MATLAB EXPO

Simscape를 이용한 멀티도메인 물리 모델링

이종일 부장, 매스웍스코리아

Can you analyze how the system behaves before building any physical prototypes?

How do you model the electromechanical and multibody components?

How to analyze the system behaves before building any physical prototypes?

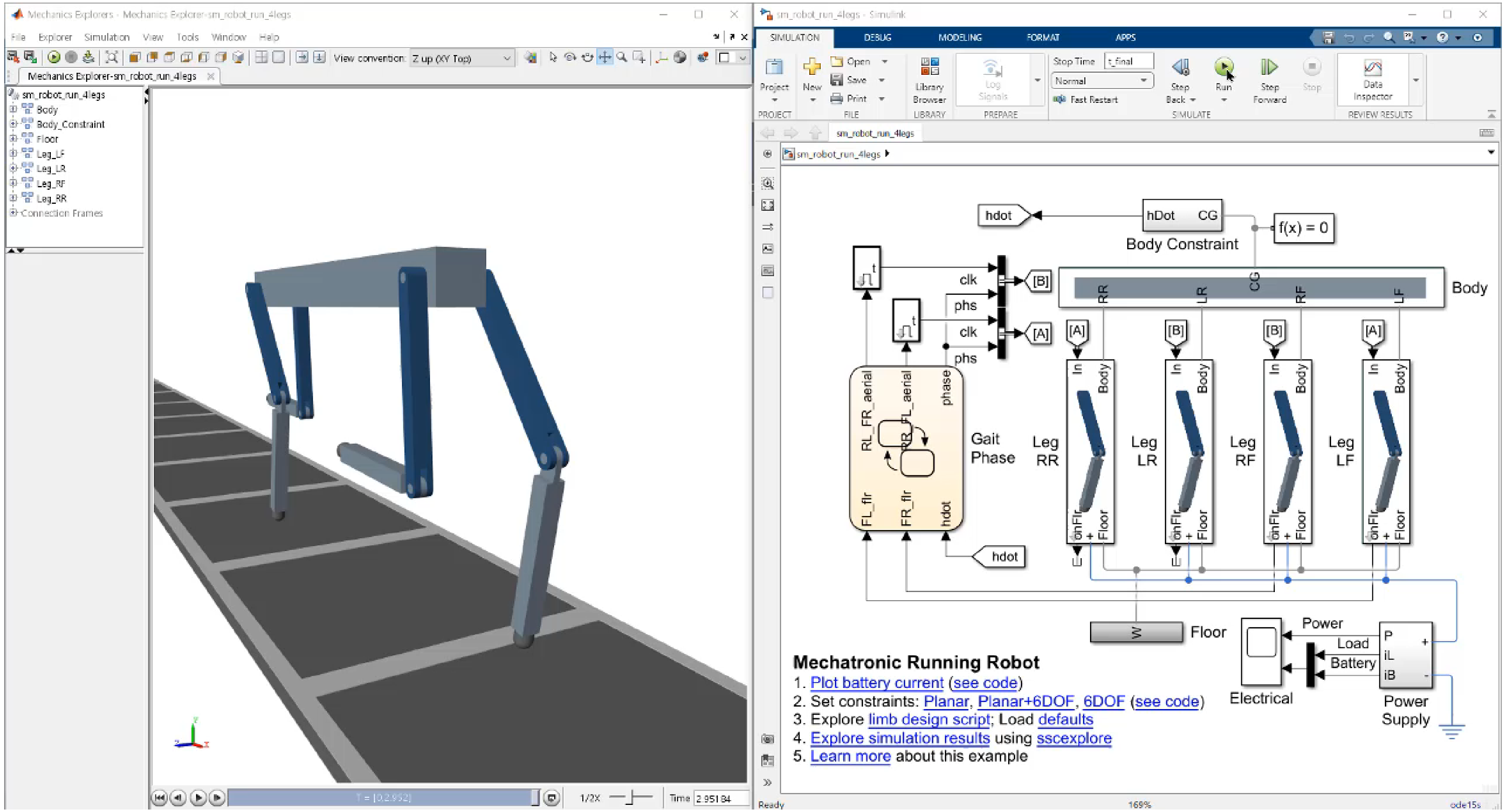
Solution :

- Simscape & Simscape Multibody

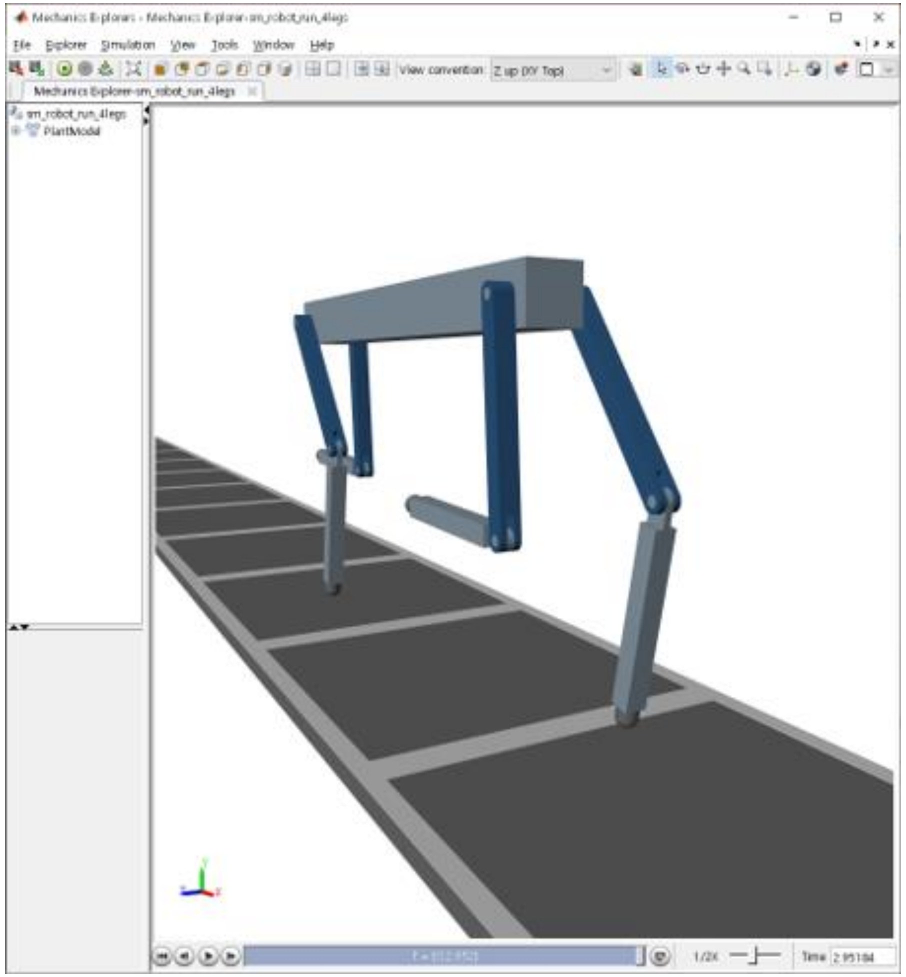
Benefit :

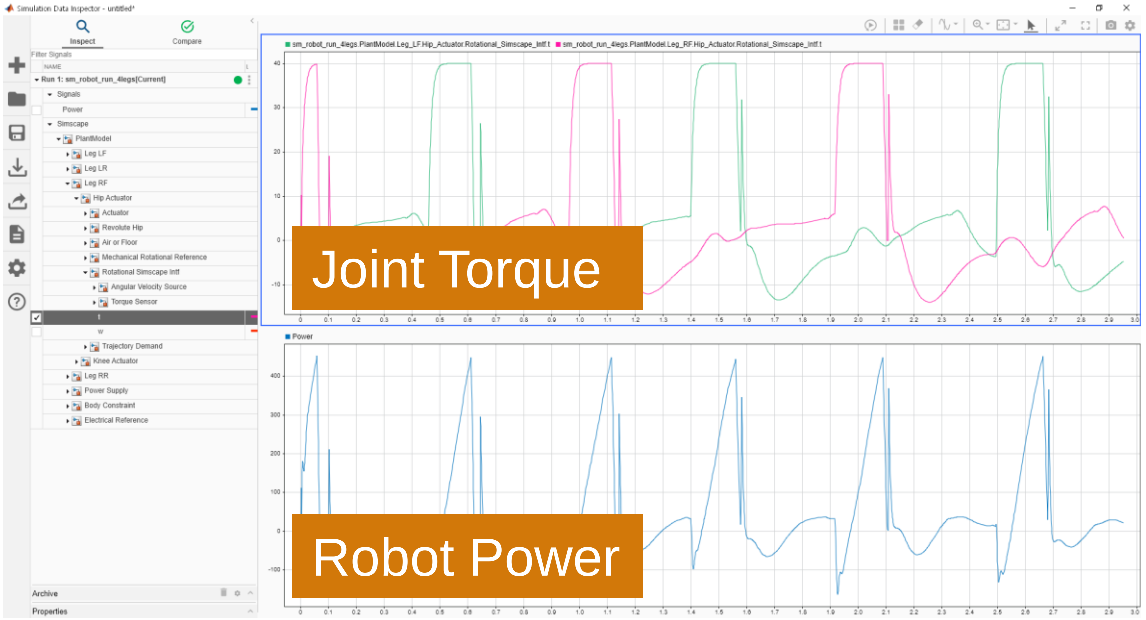
- Perform multiple systems such as mechanical, electrical system
- Visualize to understand system behavior
- Evaluate performance criteria to decide system requirements

How to analyze the system behaves before building any physical prototypes?



How to analyze the system behaves before building any physical prototypes?





- **Confirm system requirements of performance**
- **Check design requirements of motor, gear, battery**
- **Evaluate new control algorithm and calibration data**

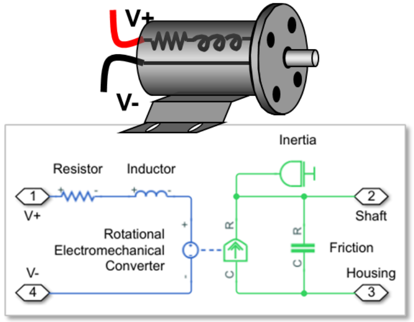
Agenda

- **Simscape Overview**
- **Demos**
- **Applications**
- **Key Takeaways**

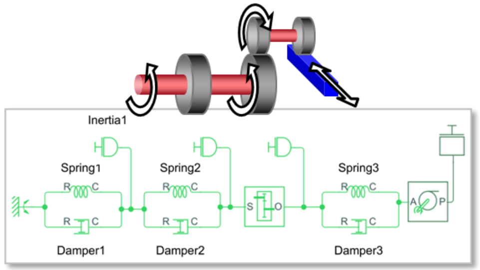
Simscape Overview

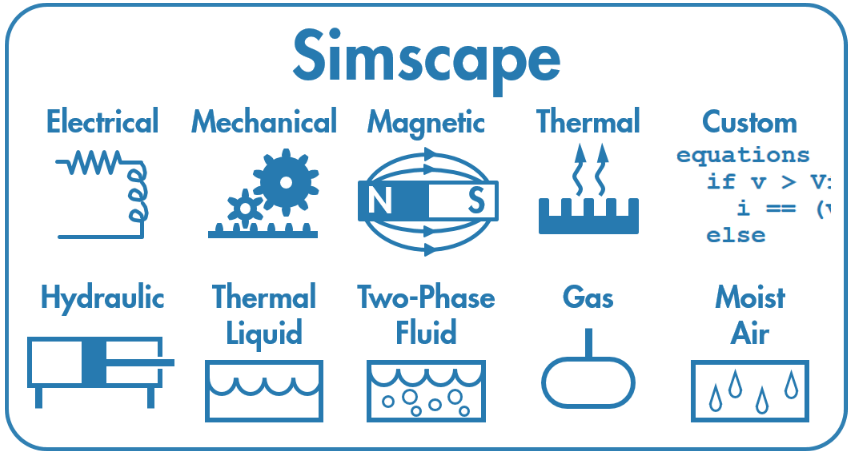
- Multidomain physical systems within the Simulink environment

Electro-mechanical

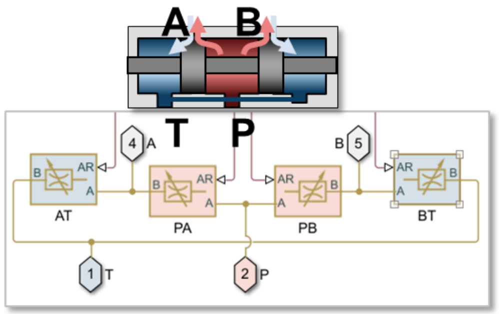


Mechanical *(translation and rotation)*

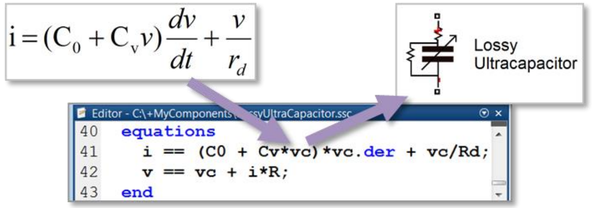




Hydraulic



Custom



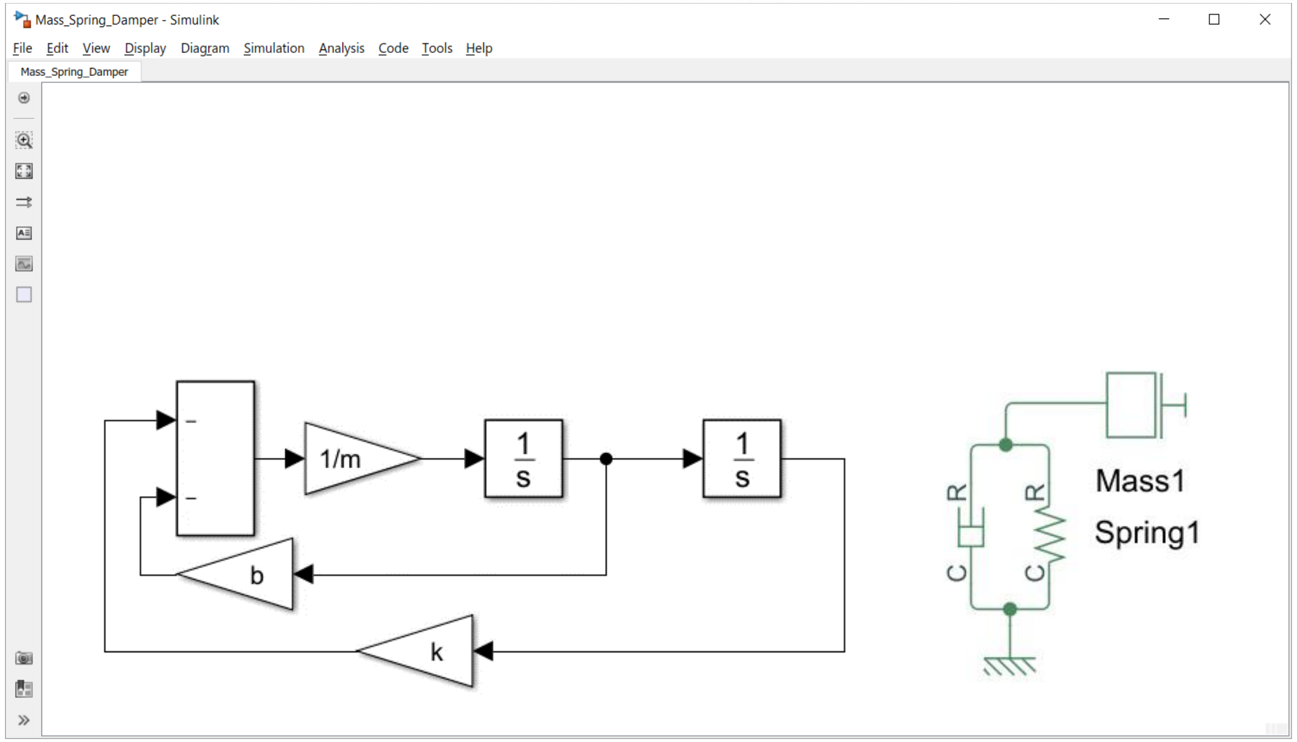
Simscape Overview

$$F_{Spring} = k_{Spring} * (x_{Mass})$$

$$F_{Damper} = b_{Damper} * \left(\frac{dx_{Mass}}{dt}\right)$$

$$\frac{d^2 x_{Mass}}{dt^2} = \frac{-F_{Spring} - F_{Damper}}{m_{Mass}}$$

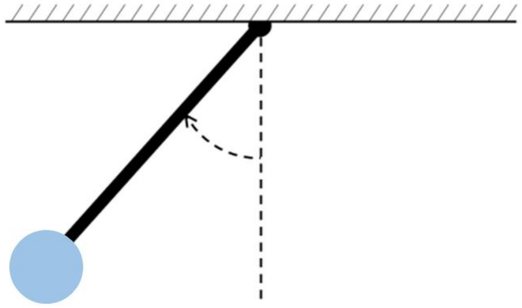
- Equations derived automatically
- Assemble schematics that simulate
- With Simscape you can:
  - Test without hardware prototypes
  - Optimize system-level performance
  - Design control systems and logic
  - Refine requirements for system



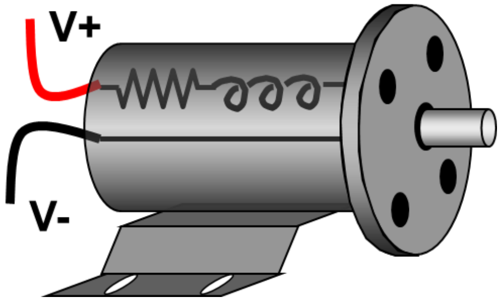
Input/Output Block Diagram

Simscape

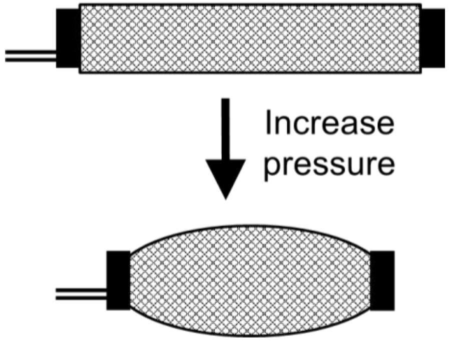
How to build walking robot?



