MATLAB / Simulink Lab Course

Physical Modeling

Lehrstuhl für
Flugsystemdynamik

Outline

Introduction – Reasons for Physical Modeling

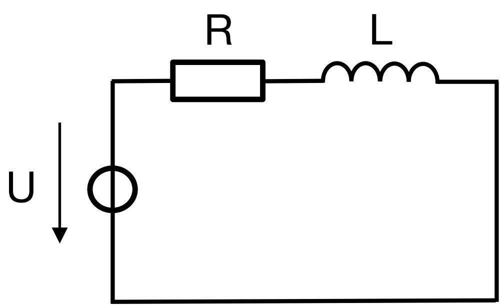
- **Reasons** for Physical Modeling
  - **Easy and intuitive modeling** of even complex and multi-domain physical systems
  - **Timesaving** and **cost-saving** modeling → faster modeling and insight into the system
  - **Virtual prototypes** in early stage of development
  - Observing variables without changing the model

1. Introduction

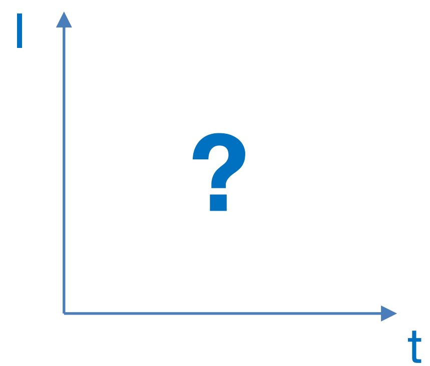
Introduction – What is Physical Modeling?

- Example 1: How to **model** this electric circuit using **ordinary methods**?

  Goal: Calculate current over time



U = 12 V; R = 6 Ω; L = 1 H



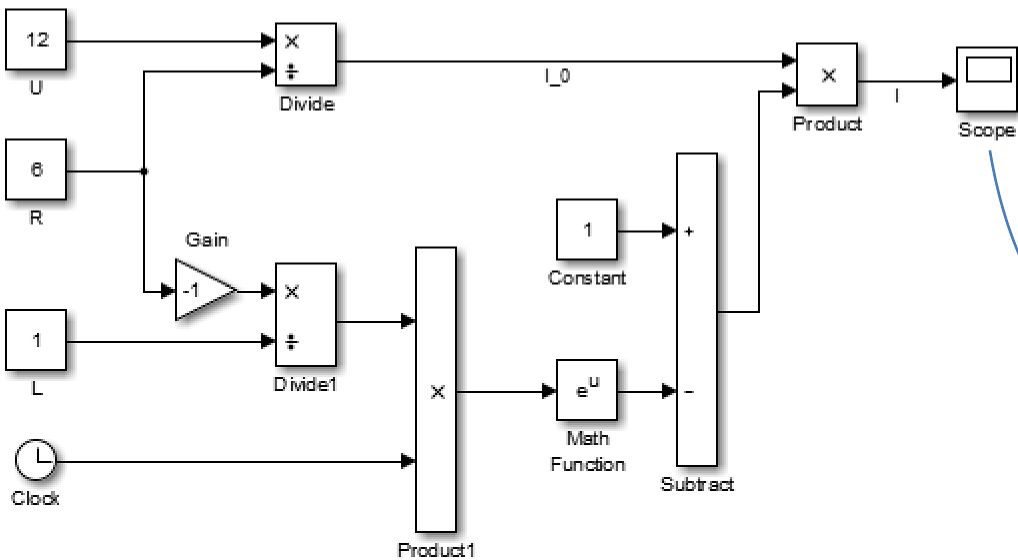
- **Equations** describing the system behaviour

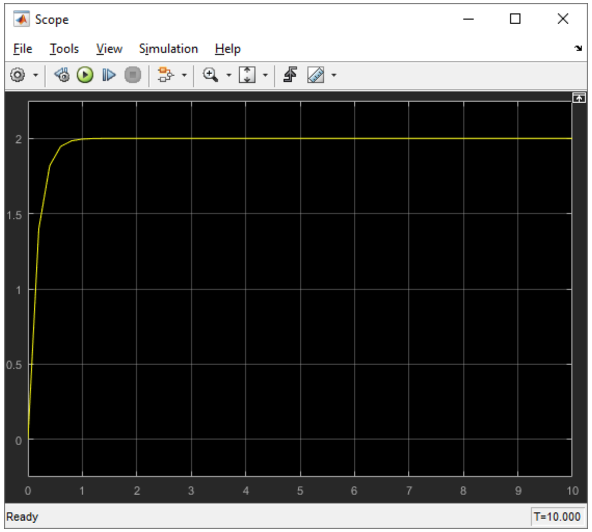
$$I = \frac{U}{R}$$

$$I_L(t) = I \cdot \left(1 - e^{-\frac{R}{L}t}\right)$$

Introduction – What is Physical Modeling?

- Implementing a Simulink diagram

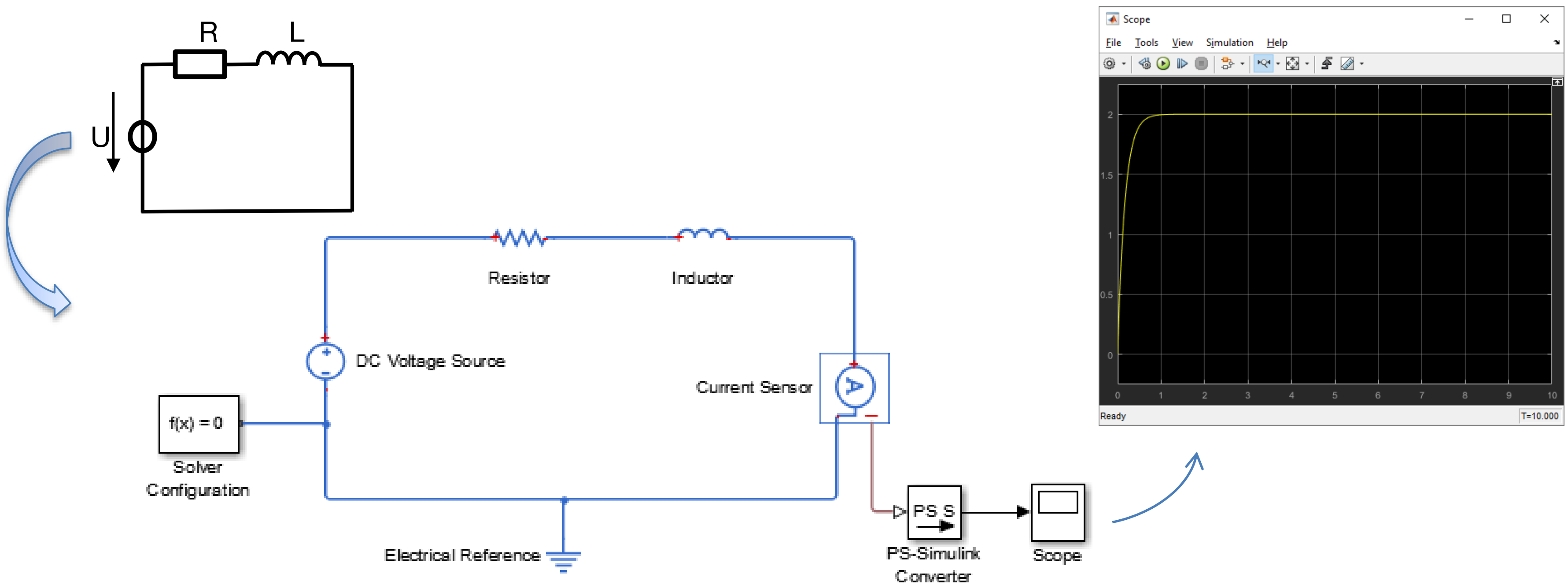




Note: A Simulink diagram represents a **chain of mathematical operations.** The graph is a **directed graph** and the "lines" are representing **numerical signals.**

Introduction – What is Physical Modeling?

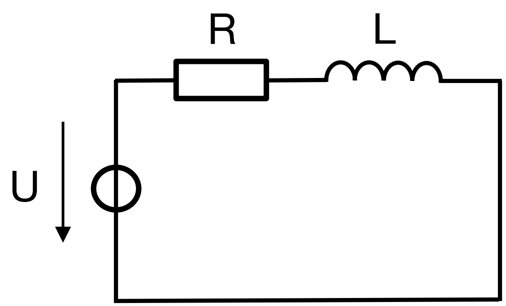
- How to **model** the same system using **Physical Modeling (Simscape):**

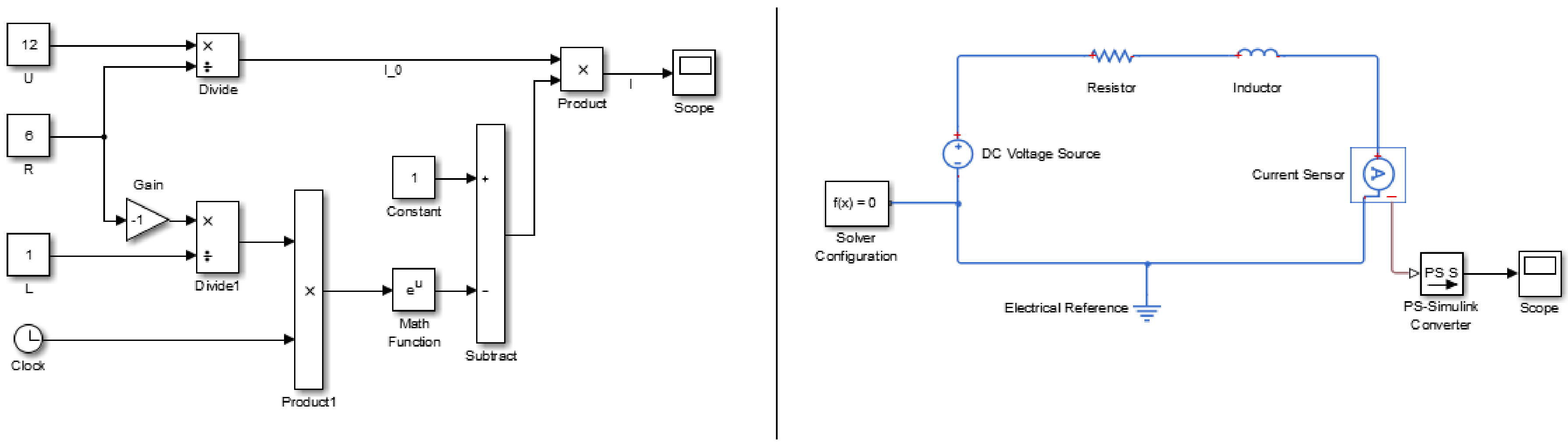


A Simscape graph represents **differential algebraic equations** (DAEs). These graphs are **undirected graphs** and "lines" are **physical signals** (PS) that **link equations.**

Introduction – What is Physical Modeling?

