Getting Started with OpenSim

How can we learn all the basics of OpenSim?
A good place to start learning OpenSim is to first go through the tutorials and examples as found on our documentation wiki.

Are there good help files/tutorials for MATLAB scripting?
Our page on Scripting with MATLAB is a good start. It contains useful information including how to set up your environment, a list of examples that we distribute with OpenSim, and some other helpful tips and troubleshooting steps.

Is there any way to ask questions of OpenSim experts and consult with them about our projects?
The OpenSim forum is a great way to connect with OpenSim experts around the world. Users can also apply to participate in OpenSim workshops that occur a few times per year. You can sign up for the OpenSim mailing list to receive announcements about those opportunities.

Which Simulation Pipeline Is Best?

Which method is better: forward or inverse dynamics? Can we say that, for upper and lower limb modelling, forward and inverse dynamics simulation respectively are more suitable?
Forward and inverse methods are both valuable methods with different goals, and neither method is always better than the other. It is important to choose the method that is needed to answer your research question, and the webinar provided examples of many studies to help guide this process. In general, we suggest choosing the easiest and quickest methods that are sufficient for your problem. For example, forward dynamic simulations of the upper extremity can be easier to generate compared with simulations of the lower extremity, as upper extremity motions don't generally require simulating complicated foot-floor contact.

Which of the pipelines can be used if marker (motion capture or MOCAP) data is not available, for example to estimate muscle forces reliably? How accurate would the results be?
In general, if accurate muscle force estimation is needed, we highly recommend inverse methods over forward methods. Since the motion is used as a constraint in inverse methods, it provides more confidence in these estimations. Furthermore, with forward methods, simplified models are often used, which may group muscles together (e.g., one muscle for three vasti muscles) and thus can only give estimates for muscle groups. There are many datasets (e.g., Grand Challenge to Predict in Vivo Knee Loads, Gait in Children with Spastic Cerebral Palsy, Running at Multiple Speeds) that have been shared by the community that we encourage you to use if you are not able to collect your own motion capture.

If a forward method is necessary, all forward methods can estimate muscle forces, although there is less confidence in these estimates. If your motion is simple enough, using the forward dynamics tool is a quick way to get rough estimates. Direct collocation could be used for more complicated motions, and can generate simulations faster than shooting methods or reinforcement learning.

Which is better for joint reaction force analysis: CMC or SO?
Static optimization (SO) and CMC have both been successfully used for joint reactions analysis as they estimate the muscle forces necessary for calculating joint reaction forces. Often, the two methods will give similar results with respect to the timing of when muscles activate; however, CMC will tend to give higher forces since it typically yields solutions with more co-contraction. When your research question depends on the interaction between muscle and tendon during a motion or when elastic storage of energy in tendon is a known or likely contributor to the motion of interest (e.g., high-force motions like running), then you should use CMC or a framework that models tendon-dynamics. For either static optimization or CMC, validating that the muscle forces are reasonable for your motion is the most important step to understanding which method is best for your problem.

I am adding an external torque to the right foot to simulate high ankle sprain injuries during gait. Can I modify existing gait files (such as ground reaction force files) and run forward dynamics to observe fibular motion? If that is not possible, what would be the best pipeline for observing the motion?
For problems in which you want to study the effect of changing the skeletal motion or the ground contact forces, it can be difficult to use inverse methods. For this problem, we would suggest looking at a direct collocation package such as OpenSim Moco.

I have real experimental data for osteoarthritis patients and am trying to determine if a hip or ankle exoskeleton would be best to assist walking. I have joint angles, moments, and power. What is the best pipeline for this?
A good place to start could be to use CMC to find a motion that has the same joint angles and moments but with an ideal torque actuator at the hip or ankle. This was done previously for studying hip, knee, and ankle devices for walking in an article titled "Simulating ideal assistive devices to reduce the metabolic cost of walking with heavy loads", and for running in an article titled "Simulating Ideal Assistive Devices to Reduce the Metabolic Cost of Running".

My research question is whether lateral sway of the bicycle is the optimal strategy for cyclists to use during sprint cycling, i.e., travel 250 m as fast as possible. Which pipeline would you recommend?
It can be helpful to break down complex questions into smaller pieces that are testable by more targeted simulations. For instance, if you are interested in whether the sway of the bicycle itself is important, then a simulation without a complex musculoskeletal muscle could be useful. It could also be possible to gain insight through inverse methods by using data of individuals cycling with lateral sway and without lateral sway. If it is necessary to predict a new motion with a complicated model, direct collocation is likely the best option of the methods for this case, and

careful validation should be used to gain confidence in the results (e.g., showing you can accurately predict known motions).

Input Data

What are the modes of input that OpenSim can take? c3d? MRI? What other modalities?
The core OpenSim software uses the file formats of .trc for marker trajectories and .mot for force plate data. We introduced a C3D reader into OpenSim as of version 4.0. A list of tools for converting experimental data for use in OpenSim can be found on our page Tools for Preparing Motion Data. EMG data can be used both as constraints in an inverse problem, such as in CMC, or as inputs to a controller in a forward simulation.

