Introduction to OpenSim for the Warrior Web

Welcome to the OpenSim Project for the Warrior Web. OpenSim is an extensible platform for visualizing, manipulating, simulating, and analyzing neuromusculoskeletal models to study the interaction between Warrior Web technologies and the neuromuscular system. OpenSim provides a graphical user interface (GUI) and an application programming interface (API) for developers. Read more on our About OpenSim page.

The sections below review the resources we've created to enable you to develop models of humans and devices and analyze simulations of motion:

- Getting Started
- Introduction to OpenSim
- Using OpenSim to Model and Analyze Warrior Web Devices
- Contact Us and Get Help

Getting Started

1) Register for an account on Simtk.org.

The Simtk.org site hosts the OpenSim project and many other biomedical computing projects. Creating an account will allow you to download the OpenSim software and models, participate in user forums, create your own projects, and more.

2) Email your Simtk.org username to opensim@stanford.edu

We will add you to the Simtk project we've created specifically for Warrior Web teams. This project is a specialized set of resources and links for Warrior Web technology developers using OpenSim to model device effectiveness, including a discussion forum, mailing list, and a repository for accessing and sharing software, models, and code.

3) Download and Install OpenSim

Download the OpenSim application from the Downloads page of the main OpenSim project. The OpenSim Graphical User Interface (GUI) is compatible with Windows machines. The downloads page includes the current release, OpenSim 2.4. In the coming weeks, we will add a beta release of 3.0, our next version of the software. Refer to the Installing OpenSim page for more information on the install process.

Introduction to OpenSim

1) Do the Tutorials

As a first step, particularly if you are new to biomechanical modeling and simulation, we recommend that you complete our series of three introductory tutorials. The tutorials are included with your installation of OpenSim and are also available online:

Tutorial 1 - Intro to Musculoskeletal Modeling

Tutorial 2 - Simulation and Analysis of a Tendon Transfer Surgery

Tutorial 3 - Scaling, Inverse Kinematics, and Inverse Dynamics

We've also created an exercise geared specifically to Warrior Web teams: OpenSim Exercise: Evaluate Ankle Inversion Injury Risk During a Drop Landing.

2) Review the OpenSim Overview Guide

Our Guide to OpenSim Workflow and Tools includes an overview of the OpenSim workflow, an introduction to each of the OpenSim tools, and corresponding, hands-on examples. As a next step, we recommend that you work through this guide to gain more in depth knowledge about how OpenSim works and how to use the software in real-world applications.

3) Bookmark the OpenSim Support Site

We have a comprehensive online support site that lists all of the available OpenSim resources. The main support page also features a search box that lets you search all of these resources and see the results in one place. Bookmark this page and use it as a starting point when you need help.

There are a few resources that will be particularly helpful to Warrior Web teams getting started with OpenSim:

- The OpenSim User's Guide, documenting all tools and other features of the OpenSim GUI
- A Theory and Publications page that links to documents describing OpenSim and its underlying algorithms
- A page of Examples and Tutorials demonstrating the use of OpenSim's feature set
- A guide to Collecting Experimental Data for simulation
- Teaching Materials, including slides, handouts, and other materials from past workshops and courses.
- Libraries of Musculoskeletal Models and Simulation Data. There are several musculoskeletal models and data sets included with your OpenSim distribution (in the folder "examples" or "Models"). The libraries on Simtk.org include additional models developed by researchers at Stanford and elsewhere.
- A Developer's Guide for getting started with using the OpenSim API. Using the OpenSim API allows you to extend the functionality of OpenSim by adding new model components like custom controllers.
- Doxygen documentation of the OpenSim API. The OpenSim doxygen documents the underlying classes that make up OpenSim (Bodies, Joints, Analyses, etc.). You can browse the doxygen to see the class hierarchy and learn more about all of the existing classes in the OpenSim API.
- If you want to add a new component to an OpenSim model (e.g. a spring or controller), you can use the Available Objects feature in the GUI to find the component's XML representation. Go to Help -> Available Objects in the GUI.

Using OpenSim to Model and Analyze Warrior Web Devices

You can use OpenSim to model your devices and understand how they interact with the musculoskeletal system during movement. This section summarizes the current and planned capabilities of OpenSim and describes examples of the types of questions you can answer with OpenSim

What can you do with OpenSim?

The current capabilities of OpenSim allow you to:

- Calculate and analyze the dynamics of full-body, three-dimensional human motion, including kinematics (joint angles), kinetics (joint torques), and dynamics (force-driven motion).
- Generate muscle-driven simulations of motion. With a simulation driven by muscle forces, you can determine what muscles are active and when and how much force they are generating.
    - Using the Induced Acceleration Analysis tool, you can then determine how individual muscles are accelerating the joints and bodies that make up the musculoskeletal system.
    - Using the Joint Reactions Analysis, you can determine how joints are being loaded during motion.
- Model your device and its interaction with the human musculoskeletal system. In a simulation framework, you can rapidly iterate to optimize your design and perform proofs of concept.

Examples

1) Your team would like to reduce metabolic cost during walking and running using a passive spring element at the

hip. As an initial proof of concept, you want to understand how the device would affect the psoas, vasti, and soleus - important muscles for locomotion. After the proof of concept, you want to find the optimum stiffness for the spring.

- There are several existing, published simulations of walking and running. Select the speeds you're interested in and re-run the nominal simulations. Examine psoas, vast, and soleus activations, forces, and moments over the course of the gait cycle. (This should match the published results.)
- Model your device and add it to the OpenSim musculoskeletal model. To model the passive spring, you can a linear bushing element in OpenSim. To see an example of a model with a bushing, refer to the OpenSim Exercise: Evaluate Ankle Inversion Injury Risk During a Drop Landing.
- Re-generate the simulation for the musculoskeletal model with the device. Use the Computed Muscle Control tool in OpenSim to generate a muscle-driven simulation and compare the new activations and forces to the values from the nominal simulation for each locomotion type/speed.
- Perform a design optimization. You can repeat this process to test different spring stiffnesses depending on running speed, subject anthropometry, and load carriage.

