

# OpenSim Moco Cheat Sheet for the Matlab Interface

## MocoStudy

### MocoProblem

Access the MocoProblem from the study.

```
problem = study.updProblem();
```

**Set the model.**

```
problem.setModel(Model('model_file.osim'));
```

**Set variable bounds.**

Set initial time to 0; final time between 0.5 and 1.5 s.

```
problem.setTimeBounds(MocoInitialBounds(0),  
    MocoFinalBounds(0.5, 1.5));
```

The coordinate value must be between 0 and  $\pi$  over the phase, and its initial value is 0 and its final value is  $\pi/2$ .

```
problem.setStateInfo('/jointset/j0/q0/value',  
    [0, pi], 0, pi/2);
```

The control for actuator 'tau0' must be within [-50, 50] over the phase.

```
problem.setControlInfo('/tau0', [-50, 50]);
```

**Optimize static model properties.**

Create parameter 'myparam' to optimize the mass of Body 'bodyset/b0' within [0.1, 0.5].

```
problem.addParameter(MocoParameter('myparam',  
    '/bodyset/b0', 'mass', MocoBounds(0.1, 0.5)));
```

**Add goals to the problem.**

Control · ControlTracking · FinalTime  
StateTracking · MarkerTracking · TranslationTracking  
OrientationTracking · JointReaction

Minimize the sum of squared controls with weight 1.5.

```
problem.addGoal(MocoControlGoal('effort', 1.5));
```

**Add path constraints to the problem.**

Define time-dependent bounds for controls.

```
pathCon = MocoControlBoundConstraint();  
problem.addPathConstraint(pathCon);
```

### MocoSolver

**Initialize the CasADi or Tropter solver.**

```
solver = study.initCasADiSolver();  
% alternative: solver = study.initTropterSolver();
```

**Settings for Tropter and CasADi solvers.**

Solve the problem on a grid of 50 mesh intervals.

```
solver.set_num_mesh_intervals(50);
```

Transcribe the optimal control problem with the Hermite-Simpson scheme (alternative: 'trapezoidal').

```
solver.set_transcription_scheme('hermite-simpson');
```

Loosen the convergence and constraint tolerances.

```
solver.set_optim_convergence_tolerance(1e-3);  
solver.set_optim_constraint_tolerance(1e-3);
```

Stop optimization after 500 iterations.

```
solver.set_optim_max_iterations(500);
```

By default, the Hessian is approximated from first derivatives. Set to 'exact' to use an exact Hessian.

```
solver.set_optim_hessian_approximation('exact');
```

Create a guess, randomize it, then set the guess.

```
guess = solver.createGuess(); guess.randomizeAdd();  
solver.setGuess(guess);
```

Set the guess from a MocoTrajectory or MocoSolution file.

```
solver.setGuessFile('previous_solution.sto');
```

**Settings for only CasADi solver.**

By default, CasADi uses 'central' finite differences; 'forward' differences are faster but less accurate.

```
solver.set_finite_difference_scheme('forward');
```

Turn off parallel calculations.

```
solver.set_parallel(0);
```

Monitor solver progress by writing every 10th iterate to file.

```
solver.set_output_interval(10);
```

Solve the study and obtain a MocoSolution.

```
solution = study.solve();
```

Visualize the solution.

```
study.visualize(solution);
```

Compute outputs from the solution.

```
outputs = StdVectorString();  
outputs.add('.*active_force_length_multiplier');  
table = study.analyze(solution, outputs);
```

## MocoTrajectory and MocoSolution

Create a MocoTrajectory.

```
traj = MocoTrajectory('MocoStudy_solution.sto');
traj = MocoTrajectory.createFromStatesControlsTables(
    states, controls);
```

Get time information.

```
traj.getNumTimes();
traj.getInitialTime(); trajectory.getFinalTime();
traj.getTimeMat();
```

Get names of variables.

```
traj.getStateNames(); traj.getControlNames();
traj.getMultiplierNames(); traj.getParameterNames();
```

Get the trajectory/value for a single variable by name.

```
traj.getStateMat(name); traj.getControlMat(name);
traj.getMultiplierMat(name); traj.getParameter(name);
```

