

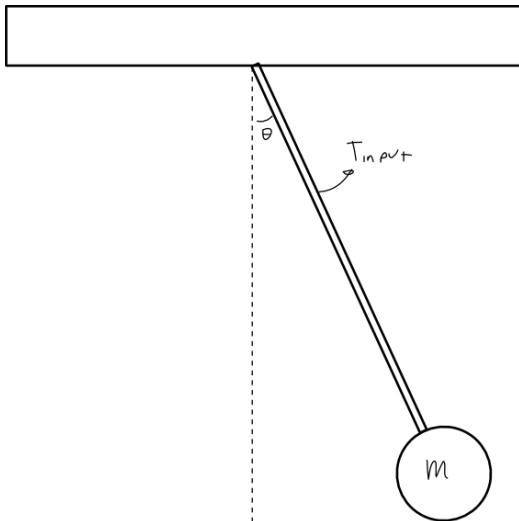
# System Modeling Using Simscape

## An introduction to Simscape

Simscape is a GUI modeling environment for multi-domain physical systems where object behaviors are predefined and governed by relevant physical laws. The user does not need to derive the mathematical model of the system. Simscape objects are available in the Simulink library browser under Simscape. Several toolboxes exist for modeling systems in different physical domains.

## EXAMPLE: Modeling a pendulum

Consider the pendulum as shown:



### Mathematical model of the system:

Using Newton's law (and considering viscous friction losses and a spring force):

$$\text{Torque due to gravity: } T_g = mgl \sin\theta$$

$$\text{Torque due to friction: } T_f = b\dot{\theta}$$

$$\text{Position dependent torque: } T_k = k\theta$$

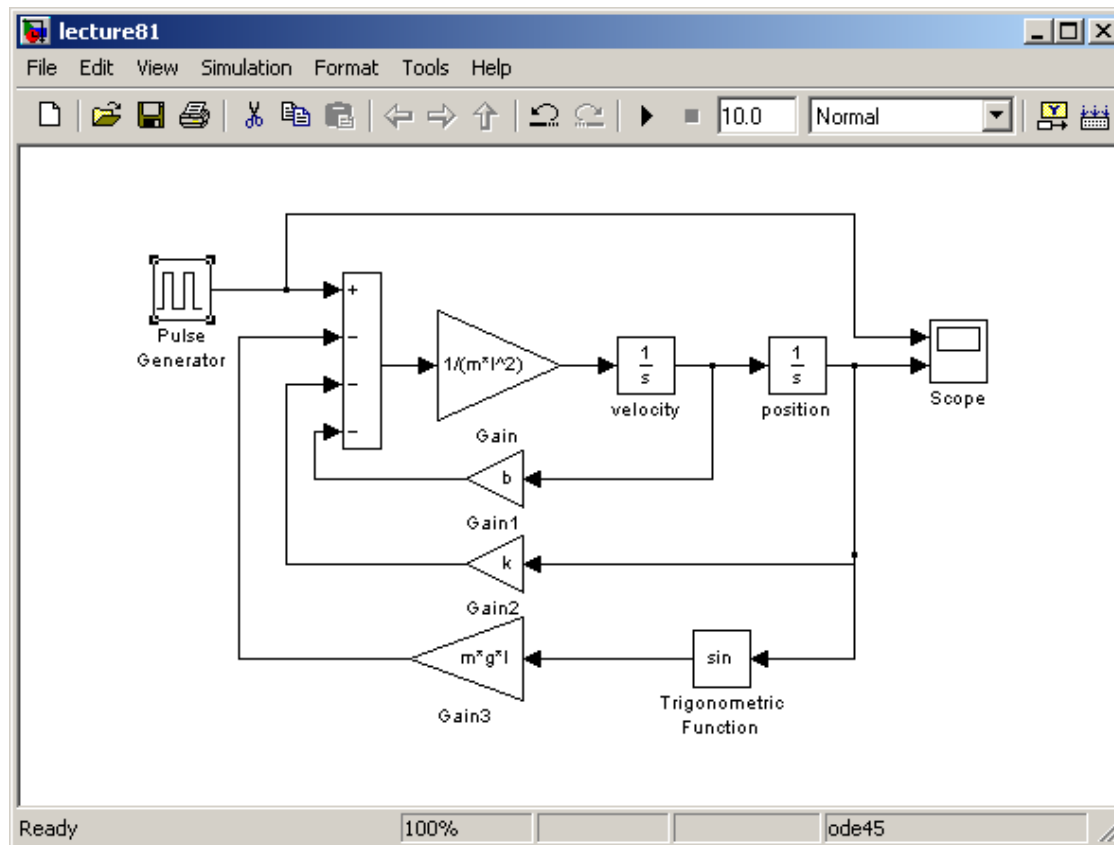
$$I\ddot{\theta} = \Sigma T; I_{\text{pendulum}} = ml^2$$

