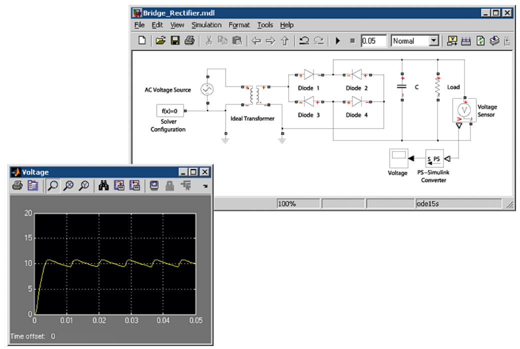
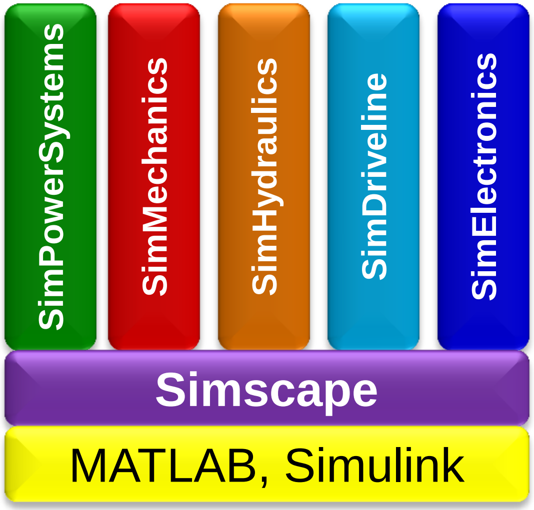
MathWorks Technology Session at GE