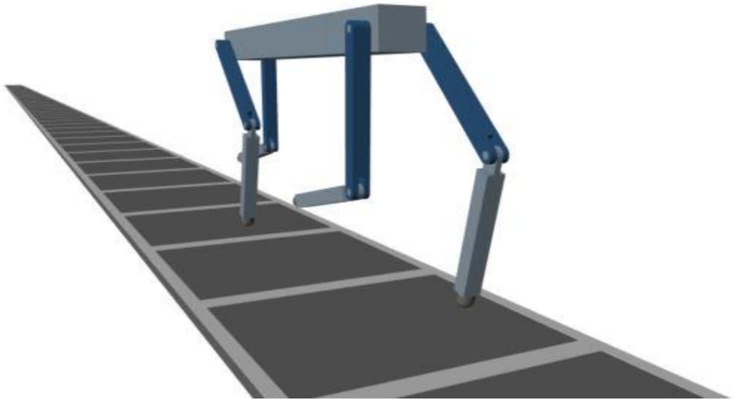
Pendulum



Motor

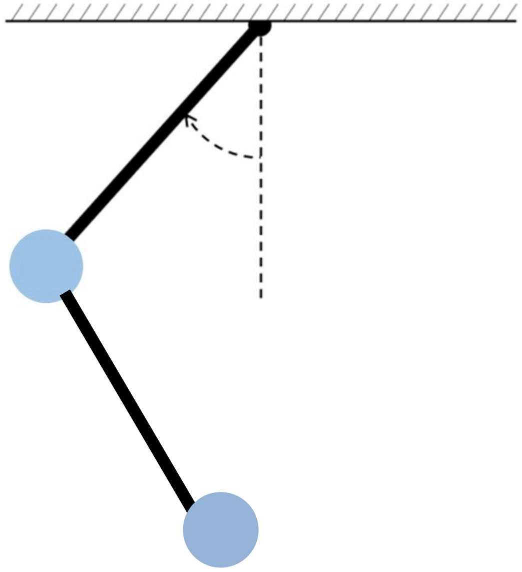


McKibben air muscle

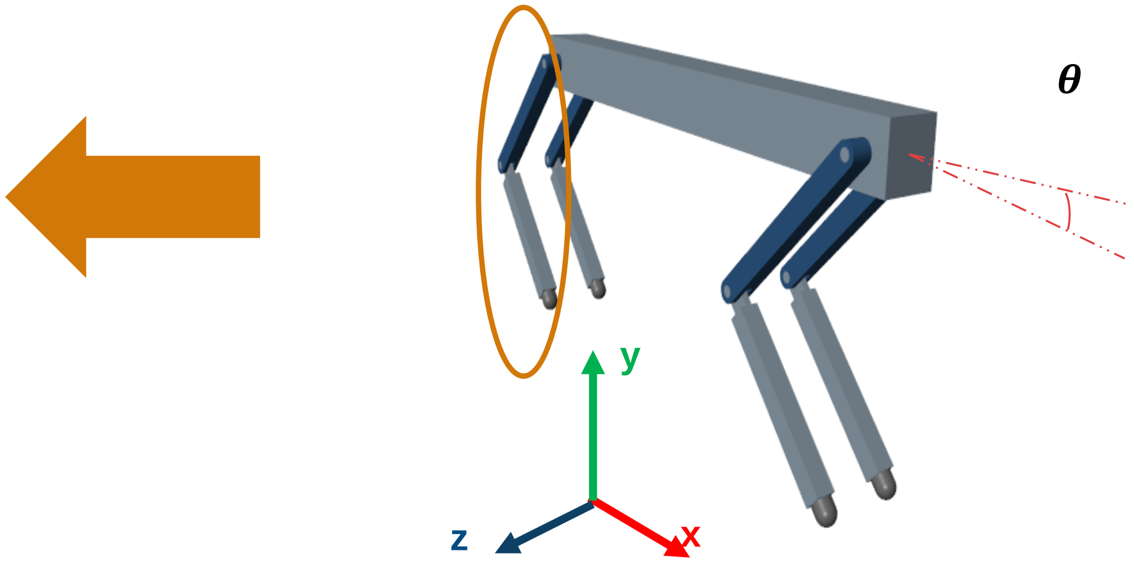


Walking Robot

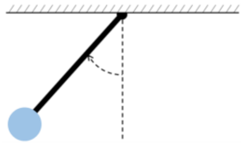
Demos – Design Inverted Pendulum



Double Pendulum

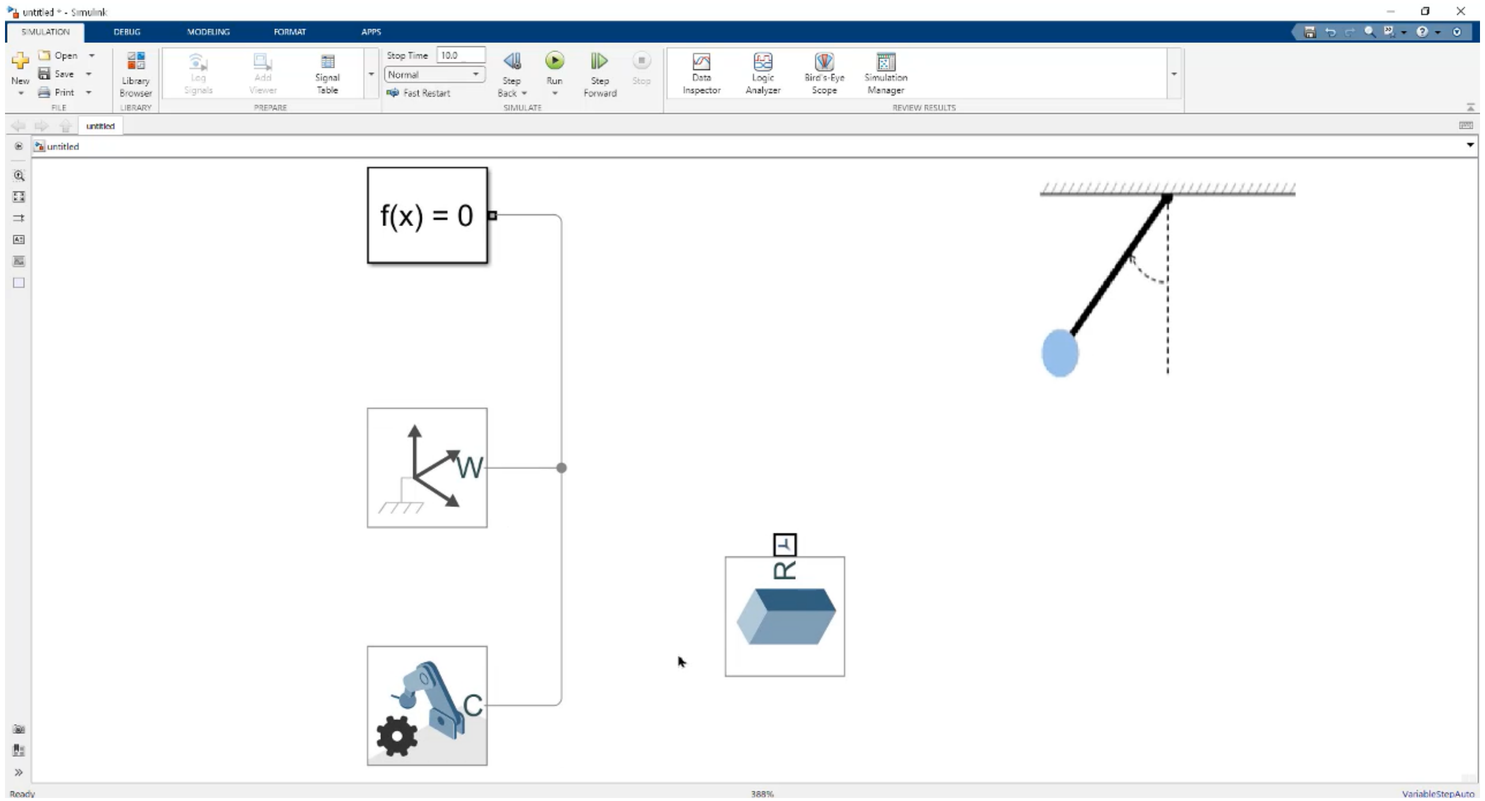


Demos – Design Inverted Pendulum

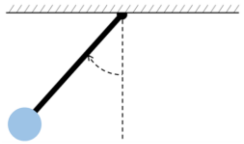


Pendulum

- Start from Simulink
  - Use Simulink in toolstrip
  - Command as “smnew”
- Clean up canvas
  - Delete unused block
  - Delete ref. descriptions
- Insert block to build model
  - Use ref. image for design
  - Align blocks from format tab



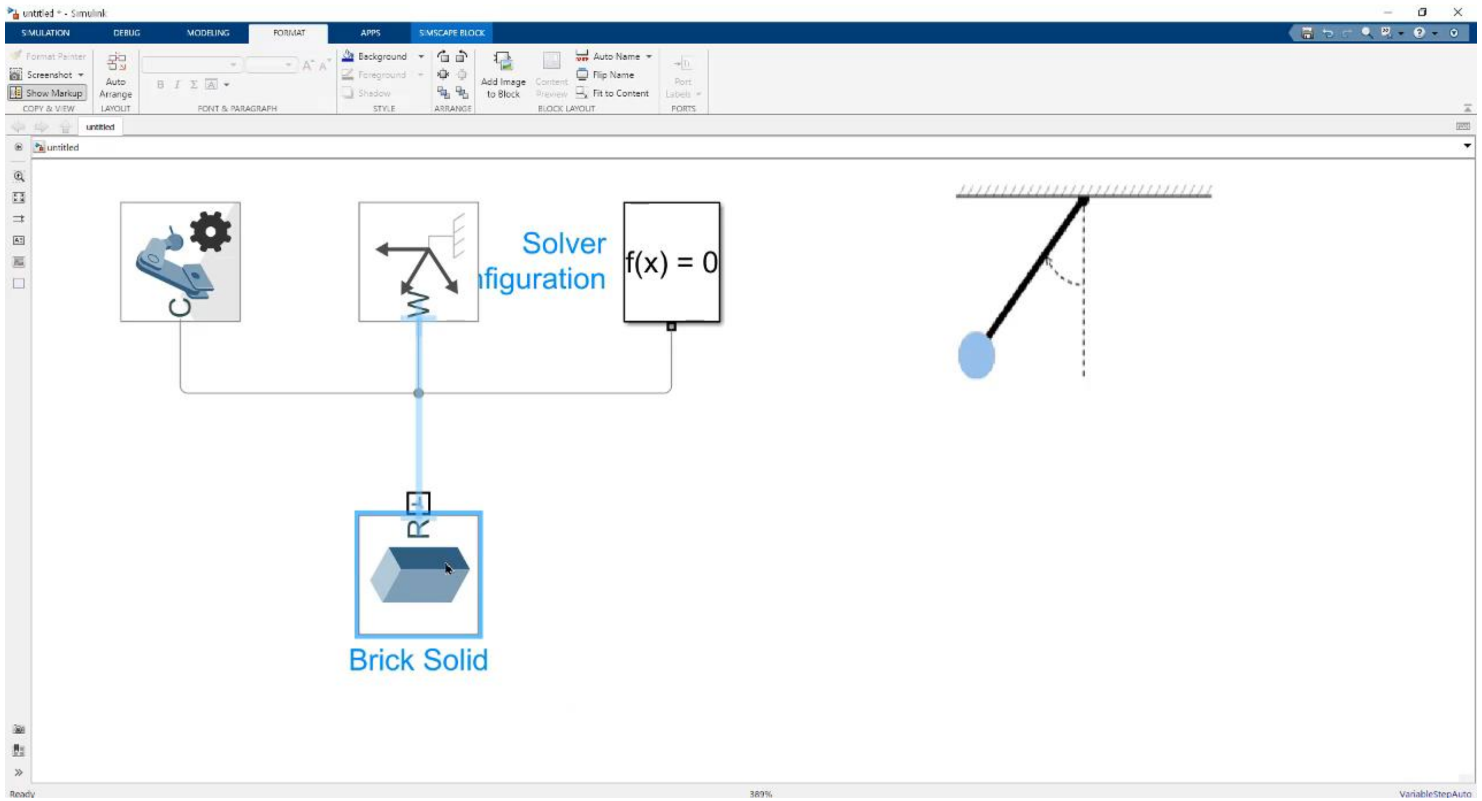
Demos – Design Inverted Pendulum



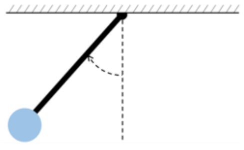
Pendulum

- Parameterize blocks
  - Update dimensions
    [1 1 1] ➔ [1 0.1 0.1]

- Update models
  - Refresh model data (F5)
  - Change View Convention

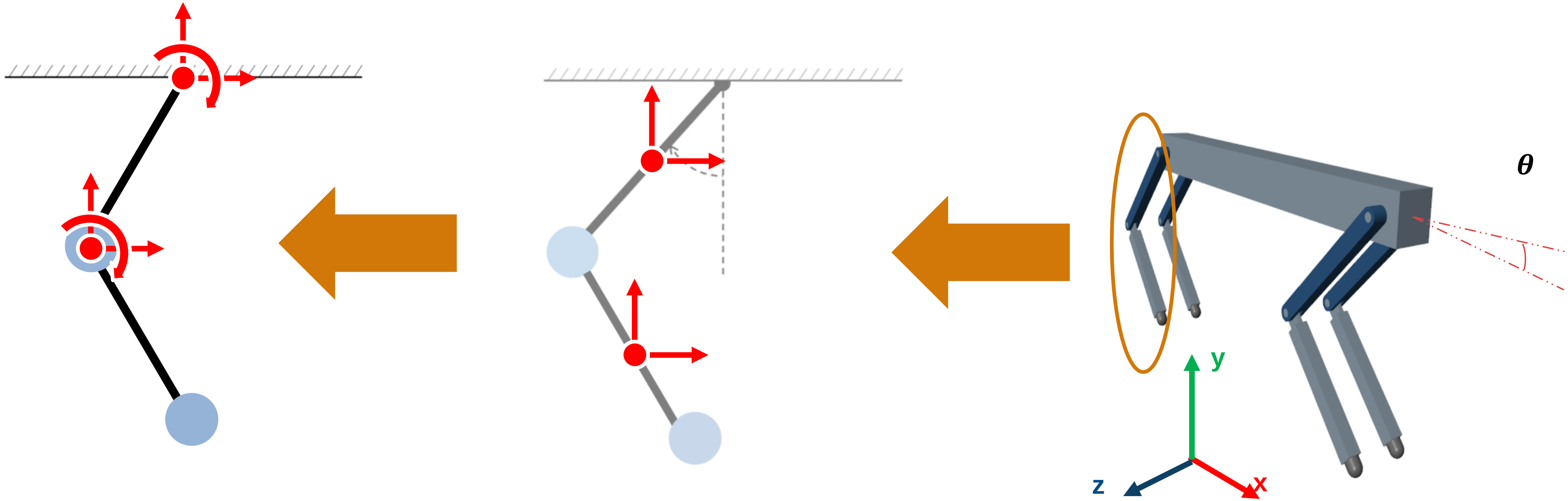


Demos – Design Inverted Pendulum

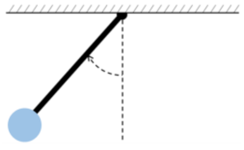


Define Coordinate Frames

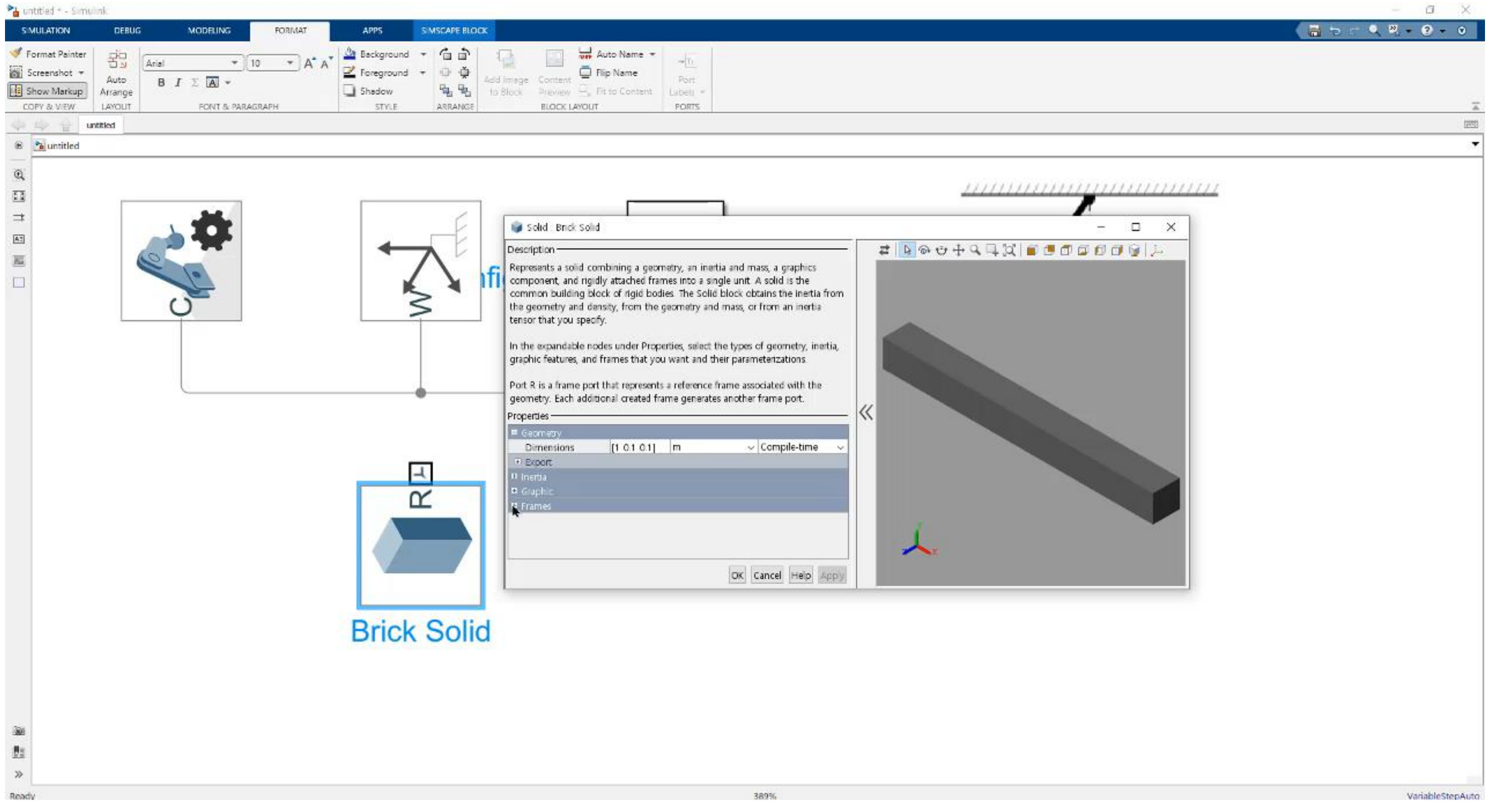
- Add new coordinate frame to create joint at certain features (faces, edges, ETC)



Demos – Design Inverted Pendulum

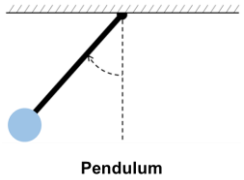


- Add new frame to link joint
  - Select surface to add new frame using “Based on geometric feature”
  - Add two new frame at the end of block
  - Rename of new frame as “Base” and “End”



