



EXP.NO3

Introduction to the Musculoskeletal Modeling

Introduction to OpenSim

Musculoskeletal models enable us to study neuromuscular coordination, analyze athletic performance and estimate musculoskeletal loads. OpenSim is an open-source software that allows users to develop, analyze, and visualize models of the musculoskeletal system, and to generate dynamic simulations of movement. In OpenSim, a musculoskeletal model consists of rigid body segments connected by joints. Muscles span these joints and generate forces and motion. Once a musculoskeletal model is created, OpenSim enables users to create custom studies, including investigating the effects of musculoskeletal geometry, joint kinematics, and muscle-tendon properties on the forces and joint moments the muscles can produce. With OpenSim, our goal is to provide a framework that allows the biomechanics community to create, share, and extend a library of models and dynamic simulation tools that can be used to study and quantify human and animal movement.

Purpose

The purpose of this EXP. is to introduce users to OpenSim by demonstrating the utility of a graphics-based musculoskeletal modeling framework to investigate how muscle-tendon lengths and moment arms depend on limb configuration. In this exp., you will:

- Become familiar with OpenSim's graphical user interface (GUI).
- Discover some limitations of musculoskeletal models.
- Explore differences between uni-articular ("1-joint") and bi-articular ("2-joint") muscles.
- Use OpenSim to approach an important clinical problem

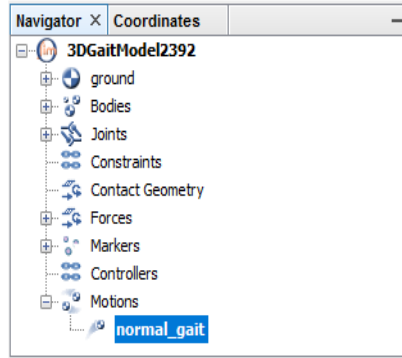
Introduction to the OpenSim GUI

There are several key components of the OpenSim GUI that will be referred to throughout the tutorial. The table below will introduce you to these GUI components.

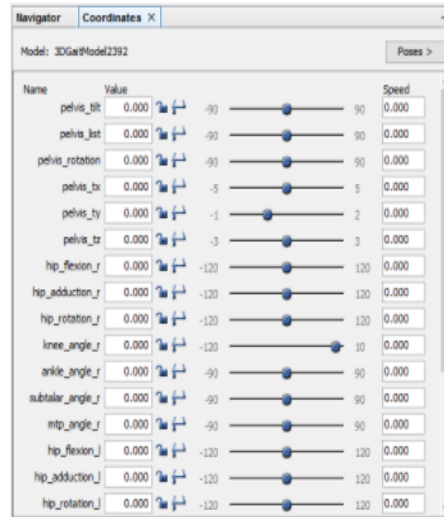
Note: A model is loaded in this example to illustrate the GUI, when you open OpenSim for the first time, there will be no models loaded.

GUI Components	
Title	Screenshot
Toolbar	
Motion Textbox	
Motion Slider/ Video Controls	
Visualizer Window	

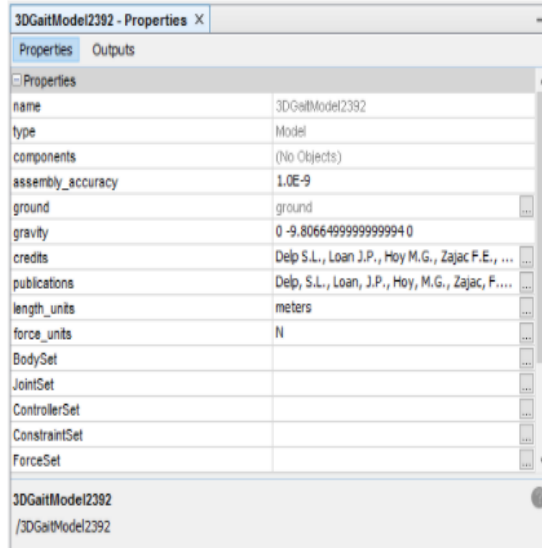
Navigator
Window



Coordinates
Window



Properties
Window



Musculoskeletal Model of the Lower Extremity

In this section, you will load a model of the lower extremity into OpenSim and make the model "walk." The model represents an adult subject with an approximate height of 1.8 m and an approximate mass of 75 kg. The model consists of 13 rigid body segments and includes the lines of action of 92 muscles (43 per leg and 6 at the torso).