- Comparing both models





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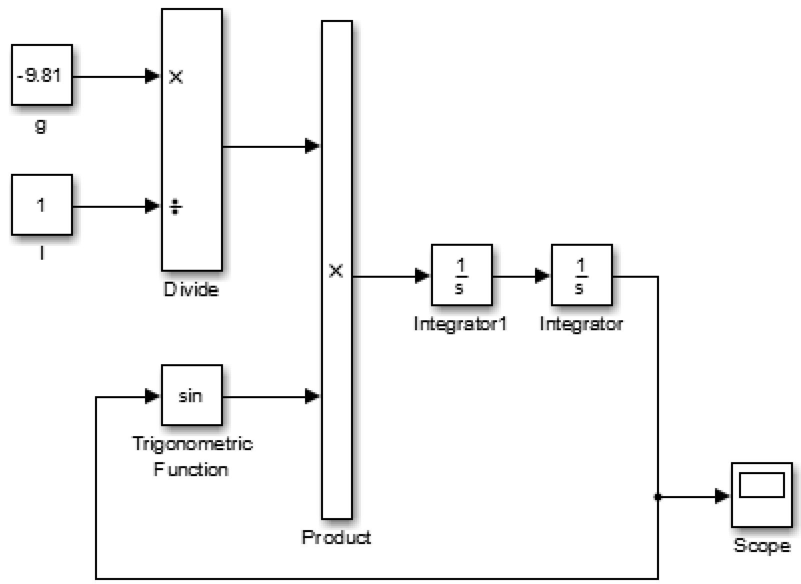
Introduction – What is Physical Modeling?

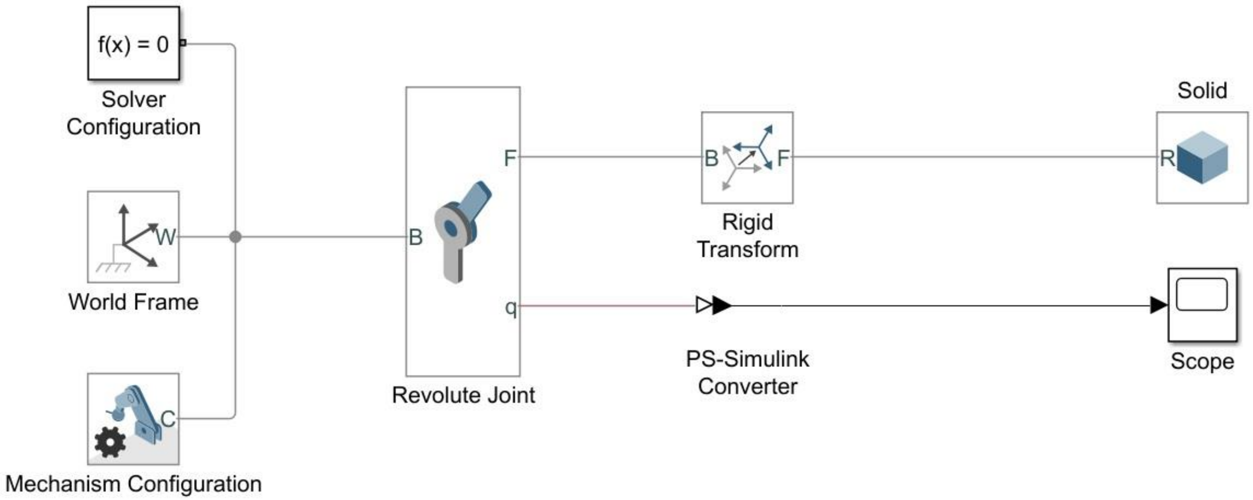
- Example 2: This diagram represents what mechanical system?



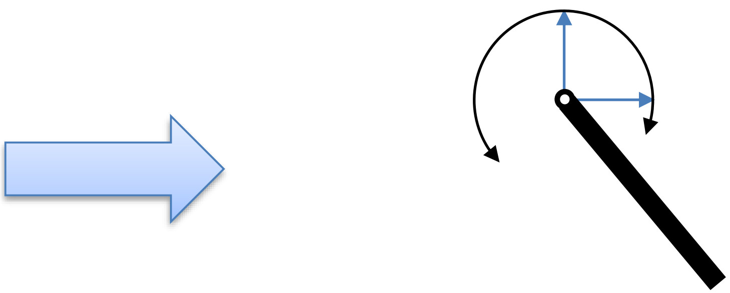
?

Introduction – What is Physical Modeling?

- The **physical model** of the same system offers a lot more information.



- This model containts:
  - Body
  - Revolute Joint
  - Coordinate Frame
  - …

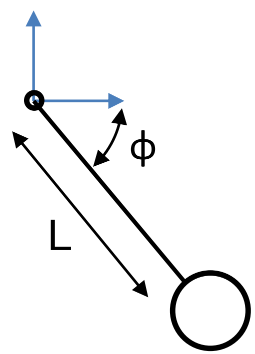


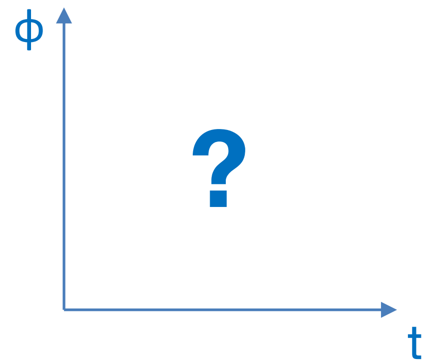
Introduction – What is Physical Modeling?

- How to **model** this pendulum using **ordinary methods**?

Goal: Calculate angle over time

L = 1m



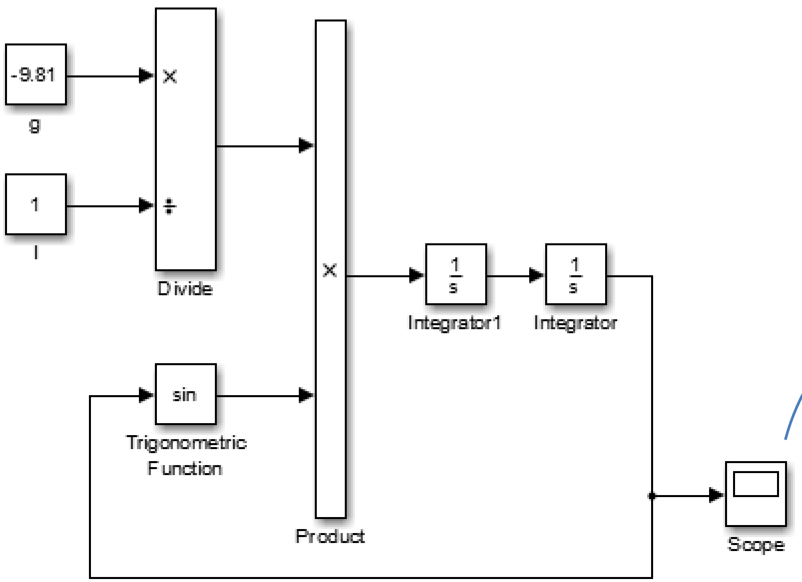


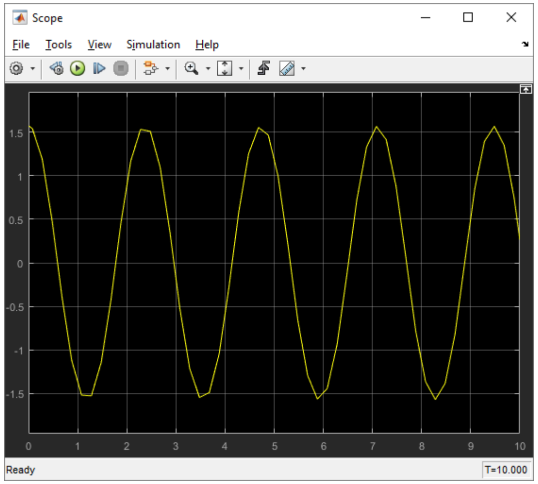
- Differential equation describing system behaviour:

$$\ddot{\phi}(t) + \frac{g}{L} \cdot \sin(\phi(t)) = 0$$

Introduction – What is Physical Modeling?

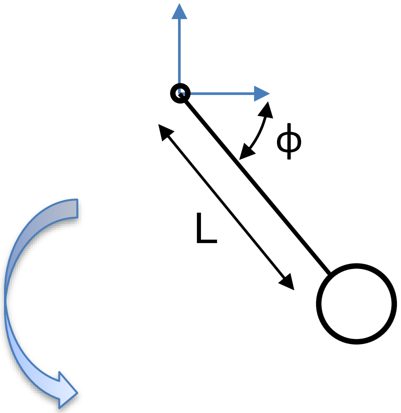
- Implementing a Simulink diagram

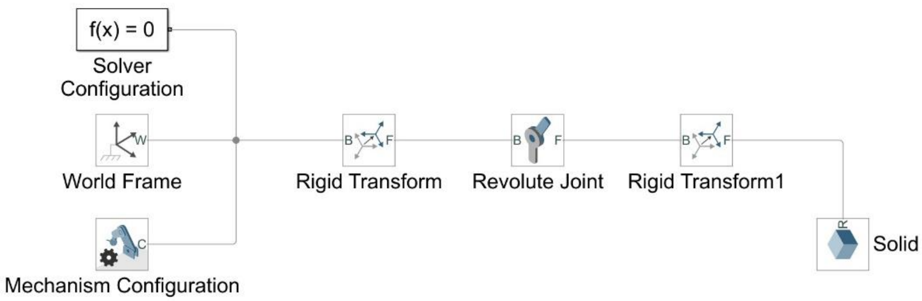


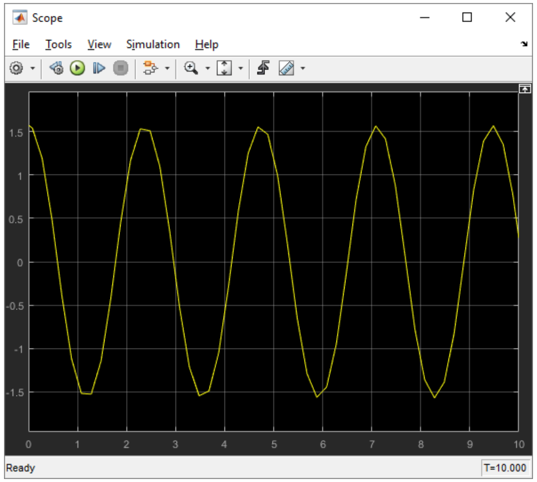


Introduction – What is Physical Modeling?

