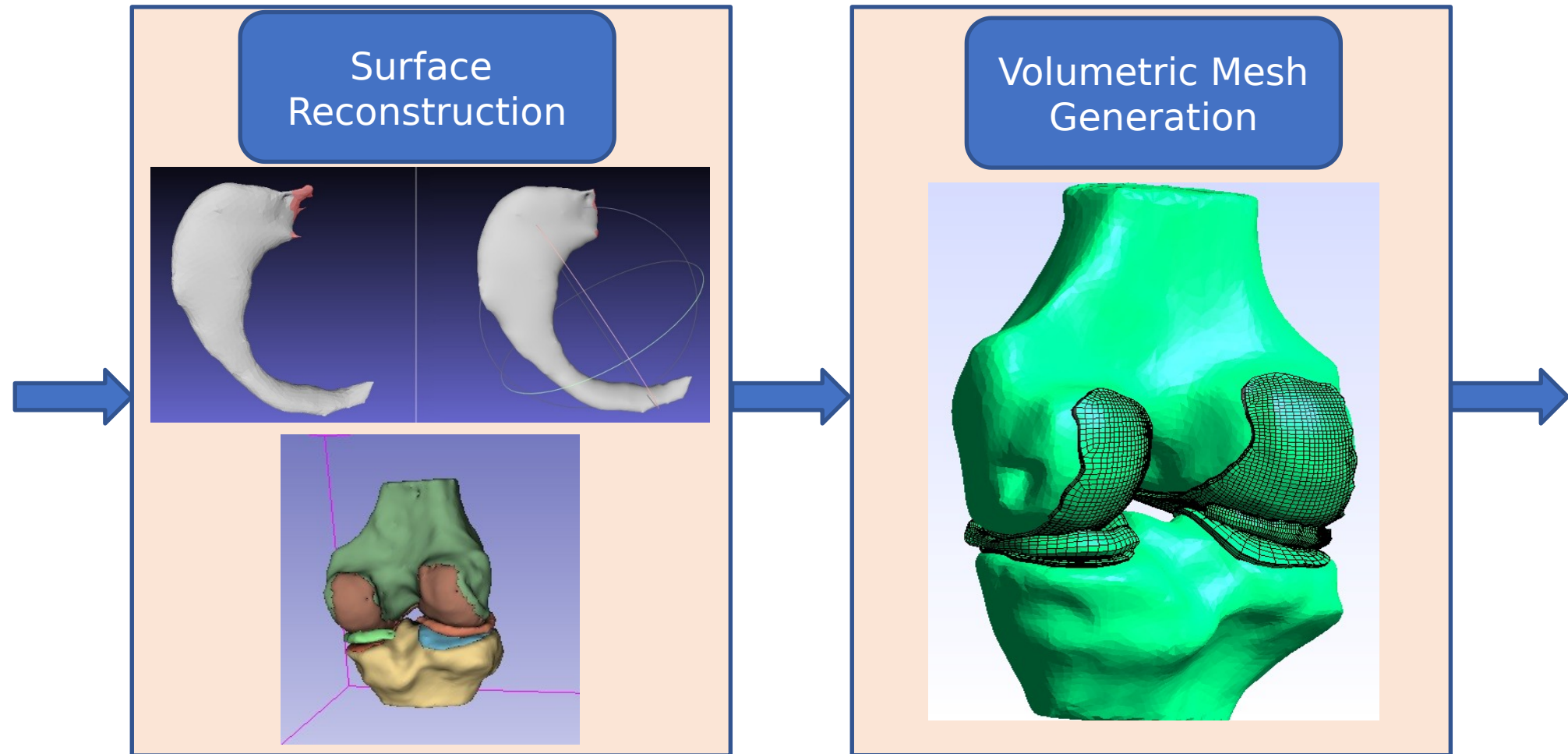
Knee Modeling and Simulation



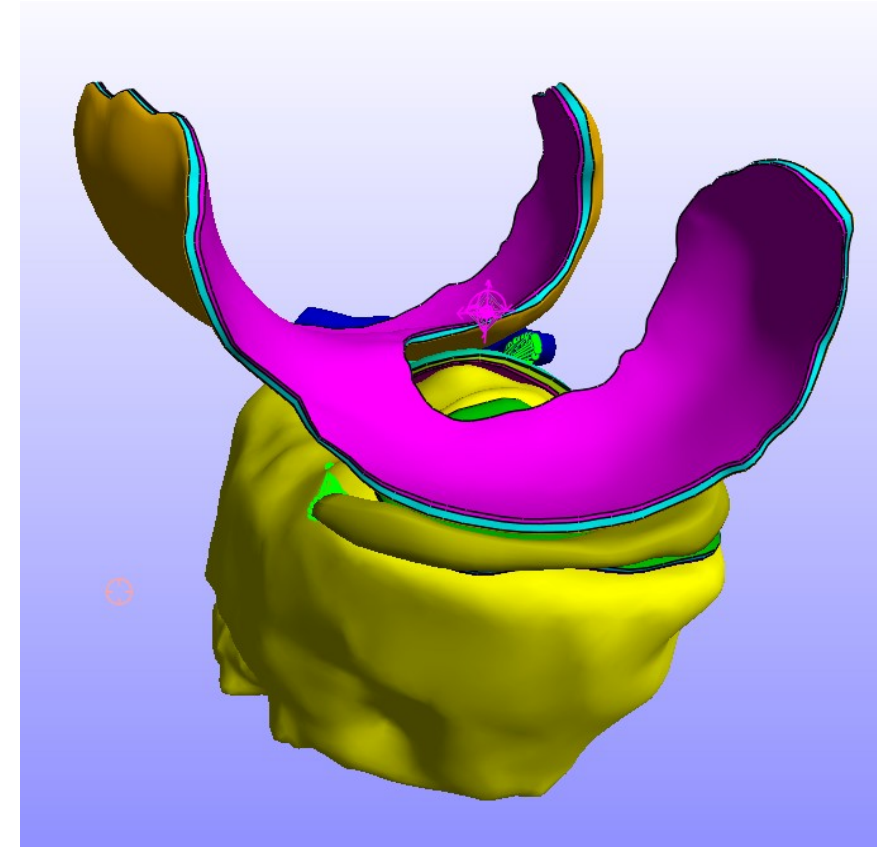