Loading a Model

The first model you will analyze is **gait2392.osim**. To load this musculoskeletal model into OpenSim:

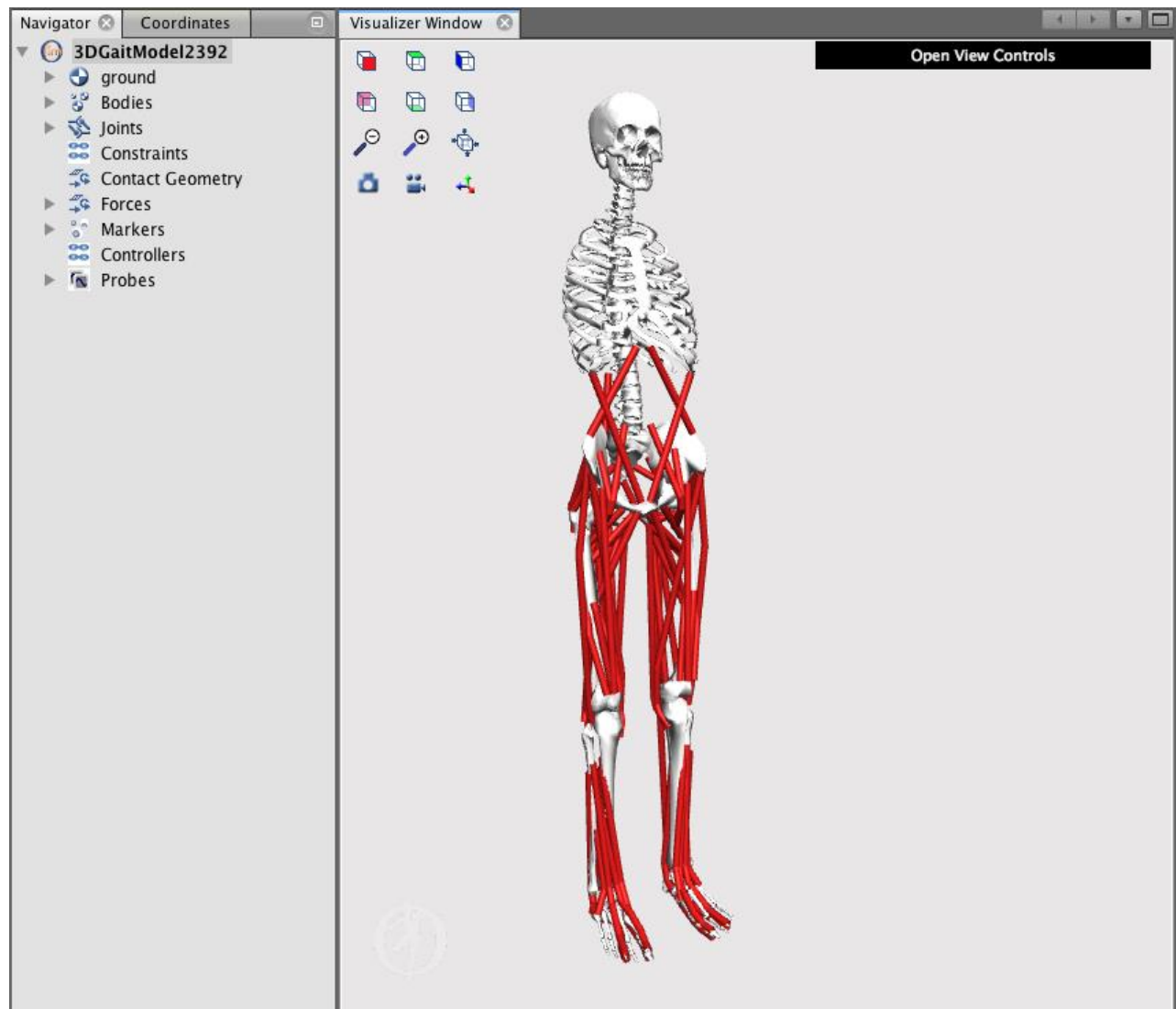
- Click the **File** menu and select **Open Model**.
- Find the **Models** folder, which is located in your Documents folder e.g., Documents\OpenSim\4.0 for a PC or, e.g., Documents/OpenSim/4.0 for a Mac.