- How to **model** the same system using **Physical Modeling (Simscape Multibody):**

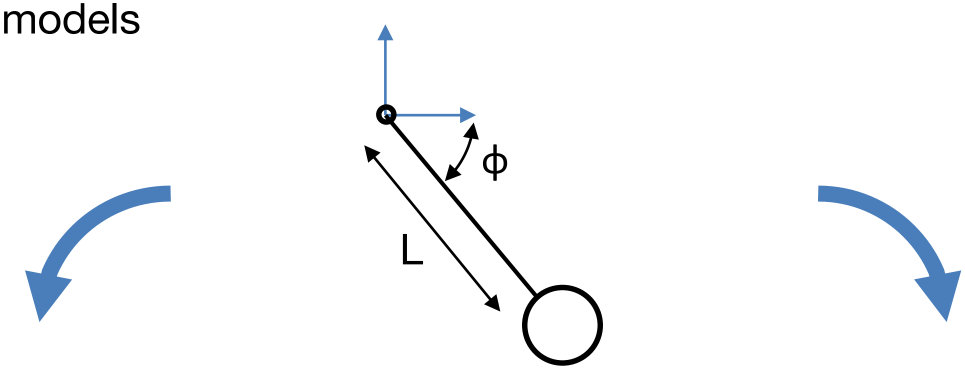


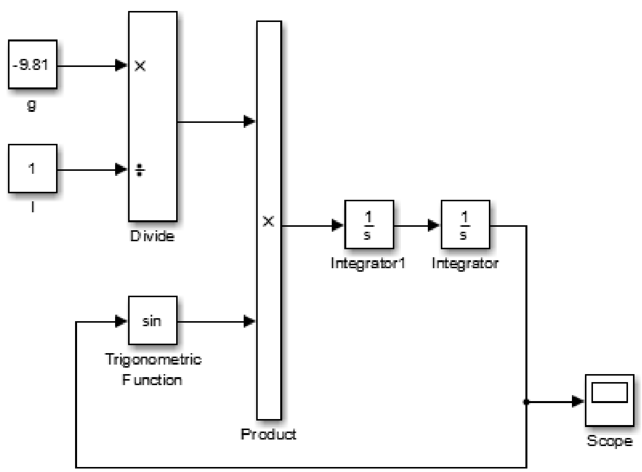


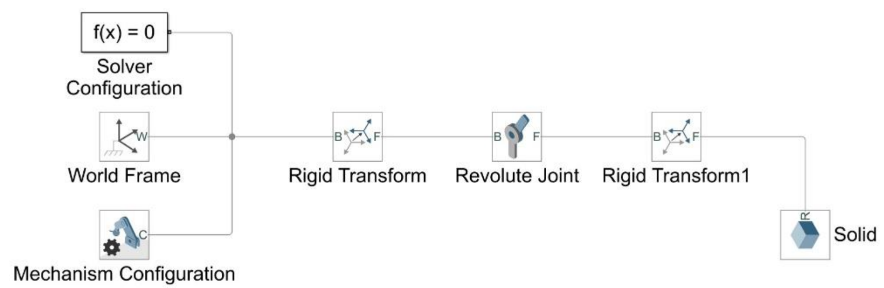


Introduction – What is Physical Modeling?

- Comparing both models



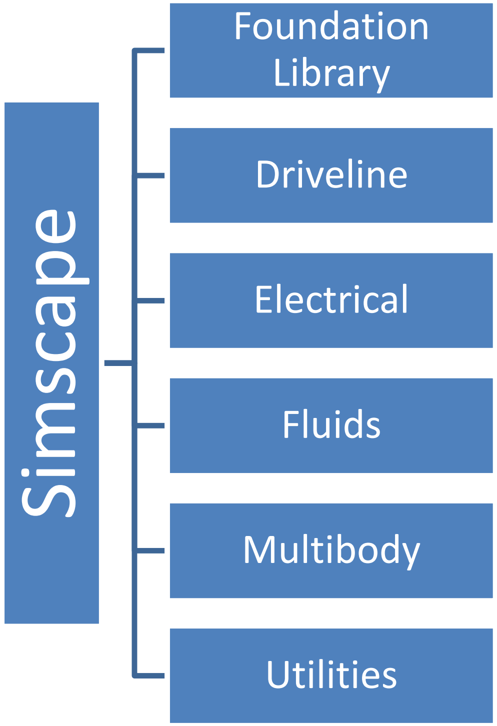




Lehrstuhl für Flugsystemdynamik

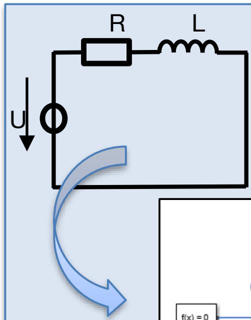
Introduction – Simscape Toolbox

- Simscape Toolbox is useful for **modeling and simulating physical systems** within the Simulink environment.
- Predefined blocksets in the **Foundation Library** for several physical domains: electrical, mechanical, thermal, …
- **Multi-domain** physical modeling
- Further libraries with predefined blocksets fitted for certain physical domains:
  - Simscape Driveline
  - Simscape Electronics
  - Simscape Fluids
  - Simscape Multibody
  - Simscape Power Systems

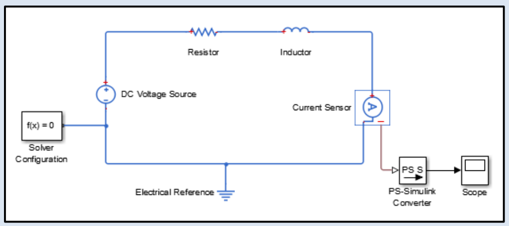


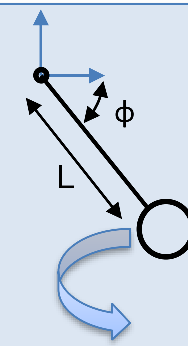
Introduction – Simscape Toolbox

- Use toolboxes that **suit your problem and it's physical domain.**

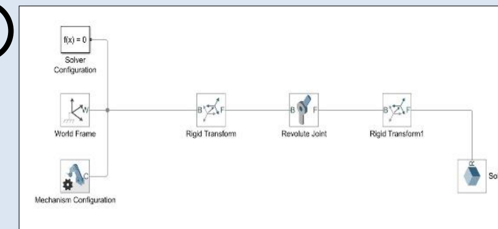


Problem in electrical domain
→ Foundation Library – Electrical
→ SimElectronics





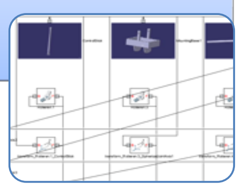
Problem in mechanical domain
→ Simscape Multibody



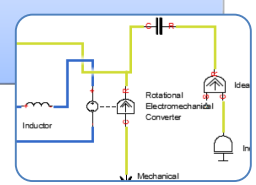
- **Combine** models that were built with different toolboxes:

Example:

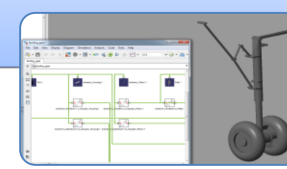
Creating a MBS of the kinematic system in Simscape Multibody



Modeling an electrical actuator using Simscape

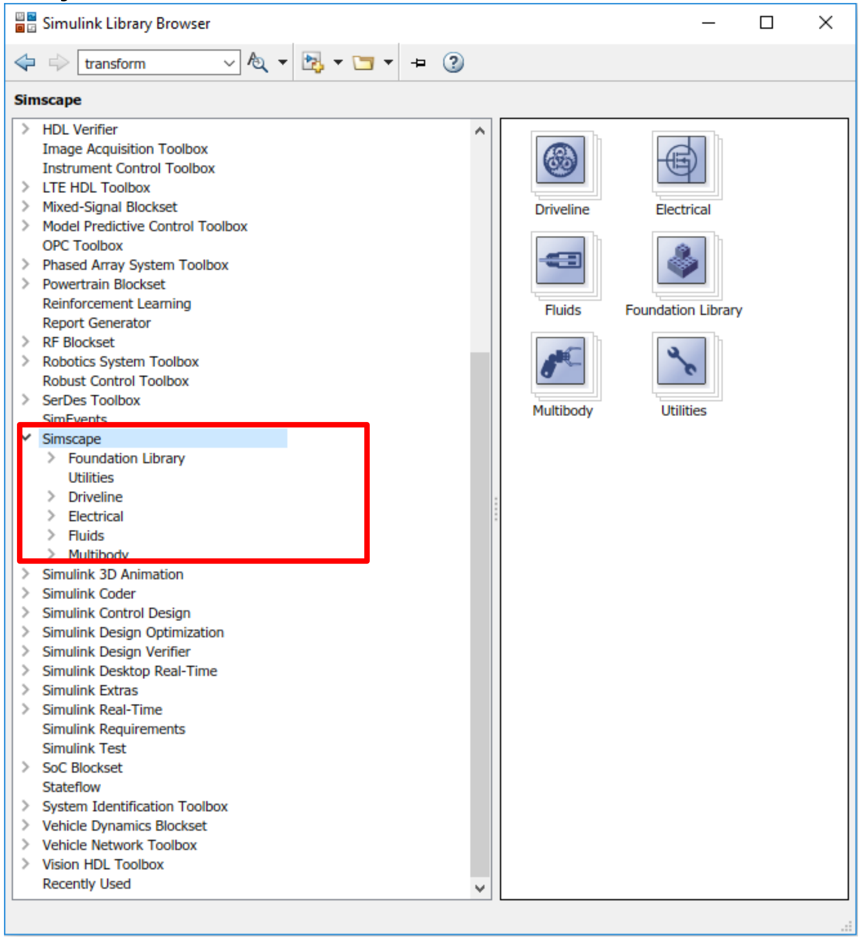


Combination of both products (Simscape Multibody and Simscape) produces a detailed simulation model of the mechatronic system



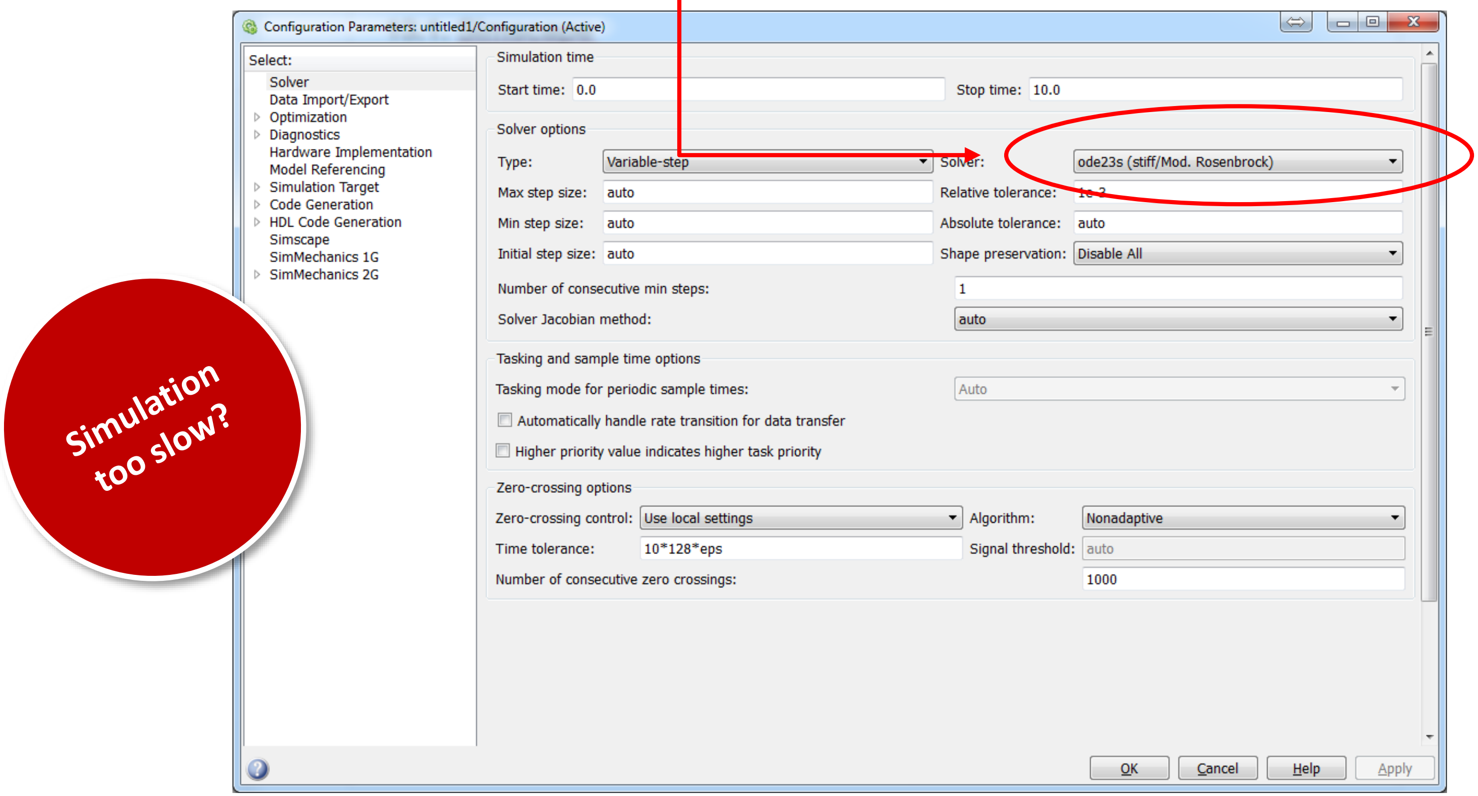
Introduction – Simscape Toolbox

- Find the Simscape Library and it's toolboxes:



Introduction – Simscape Toolbox

- Generally stiff solvers (*ending with a s*) are performing much better at physical problems. To set solver settings press CTRL+E in diagram window:



2. Multibody Simulation using Simscape Multibody

Multibody Simulation using SimMechanics

- What is Multibody-Simulation (MBS)?
  - Numerical simulation
  - Composition of **rigid bodies** that are interconnected via **joints** (kinematic constraints)
  - Perform **motion analysis** and calculate forces

- Market Overview:
  - **SimMechanics (Simscape Multibody)** (MathWorks)
  - SIMPACK (Dassault Systèmes)
  - Multiphysics (COMSOL)
  - Multibody Dynamics

Multibody Simulation using Simscape Multibody

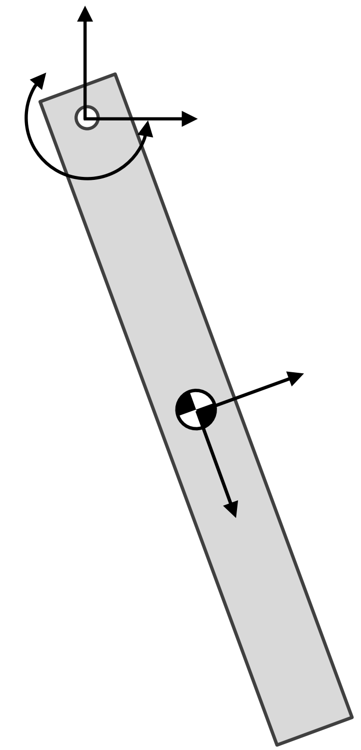
- What is **Simscape Multibody**
  - Toolbox of Simscape that provides a multibody simulation environment for 3D mechanical systems
  - **Model-Based Design** of MBS models
  - First & **Second Generation**

- **Advantages** of Simscape Multibody
  - MBS-Tool **inside** of the MathWorks world
  - Use Simscape Multibody blocks in the Simulink diagram environment
  - **Add electrical, hydraulic and pneumatic components** to your mechanical model (Simscape)
  - Easy 3D visualization of the system dynamics via *Mechanics Explorer*

Multibody Simulation using Simscape Multibody

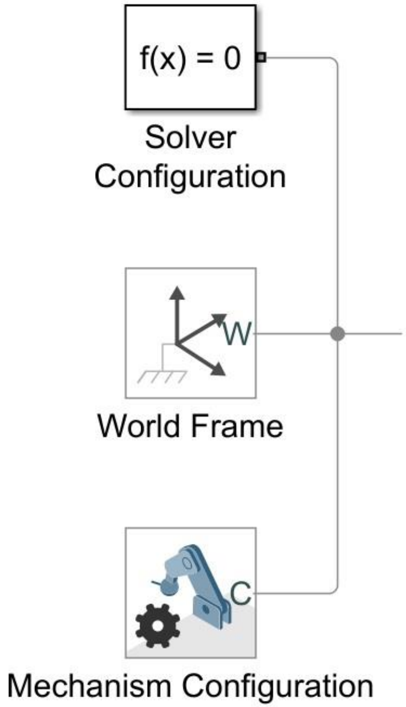
Components of a classical MBS model:

- **Solids** with a defined mass, inertia, center of gravity, …
- **Joints** to constrain relative motion
- **Coordinate Frames** for positions and orientations



Multibody Simulation using Simscape Multibody – Preparing the Model

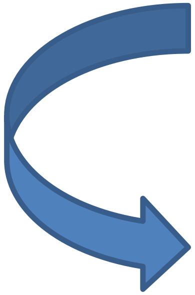
- Any Simscape Multibody model requires the following blocks:
  - **Solver Configuration**
    One block per physical network is needed.
    Simulink Library – Simscape - Utilities
  - **World Frame**
    Fixed reference frame for the mechanism
    Simulink Library – Simscape –Multibody – Frames and Transforms
  - **Mechanism Configuration**
    Mainly for setting direction and units of gravity
    Simulink Library – Simscape – Simscape Multibody -Utilities

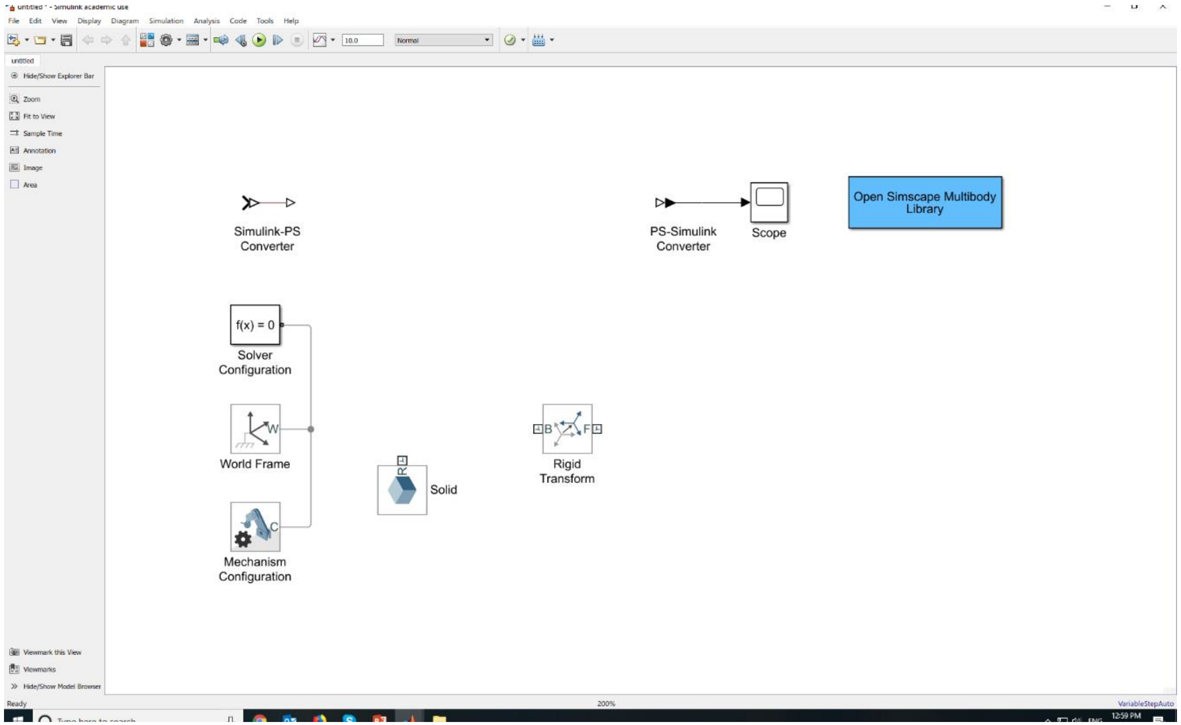


Multibody Simulation using Simscape Multibody – Preparing the Model

- Or use the smnew command to open a **prepared Simscape Multibody model**:

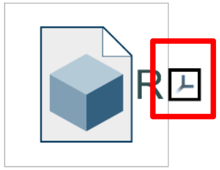
```
>> smnew
```



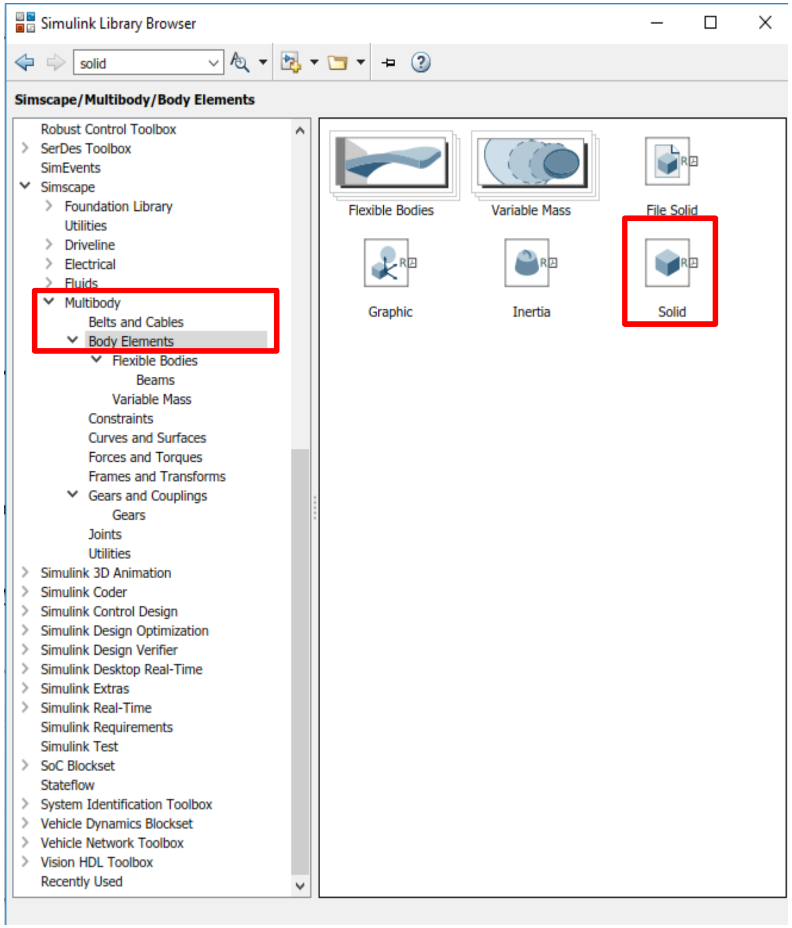


Multibody Simulation using Simscape Multibody – Defining Solids

- *Solid* blocks represent **rigid bodies** with a specific mass, inertia and geometry in a multibody simulation.
- Find the *Solid* block:
  Simscape > Multibody > Body Elements
- Drag and drop a *Solid* block for each body in your mechanical system to the Simulink diagram.
- Each *Solid block contains one coordinate frame*:



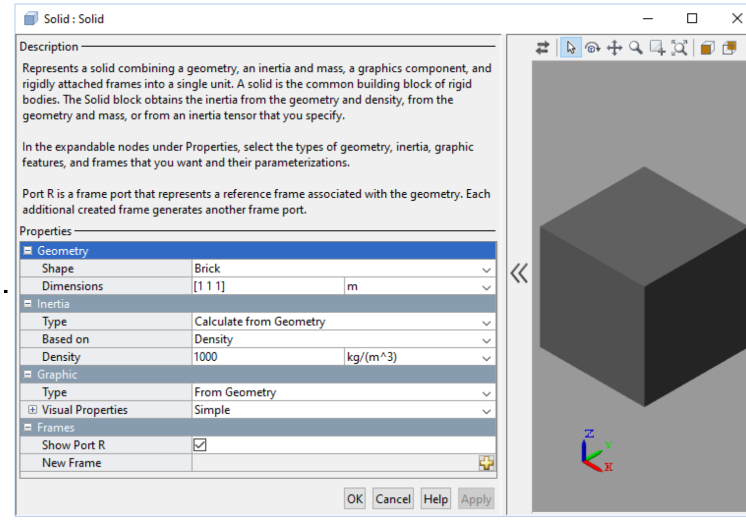
Solid

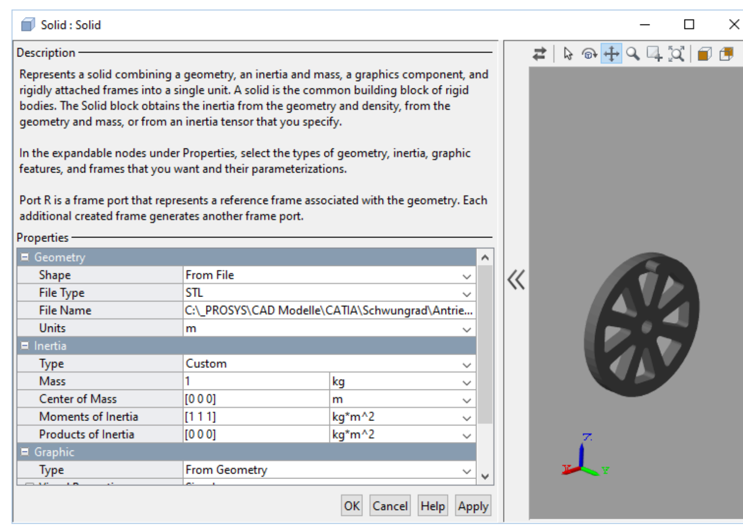


Multibody Simulation using SimMechanics – Defining Solids

There are various ways to define solids:

- Geometry:
  - Predefined Shapes:
    - Simple geometries using predefined shapes (Brick, Cylinder, Sphere, …).
    - Only parameters regarding dimensions must be entered.
    - Advantage: Inertia can be calculated from geometry.
  - From File:
    - Shapes can be easily defined using STL or STEP files.
    - Advantage: Very simple import of complex shapes.
- Inertia:
  - Calculated from Geometry:
    - Only available if a predefined Geometry Shape is used.
    - Inertia is calculated automatically based on a given density.
  - Point Mass:
    - Entered mass is positioned in the part's origin.
  - Custom:
    - Besides the mass itself, information about the CG or inertia tensor is required.





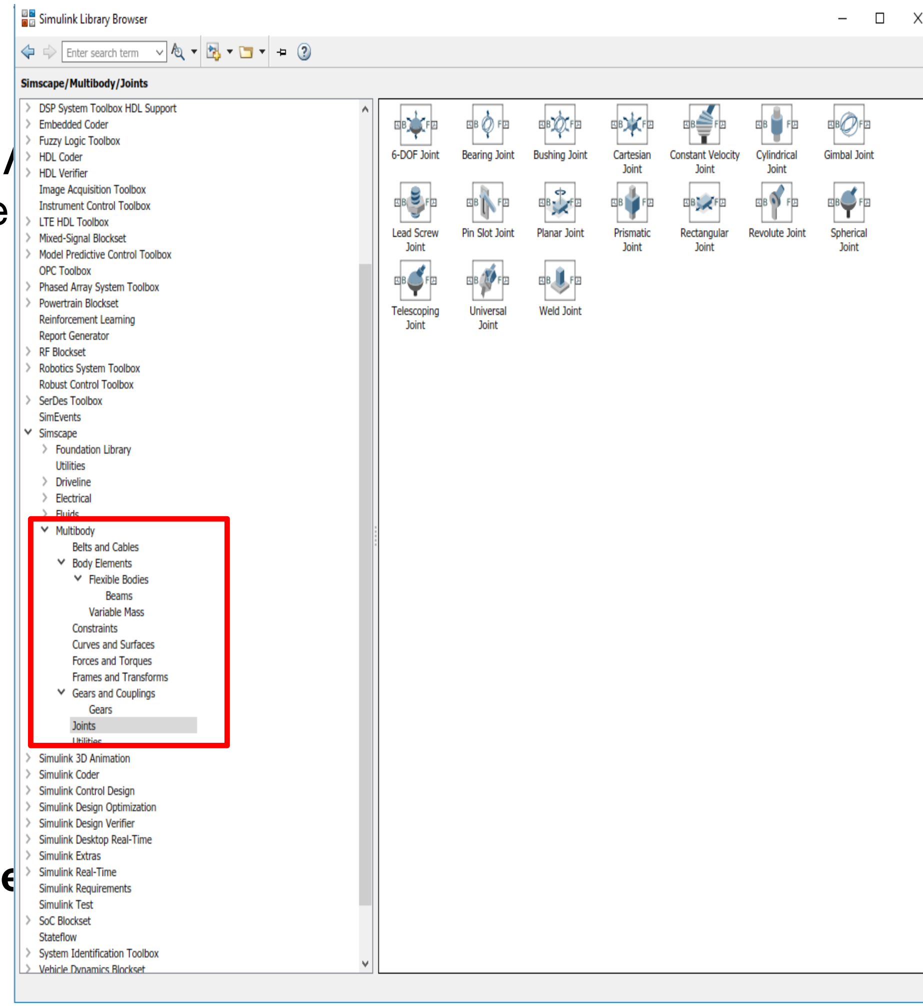
Multibody Simulation using Simscape Multibody – Defining Joints

- *Joint* blocks are used to connect solids, respectively their coordinate frames to each other. They enable **translational and / or rotational degrees of freedom** to these connections.

- Joints represent **frictionless** connections!

- Find joints:
  Simscape > Multibody >Joints
  Drag and drop a *Joint* block for each connection in your mechanical system to the Simulink diagram.

- Each *Joint* block contains *two coordinate frames*. **The z-axis plays an important role**

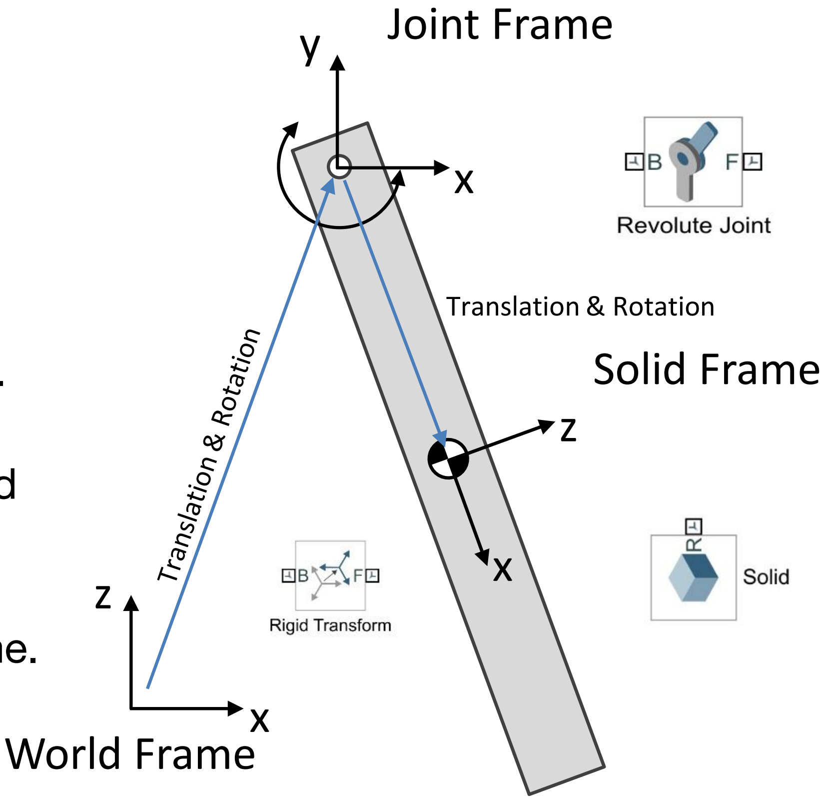


Multibody Simulation using Simscape Multibody – Defining Coordinate Frames

- Coordinate frames can be copied, moved and rotated using the *Rigid Transform* block. This is required for positioning joints and solids.
- Find *Rigid Transform* blocks:
  Simscape > Multibody > Frames and Transforms

Example: Pendulum

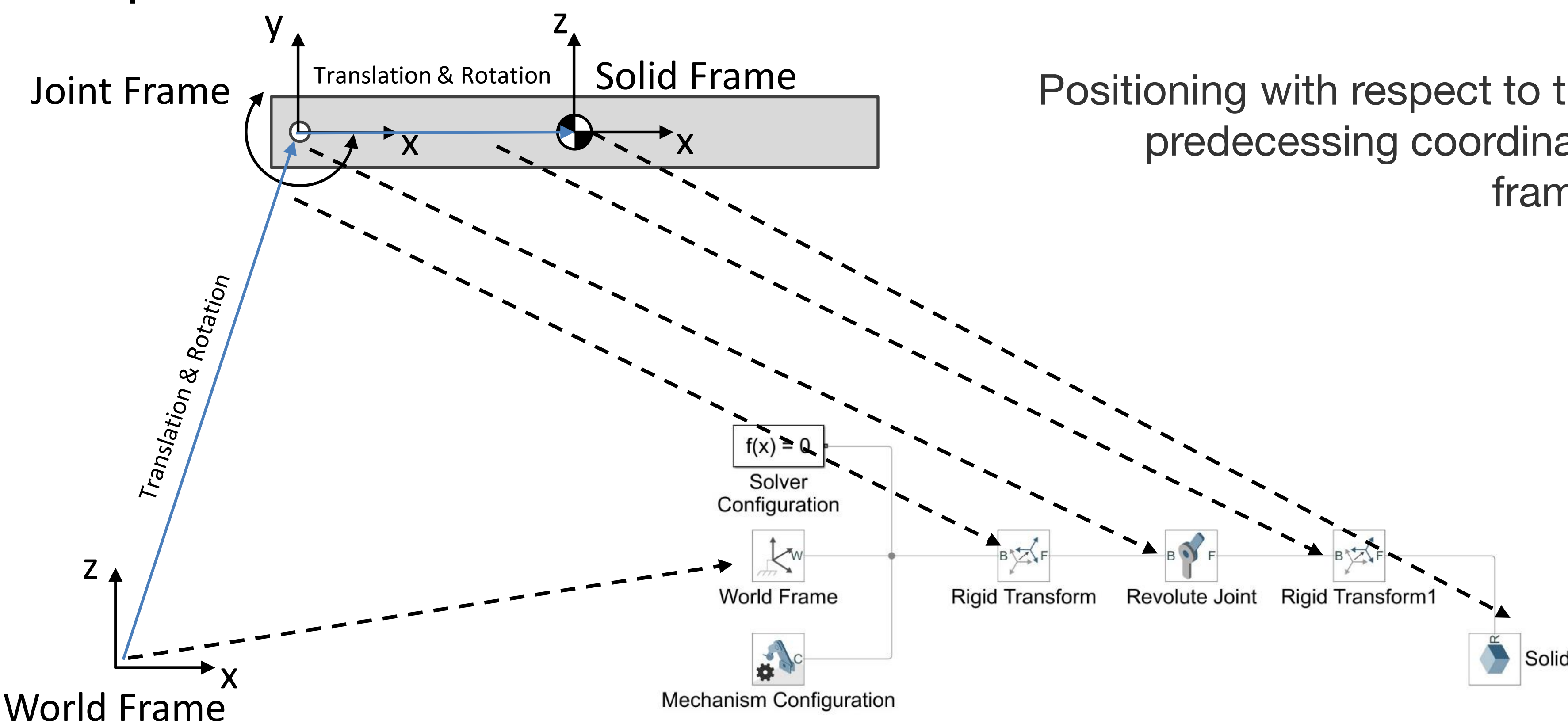
1. World frame is copied and translated.
2. A revolute joint creates a rotational degree of freedom by creating another coordinate frame.
3. This coordinate frame is copied, translated and rotated.
4. A solid block is created at this coordinate frame.