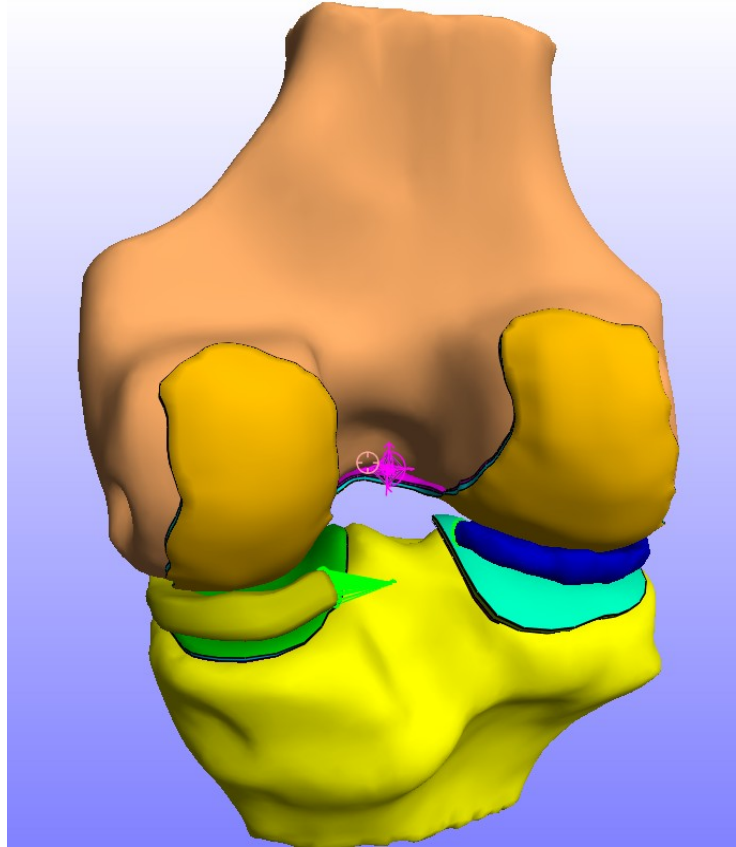
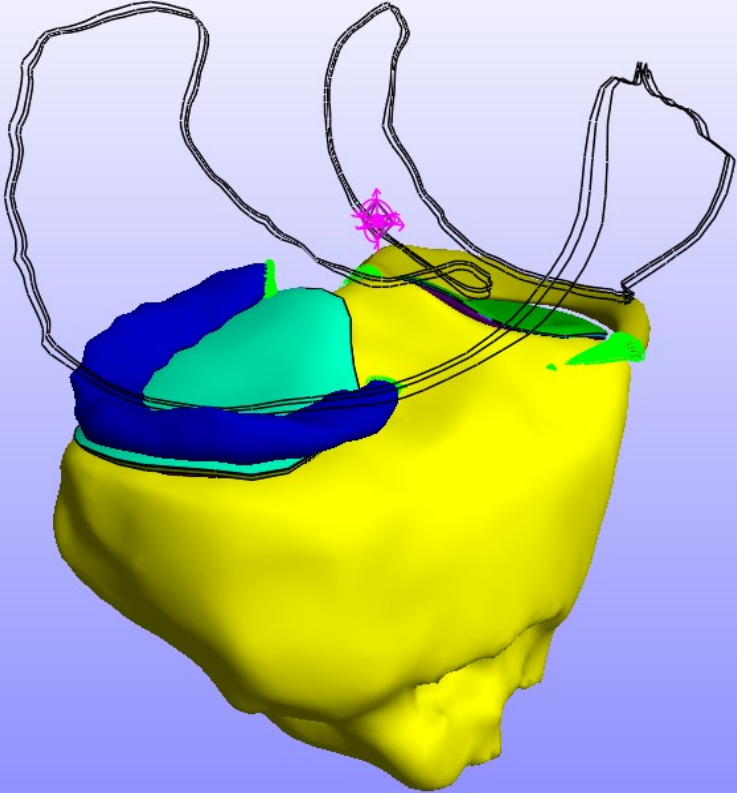
Automatic Segmentation