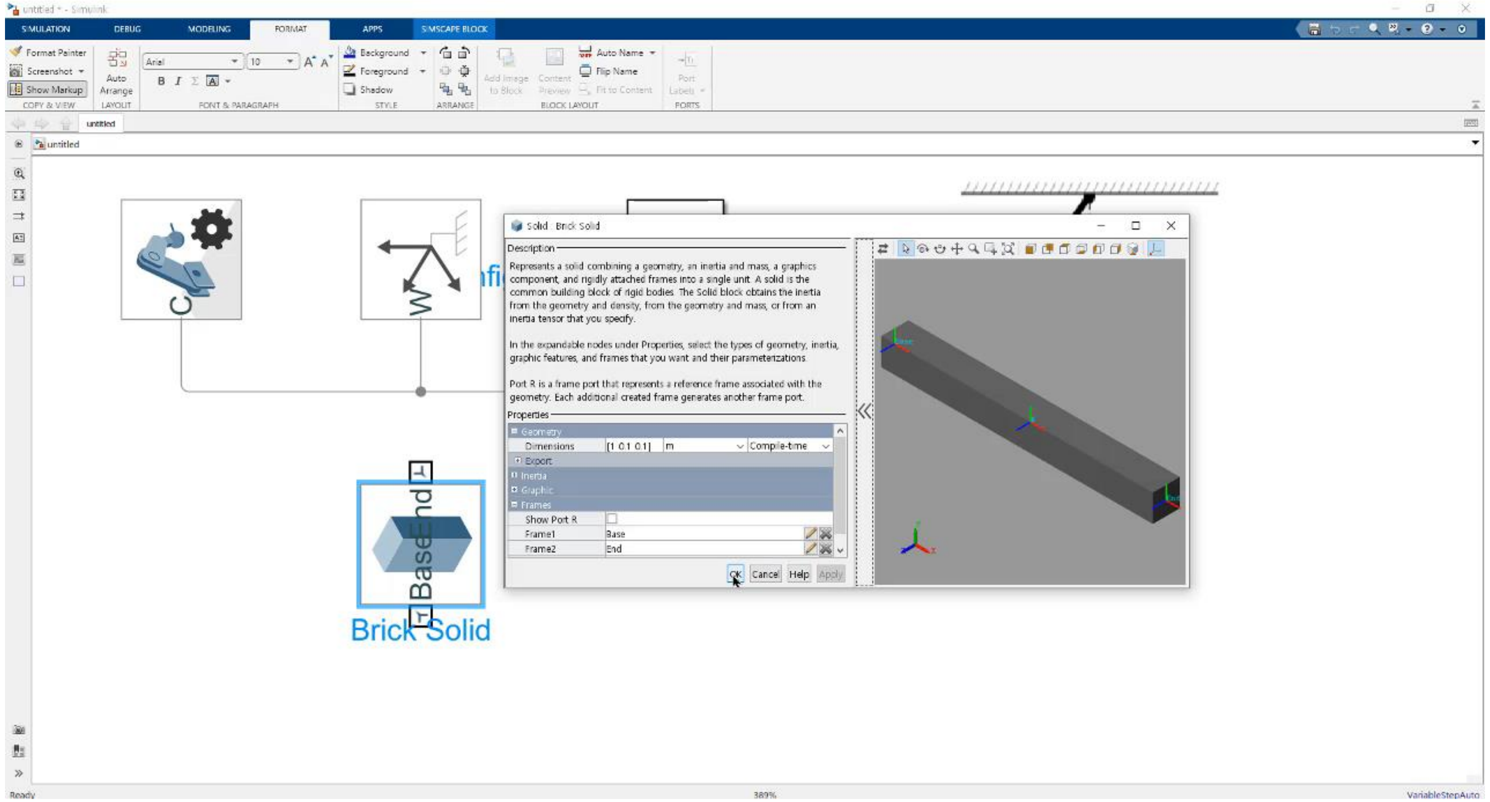
- Update models
  - Refresh model data (F5)

Demos – Design Inverted Pendulum

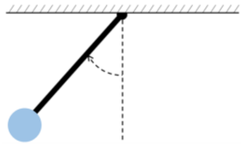


- Connect blocks with joint
  - Resize block to connect model
  - Insert “Revolute Joint” and connect block between Brick Solid block and World Coordinate

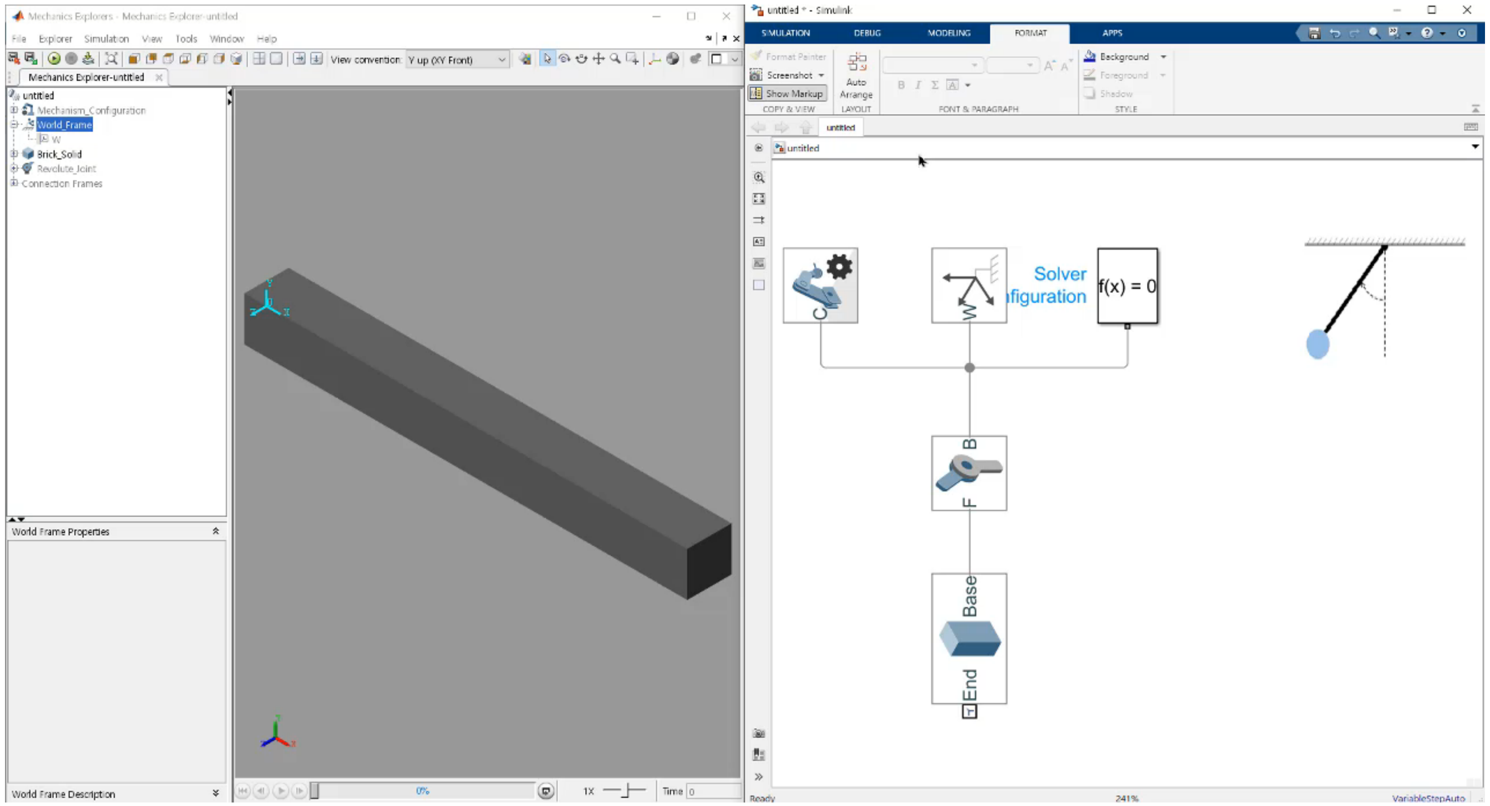
- Update models
  - Refresh model data (F5)
  - Change view convention



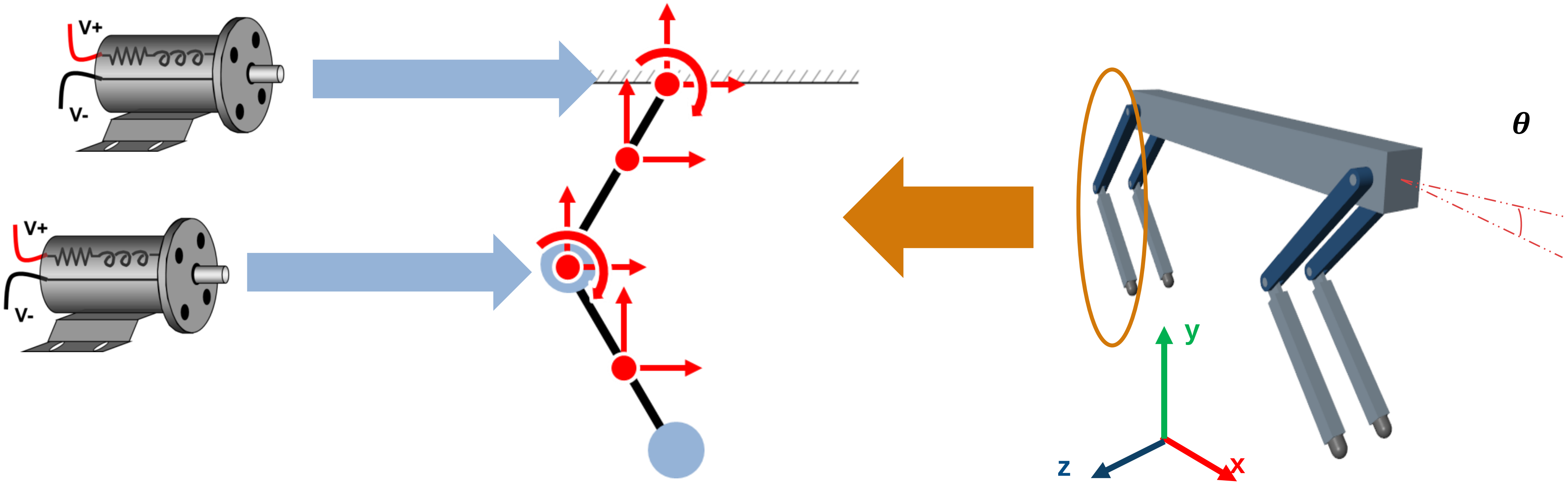
Demos – Design Inverted Pendulum



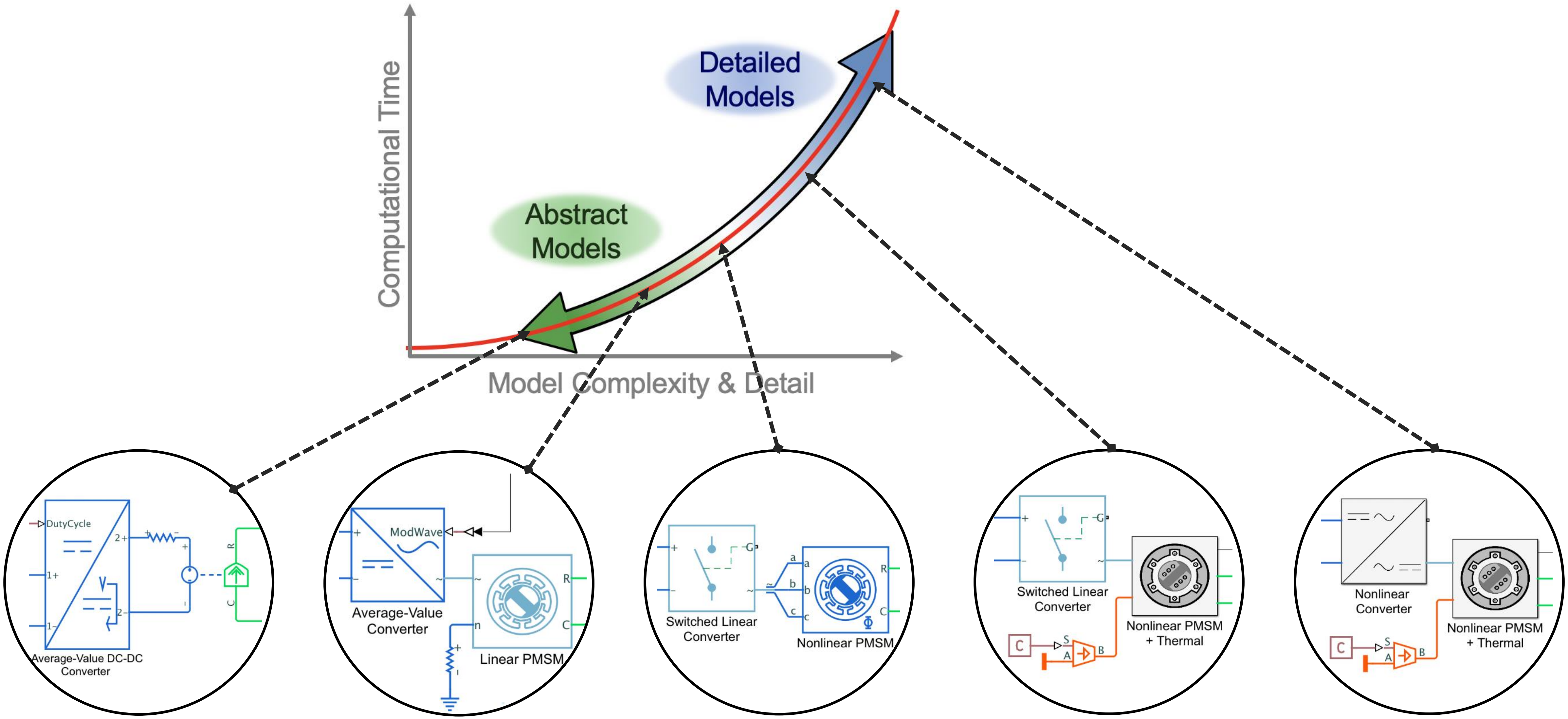
- Run simulation
  - Modify coordination of gravity
    [0 0 9.81] ➔ [0 9.81 0]
- Extend model complexity
  - Copy & Paste your model to extend application
  - Physical network model can be utilized easily without delivering equation



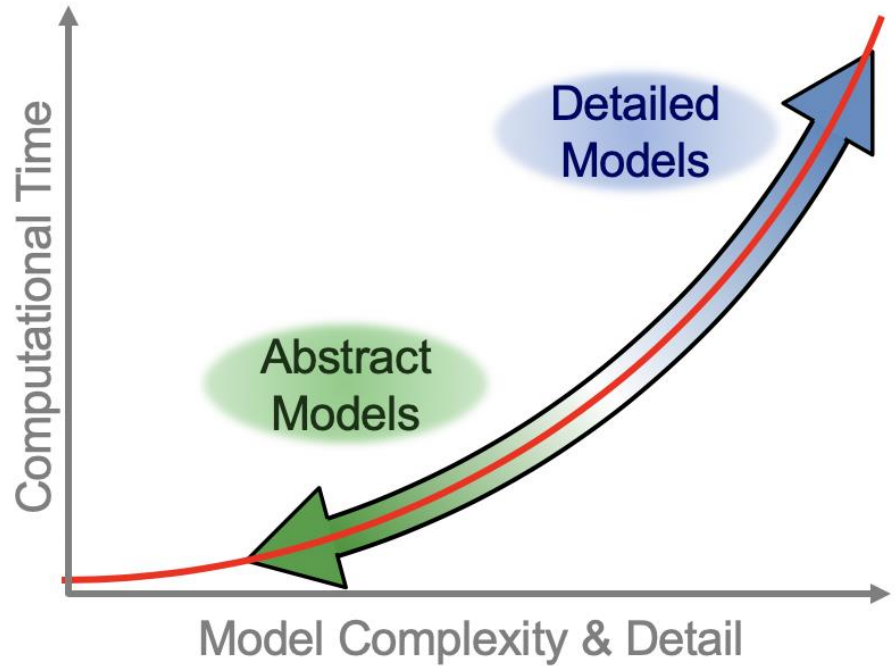
Demos – Estimate Motor Parameters



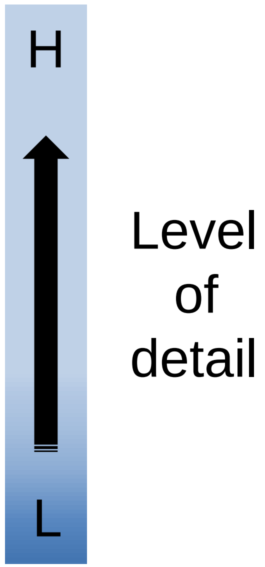
Configure the Model to Balance Model Fidelity and Simulation Speed



In Summary, Simscape Electrical Lets You Model Electrical Systems with Varying Level of Detail