Multibody Simulation using Simscape Multibody – Assembling Mechanisms

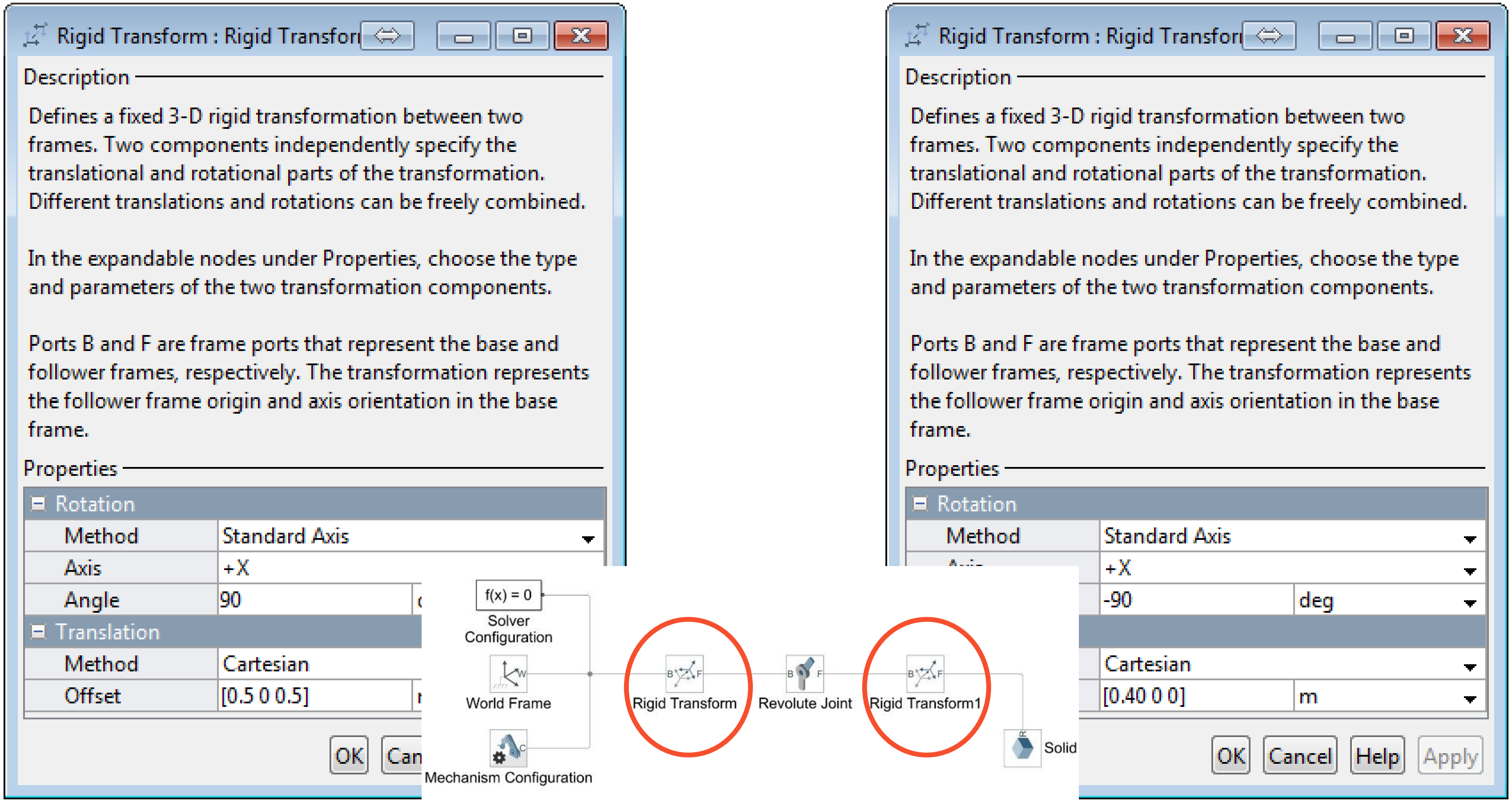
Assembling a mechanism means primarily to position all components to each other and link certain solids via joints.

Example: Pendulum

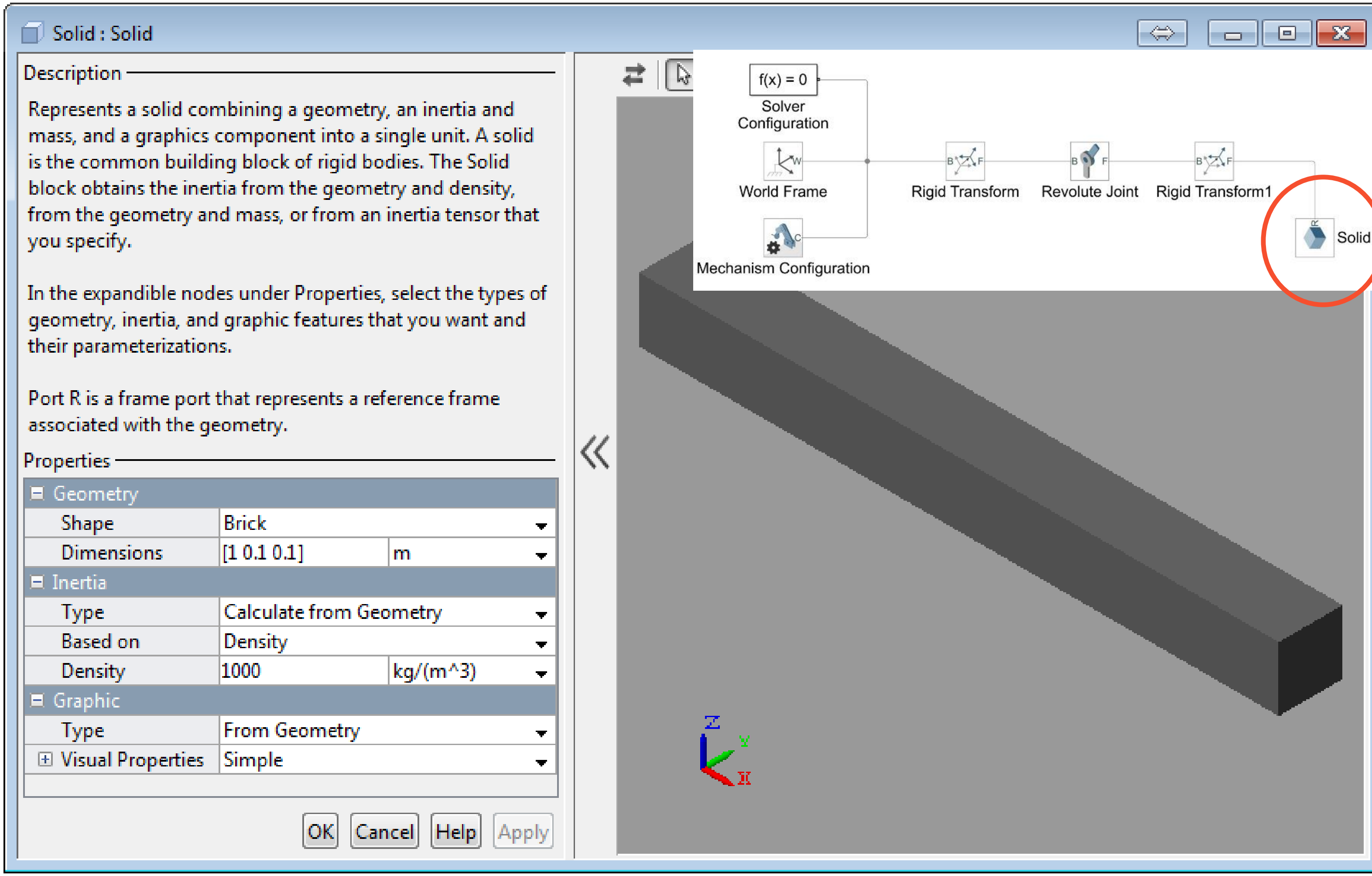


Positioning with respect to the predecessing coordinate frame.