Note: When you first launch OpenSim, the default to install models and scripts files is your Documents folders (you do have the choice to change the folder where you want to install these files). There are several different example models and motions in the Models folder. All of the model and motion files used in the remainder of the tutorial will be located in this Models folder.

- Open the **Gait2392_simbody** folder, select the file **gait2392_simbody.osim**, and click Open.

After loading a model, the Navigator Window will display the model with a given model name, you can change this model name if multiple models are open to distinguish each model. The Navigator window also provides specific information about the bodies, muscles, and joints in the model. If the Navigator window is not visible, click the Window menu and select Navigator. Use the buttons to the left of the Navigator to expand or collapse the heading.

Note: If already opened, you can also view the Navigator window by clicking its title bar.




Viewing a Model

OpenSim allows you to orient the model using your mouse

Camera Action	Windows	Mac
<i>Rotate</i>	left-click and hold (PC or mouse)	single-finger click and hold (Mac trackpad)
<i>Translate</i>	right-click and hold (PC or mouse)	two-finger click and hold (Mac trackpad)
<i>Zoom</i>	scroll up or down (PC or mouse)	pinch or expand (Mac trackpad).

In addition to your mouse, there are six orienting icons located along the right side of the View window.



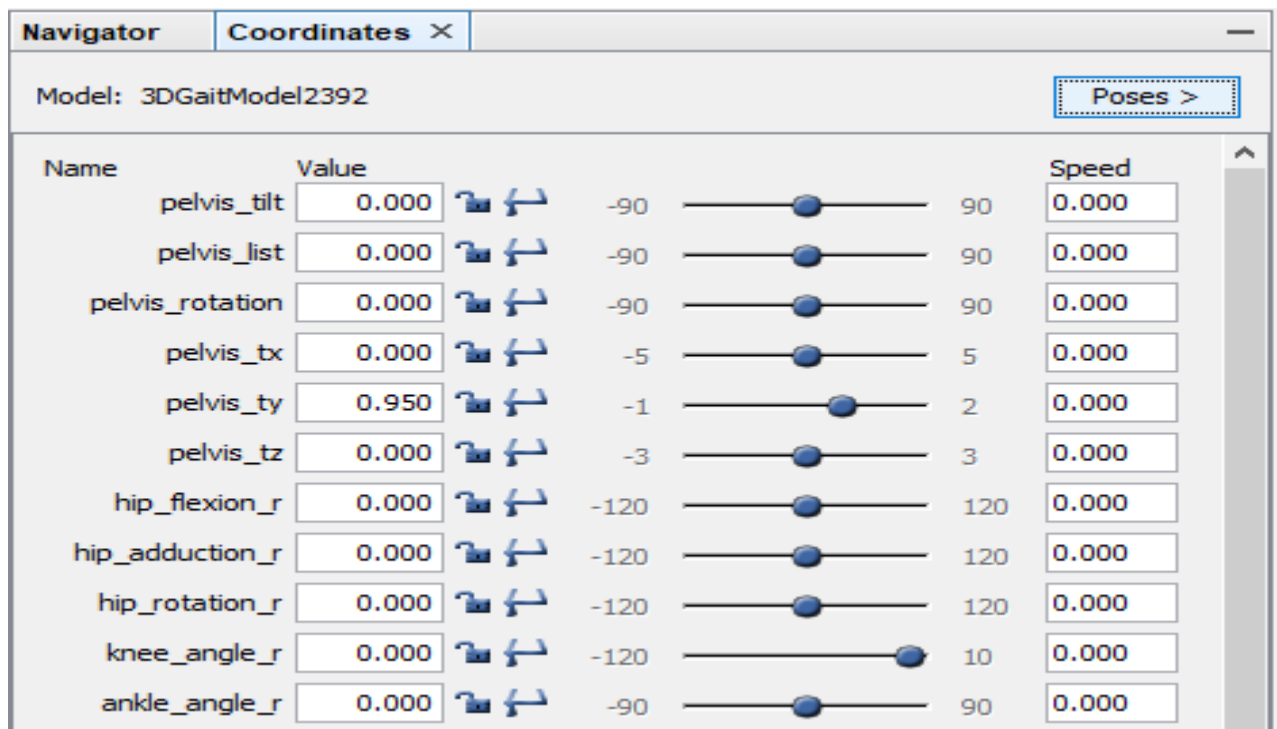
- To change the camera to view from the $-X$ direction, click the icon .
- Similarly, click on the other icons to view from the other principal directions.
- Double click on a body to center it on the screen.