Physical System Modeling with Simulink / Simscape





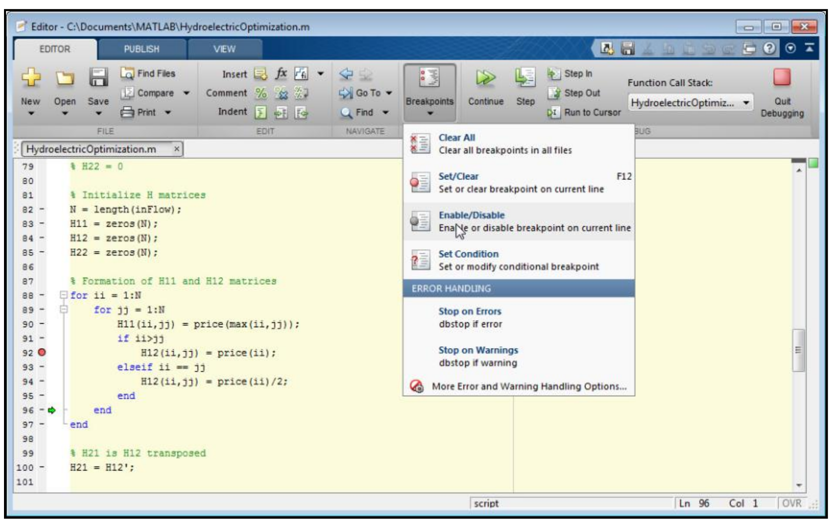
September 13, 2012

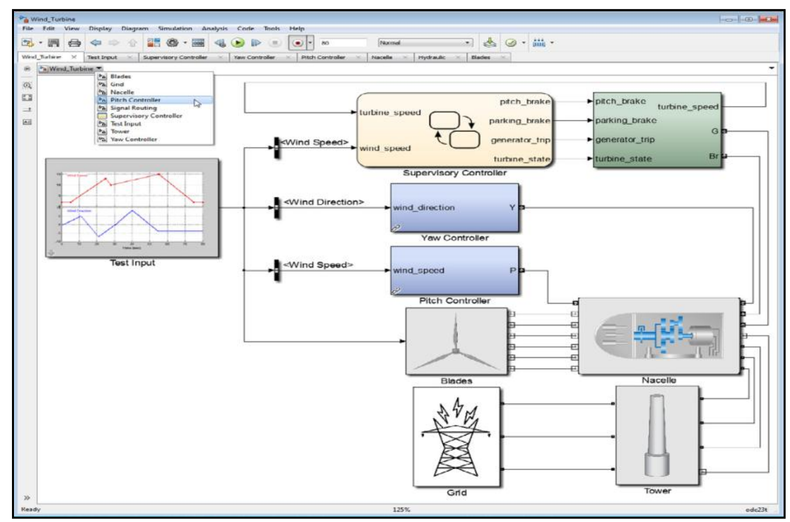
Wit Nursilo
Application Engineer

Tom Priestley
Account Manager

Release R2012b Now Available

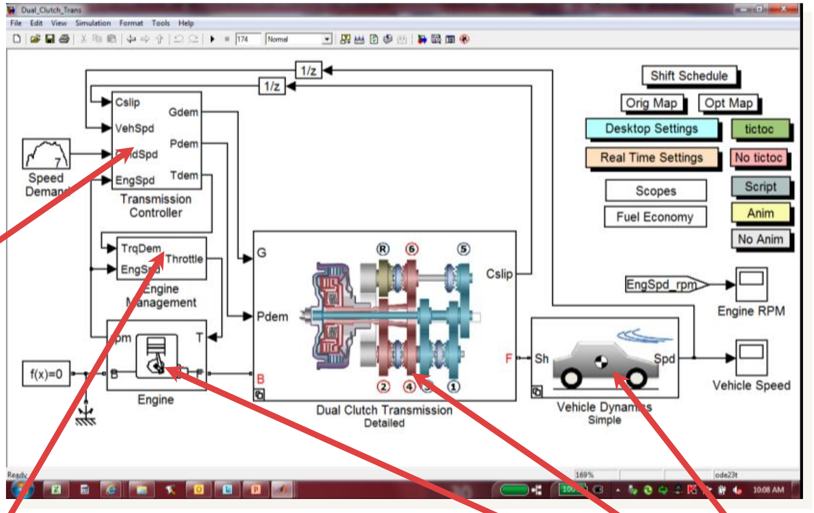
- Redesigned User Interfaces
  - **MATLAB:** Context-sensitive toolstrip
  - **Simulink:** Integrated model editor and debugger





Simulink Extensions

Simulink



Stateflow

Logic and State Machine modeling

SimEvents

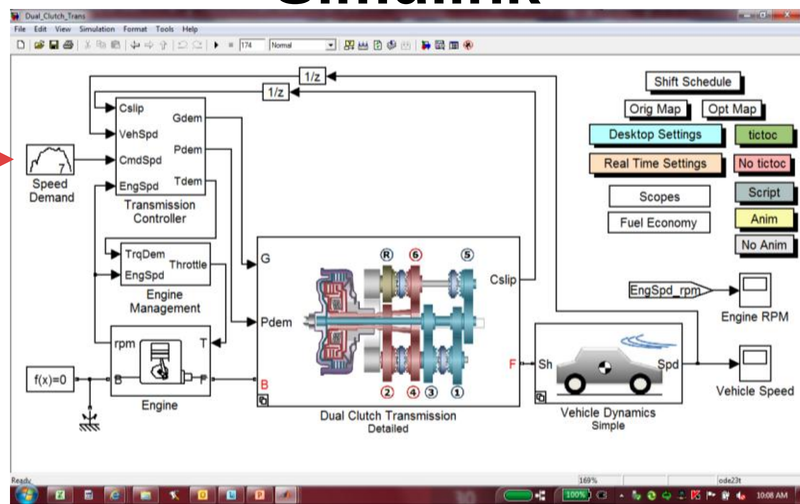
Discrete Event modeling

Simscape

Physical System modeling

Simulink Blocksets

Simulink



Aerospace Blockset

Gauges Blockset

Other

DSP System Tbx
Data Acquisition Tbx
Simulink Ctrl Design

SimEvents

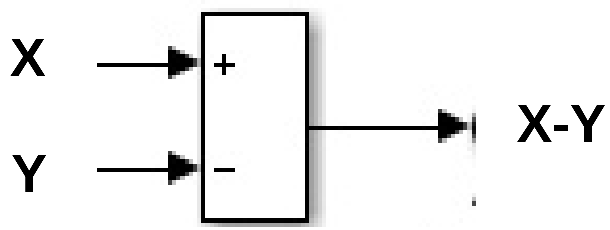
Simscape

SimMechanics | **SimDriveline** | **SimHydraulics**

SimRF | **SimElectronics** | **SimPowerSystems**

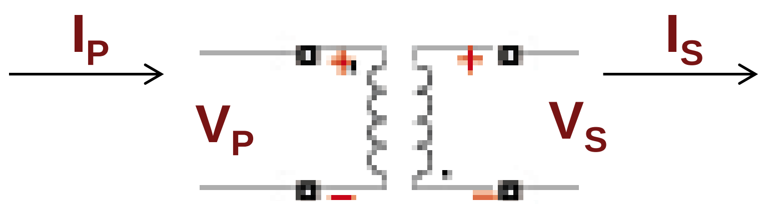
How Does Simscape Work?

Simulink:



Iterative Solution

Simscape:



$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

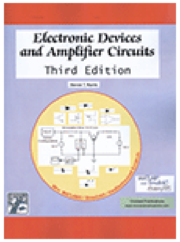
Simultaneous Solution

Tools for Further Investigation

- **Training**
  - Physical Modeling of Multidomain Systems with Simscape (1 day)
  - Physical Modeling of Multidomain Systems with SimMechanics (1 day)
  - Q4 public classes in France, Germany, Spain, Japan, US.
  - www.mathworks.com/services/training/index.html

- **Tutorials**
  - Physical modeling examples: http://www.mathworks.com/matlabcentral/fileexchange/17238-physical-modeling-tutorial-exercises
  - More at www.matlabcentral.com