Multibody Simulation using Simscape Multibody – Assembling Mechanisms

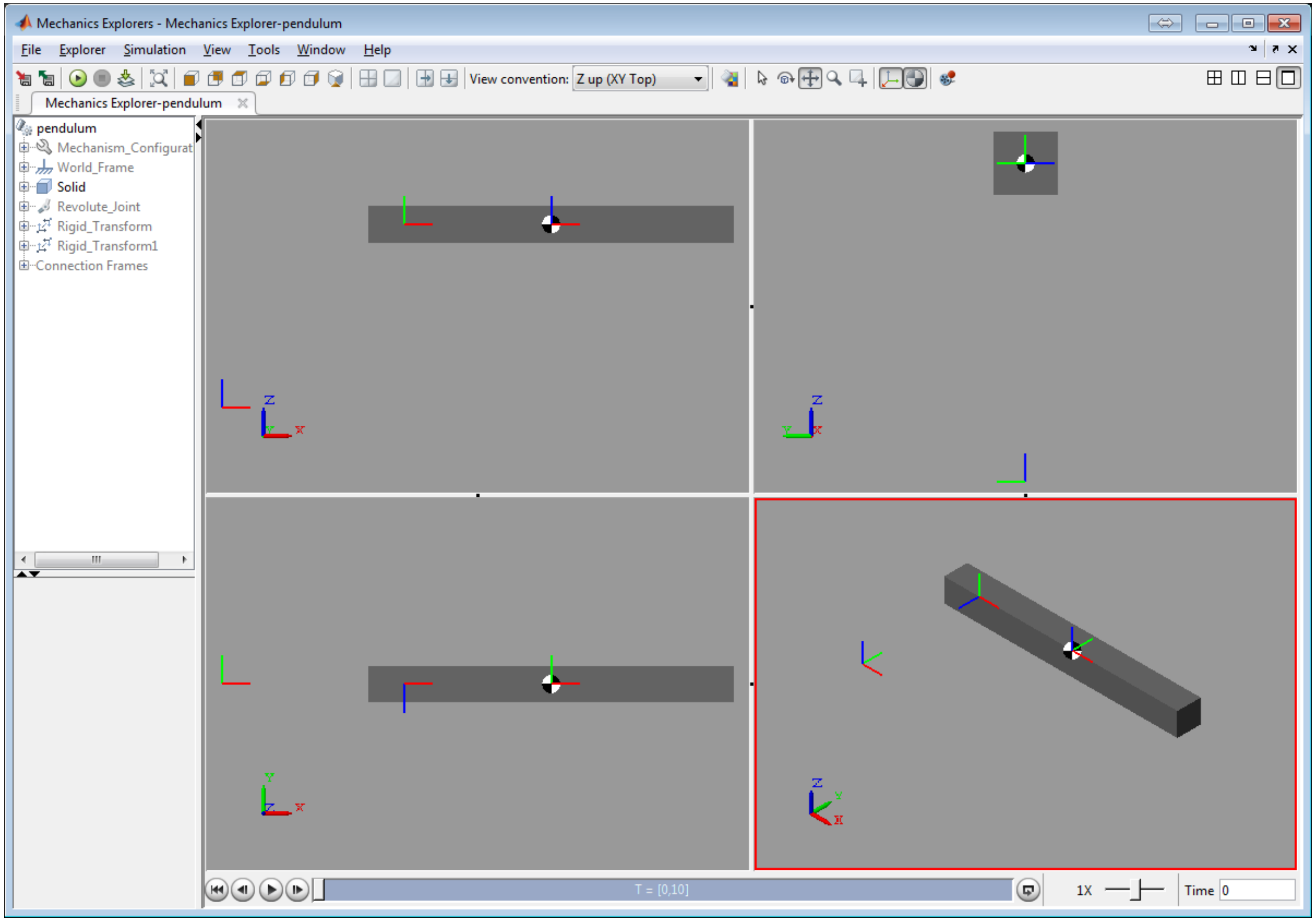


Multibody Simulation using Simscape Multibody – Assembling Mechanisms



Multibody Simulation using Simscape Multibody – Visualization

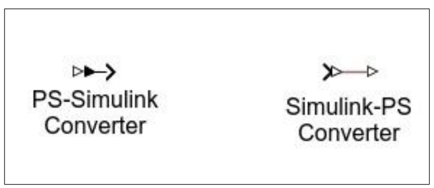
After updating the diagram (CTRL+D) or running the simulation, the mechanism is visualized via the *Mechanics Explorer*.



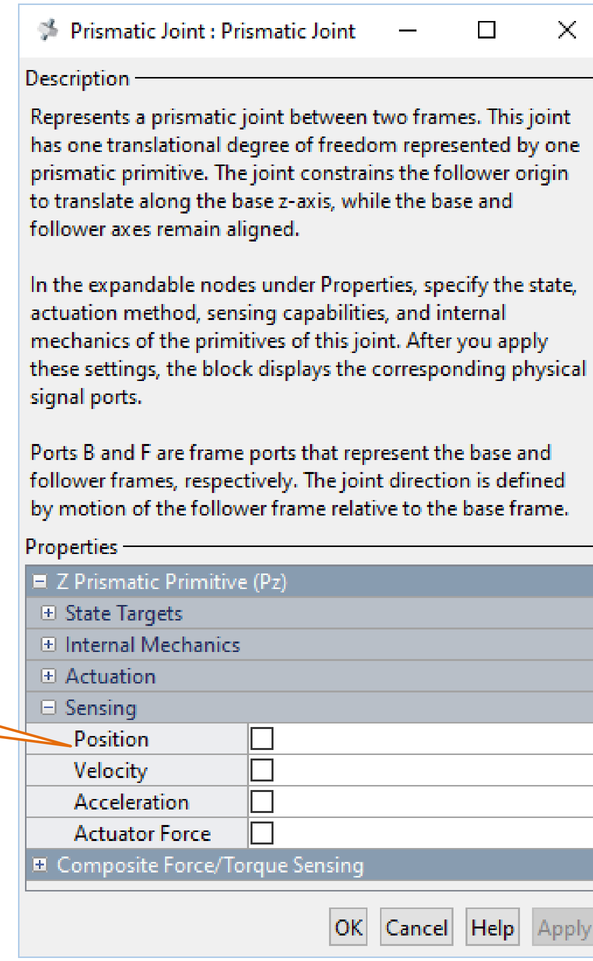
3. Configure Joint Settings

Configure Joint Settings – Sensing Joint Quantities

- Joints allow to:
  - measure physical values
  - actuate their degrees of freedom
- Input values as well as output values, such as velocities or forces, are **physical signals**.
- Converter blocks the PS-Simulink Converter and the Simulink-PS Converter are used to convert signals to the correct format: *Simscape > Utilities*



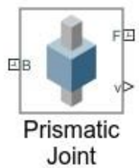
Select variables to measure.



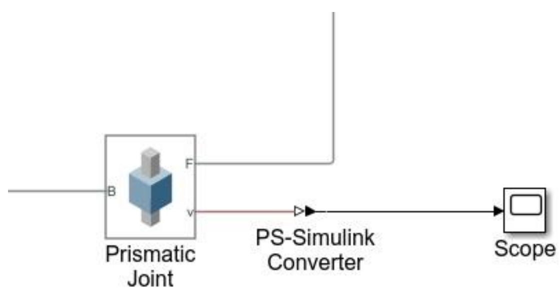
- Possible measurement variables (referred to dof): Position, Velocity, Acceleration, Actuator Force

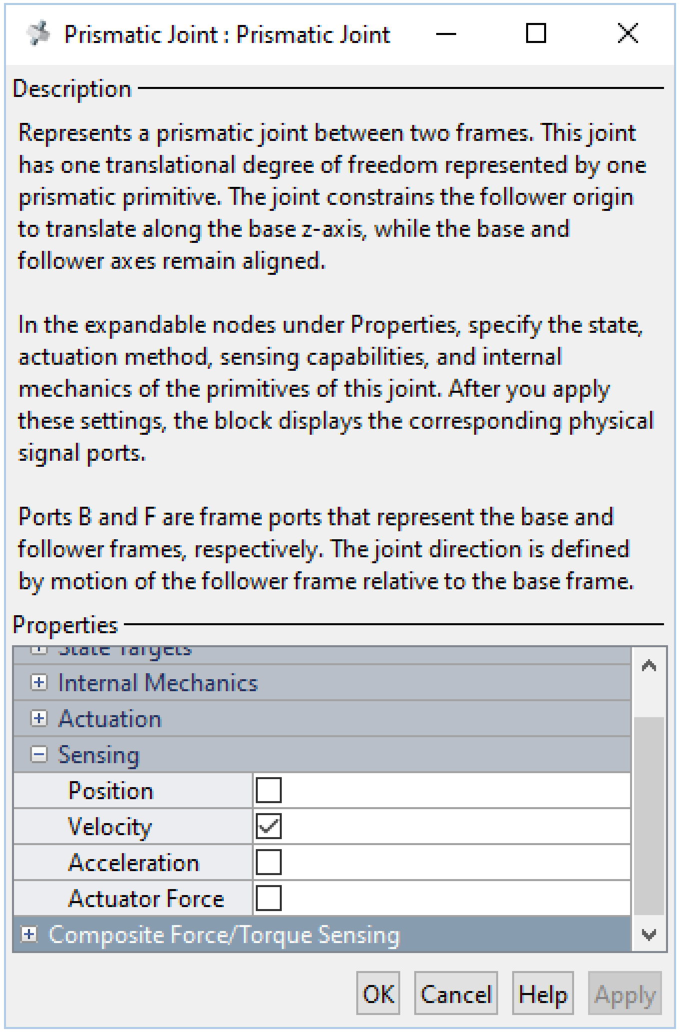
Configure Joint Settings – Sensing Joint Quantities

- An additional port (PS) appears for every chosen measurement variable:



- Use *PS-Simulink Converter* blocks to process measurements with e.g. *Simulink* blocks:

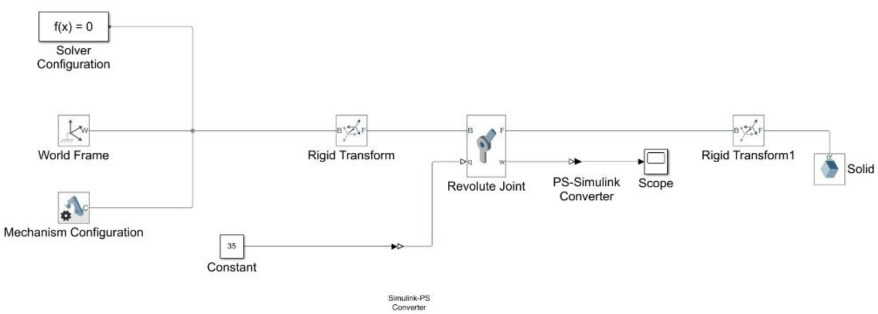


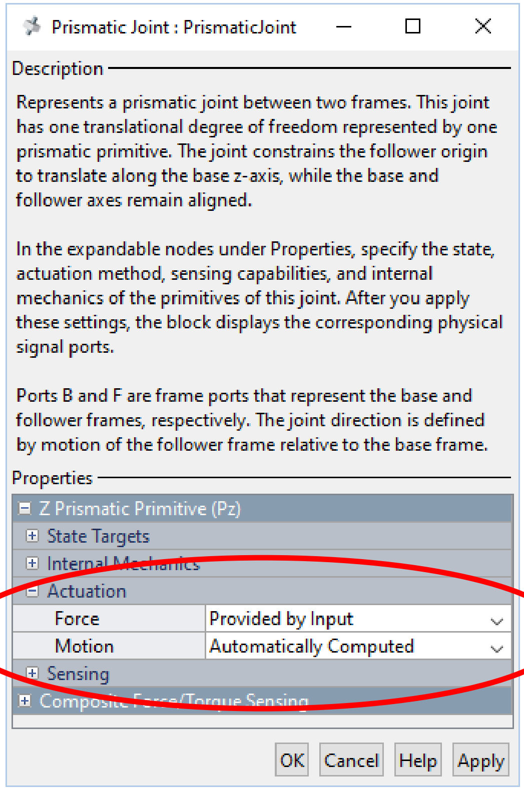


Configure Joint Settings – Actuating Joints

- Acuating modes:
  - Force / Torque driven: A force / torque is given, corresponding motion is calculated
  - Motion driven: A motion signal is given, corresponding force / torque is calculated

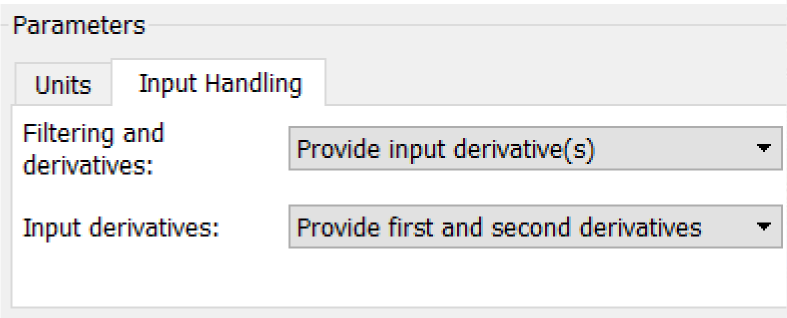
- Force / Torque driven actuation:
  - Input: Force / torque
  - Automatically computed: Motion
  - Example:

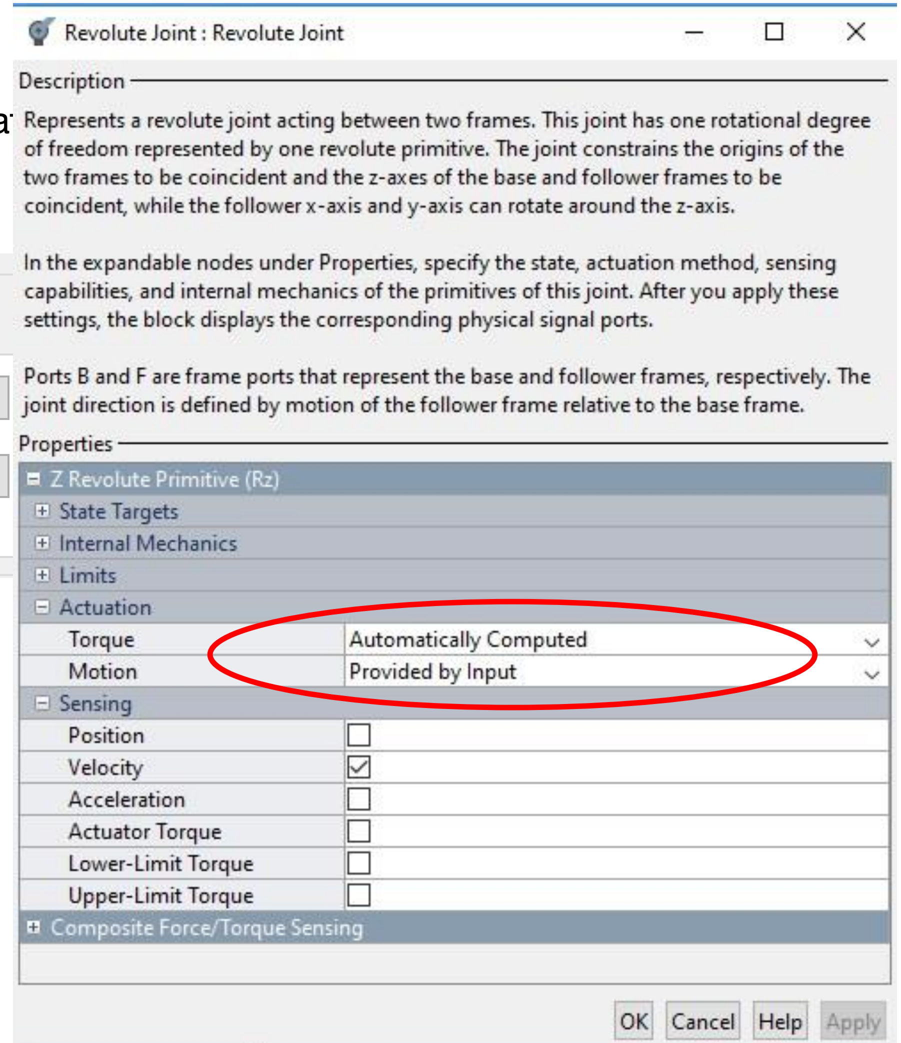




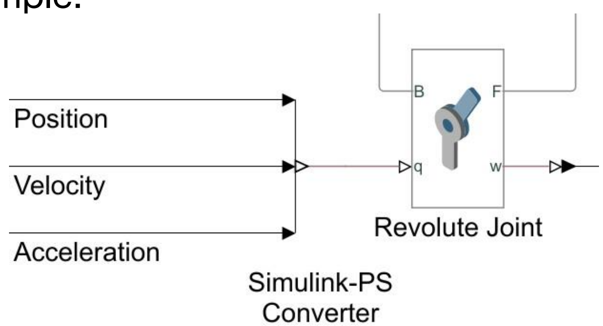
Configure Joint Settings – Actuating Joints

- Motion driven actuation:
  - Input: Motion signal (position, velocity, accelera
  - Automatically computed: Force / torque
  - S-PS block needs specific setting:

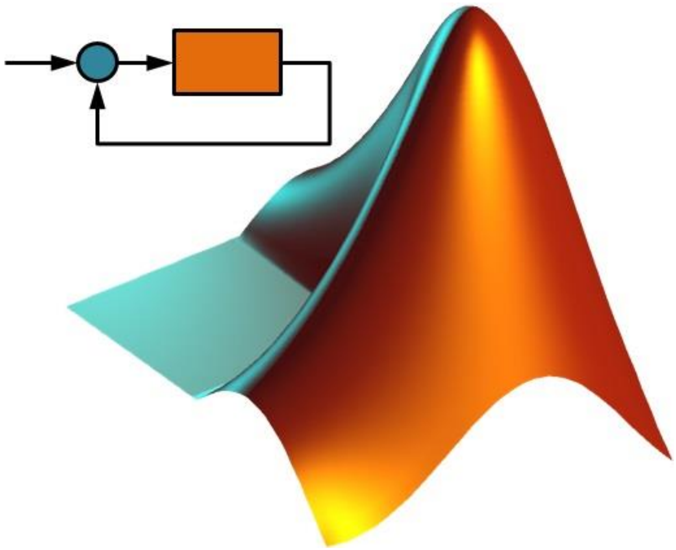




- Example:

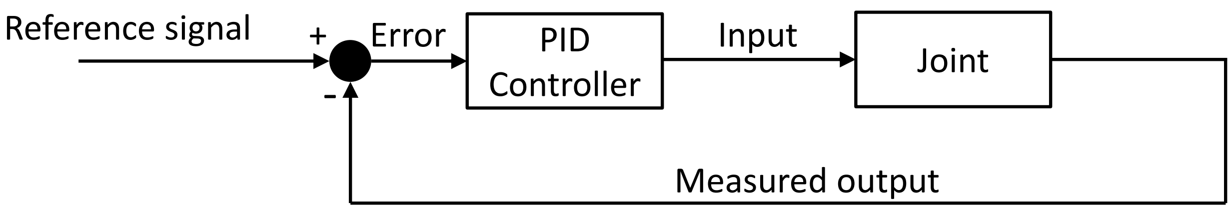


4. Combining Simscape Multibody and Simulink Models



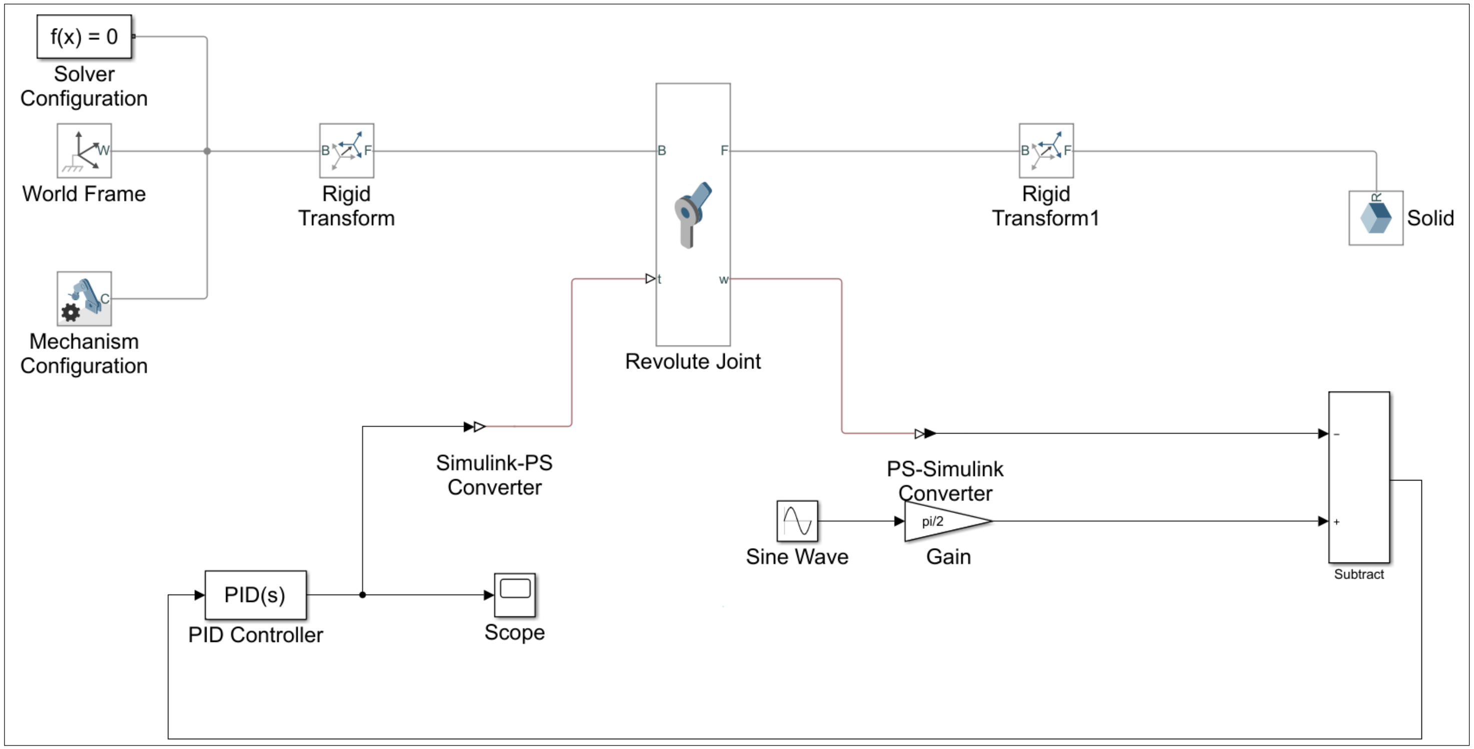
Combining Simscape Multibody and Simulink Models

- Interface to Simulink: *PS-Simulink* and *Simulink-PS* blocks
- Use **toolboxes that suit your problem**, e.g. Stateflow for logics, Simulink for controllers etc.
- Example: Use PID Controller to actuate joint



Combining Simscape Multibody and Simulink Models

Example: *PID Controller* block used to actuate joint



5. CAD Import

Simscape Multibody Interfaces

Advantages of Interfaces:

- Fast translation of even complex CAD models to Simscape Multibody models
- Reduction of error sources
- Intercommunication of CAD software and Simscape Multibody

Simscape Multibody Link

- MathWorks offers *Simscape Multibody Link* to export CAD data to Simscape Multibody
- Supported CAD tools: SolidWorks, PTC Creo, Autodesk Inventor
- Steps:
  - Creation of a xml and stl files
  - Generate a Simscape Multibody model from a xml import file using the *smimport* command

```
>> [H,dataFileName] = smimport(xmlFileName)
```

- Missing functionality:
  - Interface is not bidirectional
  - No support for Dassault Systèmes CATIA
  - No direct connection - Indirect way over xml file

TUM-FSD Interface

- TUM-FSD developed an interface (ProSys) between CAD tools and Simscape Multibody
- Advantages:
  - Bidirectionality: MATLAB can change CAD Parameters
  - Apply MATLAB methods on CAD model (optimization algorithms, sensitivity analysis, …)
  - Direct communication (no route over external file)
  - Support of CATIA V5