Before continuing, click the icon  to reset the visualizer view

Model Coordinates

The Coordinates **window** contains sliders that correspond to joint **coordinates**, or degrees of freedom, in the model. To see the Coordinates window, click the Window menu and select Coordinates. For the current model, the orientation of the pelvis corresponds to the orientation of the model with respect to ground.

Note: If already opened, you can also view the Coordinates window by clicking its title bar.



Name	Value	Range	Speed
pelvis_tilt	0.000	-90 to 90	0.000
pelvis_list	0.000	-90 to 90	0.000
pelvis_rotation	0.000	-90 to 90	0.000
pelvis_tx	0.000	-5 to 5	0.000
pelvis_ty	0.950	-1 to 2	0.000
pelvis_tz	0.000	-3 to 3	0.000
hip_flexion_r	0.000	-120 to 120	0.000
hip_adduction_r	0.000	-120 to 120	0.000
hip_rotation_r	0.000	-120 to 120	0.000
knee_angle_r	0.000	-120 to 10	0.000
ankle_angle_r	0.000	-90 to 90	0.000

- The first three sliders—pelvis tilt, list, and rotation— correspond to rotations of the pelvis about the Z, X, and Y-axes of the "pelvis" reference frame. To rotate the pelvis about the Z-axis, drag **the pelvis_tilt slider**. Similarly, to rotate the pelvis about the other two axes, drag the corresponding slider.

- The next three sliders—pelvis tx, ty, and tz— correspond to translations of the pelvis along the X, Y, and Z-axes of the "ground" reference frame.

Note: Rotating and translating the model this way changes the orientation and location of the model with respect to ground, and is different than rotating or translating the model view in the visualizer.

- The remaining sliders correspond to joint rotations and control a single degree of freedom. To rotate the joints, drag the sliders or type in a desired joint angle in the adjacent textbox.
- Using the tools in the **Poses** menu, you can restore the model's default pose, save the current pose, or set the current pose as the model's new default.
- ✓ For now, restore the default coordinates by clicking the **Poses** button and selecting **Default**.
- ✓ Later on in the tutorial, you will save a new pose. To do this, once you've posed the model, select **New** in the Poses menu, type in a name for the **pose**, and click OK. Your saved pose will appear under "Default" when you click **Poses**.
- ✓ To set a new model default pose, after posing the model as desired, select **Set Default** in the **Poses** menu. You will need to save the model for the new Default Pose to be saved.

Muscles in a Model

Muscle-tendon paths are represented in OpenSim by a series of points connected by line segments. To see a list of all the muscles:

- In the Navigator, expand the **3DGaitModel2392** (model name) **Forces**, **Muscles**, and **all** headings.
- To display a single muscle, right-click on a specific muscle name under the all group, e.g., glut_med1_r, and select **Display > Show Only** from the popup menu.
- To toggle the display of all muscles, **right-click** on the Muscles or **all** heading, and select **Display > Show or Display > Hide**
- Rather than a single line of action, some muscles can be represented by multiple lines. In this model, the gluteus medius is an example of a muscle represented by multiple lines of action (e.g., glut_med1_r, glut_med2_r, glut_med3_r).