2) You've developed a prototype and it isn't improving metabolic cost as much as you thought, particularly at faster walking speeds or when carrying loads. You want to understand why and determine how to improve the device design. You've collected motion data, EMG for a subject walking with and without the device, at fast and slow speeds (see Collecting Experimental Data) . You also know the time history of the forces your device is applying to the subject.

- Import your experimental data in to OpenSim. (See Preparing Your Data.)
- Generate simulations using the OpenSim workflow. (See Guide to OpenSim Workflow and Tools). For trials where the subject is wearing the device, use the external loads tool to apply forces. (See External Loads Specification.)
- Examine muscle activations and forces for big muscle groups (e.g. the gluteals, vasti, and plantarflexors). How do the simulated activations compare to previously reported values in the literature? How are the activations different in simulations with and without the device? This will point you to ways the device may be having an unexpected impact on muscle function.
- Examine muscle-tendon dynamics using a Muscle Analysis (see Analyses). This could reveal additional information about how the device affects muscle function and point to ways to modify and improve the device.
- Iterate based on your analysis to improve the device design

3) You've developed a prototype and you want to predict if it will mitigate musculoskeletal injuries. See OpenSim Exercise: Evaluate Ankle Inversion Injury Risk During a Drop Landing for a hands on exercise exploring injury risk with a simulation.

4) Past studies from our lab, using OpenSim, have examined muscle function and metabolics during walking and running. Review these papers to find out more about how muscles contribute to movement and find out more about modeling and simulation research methodology: Neuromuscular Biomechanics Lab Publications Page.

Limitations and What's Coming Next

As with any modeling and simulation tool, there are limitations. We are working to address many of these over the coming year.

1) Predicting New Motions

For complex, full-body, three-dimensional motions like walking and running, we are currently tied, for the most part, to generating simulations that track experimentally measured motions. Understanding and modeling how the human motor control system will respond to a perturbation or the addition of a device and alter the body's kinematics is a challenging and ongoing area of investigation.

- We are working on developing new predictive controllers for synthesizing motions without experimental data. As part of our Warrior Web effort, we will Incorporate novel neuromuscular controls into OpenSim that generate biomechanically accurate human motion such as reflex response, walking, and running in scenarios perturbed from measured motion or synthesized de novo. Phase 1 implements reflex driven motion synthesis tools. Phase 2 implements central nervous system (CNS) motion synthesis tools.

- In the meantime, you can alter muscles properties (e.g. strength) or add an assistive device (see the examples above) and generate a simulation that tracks an existing experimentally-measured motion. You can then examine how these alterations affect the distribution of forces among muscles and added devices.
- In some cases, you can also make small changes to a simulation and run a short time scale perturbation to determine how the change affects the motion. For one example, see Reinbolt et al., 2009. In this study, the researchers used a simulation to understand whether changing pathological muscle activations would improve gait kinematics.
- We also have a simple reflex controller. Refer to our example, OpenSim Exercise: Evaluate Ankle Inversion Injury Risk During a Drop Landing.

2) Metabolics Assessment

As part of our development for the warrior web project, we will integrate metabolics assessment into the OpenSim GUI on a whole body and per muscle basis. These metrics will take into account factors like activation-dependent muscle heat generation, in addition to mechanical work. We will validate our metabolics calculators by comparing our estimates to experimentally measured metabolic cost for a variety of motions. In the meantime, comparing muscle activations for a simulation with and without an assistive device will give you an estimate of the device's impact on metabolic cost (see the examples section above). If you have EMG or muscle activations for walking you can also use the linear regression model in this paper to estimate metabolic cost: Silder et al, 2012

3) Injury Risk Assessment

We will add injury risk metrics for the knee and ankle to OpenSim as part of our development for the Warrior Web project. In the meantime, you can use OpenSim's Joint Reactions Analysis to estimate the loads on a given joint during a simulated motion. Also see our Example - Estimating Joint Reaction Loads. In many cases, examining kinematics also provides insight (see OpenSim Exercise: Evaluate Ankle Inversion Injury Risk During a Drop Landing).

4) New Models and Simulated Motions

There are many models and simulations already available, developed in our lab and elsewhere. See the Neuromuscular Model Library and Motion and Simulation Data Library to find existing models and data. We will also be expanding and improving the available set of models and simulated motions as part of our work for the Warrior Web project.

Contact Us and Get Help

We anticipate questions and issues, so we've set up several ways for you to contact us and get support.

1) OpenSim User Forum

You can post questions on our general OpenSim user forum. Or search past entries to see if your question has already been asked by other users.

2) Workshops and Webinars

We run many workshops and webinars. You can watch past webinars online. To find out about upcoming events, go to the OpenSim website or sign up for our general OpenSim mailing list. We also plan to hold workshops specifically for Warrior Web teams as part of our effort on the project.

3) SimTK project page for Warrior Web teams

We created a Simtk project page for Warrior Web teams. Send us your Simtk username to join the project (opensim@stanford.edu). The project page includes:

- A discussion forum for Warrior Web specific questions and ideas
- A mailing list for Warrior Web specific announcements, updates, and events
- A repository for accessing and sharing software, models, and code
- Access to early beta versions of plugins, models and more.

4) Email, Phone, and Skype

We are also happy to provide support via email, phone or Skype. You can reach us at opensim@stanford.edu.