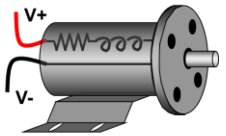


Proven Technology

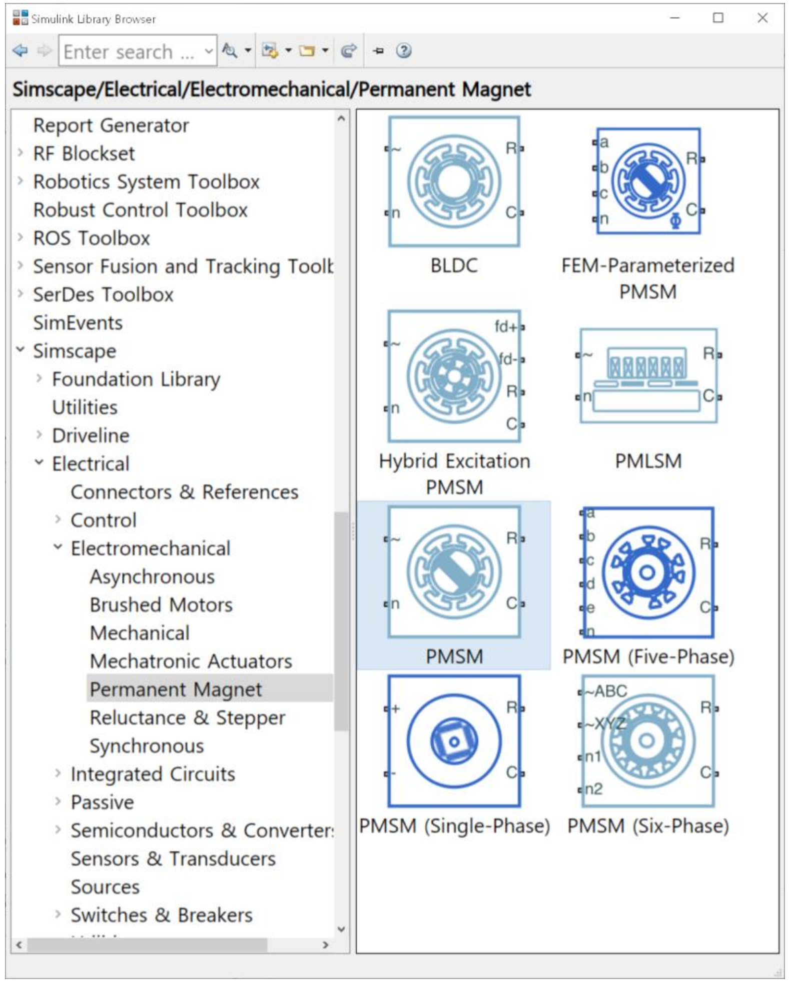


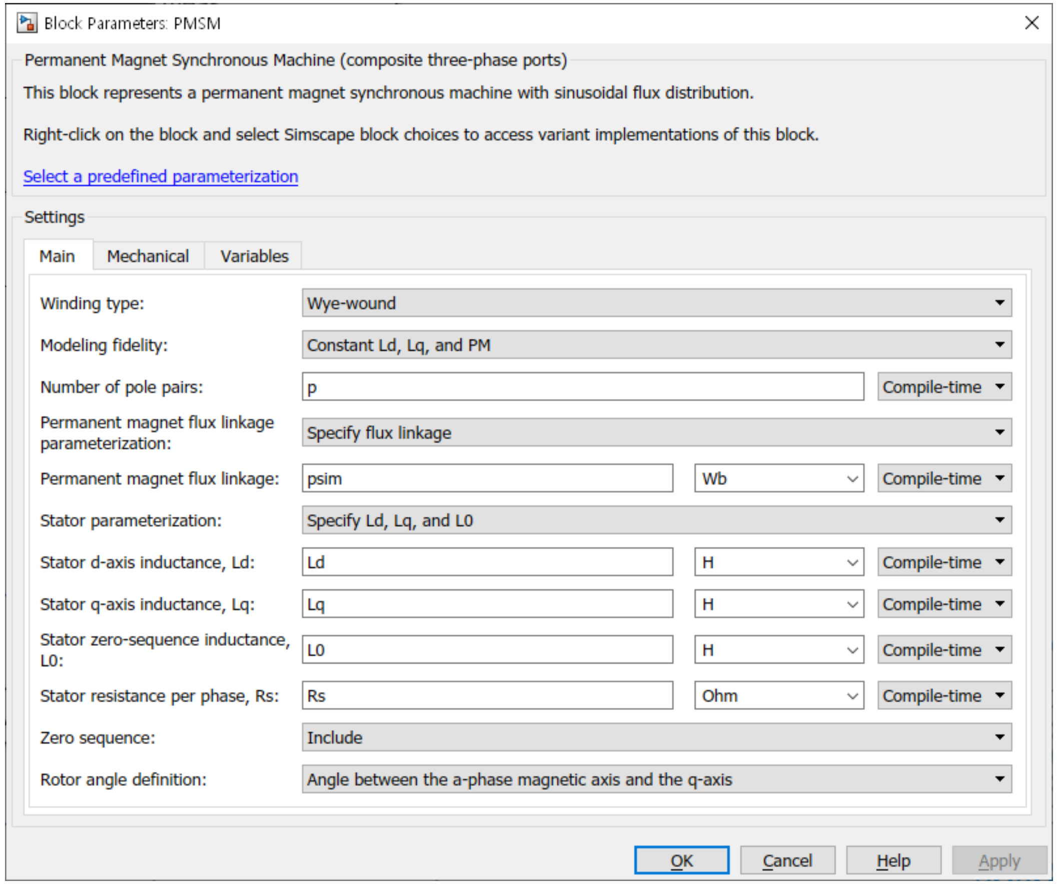
Proof-of-Concept

Supported Different Type of Motor Model in Simscape Electrical



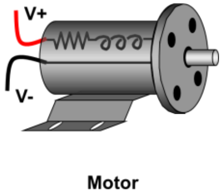
Motor

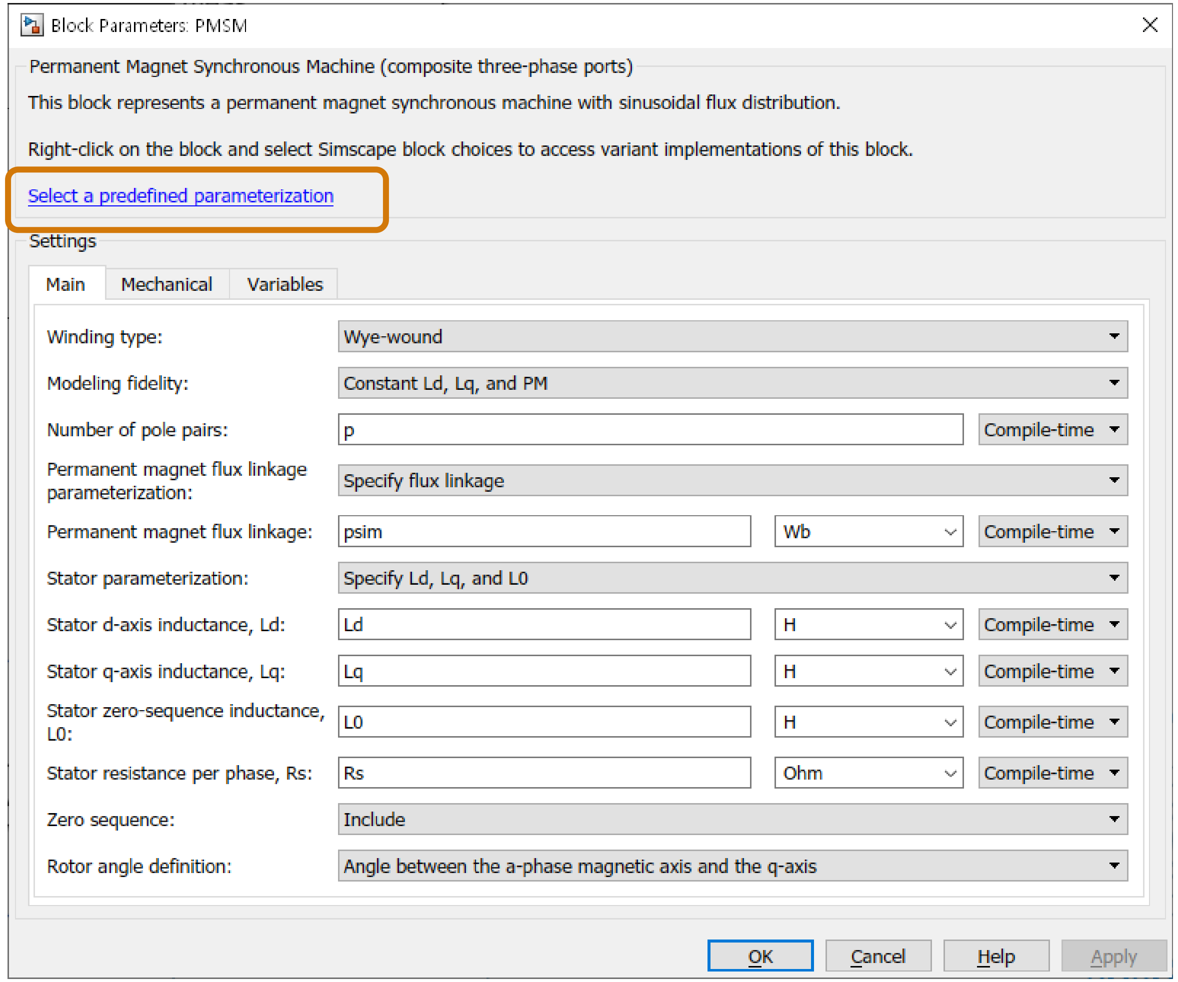


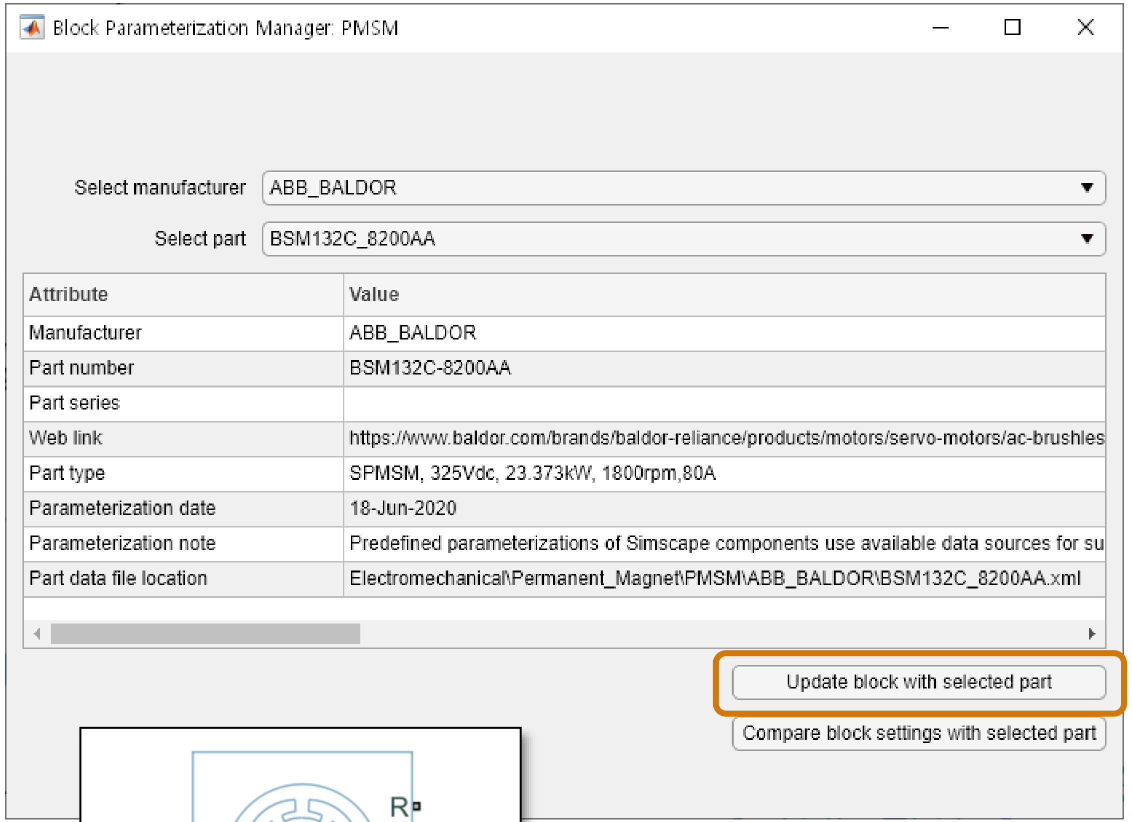


Parameterization of Motor Modeling Using Simscape Electrical

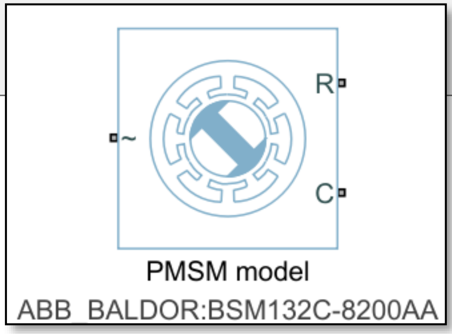
Select a predefined parameterization



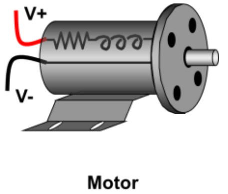




Attribute	Value
Manufacturer	ABB_BALDOR
Part number	BSM132C-8200AA
Part series	
Web link	https://www.baldor.com/brands/baldor-reliance/products/motors/servo-motors/ac-brushles
Part type	SPMSM, 325Vdc, 23.373kW, 1800rpm,80A
Parameterization date	18-Jun-2020
Parameterization note	Predefined parameterizations of Simscape components use available data sources for su
Part data file location	Electromechanical\Permanent_Magnet\PMSM\ABB_BALDOR\BSM132C_8200AA.xml

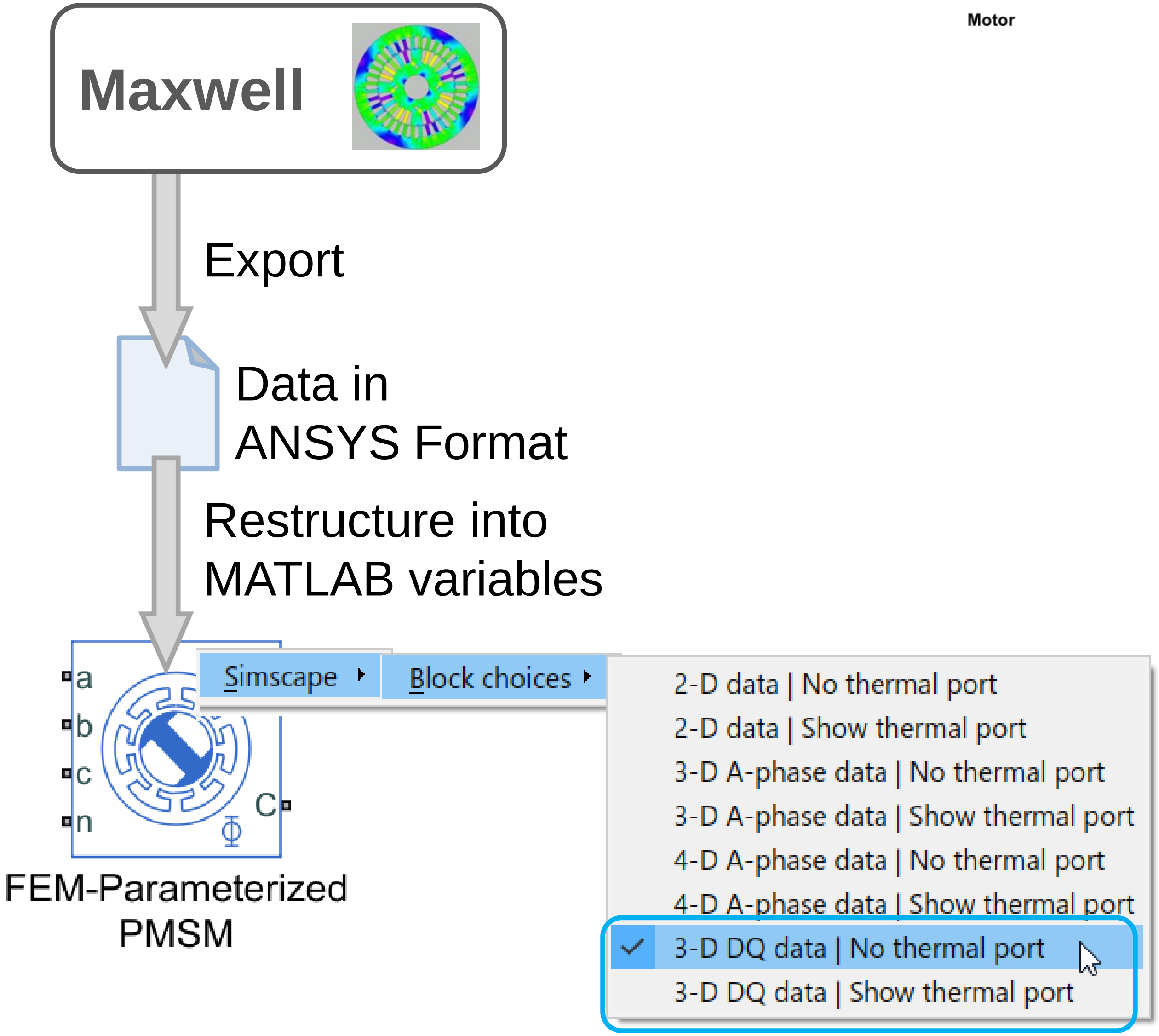


Parameterization of Motor Modeling Using Simscape Electrical

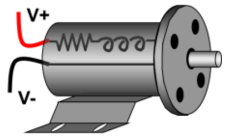


Nonlinear PMSM Model

- Define PMSM behavior using d- and q-axis flux linkage
- Parameterization option is directly compatible with Maxwell, JMAG and Motor-CAD data
  - With a few changes to text file, MATLAB variables that match block parametrization can be generated

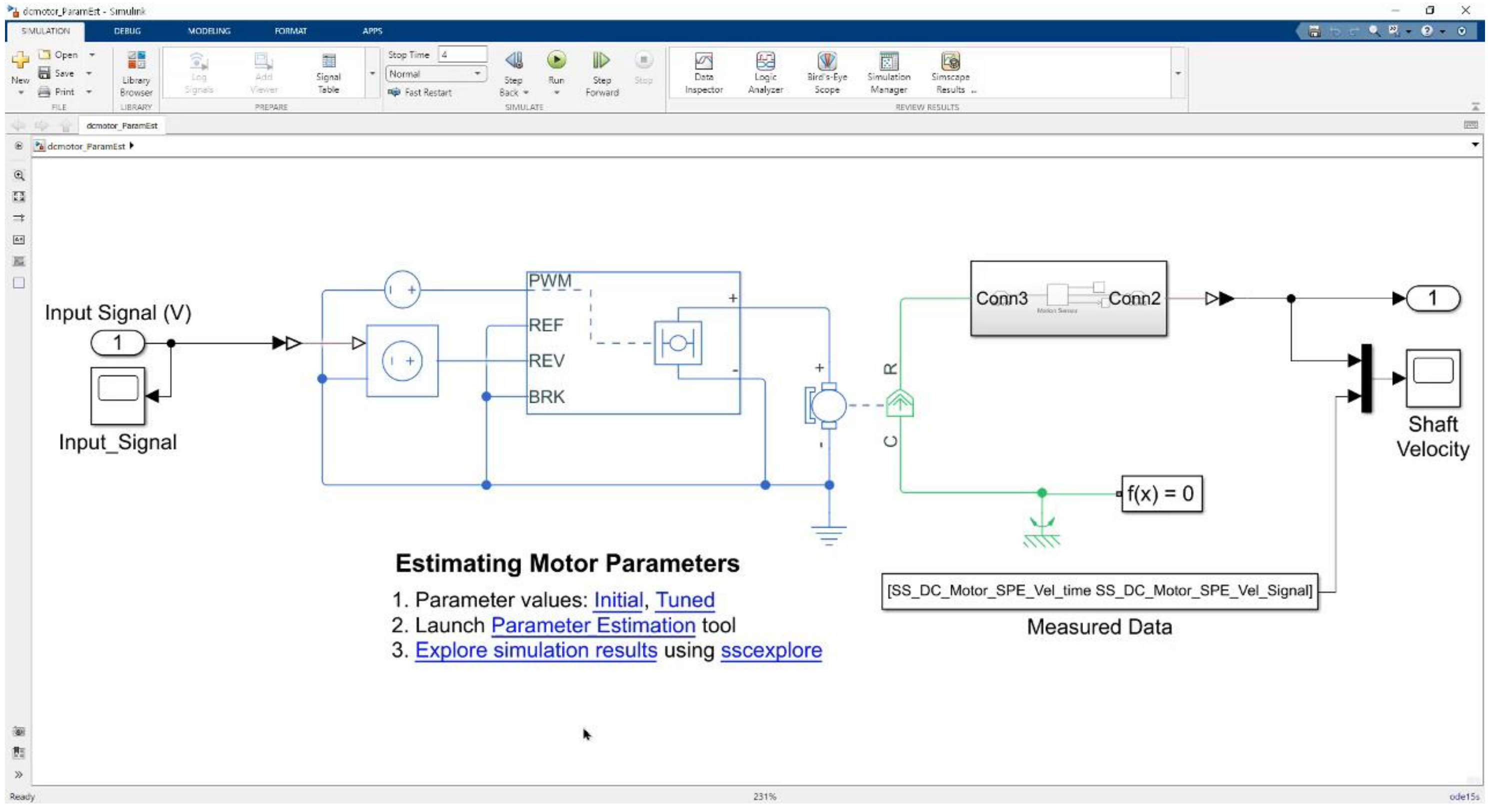


Demos – Estimate Motor Parameters

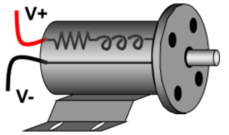


Motor

- Motor modeling
  - Simscape Electrical supports multiple type of motor and driver
- Parameterize components
  - Simulink Design Optimization support parameter estimation