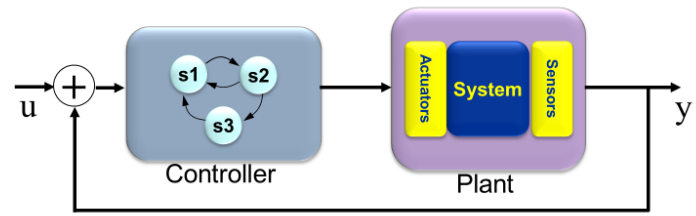
- **Books**
  - www.mathworks.com/support/books/index.html



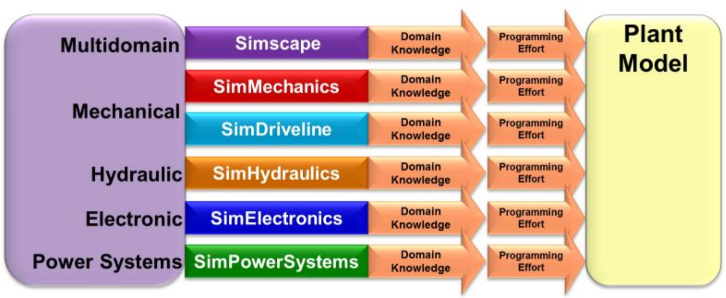
ISBN: 978-1-934404-25-6

Key Takeaways

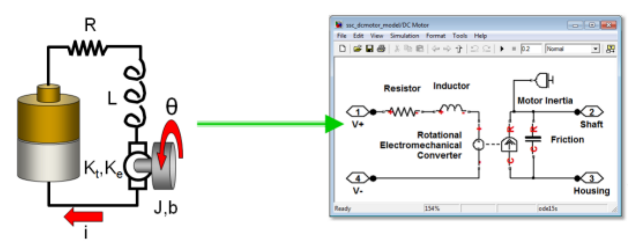
- **Optimize system performance**
  - Develop in a single environment



- **Multi-domain Physical System**



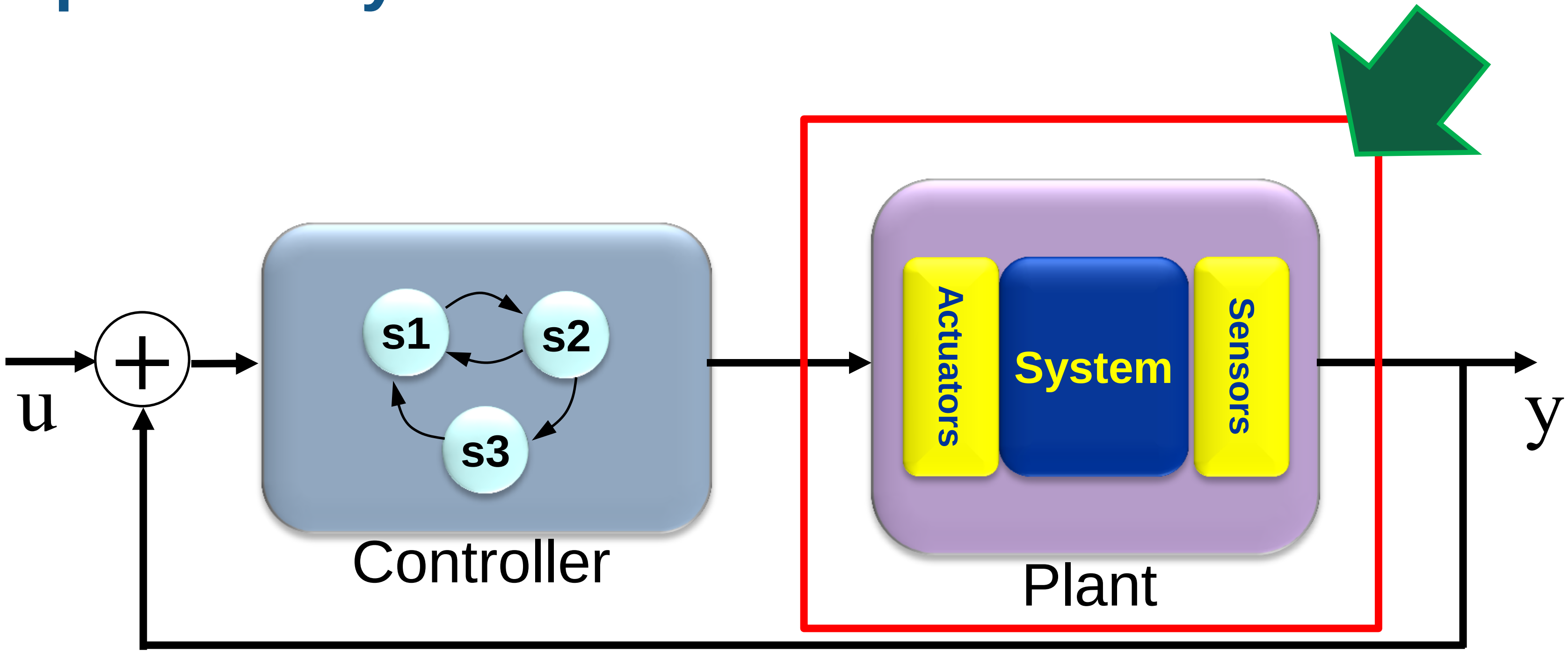
- **Eases process of modeling physical systems**