For some muscles, two points, the muscle origin and insertion, are sufficient to describe the muscle path. For other muscles that wrap over bones or are constrained by retinacula, intermediate wrapping or via points must be defined. To view these wrapping points:

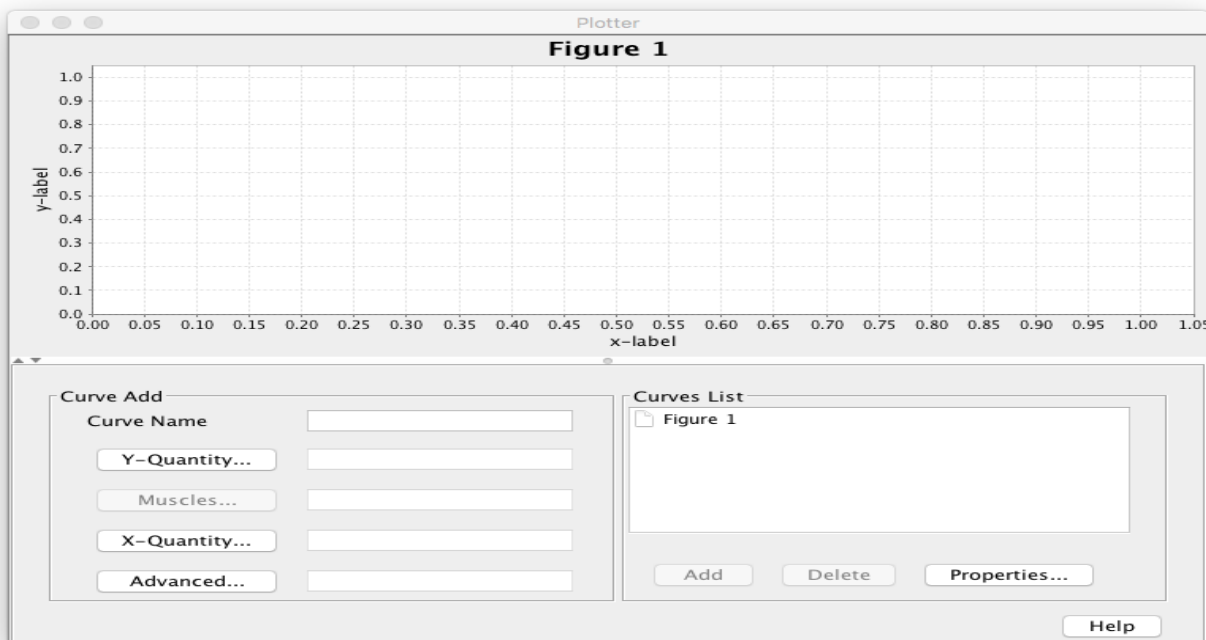
- Restore the default model **pose** by clicking the Poses button and selecting **Default**. Then zoom in on the right knee joint.
- Right click on the **R_knee_ext** muscle group and select Show only.
- Fully flex the right knee using the **knee_angle_r** Coordinates slider.
- Notice that wrapping points are introduced in some of the knee extensors at certain knee angles, such that the muscle paths develop kinks and appear to wrap around the bones.
- Some muscles in the lower limb model pass through the bones or deeper muscles at extreme ranges of motion.

Joint Angles, Muscle-tendon Lengths, & Moment Arms

In this section, you will investigate how muscle-tendon lengths and moment arms depend on limb configuration. Musculoskeletal geometry is very important to the function of muscles and to the development of quantitative musculoskeletal models. Muscle-tendon forces depend on the muscle-tendon length, and joint moments depend on both muscle-tendon forces and moment arms. Therefore, accurate specification of musculoskeletal geometry is essential in developing an accurate model for predicting muscle-tendon forces and joint moments.

Using the Plotter

OpenSim's Plotter allows you to plot muscle-tendon properties, such as length, moment arm, force, and joint moment.



To generate a plot of fiber-length vs. knee angle for the rectus femoris and vastus intermedius muscles:

- Return the model to its original pose by clicking **Poses > Default** in the Coordinates window.

Note: Plots are created for the current configuration of the model. Your plots will now be made for the default pose.