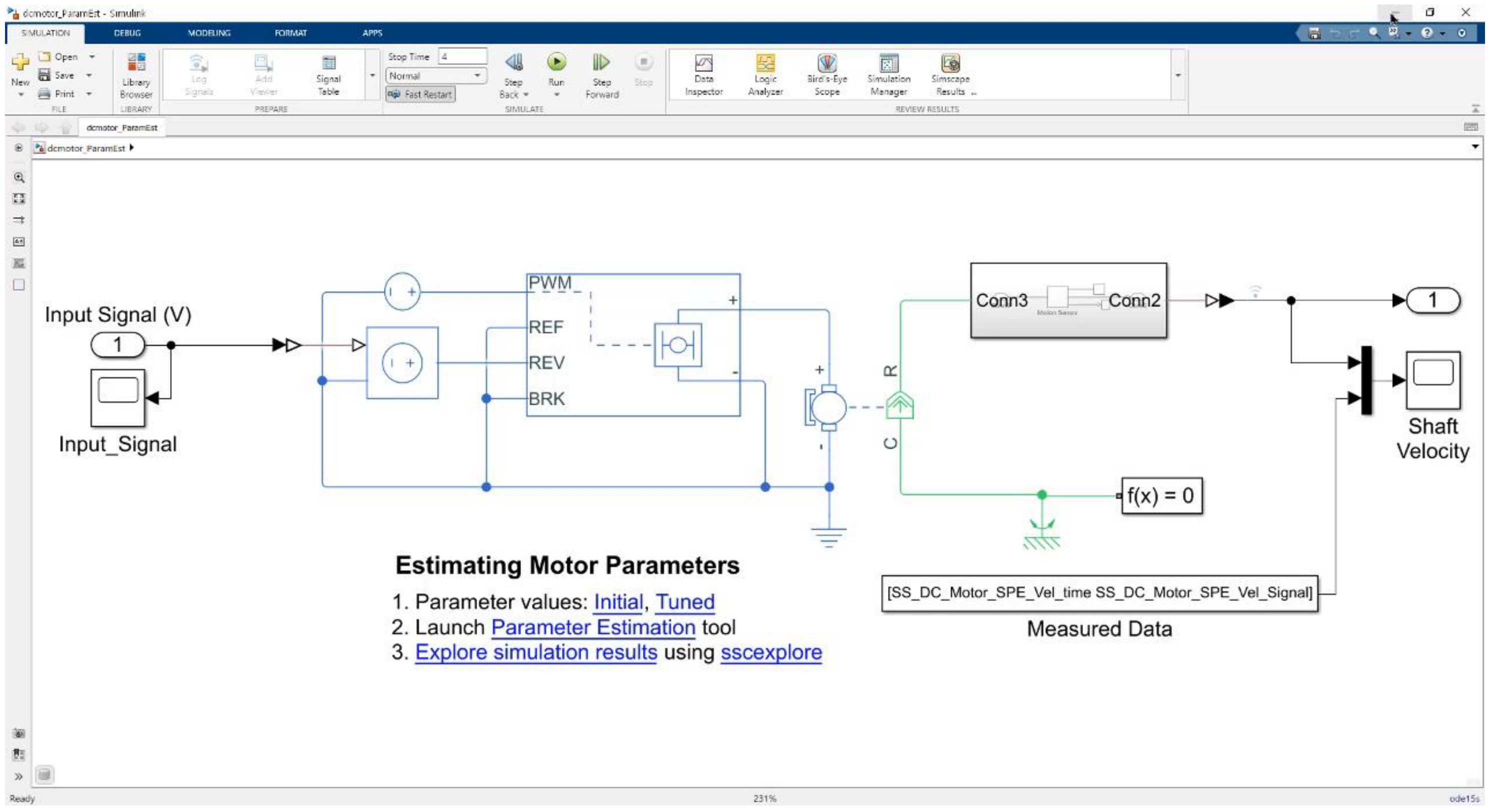
Demos – Estimate Motor Parameters



Motor

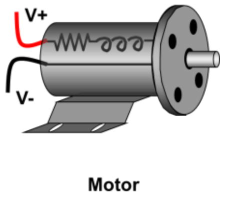
- Tip for fast simulation
  - Use Fast Restart
  - Utilize Parallel Computing toolbox

- Estimate parameters
  - Adapt experiments data to estimate components parameters using Simulink Design Optimization Toolbox

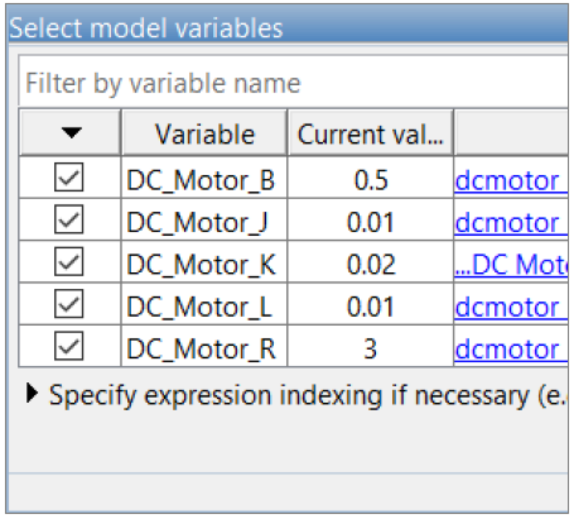


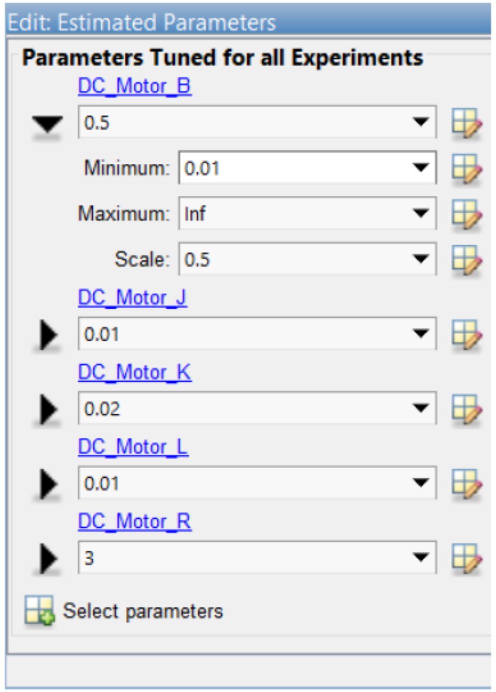
Demos – Estimate Motor Parameters

Select Parameters and Set Ranges

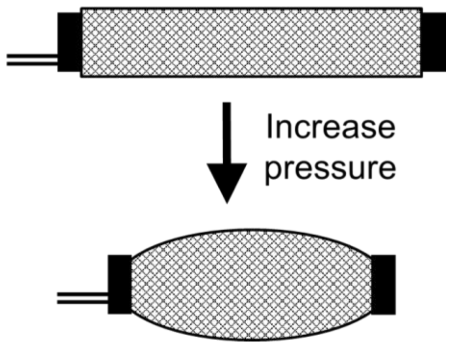


- Select the motor parameters to tune
  - Mechanical Characteristics : DC_Motor_B, DC_Motor_J
  - Electrical Characteristics : DC_Motor_L, DC_Motor_R, DC_Motor_K
- Set the valid range for each value

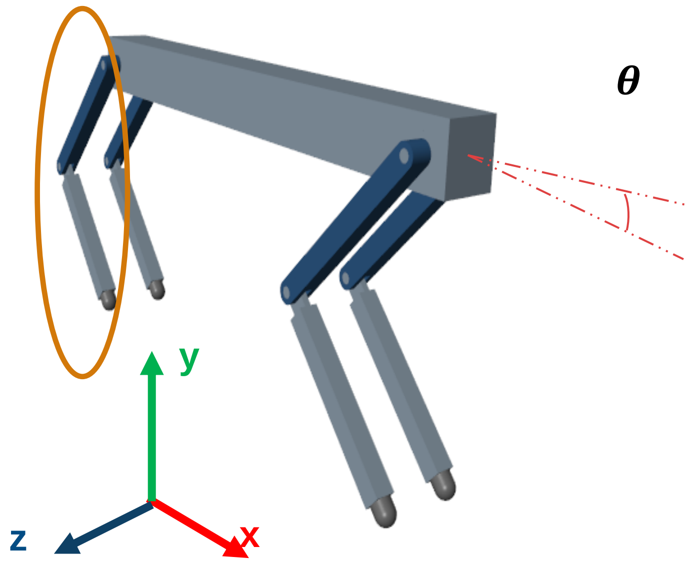




Demos – Creating custom Simscape components

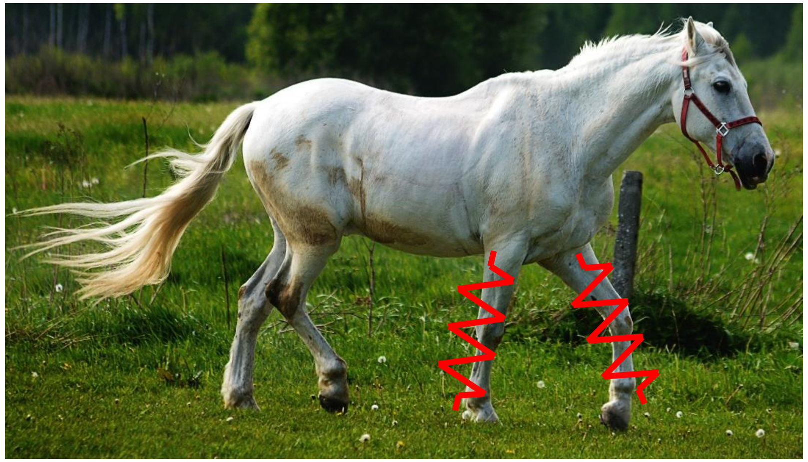


McKibben air muscle



Creating custom Simscape components

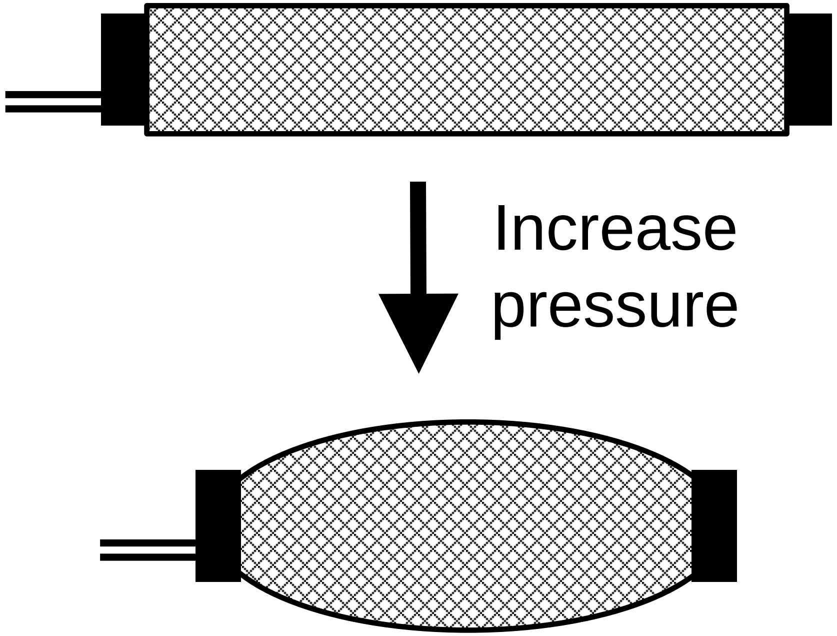
Example: McKibben air muscle



Steps:

1. Write out defining equations
2. Find starting point in Simscape foundation library
3. Incrementally add functionality, testing as you go

McKibben air muscle



Creating custom Simscape components

Step 1: Write out equations

L_u = Un-stretched length

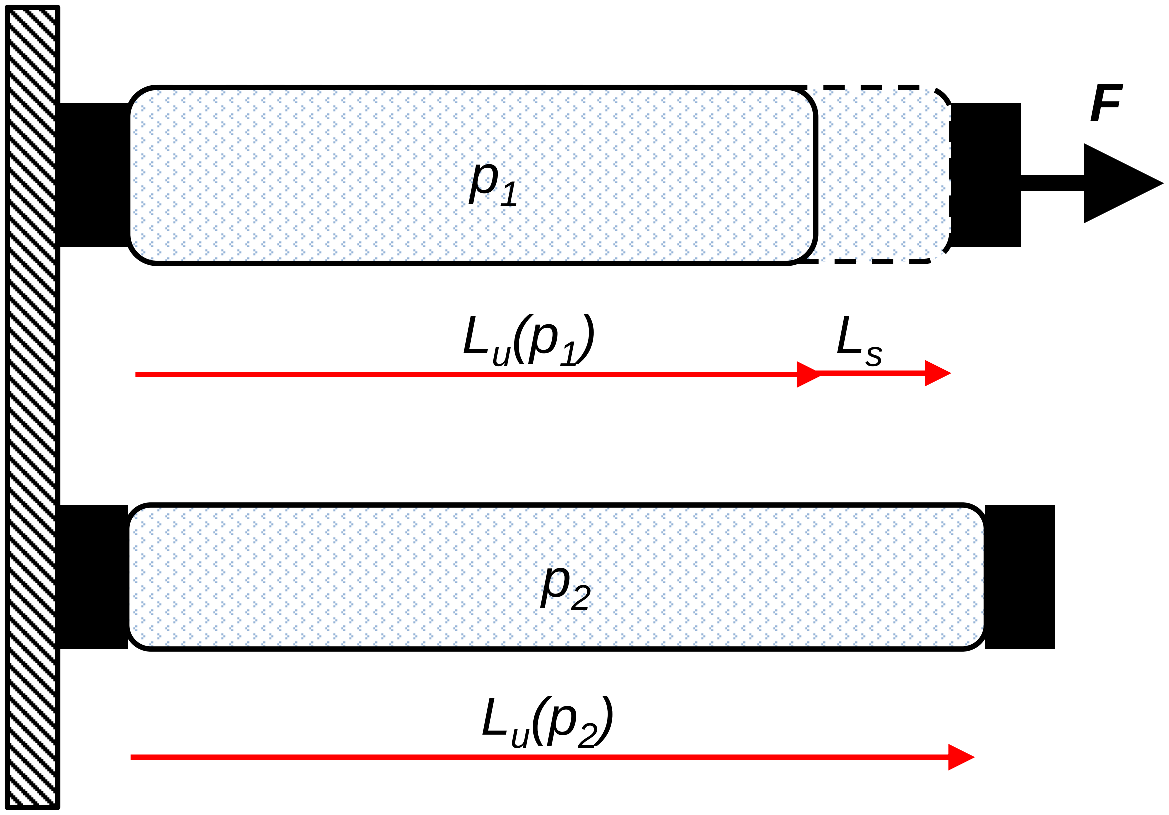
L_s = Additional stretch due to force, *F*

Assumptions:

- Volume is approximately constant
- Stretch force is proportional to L_s

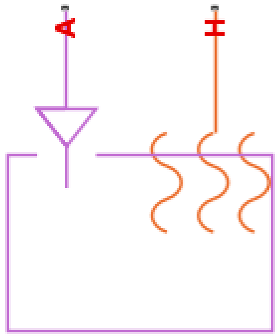
Equations:

- $L = L_u(p) + L_s$
- $F = k \times L_s$
- $pV = nRT$



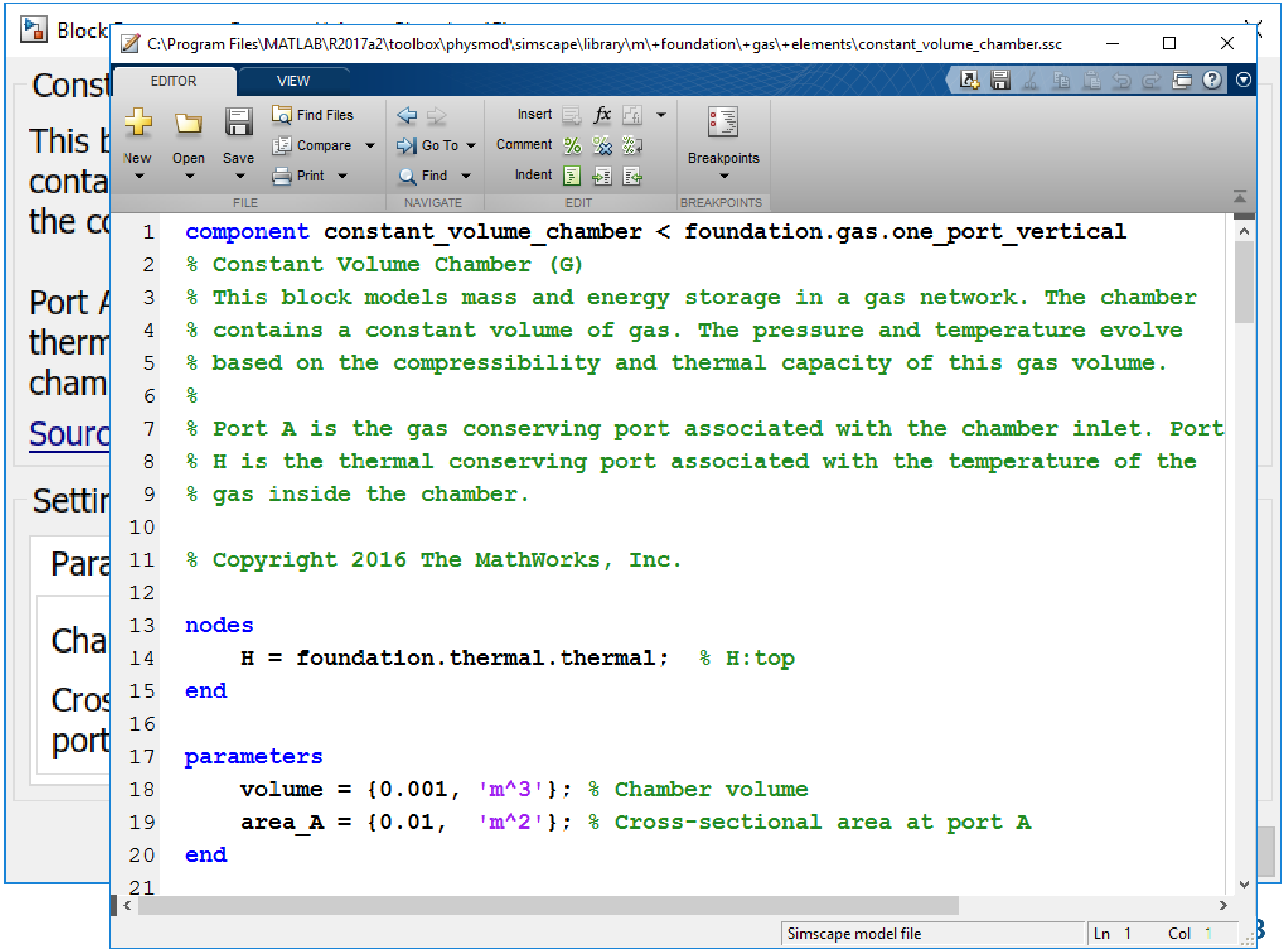
Creating custom Simscape components

Step 2: Find starting point from foundation library



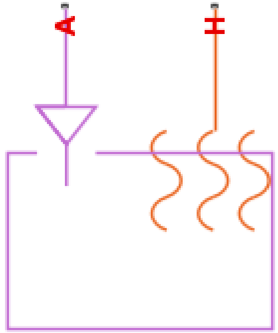
Constant Volume Chamber (G)