Agenda

- **Motivation**
- **Physical Modeling Platform for Multi-domain System**
  - Simscape Introduction
  - Simscape Language Introduction
- **Multi-domain Application Example**
- **Physical Modeling Tools**
  - SimMechanics, SimDriveline, SimElectronics, SimHydraulics, SimPowerSystems
- **Q&A**

Optimize System-Level Performance



- Simulating plant and controller **in one environment**
- **Optimize system-level performance**.

Modeling Physical Systems in the Simulink Environment

Modeling Approaches

First Principles Modeling ⟷ Data-Driven Modeling

Code
(MATLAB)

Block Diagram
(Simulink)

Modeling Language
(Simscape language)

Symbolic Methods
(Symbolic Math Toolbox)

Physical Networks
(Simscape and other Physical Modeling products)

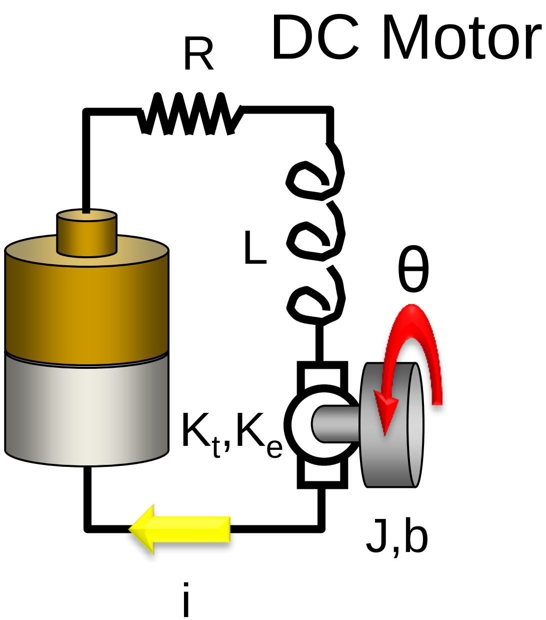
Parameter Optimization
(Simulink Design Optimization)

Neural Networks
(Neural Network Toolbox)

System Identification
(System Identification Toolbox)

Statistical Methods
(Model Based Calibration Toolbox)

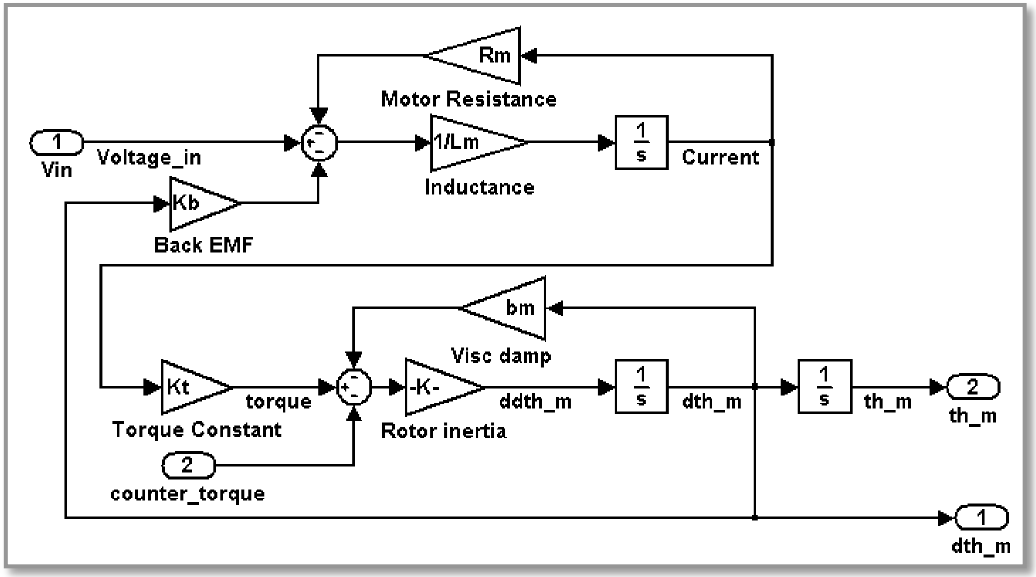
Electrical Systems in Equations



$$v = K_e\omega + i_m R_{wind} + L_{wind}\frac{di_m}{dt}$$

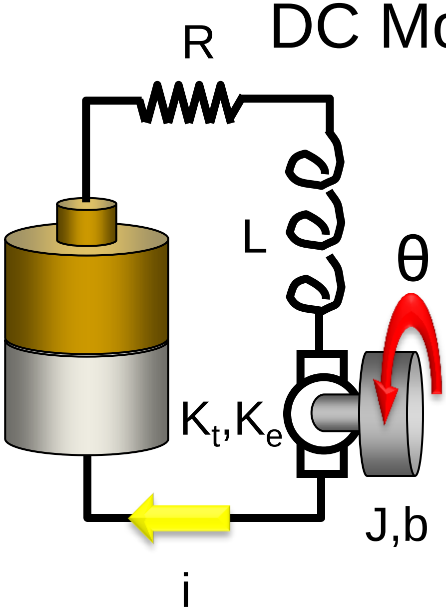
$$T = K_t i_m - D\omega - J\frac{d\omega}{dt}$$