$$ml^2\ddot{\theta} = T_{\text{input}} - k\theta - b\dot{\theta} - mgl \sin\theta$$

# Simulink Modeling of Pendulum

## Simulink model:

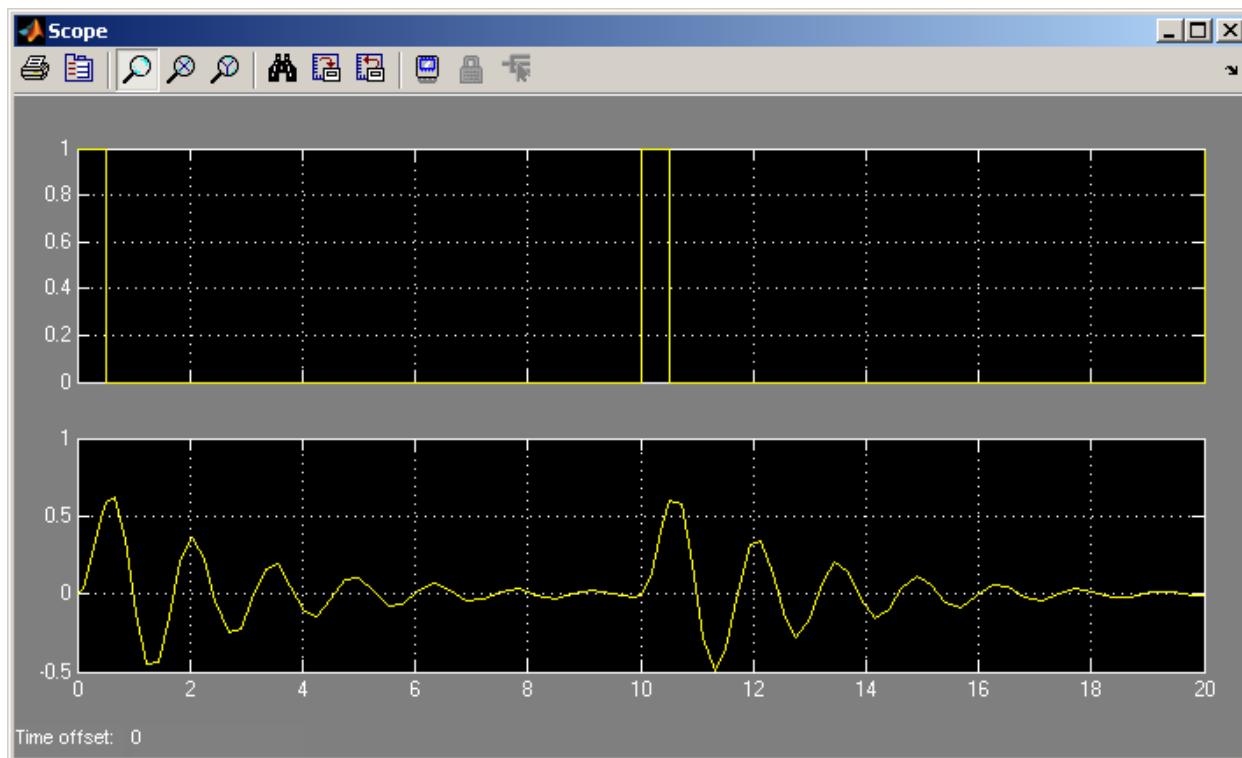
- The pendulum is a nonlinear system, and since we derived its mathematical model, we can build it in Simulink as:



# Simulink Modeling of Pendulum ...

## Simulation with Simulink:

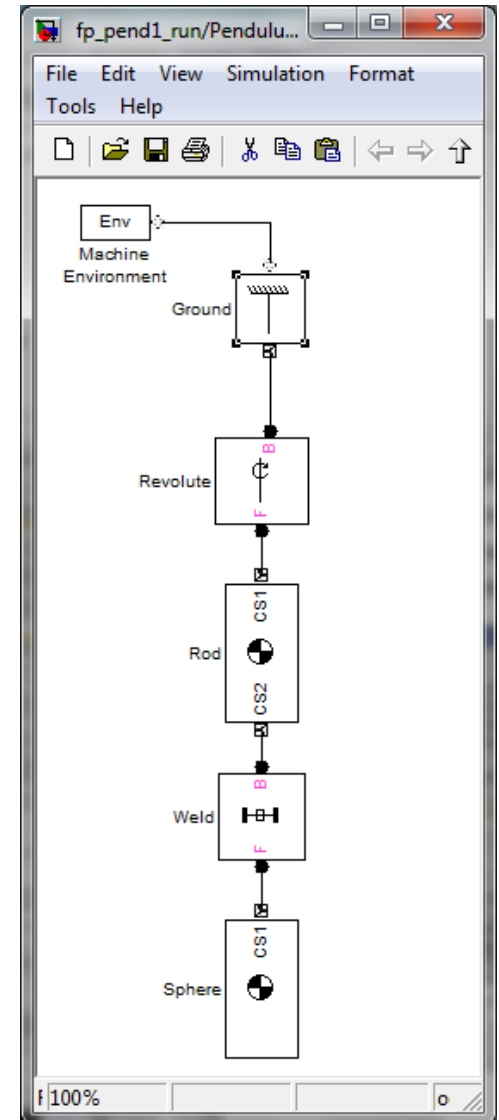
- Define values for the system parameters
  - $m=0.5\text{kg}$ ,  $l=0.5\text{m}$ ,  $g=9.81\text{m/s}^2$ ,  $b=0.1$ ,  $k=0$
- Run the Simulink model and plot the system response (angular position) to an input torque pulse.



# Simscape Modeling of Pendulum

## Simscape model:

- Modeling a system in Simscape does not require deriving the mathematical model of the system based on the physical laws
- To model the pendulum in Simscape, open the SimMechanics library and get:
  - One environment object
  - One physical reference object (ground)
  - Two physical bodies (the **rod** and the **sphere**)
  - Two joints for connecting the bodies (one fixed, one rotational (single axis))
- Connect these objects as shown



# Simscape Modeling of Pendulum ...

- Define the physical ground reference w.r.t. the environment
  - In the ground object's parameter window enable the environment port
- Define gravity as acting along the z-axis
  - In the environment object's parameter window, enter: [0,0,-9.81]
- Define the pendulum's axis of rotation w.r.t. the environment
  - In the joint object's parameter window, enter: [0,1,0] , (y-axis w.r.t. the world)
- Define the endpoints and the center of gravity (COG) of each body with respect to an adjoining body
  - The positions of objects should all be defined w.r.t. their adjoining bodies
- Define the moment of inertia of each body
  - Moment of inertia of each body is expressed as a square matrix. For example:

$$\begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}, \text{ where } \begin{cases} I_{xx}: \text{moment rotating about } x - \text{axis} \\ I_{yy}: \text{moment rotating about } y - \text{axis} \\ I_{zz}: \text{moment rotating about } z - \text{axis} \end{cases}$$

Tables of inertia moments are available online.

# Simscape Modeling of Pendulum ...

Setting up parameters for the pendulum's body (rod):

- In the parameter window of the rod's body object define its mass and moment of inertia, and set the relative position of its center of gravity (COG) and its ends with respect to the adjoining body (the reference ground)

**Block Parameters: Rod**

**Body**

Represents a user-defined rigid body. Body defined by mass  $m$ , inertia tensor  $I$ , and coordinate origins and axes for center of gravity (CG) and other user-specified Body coordinate systems. This dialog sets Body initial position and orientation, unless Body and/or connected Joints are actuated separately. This dialog also provides optional settings for customized body geometry and color.