- Has equation of state
- Need to add mechanical ports & equations



Creating custom Simscape components

Step 3: Incrementally add functionality




```
component air_muscle < foundation.gas.one_port_vertical
% Air Muscle (G)
% This block models a McKibben air muscle.

% Copyright 2016-2017 The MathWorks, Inc.

nodes
    H = foundation.thermal.thermal; % H:top
    R = foundation.mechanical.translational.translational; % R:bottom
    C = foundation.mechanical.translational.translational; % C:top
end
```

Add:

- Two mechanical ports
- Two additional new equations

$$L = L_u(p) + L_s$$

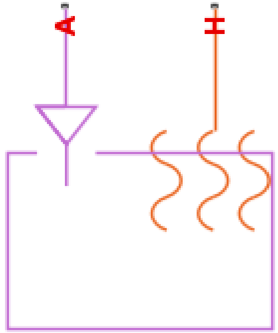
$$F = k \times L_s$$

```
L     == Ls + Lu;
force == K * Ls;
```

```
Lu = tablelookup(pVec,LuVec,p_chamber,
```

Creating custom Simscape components

Step 3: Incrementally add functionality



Add definitions for:

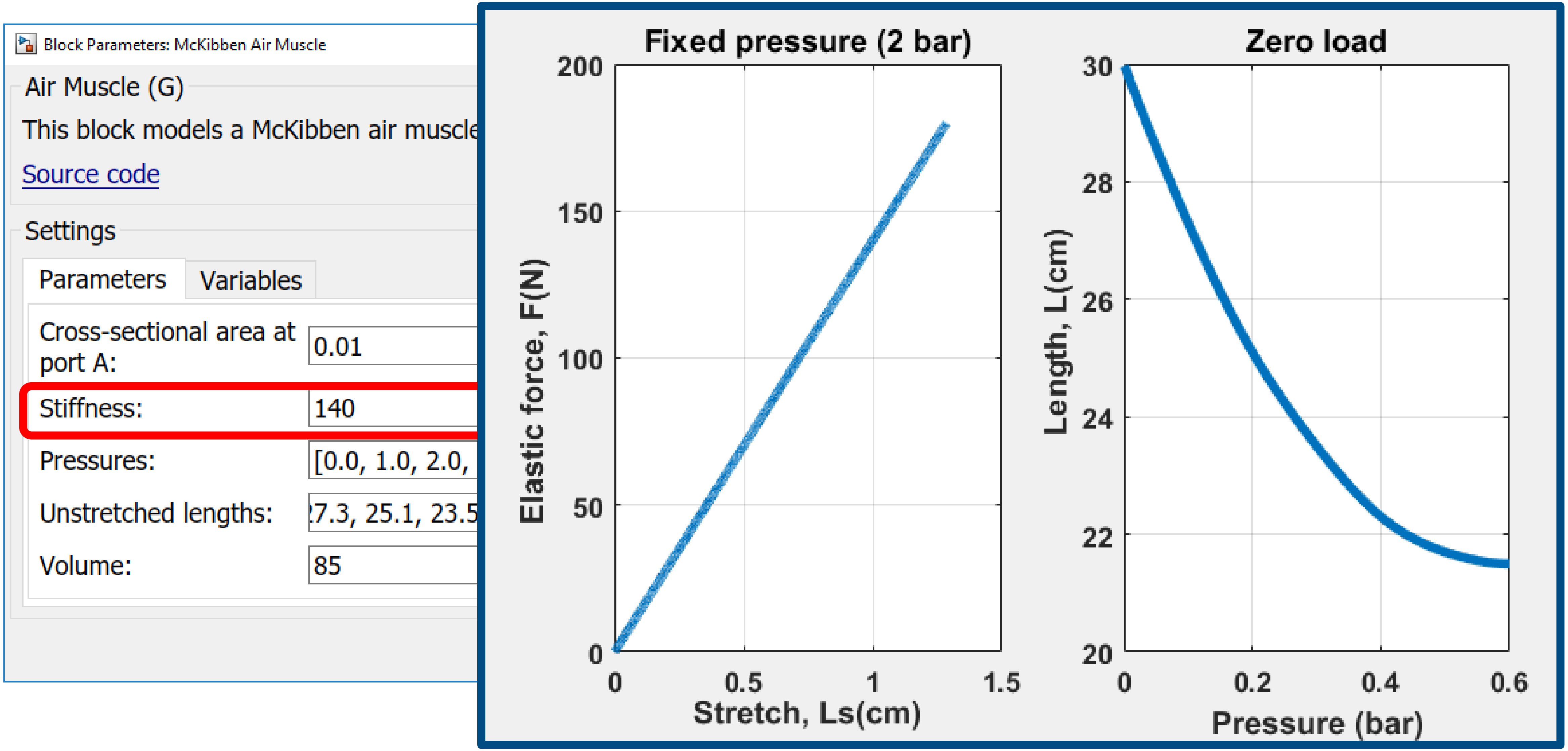
- Variables
- Parameters

```
variables
    % Mechanical variables
    force = {0, 'N'}; % Force
    Ls = {0, 'm'};     % Stretch
end
```

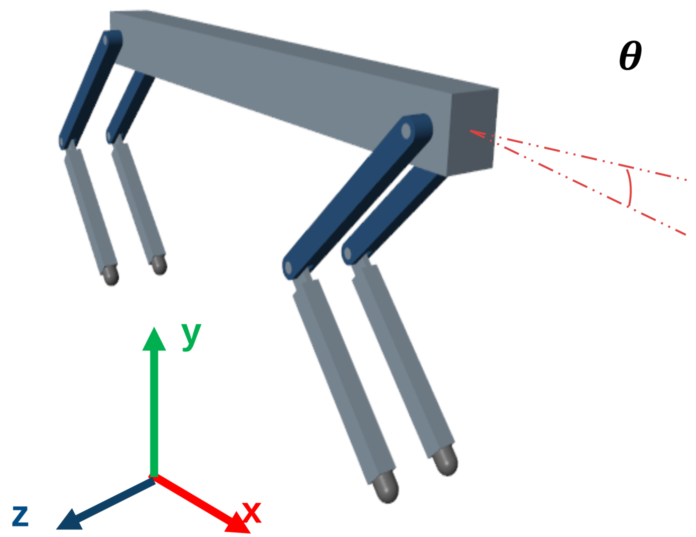
```
parameters
    K = {140,'N/cm'}; % Stiffness
    pVec = {[0 1 2 3 4 5 6] ,'bar'}; %
    LuVec  = {[30 27.3 25.1 23.5 22.3
end
```

Creating custom Simscape components

Step 4: Build library and run test model



Demos - Quadruped Robot



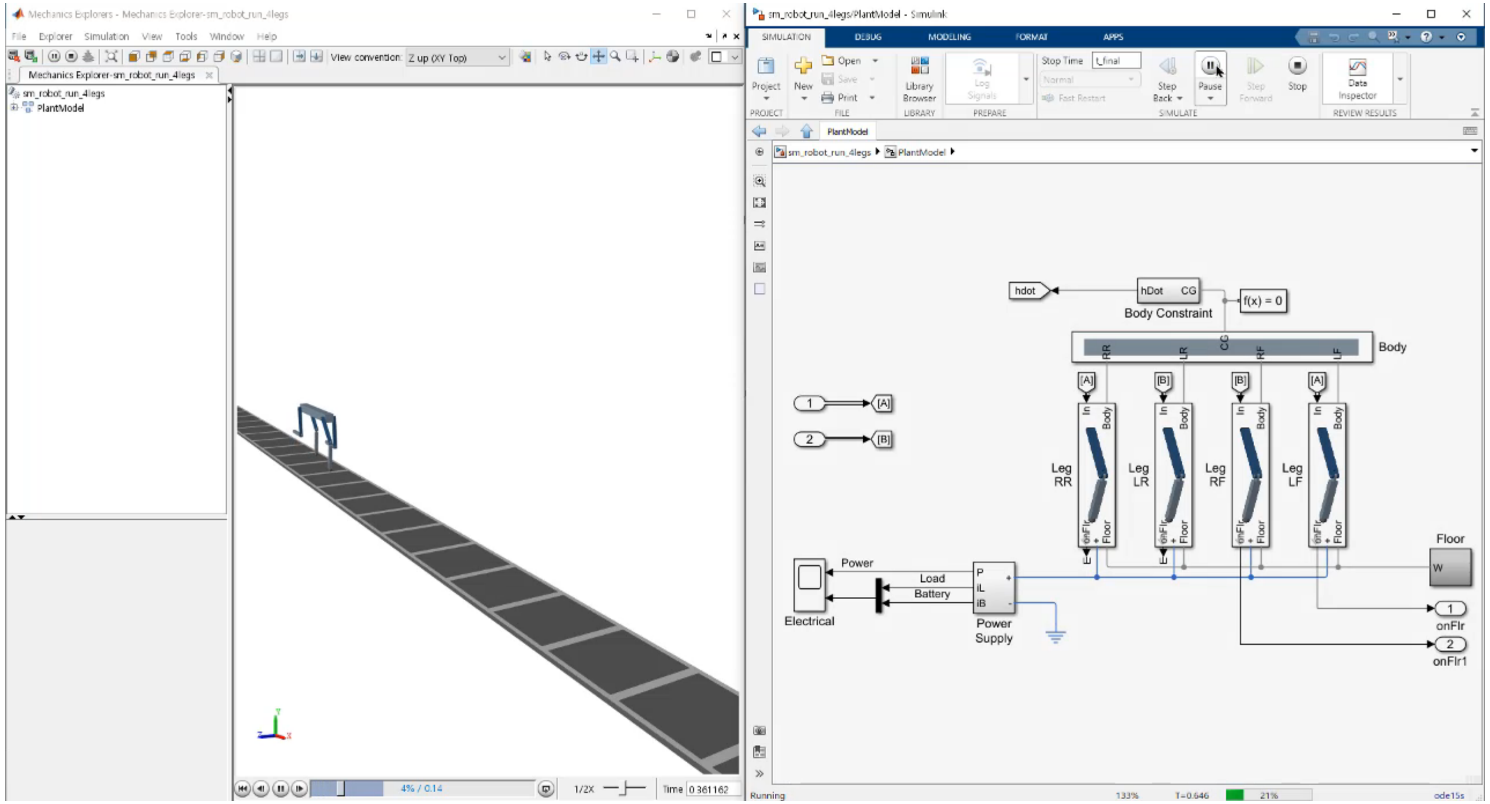
Walking Robot

Walking Robot

Demos - Quadruped Robot

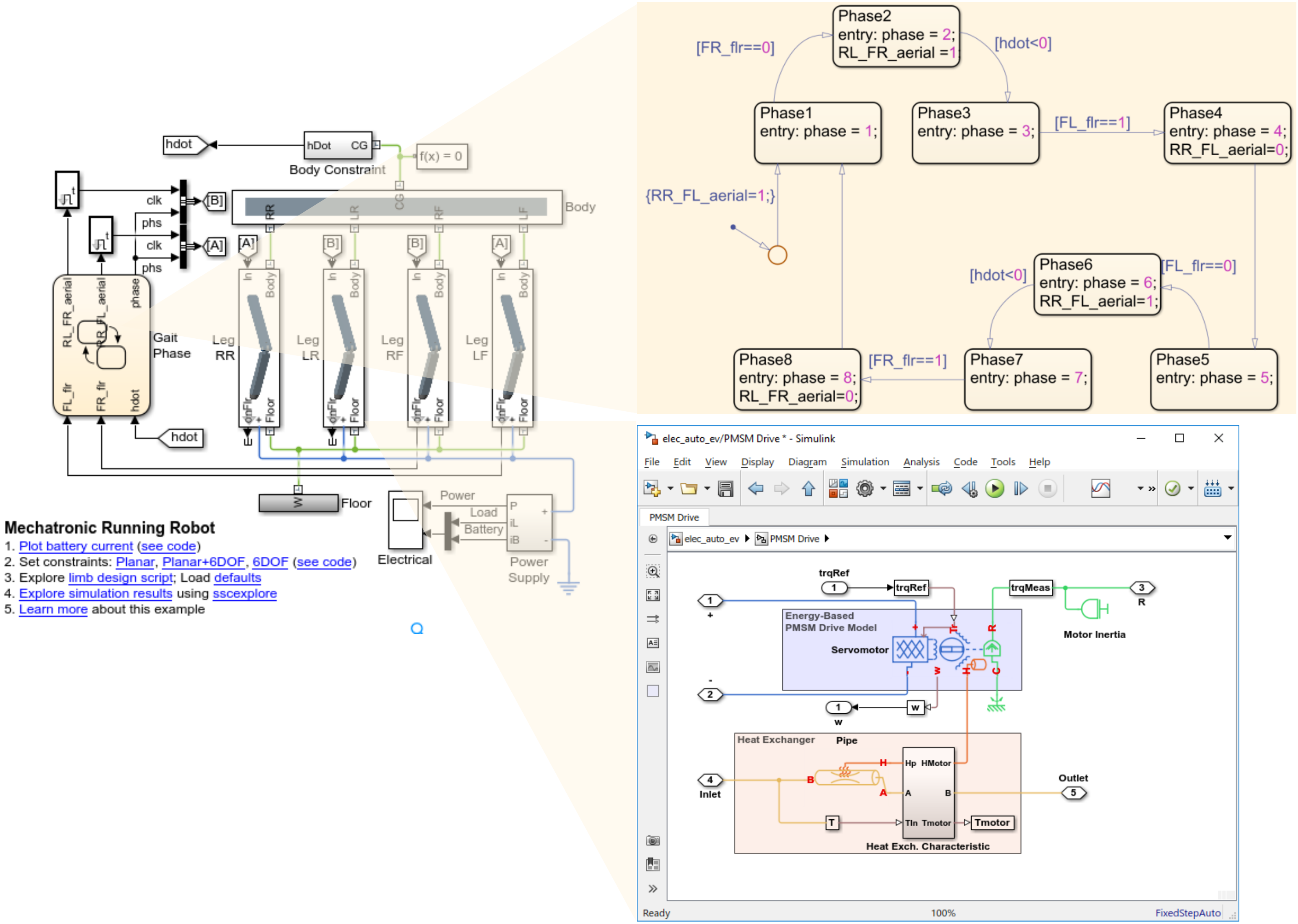
- Simulate models
  - Identify system behavior
  - Design controller

- Analyze physical system
  - Evaluate overall system requirements
  - Confirm system capacity such as battery power, motor capacity ETC



Simscape works in a variety of applications

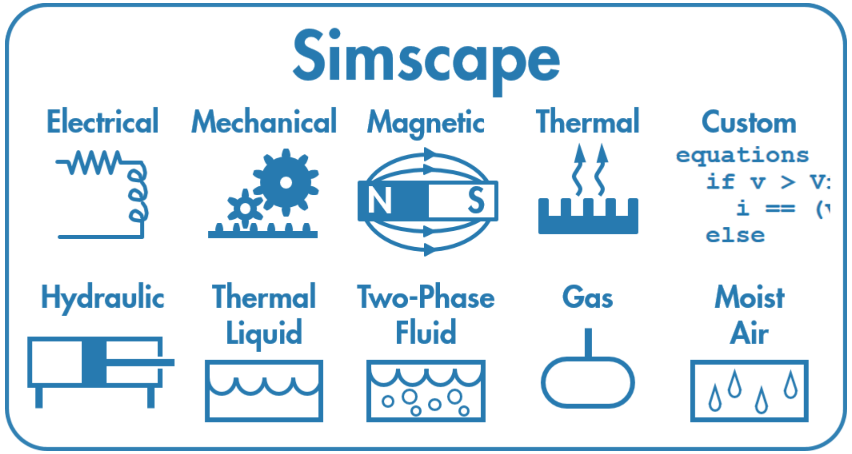
- Plant and control
- Multidomain
  - **Electrical**
  - **Mechanical**
  - **Thermal**
  - **Fluid**