Automatic Segmentation



Finite Element Modeling



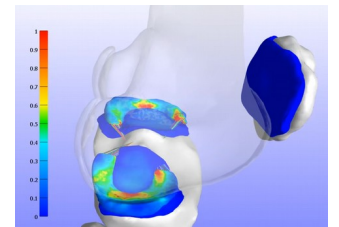
Automatic
Segmentation



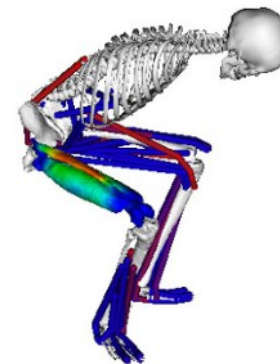
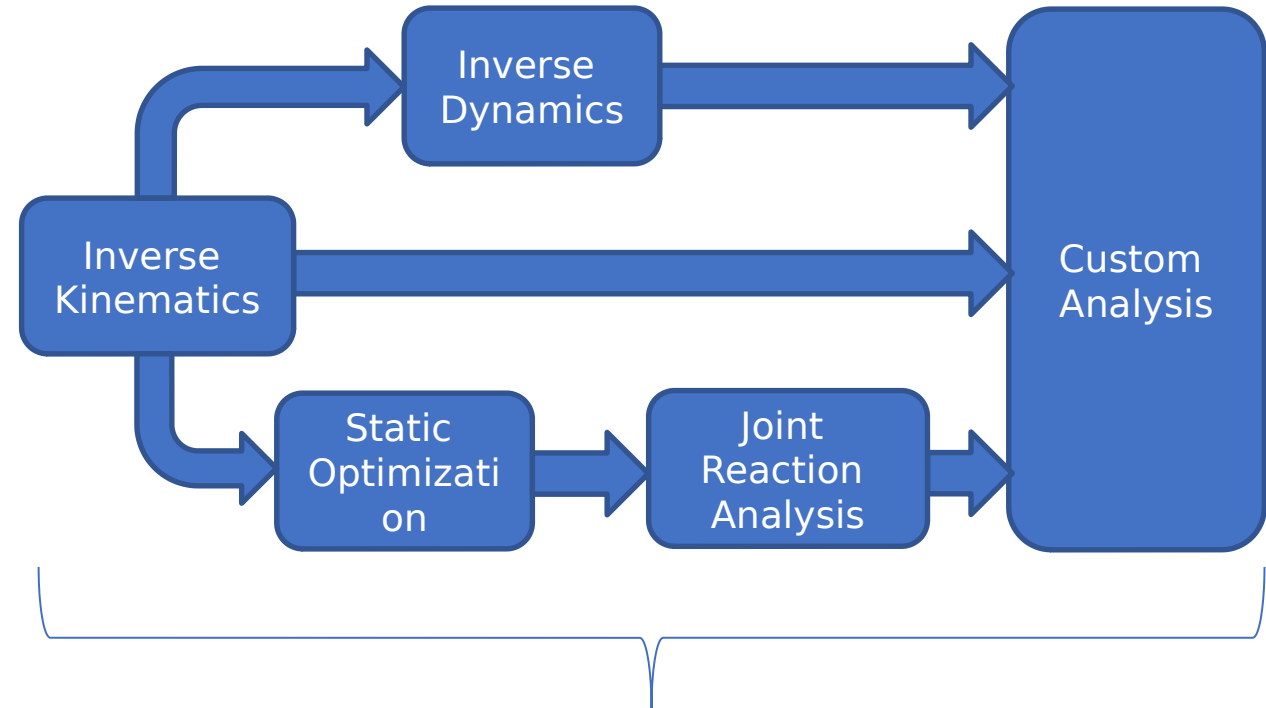
Automatic FEM
Generation