Simulink Model



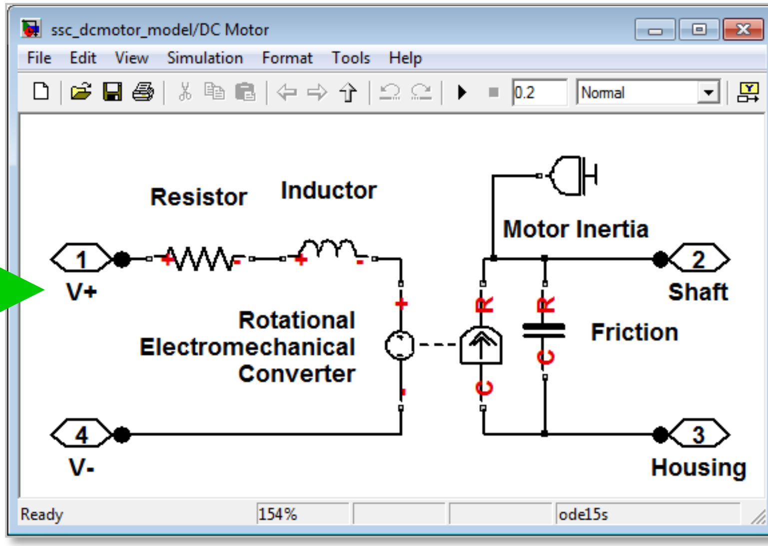
Electrical Systems in Simscape

DC Motor



$$v = K_e \omega + i_m R_{wind} + L_{wind} \frac{di_m}{dt}$$

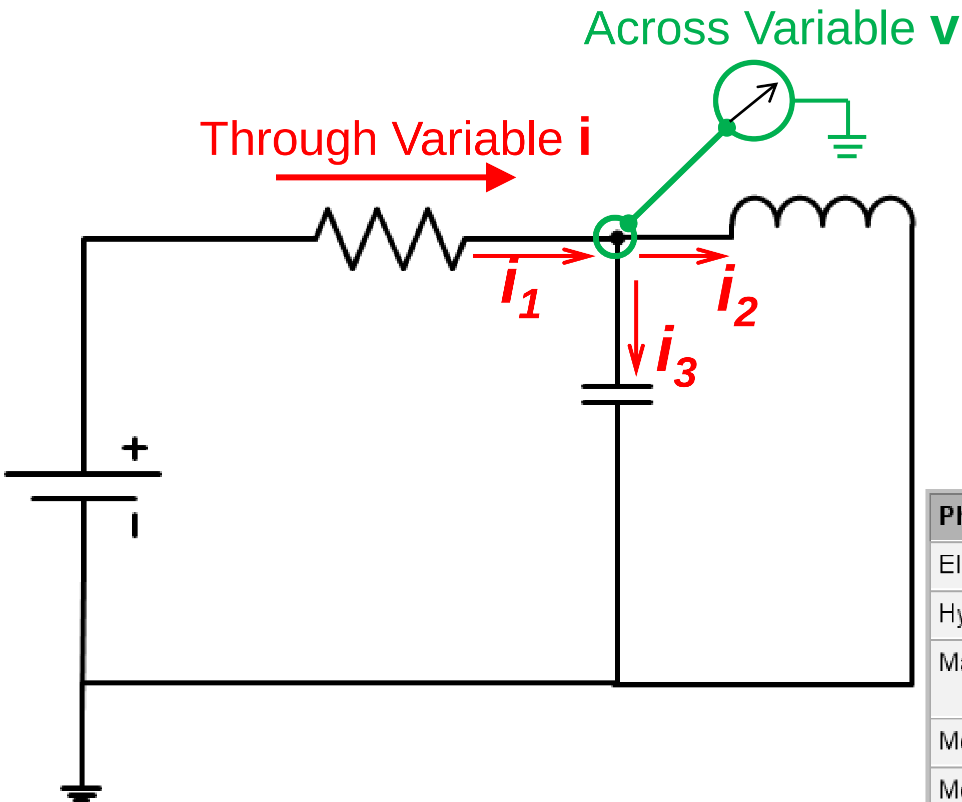
$$T = K_t i_m - D\omega - J \frac{d\omega}{dt}$$



- Simscape model advantages
  - Easier to read than equations
  - Quicker to create
  - More intuitive – easier to explain to other engineers

How Does Simscape Work?