**Mass properties**

Mass:  kg

Inertia:  kg\*m^2

**Position** | Orientation | Visualization

Show Port	Port Side	Name	Origin Position Vector [x y z]	Units	Translated from Origin of	Components Axes of
<input type="checkbox"/>	Top	CG	[0 0 -lz/2]	m	CS1	CS1
<input checked="" type="checkbox"/>	Top	CS1	[0 0 0]	m	Adjoining	Adjoining
<input checked="" type="checkbox"/>	Bottom	CS2	[0 0 -lz]	m	CS1	CS1

OK Cancel Help Apply

# Simscape Modeling of Pendulum ...

Setting up parameters for the pendulum's spherical end:

- In the parameter window of the spherical body object, define its mass and moment of inertia (to rotate about its center), and set the relative position of its center of gravity (COG) and its ends with respect to the adjoining body (the rod)
  - Note that the COG of the sphere is exactly at the endpoint of the rod

**Block Parameters: Sphere**

Body

Represents a user-defined rigid body. Body defined by mass  $m$ , inertia tensor  $I$ , and coordinate origins and axes for center of gravity (CG) and other user-specified Body coordinate systems. This dialog sets Body initial position and orientation, unless Body and/or connected Joints are actuated separately. This dialog also provides optional settings for customized body geometry and color.

Mass properties

Mass:  kg

Inertia:  kg\*m^2

Position   Orientation   Visualization

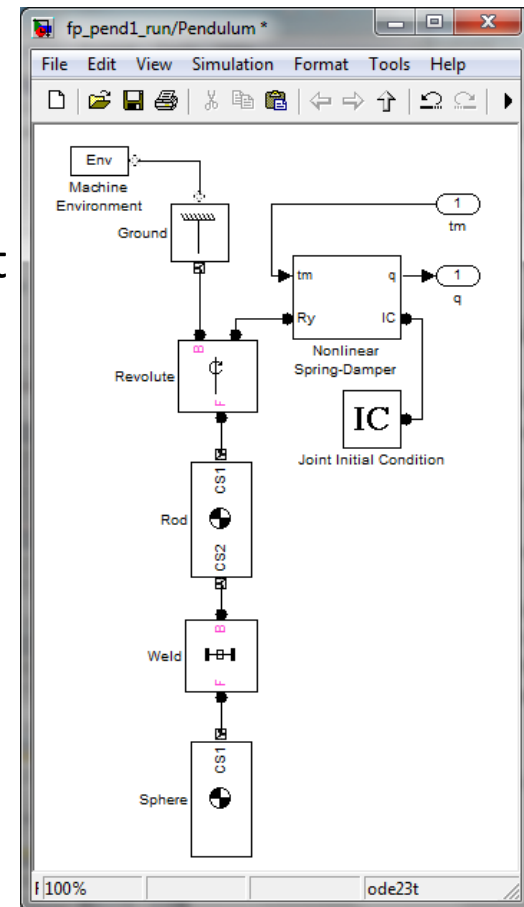
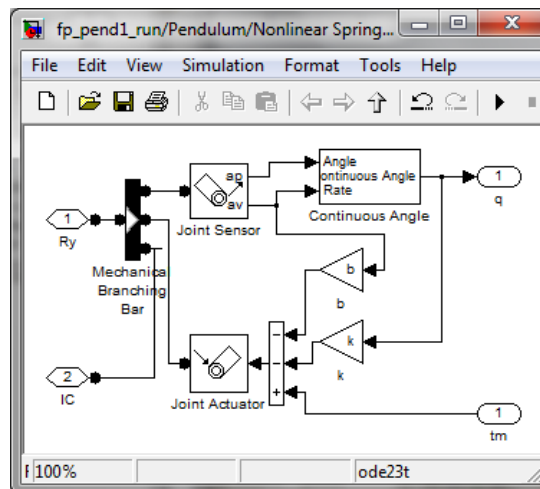
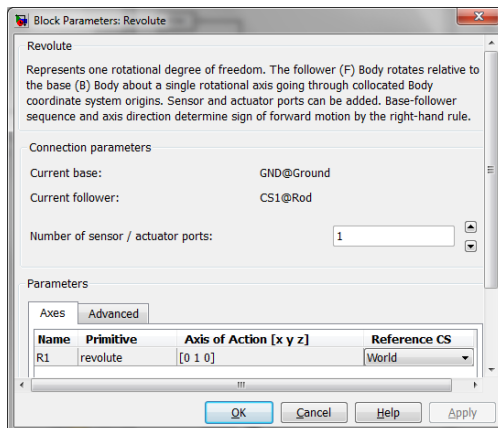
Show Port	Port Side	Name	Origin Position Vector [x y z]	Units	Translated from Origin of	Components Axes of
<input type="checkbox"/>	Top	CG	[0 0 -r/2]	m	CS1	CS1
<input checked="" type="checkbox"/>	Top	CS1	[0 0 0]	m	Adjoining	Adjoining
<input type="checkbox"/>	Bottom	CS2	[0 0 -r]	m	CS1	CS1