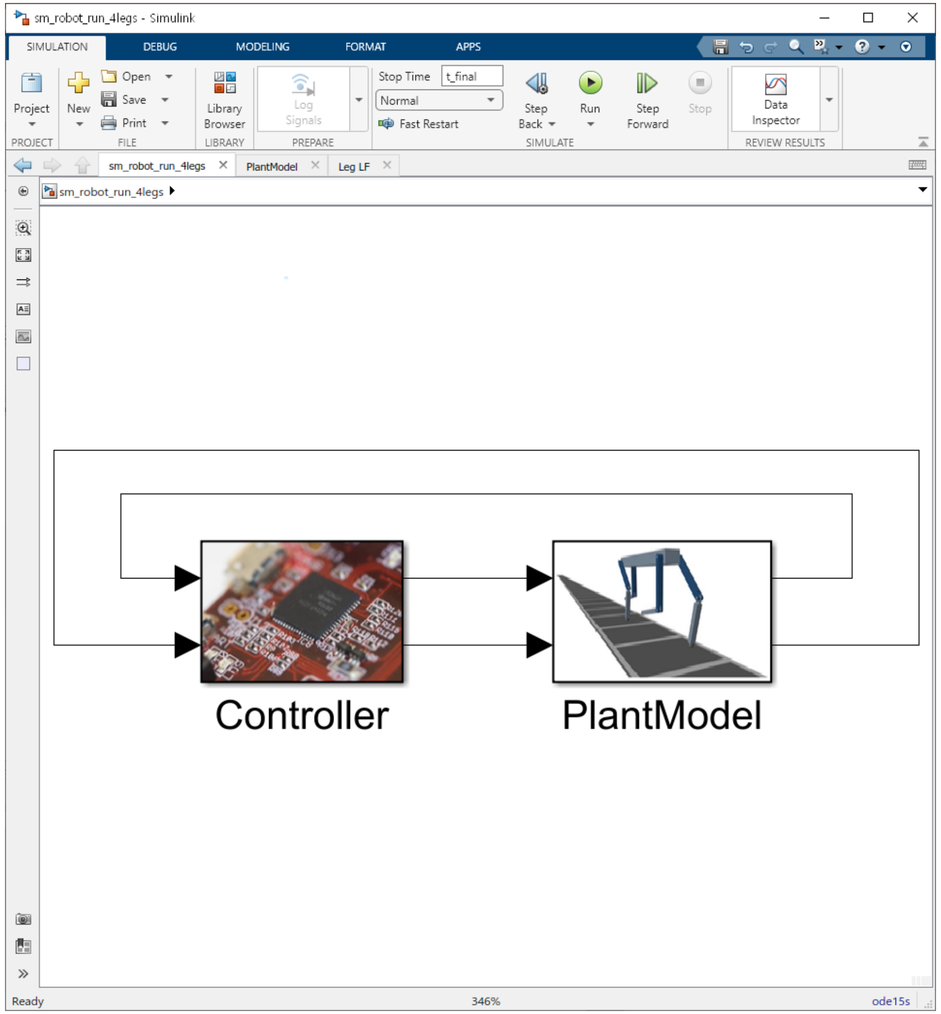
Demos - Quadruped Robot

Walking Robot

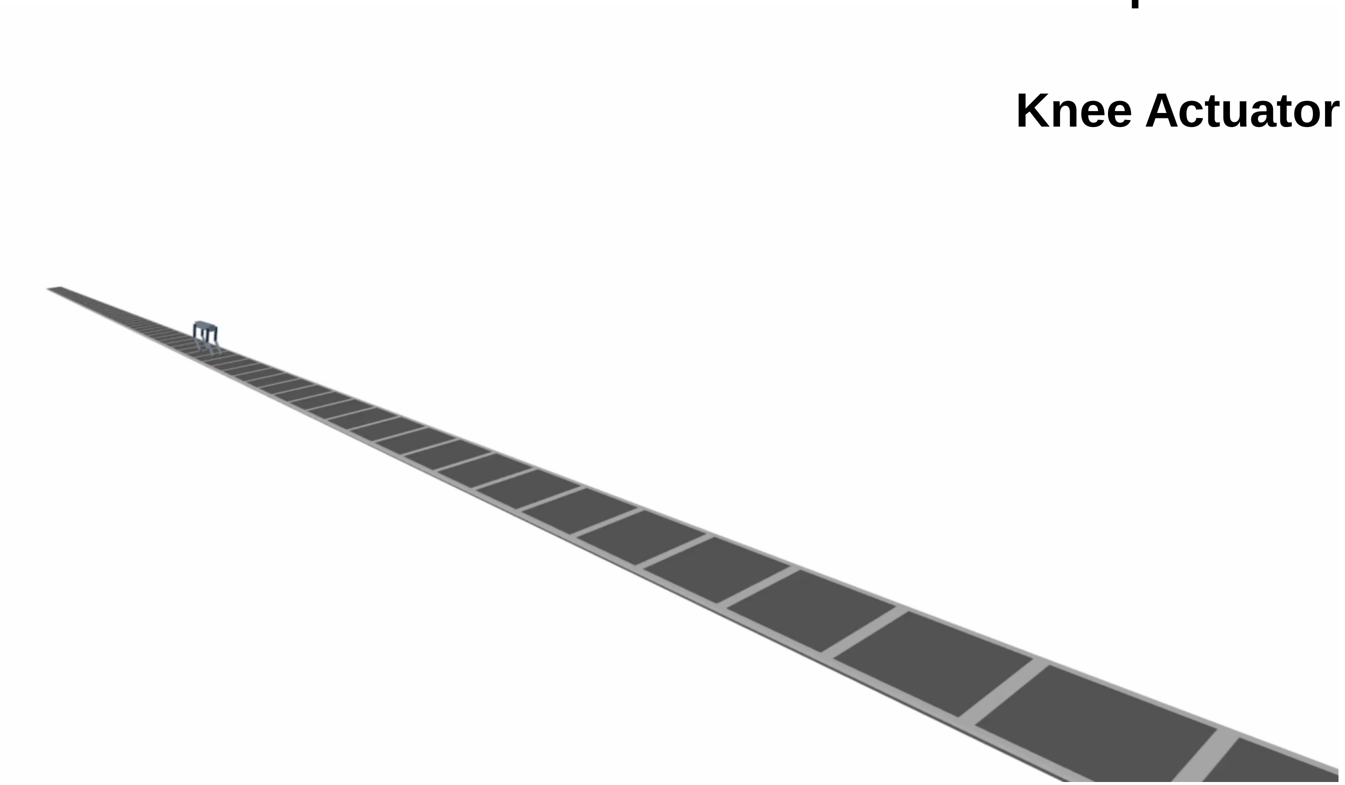
1. Can you analyze how the system behaves before building any physical prototypes?

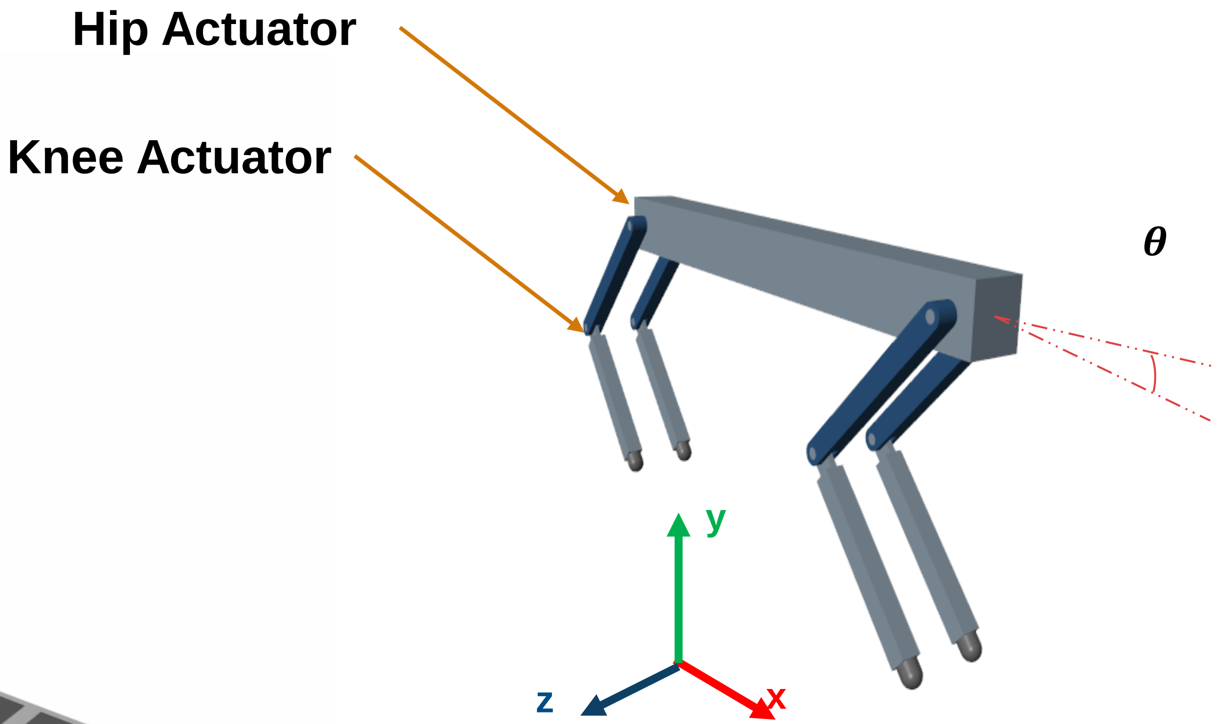


2. How do you model the electromechanical and multibody components?



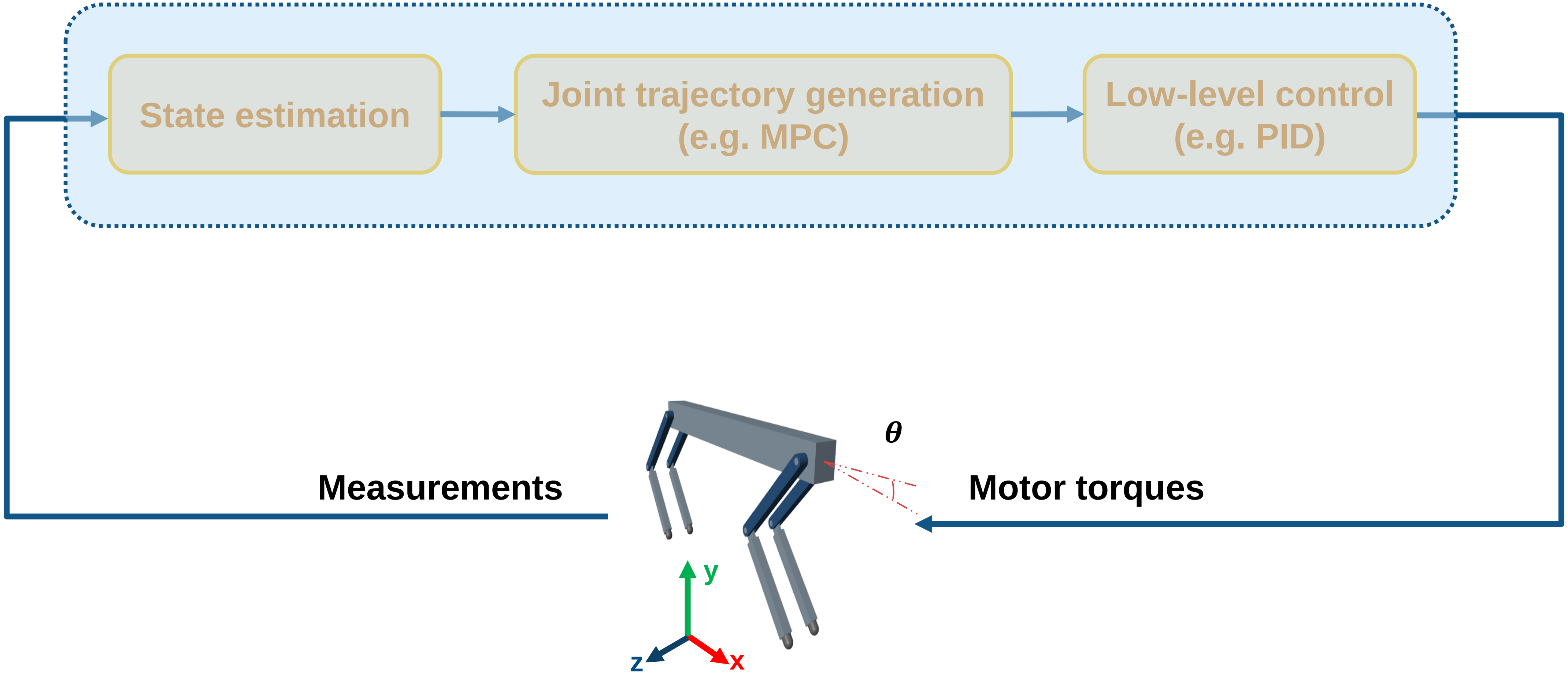
Why Should You Care About Reinforcement Learning?





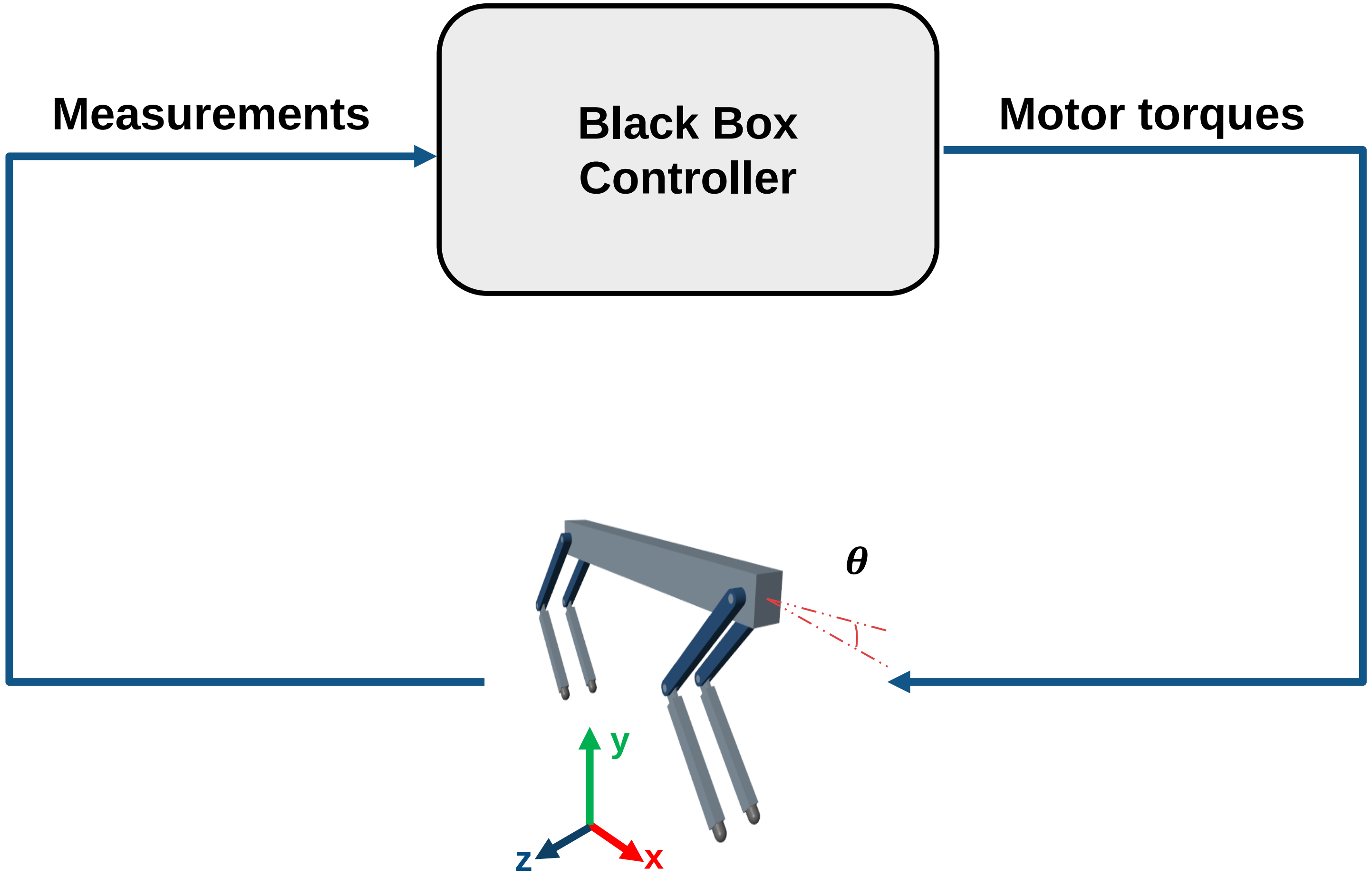
Walking Robot

One Approach Could Be…



Walking Robot

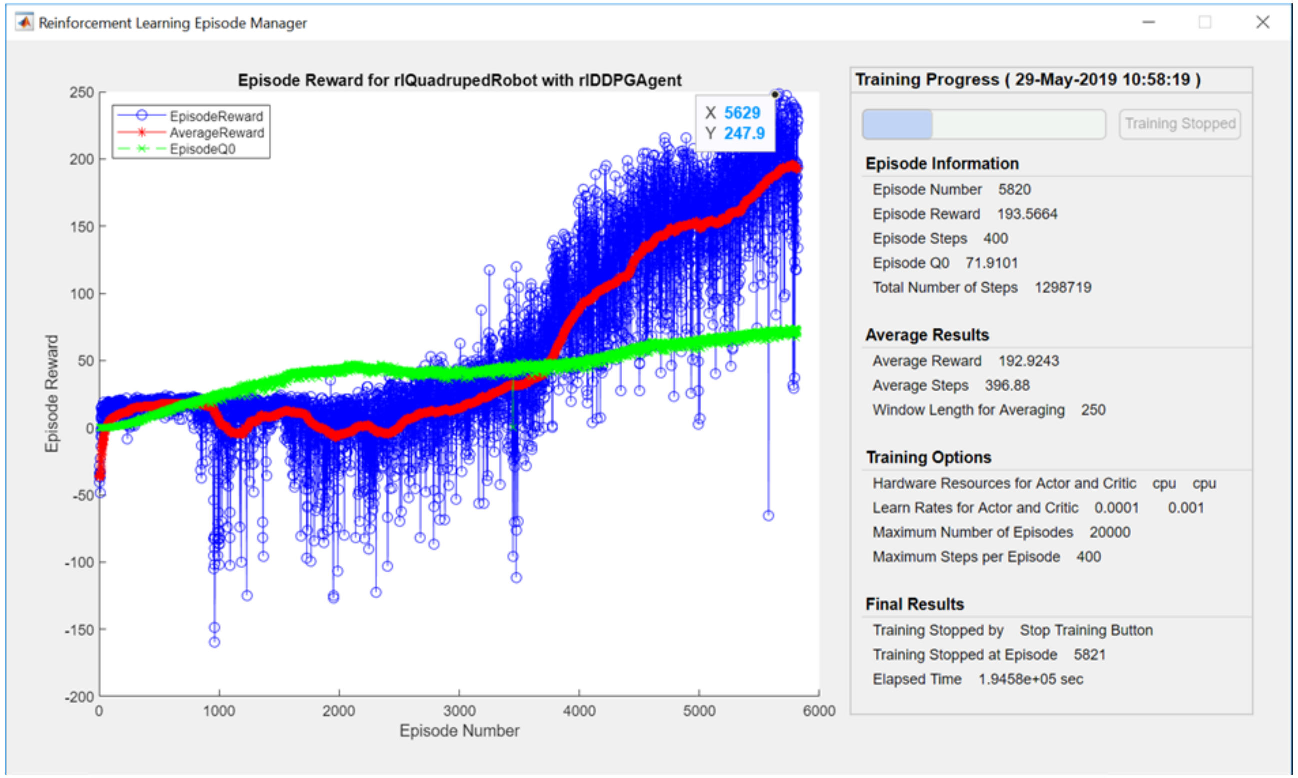
Any Alternatives?