Get the trajectories/values for all variables of a given type.

```
traj.getStatesTrajectoryMat();
traj.getControlsTrajectoryMat();
traj.getMultipliersTrajectoryMat();
traj.getParametersMat();
```

Change the number of times in the trajectory.

```
traj.resampleWithNumTimes(150);
```

Set variable values.

```
traj.setTime(times)
traj.setState(stateTraj); traj.setControl(controlTraj);
traj.setParameter(value);
traj.setStatesTrajectory(statesTraj);
traj.insertStatesTrajectory(subsetStates);
```

Randomize the variable values.

```
traj.randomizeAdd();
```

Export the trajectory.

```
traj.write('mocotrajectory.sto');
traj.exportToStatesTable()
traj.exportToStatesTrajectory(mocoProblem)
```

Compare two trajectories.

```
traj.isNumericallyEqual(otherTraj);
traj.compareContinuousVariablesRMS(otherTraj);
traj.compareParametersRMS(otherTraj);
```

Functions on only MocoSolution.

```
solution.success(); solution.getStatus();
solution.getObjective(); solution.getNumIterations();
solution.getSolverDuration();
solution.unseal(); % Access a failed solution.
```

## The Moco Optimal Control Problem

$$\text{minimize} \quad \sum_j w_j J_j \left( t_0, t_f, y_0, y_f, x_0, x_f, \lambda_0, \lambda_f, p, \int_{t_0}^{t_f} s_{c,j}(t, y, x, \lambda, p) dt \right)$$

subject to  $\dot{q} = u$

$$M(q, p)\dot{u} + G(q, p)^T \lambda = f_{\text{app}}(t, y, x, p) - f_{\text{bias}}(q, u, p)$$

$$\dot{z}_{\text{ex}}(t) = f_{\text{aux,ex}}(t, y, x, \lambda, p) \quad 0 = f_{\text{aux,im}}(t, y, \dot{z}_{\text{im}}, x, \lambda, p)$$

$$0 = \phi(q, p)$$

$$0 = v(q, u, p)$$

$$0 = \alpha(q, u, \dot{u}, p)$$

$$g_L \leq g(t, y, x, \lambda, p) \leq g_U$$

$$V_{L,k} \leq V_k \left( t_0, t_f, y_0, y_f, x_0, x_f, \lambda_0, \lambda_f, p, \int_t s_{e,k}(t, y, x, \lambda, p) dt \right) \leq V_{U,k}$$

$$y_{0,L} \leq y_0 \leq y_{0,U} \quad y_{f,L} \leq y_f \leq y_{f,U}$$

$$x_{0,L} \leq x_0 \leq x_{0,U} \quad x_{f,L} \leq x_f \leq x_{f,U}$$

with respect to  $y \in [y_L, y_U] \quad x \in [x_L, x_U]$

$$t_0 \in [t_{0,L}, t_{0,U}] \quad t_f \in [t_{f,L}, t_{f,U}]$$

$$p \in [p_L, p_U]$$

problem.addGoal()

problem.setModel()

problem.addPathConstraint()

problem.addGoal()

problem.setStateInfo()

problem.setControlInfo()

problem.setTimeBounds()

problem.addParameter()

$t$  time  
 $q(t)$  generalized coordinates  
 $u(t)$  generalized speeds  
 $z(t)$  auxiliary states  
 $y(t)$  ( $q(t), u(t), z(t)$ )  
 $x(t)$  controls  
 $p$  constant parameters  
 $\lambda$  kinematic constraint multipliers

$w_j$  weight for the  $j$ -th cost  
 $J_j$  the  $j$ -th cost  
 $s_{c,j}$  integrand used in the  $j$ -th cost  
 $M$  mass matrix  
 $f_{\text{bias}}$  centripetal and coriolis forces  
 $G$  kinematic constraint Jacobian  
 $f_{\text{app}}$  applied forces  
 $f_{\text{aux}}$  auxiliary dynamics (explicit & implicit)

$\phi$  position-level constraints  
 $v$  velocity-level constraints  
 $\alpha$  acceleration-level constraints  
 $g$  path constraints  
 $V_k$  the  $k$ -th endpoint constraint  
 $K$  number of endpoint constraints  
 $s_{e,k}$  integrand in  $k$ -th endpoint con.  
 $( )_U$  an upper bound  
 $( )_L$  a lower bound