- Network Approach



Power = Through x Across

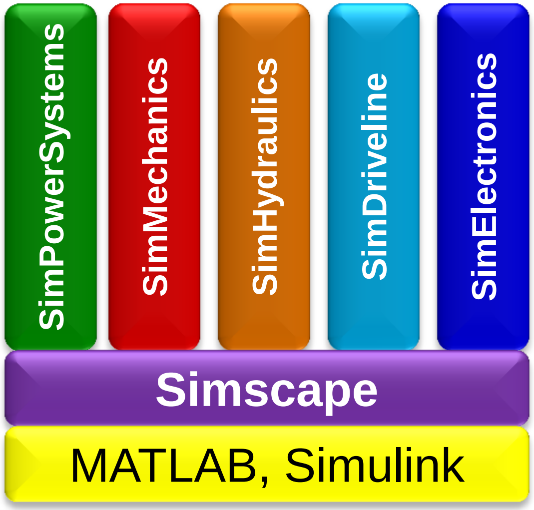
Kirchhoff's Law:

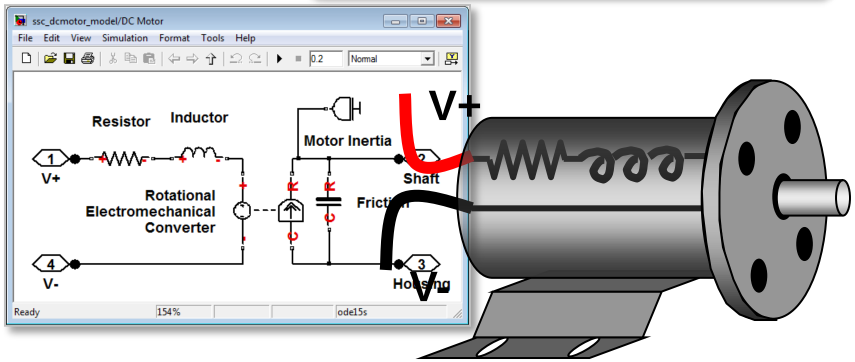
$$i_1 = i_2 + i_3$$

Physical Domain	Across Variable	Through Variable
Electrical	Voltage	Current
Hydraulic	Pressure	Flow rate
Magnetic	Magnetomotive force (mmf)	Flux
Mechanical rotational	Angular velocity	Torque
Mechanical translational	Translational velocity	Force
Pneumatic	Pressure and temperature	Mass flow rate and heat flow
Thermal	Temperature	Heat flow

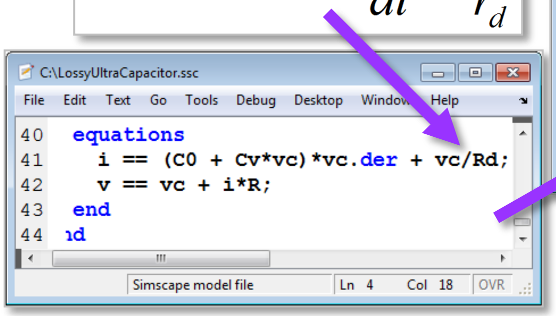
Introduction to Simscape

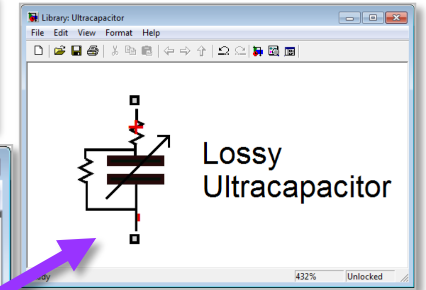
- Enables physical modeling (acausal) of multidomain physical systems
- Eases process of modeling physical systems
  - Build models that reflect structure of physical system
  - Leverage MATLAB to create reusable models





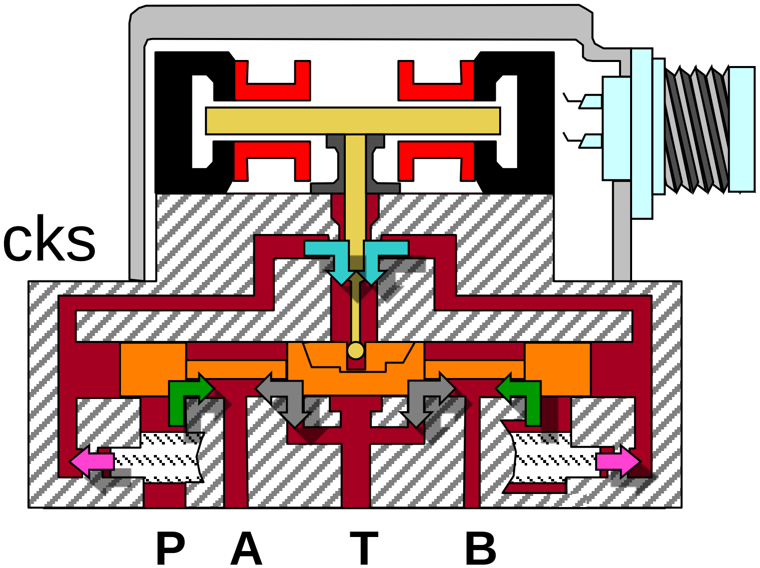
$$i = (C_0 + C_v v)\frac{dv}{dt} + \frac{v}{r_d}$$