- To open a new plot, click the **Tools** menu and select **Plot**. In the plotter window, click the **Y-Quantity** button and select **fiber-length**. This variable will appear on the y-axis.
- After selecting an appropriate Y-Quantity, you must select the muscles for which you want to generate curves. Click on the **Muscles** button and a menu will appear.
- To find muscles more quickly, you can filter the muscles by muscle group. Choose the **model** option and use the **group** drop down menu to select **R_knee_ext**. The muscles list should now only show the muscles in the right knee extensors group.
- Select rectus femoris and vastus intermedius from the list by **clicking the checkboxes** labeled **rect_fem_r** and **vas_int_r**.

Note: You do not have to close the muscles window as long as the plotter window is open, and your selections are immediately updated in the Muscles textbox. This can be helpful when creating multiple curves on the same plot, which you will do in a few more steps.

- Click **X-Quantity** and select **knee_angle_r**. This variable will appear on the x-axis.
- To add a title to the plot, click the **Properties** button and type **Fiber-Length vs. Knee Angle** into the textbox under the **Title** tab. Explore the plot properties, and then click **OK**.
- To add the curves to the plot, click **Add**.

Note: The plots use the following SI units: meters (length), Newtons (force), Newton-meters (moment).

- Do not close the plot window, as you will be adding more curves in the next section.

Assessment of Hamstrings Length During Crouch Gait

In this final section of the tutorial, you will use OpenSim to investigate a possible cause of crouch gait, one of the most common walking abnormalities among individuals with cerebral palsy. It is characterized by excessive flexion of the knee during stance phase, which is often accompanied by exaggerated flexion and internal rotation of the hip. One hypothesized cause of crouch gait is short hamstrings, and orthopedic surgeons will sometimes lengthen the hamstrings of such patients in an attempt to improve their posture and gait. However, other causes of excessive knee flexion are possible (e.g. weak ankle plantarflexors), and lengthening the hamstrings can compromise these muscles' force-generation capabilities [3]. How can a surgeon determine whether a hamstring lengthening procedure is warranted?

One possible way to judge whether a patient's hamstrings are shorter than "normal" is to develop a musculoskeletal model and compare the length of the hamstrings during the patient's crouch gait cycle to the length of the hamstrings during a normal gait cycle. Suppose that an orthopaedic surgeon has brought you some kinematic data for a patient who walks with a crouch gait. The surgeon is contemplating whether to operate and wants your opinion.