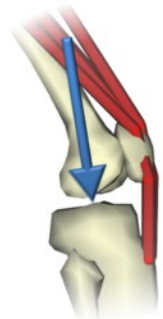
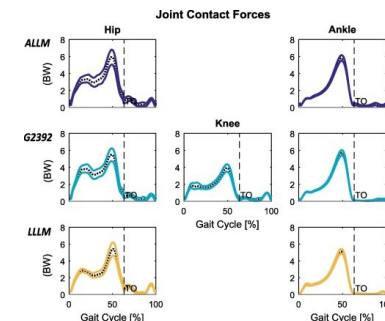
Automatic FE
Simulation



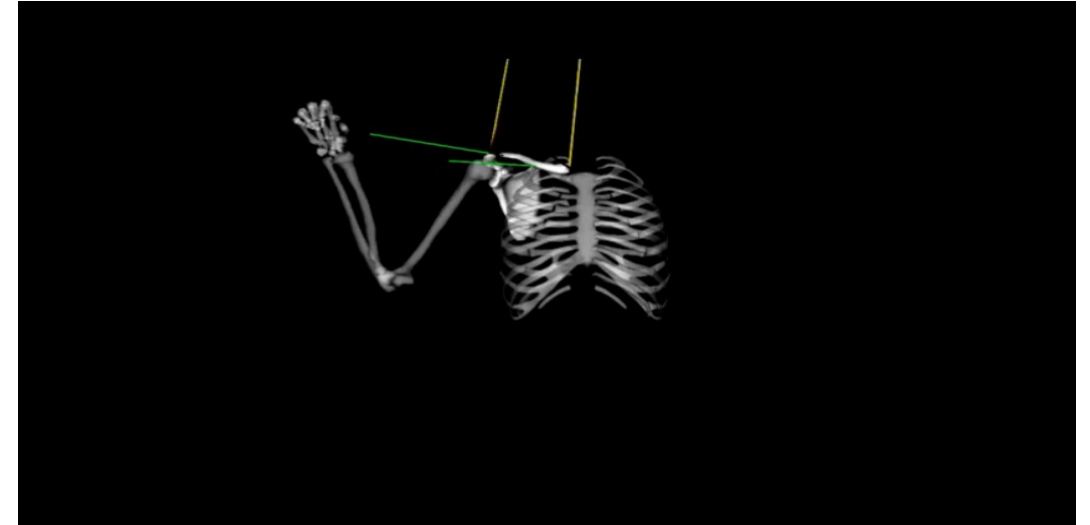
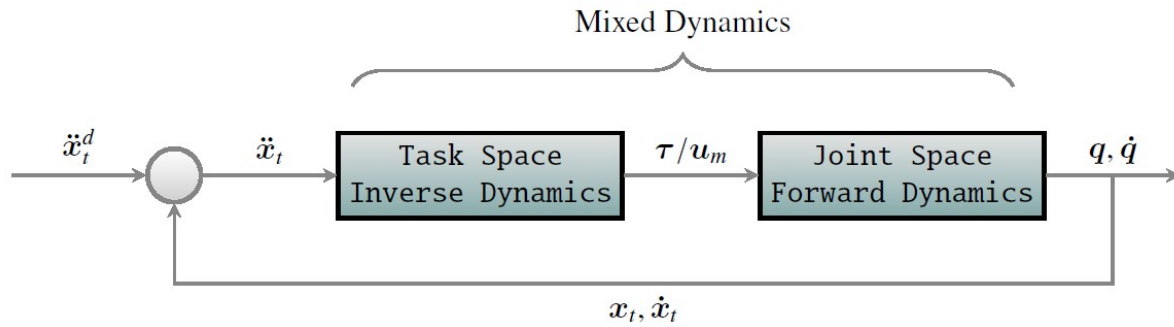
Real Time Gait Retraining