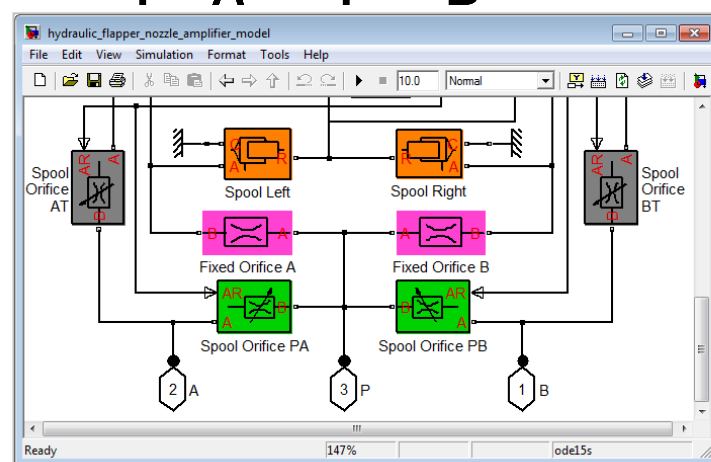




Simscape Key Features

- Foundation physical modeling blocks
  - Mechanical, electrical, hydraulic,…
- Simscape language for text-based authoring of components
- Units for signals and parameters (automatic conversion)
- Physical network solver designed for physical systems
- Simscape Editing Mode
  allow use of add-on products
  without purchasing add-on product license
- Convert to C code for deployment