While the core OpenSim software does not accept imaging modalities such as MRI, others in the community have developed and shared their own software to do this. Two such tools are the Musculoskeletal Atlas Project (MAP) client and NMSBuilder.

Are there any resources for using EMG in OpenSim?
EMG data can be used in a few ways in OpenSim. One example is using the Excitation Editor to create control inputs over time that can be used in the Forward Dynamics tool. EMG data can also be used as constraints to muscle excitations in Computed Muscle Control (see the Control Constraints section in our CMC documentation for more information). This was used in work by Hamner *et al.* in simulations of running in order to constrain some muscle activity by EMG measured from the experiments. Their project page can be found here.

Can I control a model directly with torques as input data?
Yes, torques can be used to drive a motion. You will need to modify your model to include new components to simulate the torques. Two components that are helpful for this are the TorqueActuator components, which apply torques between two bodies, and CoordinateActuators, which apply generalized forces and torques to a specific coordinate. Each of these can be used along with a PrescribedController, which can be used to feed in input signals to the actuators. To find out the XML format for adding these components to your model, refer to the XML Browser in the GUI (under the “Help” dropdown menu, click “XML Browser”).

When working with non-human animals, what inputs other than bone rigid body motion are necessary for inverse analysis? Muscle attachments and PCSA?
The requirements for the model are the same for human and non-human animals. If you only need to calculate joint torques via inverse dynamics, only the skeletal model is needed, and thus, muscles and their parameters are not needed for inverse dynamics. If you need to estimate muscle activity, you need a model of the animal of interest that contains accurate muscle and skeletal geometry relevant to the muscles and joint motions of interest.

For the inverse dynamics analysis, do you need a c3d file to load into OpenSim?
Inverse dynamics uses the output from inverse kinematics and ground reaction forces, which can be extracted from .c3d files, to calculate joint torques. You can extract the ground reaction forces from the .c3d file using existing tools. Some of these tools can be found on our documentation page Tools for Preparing Motion Data**.**

Static Optimization and CMC

What are good resources for starting with static optimization and CMC?
An intermediate example that highlights static optimization and CMC is The Strength of Simulation: Estimating Leg Muscle Forces in Stance and Swing. This example works through using the tools with a simple example to help users with static optimization, CMC, and Residual Reduction Algorithm (RRA) that is commonly used with CMC. Another intermediate example is Working with Static Optimization. The documentation for static optimization and for CMC are also helpful resources.

I have seen that static optimization was done with muscle synergy. But I've not seen CMC with muscle synergy. Is there a specific reason why CMC is not used in combination with muscle synergy?
The logic of static optimization has many fewer steps than in CMC. Because of this, it's much easier to write a custom static optimization method for your own needs, such as for muscle synergies, than a custom CMC method.

Can CMC be run for models that do not include a torso (i.e., lower extremity models with pelvis)?
CMC can be run on a model without a torso. However, you would have to adjust the model to account for the missing mass of the torso or else there will be large discrepancies between the ground reaction force and the kinematics. Even after making these adjustments, it will be important to make sure that your residuals from the CMC solution are small enough to trust your simulation results for your use case.

Forward Methods (Reinforcement Learning, Shooting Methods, Direct Collocation) and Tools

Can you comment on the possibility of merging these methods? For example, if I have a problem that's best addressed by reinforcement learning or direct collocation, would it be helpful (speed?) and a good idea (quality solution?) to use a CMC solution as the initial guess?
One way to improve the speed of more complicated algorithms such as reinforcement learning or direct collocation is to give it a good initial guess. Using a quicker method, such as CMC, to

give a good guess is a great way to do just this. We have seen users leverage this strategy for both reinforcement learning and direct collocation.

Does optimization (reinforcement learning/shooting method) for the forward methods occur within the muscle excitations, or throughout the entire forward pipeline?
So far, usage of shooting methods and reinforcement learning has been focused on choosing the muscle excitations that optimize an objective function over a whole simulation. If you're interested in learning more about these methods, previous webinars about shooting methods (and SCONE) and reinforcement learning are great places to start.

Can we send SCONE and Moco output files as input to inverse dynamics (ID) and static optimization (SO)?
The output of a forward simulation, such as from SCONE, contains all the states, including both joint kinematics and muscle states. This means that ID and SO are not necessary to run since joint torques and muscle forces can be calculated directly from the output rather than sent through a different tool.

Other Questions

I observed that in some of the forward dynamics simulations you showed, Hunt-Crossley spheres seemed to appear on the ground, rather than a generic ground half sphere. Why was that done? How did they help?
Hunt-Crossley spheres were used on the ground in a couple studies, and in these cases they created an uneven terrain. For instance, in the reinforcement learning research example, the spheres in the ground were added obstacles in the competition.

Are there good resources for investigating the underlying joint integrity of existing models in the OpenSim Resources page? How can I update/alter the degrees of freedom for certain joints?
Updating and validating a new model often takes a lot of time, so more often, it can be helpful to find pre-existing models and understand the use cases for those models. We maintain a list of models, including both OpenSim core models and community models. Many more models have been shared at https://simtk.org/.

If you decide it is still necessary to alter a model, An Overview of OpenSim Models is a good place to start to understand how the components are represented in our .osim files. It also has information about different Joint types in OpenSim.