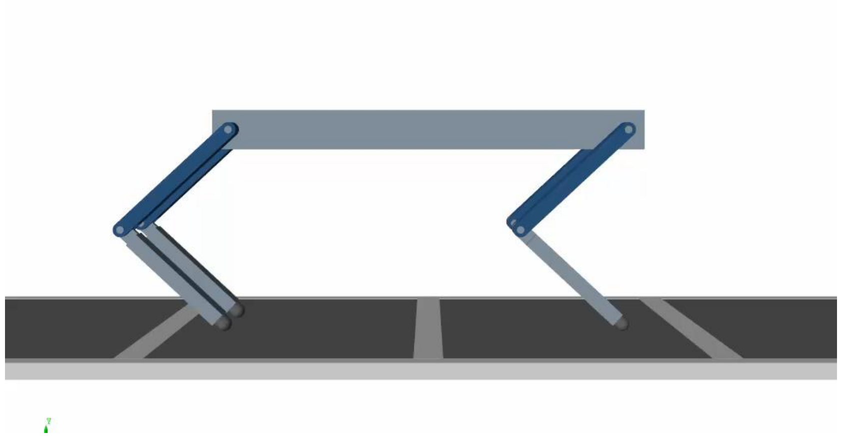


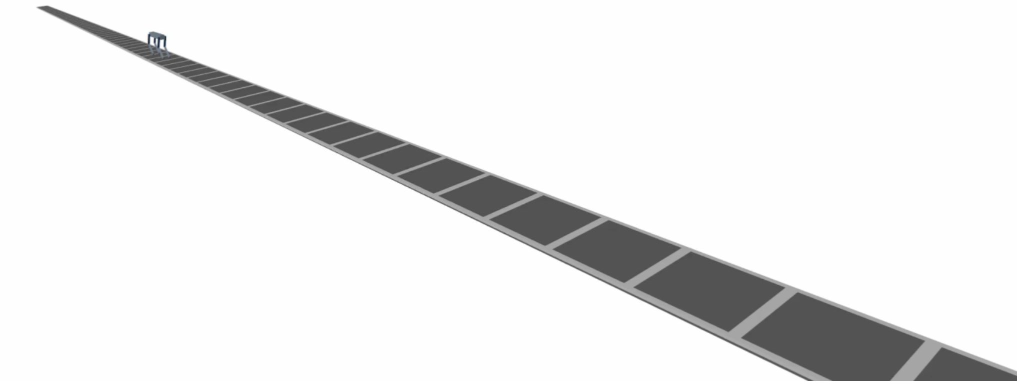
Quadruped Robot Locomotion Using Reinforcement Learning

Train quadruped robot to walk with DDPG agent

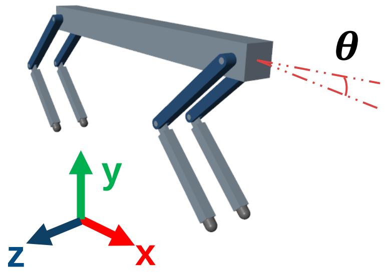
- Quadruped robot modeled in Simscape Multibody with contact forces
- Policy takes in 44 observations and outputs 8 torque values







Reinforcement Learning Model



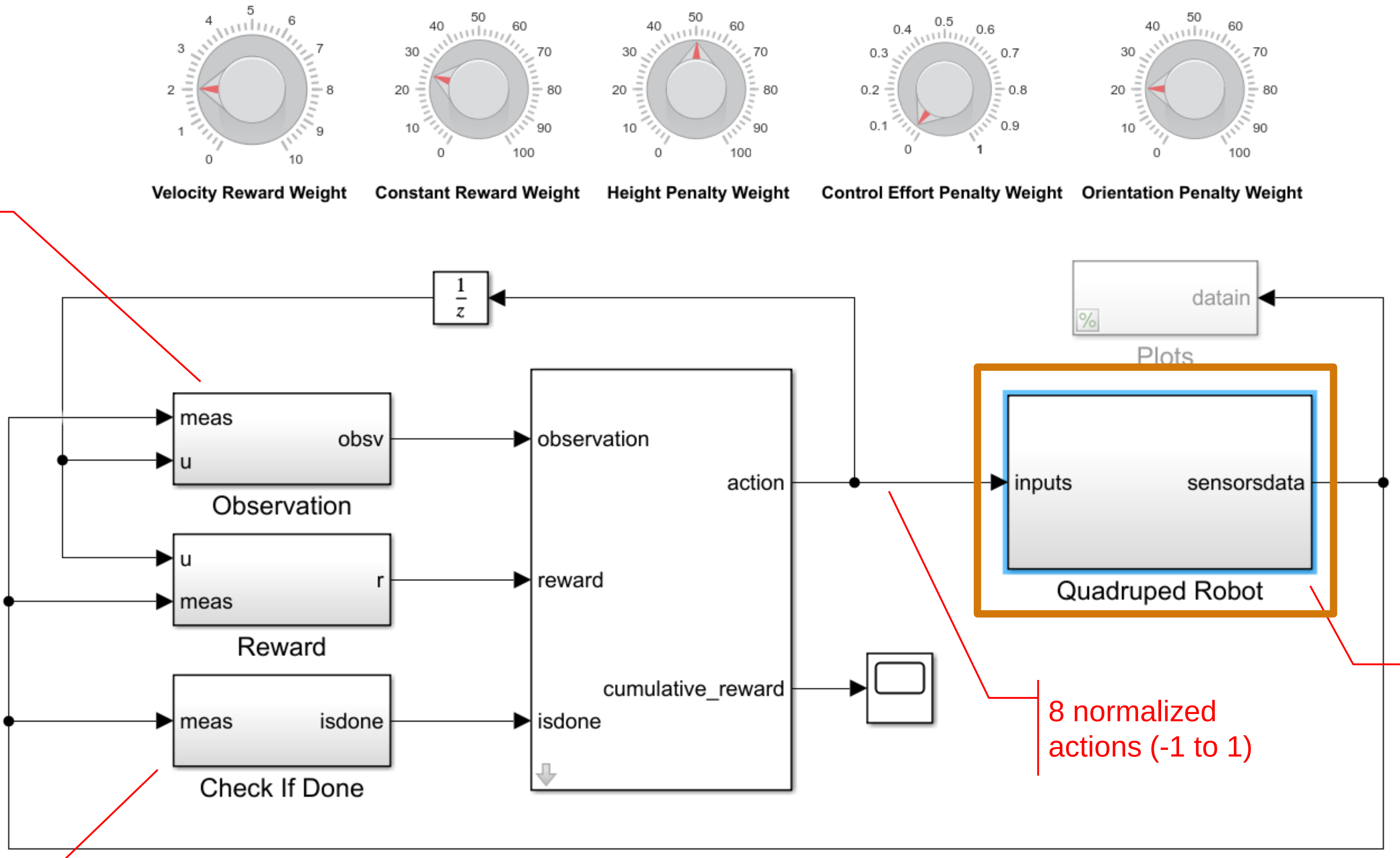
44 Observations:

Body C.M.:
2 pos (y, z)
3 vel (vx, vy, vz)
4 orient (quaternion)
3 ang vel (wx, wy, wz)

Each Leg:
2 joint ang (hip, knee)
2 joint vel (hip, knee)
2 Contact Forces

Actuation:
8 joint torques

Episode termination criteria:
Body C.M. below min. height
Head/Tail below ground
Knee below ground
Roll, pitch, yaw exceeds bounds

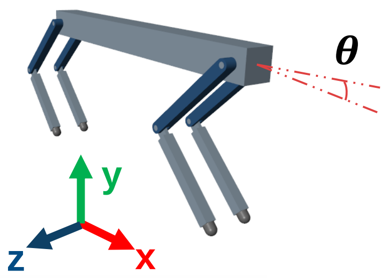


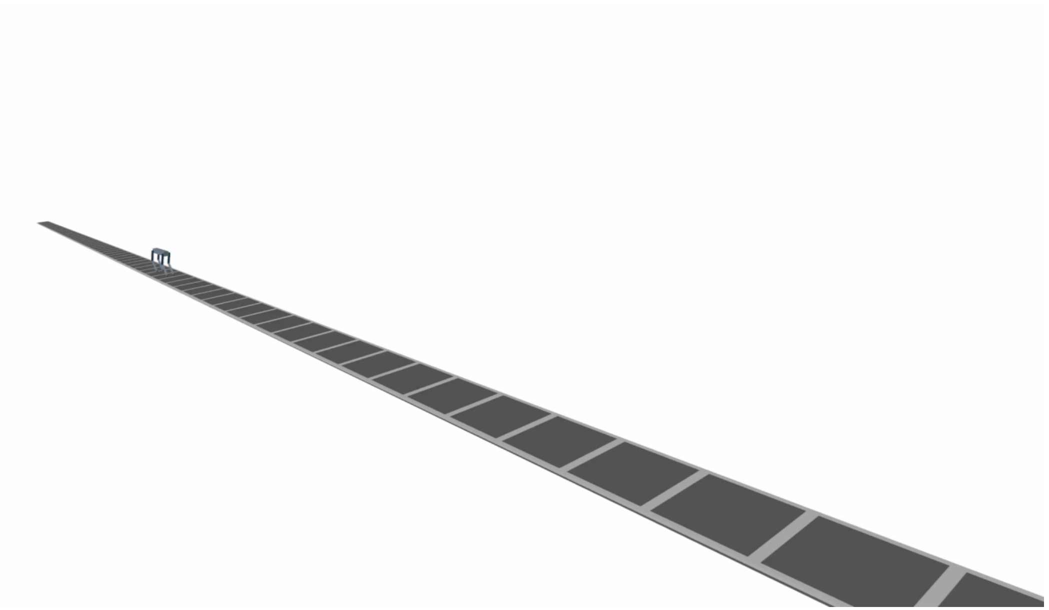
8 normalized actions (-1 to 1)

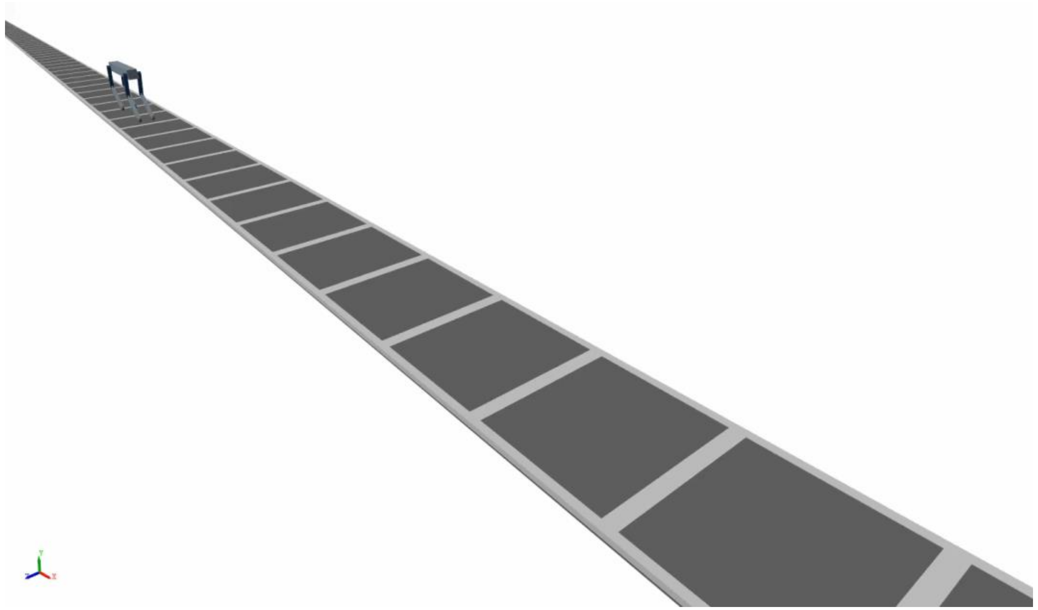
Robot model (Plant)

Quadruped Walking Robot Example

Training and Reward Function Shaping







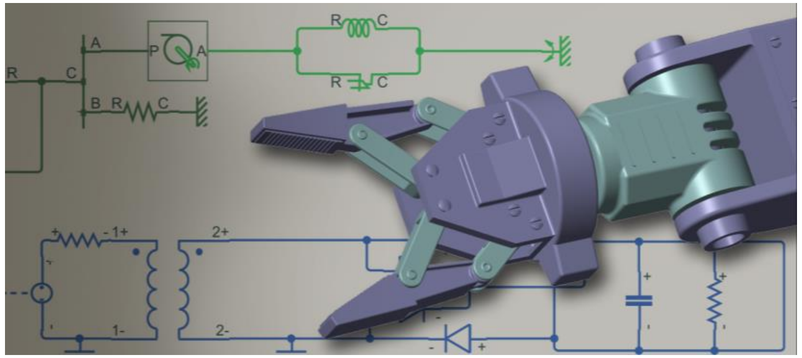
$$r_t = v_x + 25\frac{T_s}{T_f} - 50\hat{y}^2 - 20\theta^2 - 0.02\sum_i {u_{t-1}^i}^2$$

$$r = 2v_x + 25\frac{T_s}{T_f} - 50\hat{y}^2 - 20\theta^2 - 0.02\sum_i {u_{t-1}^i}^2$$

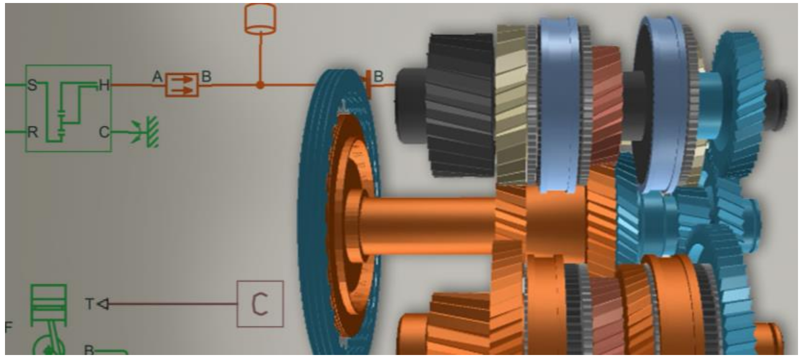
[Quadruped Robot Locomotion Using DDPG Agent - MATLAB & Simulink - MathWorks 한국]

Simscape works in a variety of applications

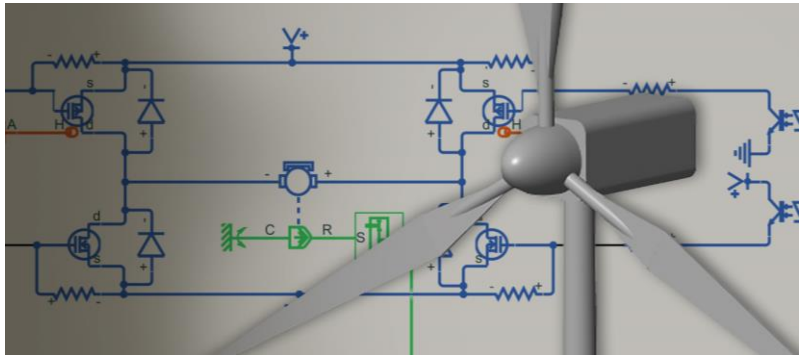
Robotics



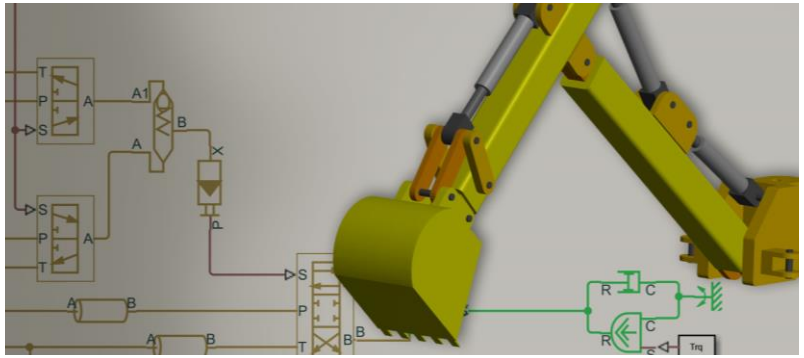
Drivelines



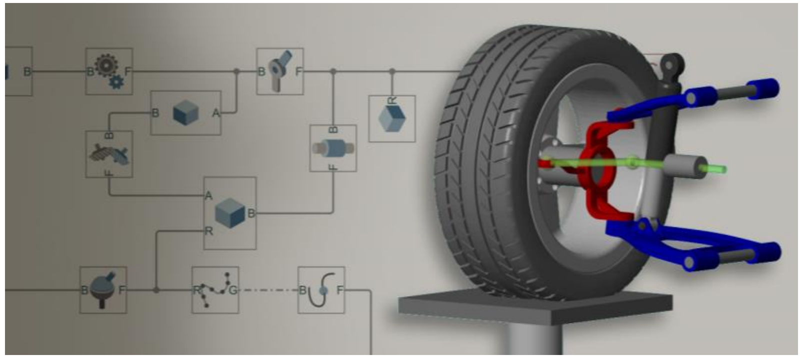
Renewable Energy



Actuation



Hybrid Vehicles



Volvo Construction Equipment Streamlines Product Development with a Real-Time, Human-in-the-Loop Simulator

Challenge

Evaluate design concepts and parameter values for construction equipment before building physical prototypes

Solution

Use Simulink, Simscape, and Simulink Real-Time to model hydraulic, mechanical, and engine systems and perform real-time, operator-in-the-loop simulations

Results

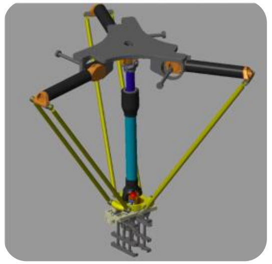
- Number of prototypes reduced
- Issues in the field resolved faster
- Controller tuned in simulation

Volvo Construction Equipment's real-time, human-in-the-loop simulator.

"It was technically impossible for us to build a full-scale hydraulic system model to run in real time without Simulink, Simscape, and Simulink Real-Time. Our simulator enables us to test new concepts for construction equipment, tune parameters, reduce lead times, and minimize issues in the field."

- Jay Yong Lee, Volvo Construction Equipment

Krones Develops Package-Handling Robot Digital Twin



The Krones Robobox T-GM package-handling robot.

Challenge

Increase the performance of an automated beverage-packaging system by incorporating a dynamic tripod robot into the design

Solution

Use Simulink and Simscape Multibody to create an accurate digital twin that supports design optimization, fault testing, and predictive maintenance

Results

- Robot performance increased
- Product development time shortened
- Testing time significantly reduced

"Simulations of the digital twin in Simulink enabled us to obtain data and insights that would be either impossible to get via hardware tests or simply too costly and time-consuming. Visualizing forces and moments helped us to understand the effects of individual components on a highly dynamic robot."

- Benedikt Böttcher, Krones

Link to user story

Key Takeaways

- Simscape helps you create models of multidomain systems in Simulink
- Explore design of physical systems, to support controller development, more…
- Simscape is widely used for many applications
- Resources are available to help you get started and succeed

MATLAB EXPO

Thank you

MathWorks®