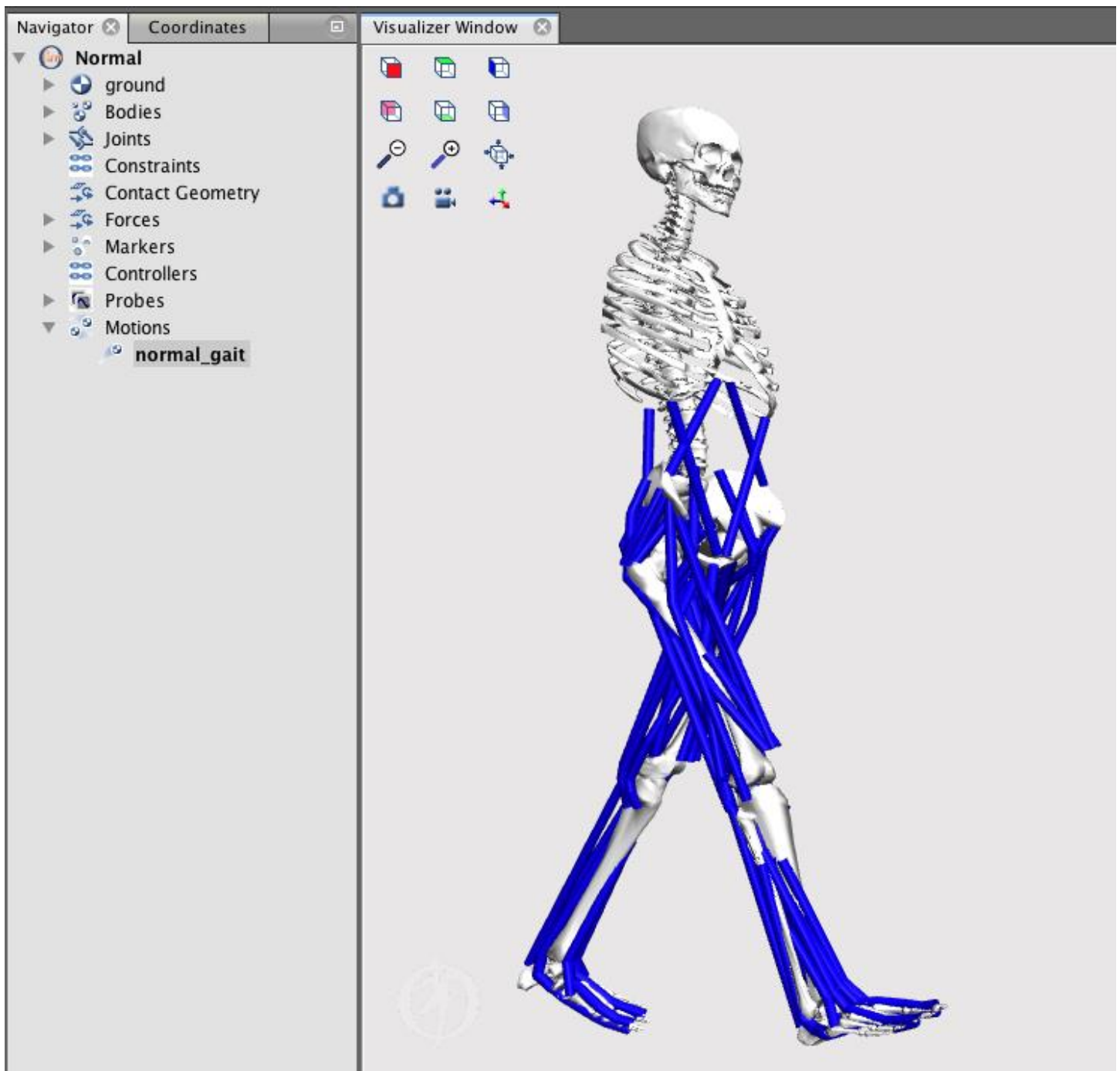
Loading a Motion

Re-open the gait2392.osim model. To animate the model, you need to load an associated motion file into OpenSim.




- Click the **File** menu and select **Load Motion**. Ensure you are in the **Gait2392\Tutorial1** directory, select the file **normal.mot**, and click **Open**. This motion file contains kinematics for a normal gait. Rename the opened model to **Normal** by **right-clicking** on the model name in the Navigator and selecting **Rename** from the popup menu.

Note: Renaming in the Navigator pane only changes the display name, it does not affect the file name of the model.

After loading a motion, its name will appear in the motion textbox, located on the toolbar. Additionally, a new branch will appear in the Navigator titled **Motions**. Expand it to see all motions loaded for a particular model, as shown. The color of the muscles change to blue after the motion is loaded.



Motion Slider

The motion slider corresponds to the current motion file. To play the current motion, drag the motion slider. To animate the model, use the video **control buttons**, e.g., click **play** . There are also buttons to **loop** , **pause** , and control the **speed** of the animation.

Multiple Models and Motions

OpenSim has the ability to load multiple models simultaneously. Follow these steps to open a second model and load a new motion:

- With the Normal model open in the Navigator, open a second version of the same model, **gait2392.osim**, and rename it to Navigator to **Crouch**. The second model you loaded automatically becomes the current model. Any action, such as loading a motion, will be applied only to the current model. Load the motion file **crouch1.mot**, which is in the **Gait2392\Tutorial1** folder.

*Note: If you do not see both models after loading, zoom out. Throughout the rest of the tutorial, these two models will be referred to as **Normal and Crouch**.*

- OpenSim can synchronize multiple motions, allowing you to animate multiple models simultaneously. To do this, expand the **Motions** branch of each model in the Navigator, hold down **Ctrl** (Windows) or **Command** (Mac), and select both motions names such that each name is highlighted. **Right-click** on either motion name, then select **Sync Motions** from the popup menu, as shown.