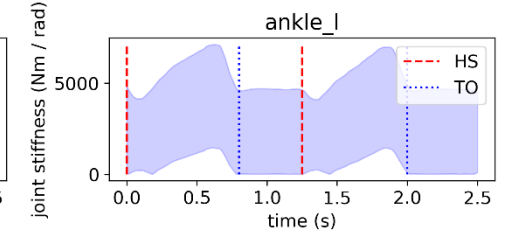
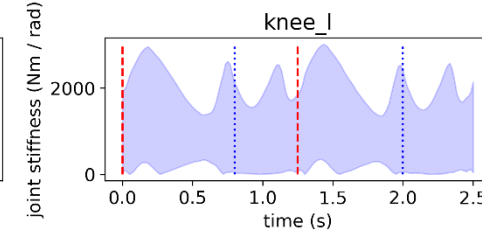
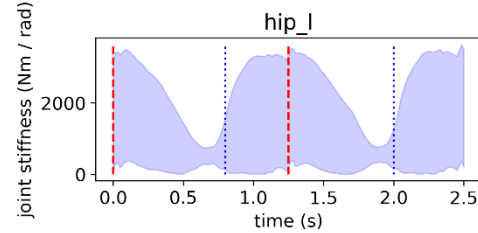
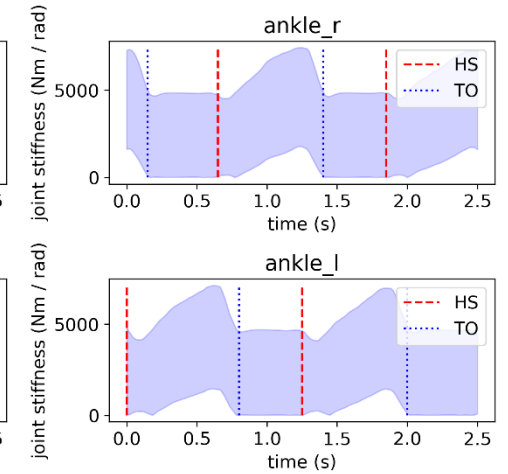
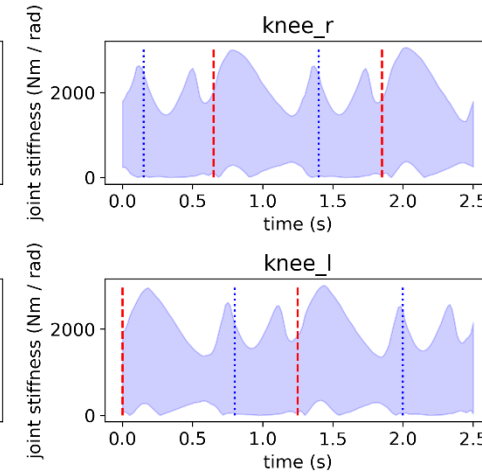
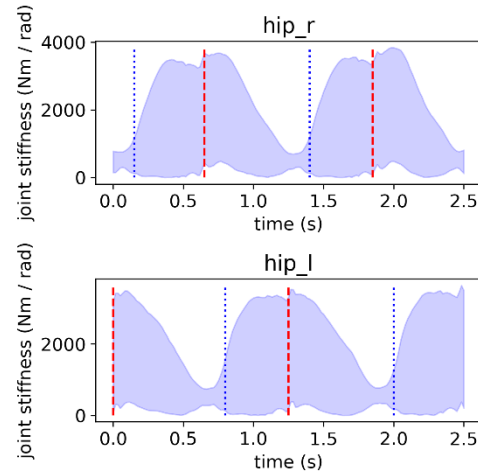
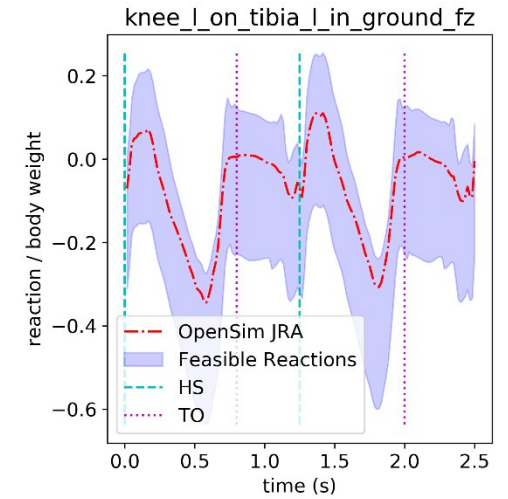
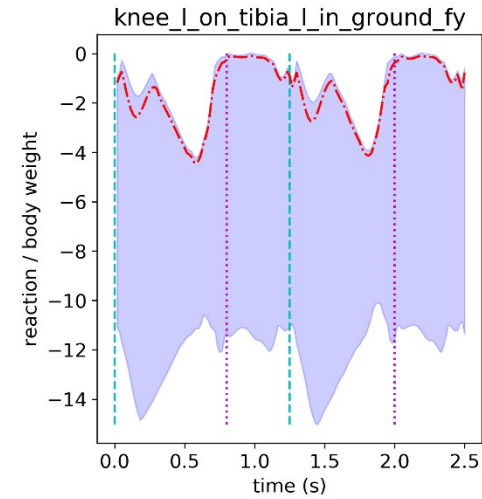
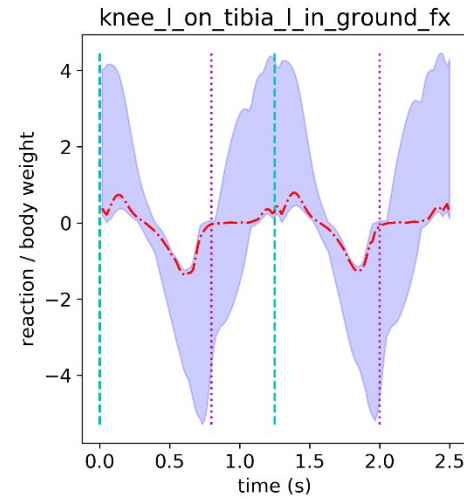
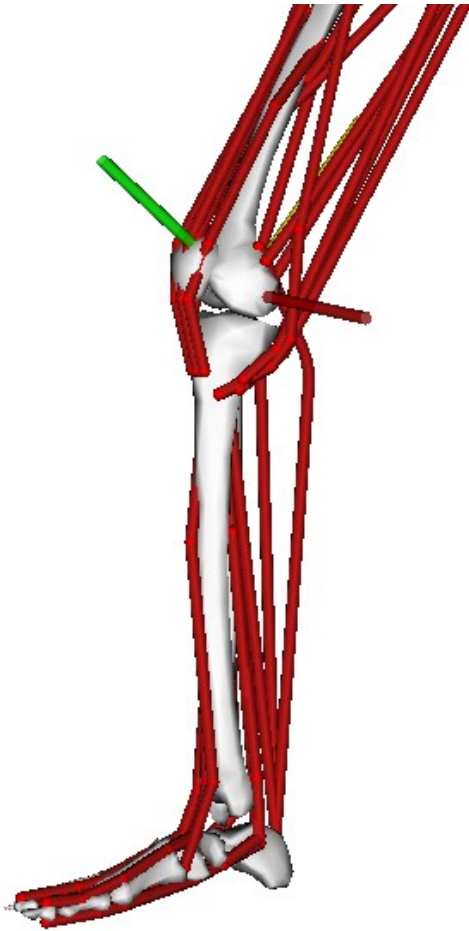
Real-Time



Design Virtual Simulation in Task Space



Feasible Muscle Forces



Useful Links

- https://simtk.org/project/xml/downloads.xml?group_id=91
- https://simtk.org/plugins/phpBB/indexPhpbb.php?group_id=91&pluginname=phpBB
- <http://simtk-confluence.stanford.edu:8080/display/OpenSim/User's+Guide>
- https://simtk.org/docman/?group_id=91
- <https://simtk.org/home/simbody/>
- https://simtk.org/docman/?group_id=47
- <http://simtk-confluence.stanford.edu:8080/display/OpenSim/Musculoskeletal+Models>