OK Cancel Help Apply

# Simscape Modeling of Pendulum ...

Adding Simulink blocks for input/output interface:

- In the Revolute Joint's parameter window, add a sensor port
- Add a Joint Actuator and a Joint Sensor object from the SimMechanics library
  - Joint actuators and sensors interface with Simulink
    - For example, to apply forces and to observe the pendulum's rotation angle
- Add a Mechanical Branching Bar object to connect the joint sensor and joint actuator to the revolute joint's port
- You may also add
  - An IC block
  - A continuous angle block

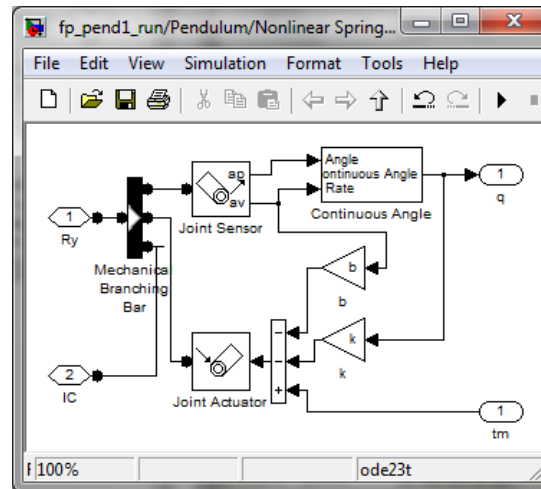




# Simscape Modeling of Pendulum ...

## Setting up parameters of the joint sensor:

- In the joint sensor's parameter window, select both the angle and angular velocity sensors
- De-select 'Output selected parameters as one signal' for individual access
- Add an external input torque from Simulink
- Apply a feedback torque to the joint as a combination of the external torque, angular position and angular velocity (due to torsional spring and friction)



**Block Parameters: Joint Sensor**

Joint Sensor

Measures linear/angular position, velocity, acceleration, computed force/torque and/or reaction force/torque of a Joint primitive. Spherical measured by quaternion. Base-follower sequence and joint axis determine sign of forward motion. Outputs are Simulink signals. Multiple output signals can be bundled into one signal. Connect to Joint block to see Connected to primitive list.

**Measurements**

Primitive Outputs

Connected to primitive: **R1**

☒ Angle Units: **rad**

☒ Angular velocity Units: **rad/s**

☐ Angular acceleration Units: **deg/s^2**

☐ Computed torque Units: **N\*m**

**Joint Reactions**

☐ Reaction torque Units: **N\*m**

☐ Reaction force Units: **N**

Reaction measured on: **Base**

With respect to CS: **Absolute (World)**

☐ Output selected parameters as one signal.

**OK Cancel Help Apply**

# Simscape Simulation of Pendulum

## Step for simulation:

1. Define the parameter values (bodies' mass and dimension, spring and friction constants, etc.) ( $m=0.001$ ;  $l_z=0.5$ ;  $l_y=0.01$ ;  $l_x=0.01$ ;  $m=1$ ;  $r=l_z/10$ ;  $k=1$ ;  $b=0.1$ ;  $g=9.81$ ;)
2. Enable animation in SimMechanics node, via configuration parameters dialog in simulation menu
3. Start simulation
  - a) Animation of the physical bodies is shown in a window
  - b) Input/output data is recorded via Simulink interface

## Simulation plots and animation