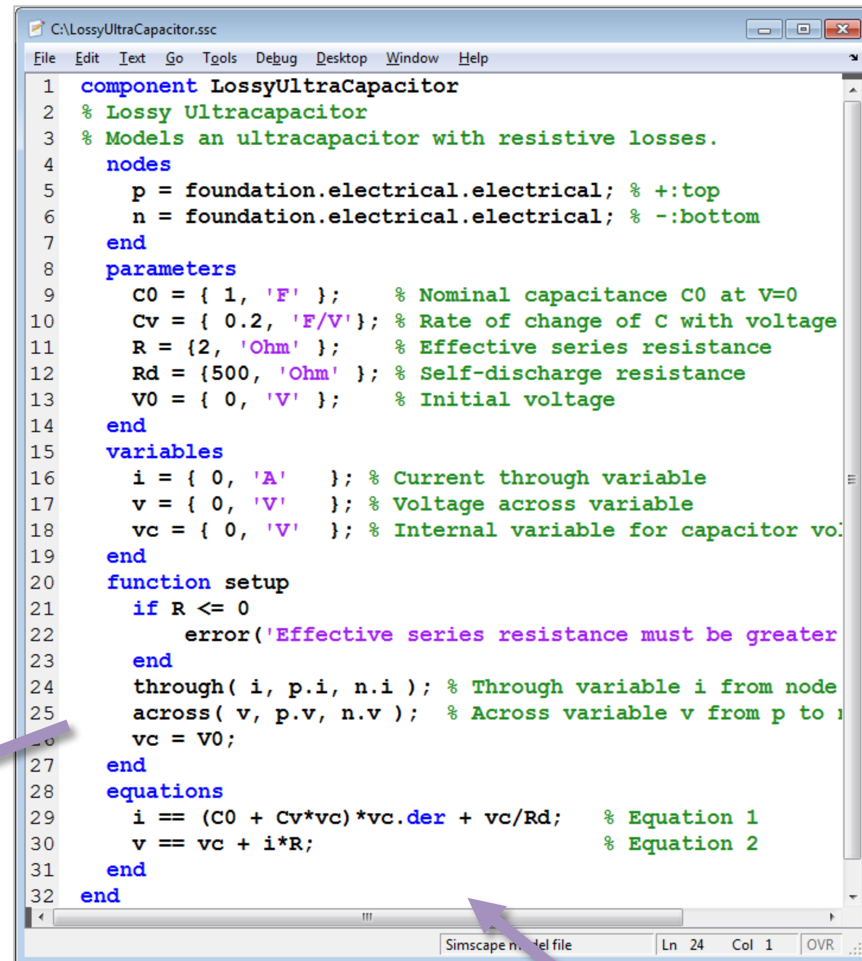


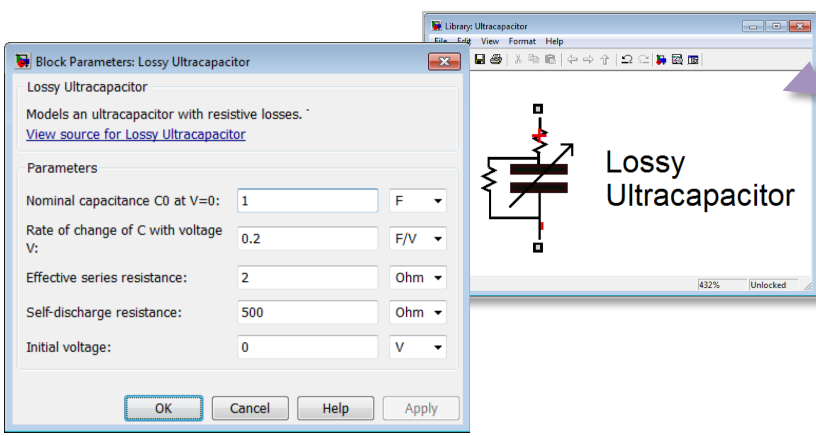


Simscape Example

Simscape Language For Modeling Custom Components

- MATLAB-based language, for text-based authoring of physical modeling domains, components, and libraries
  - Leverages MATLAB
  - Object-oriented for model reuse
  - Generate Simulink blocks
  - Save as binary to protect IP

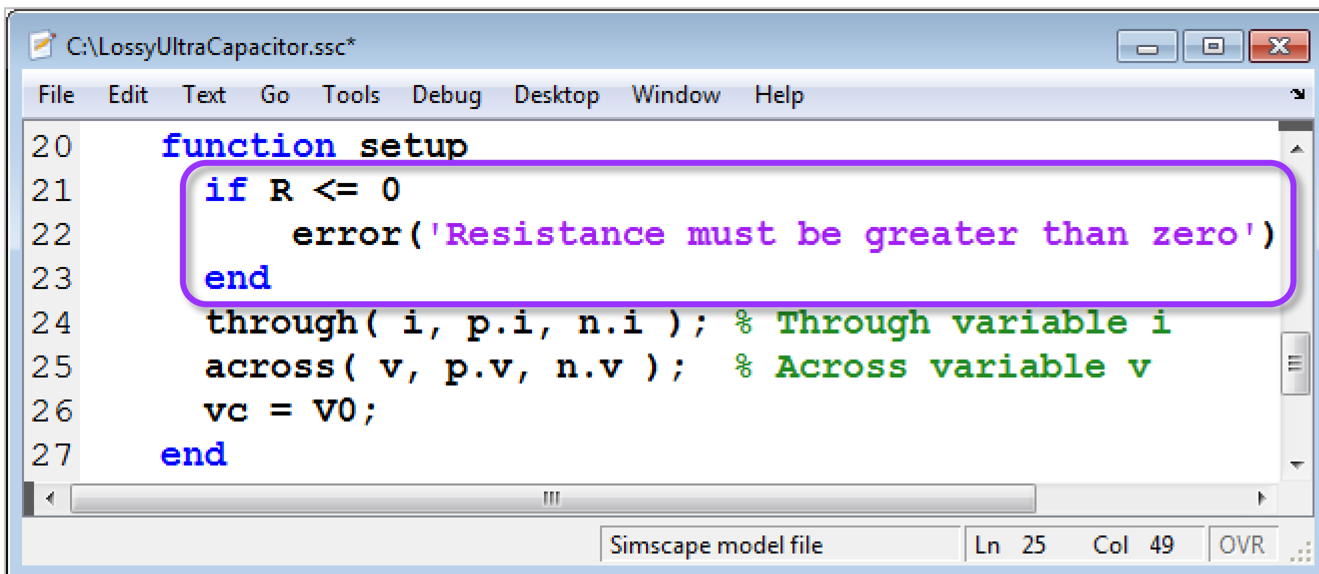




$$i = (C_0 + C_v v)\frac{dv}{dt} + \frac{v}{r_d}$$

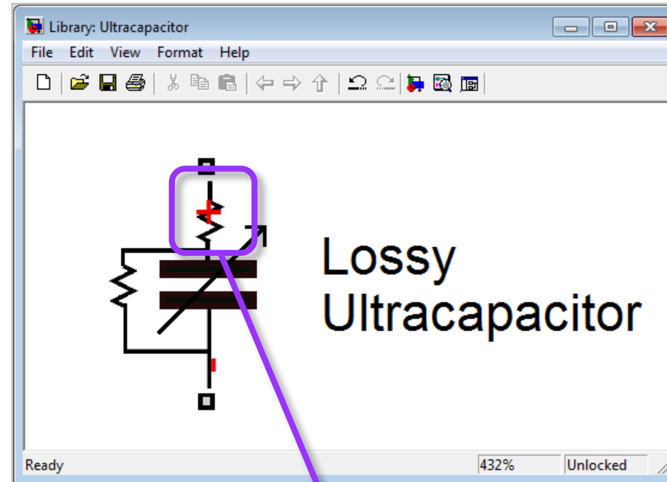
Simscape Language: Leverage MATLAB

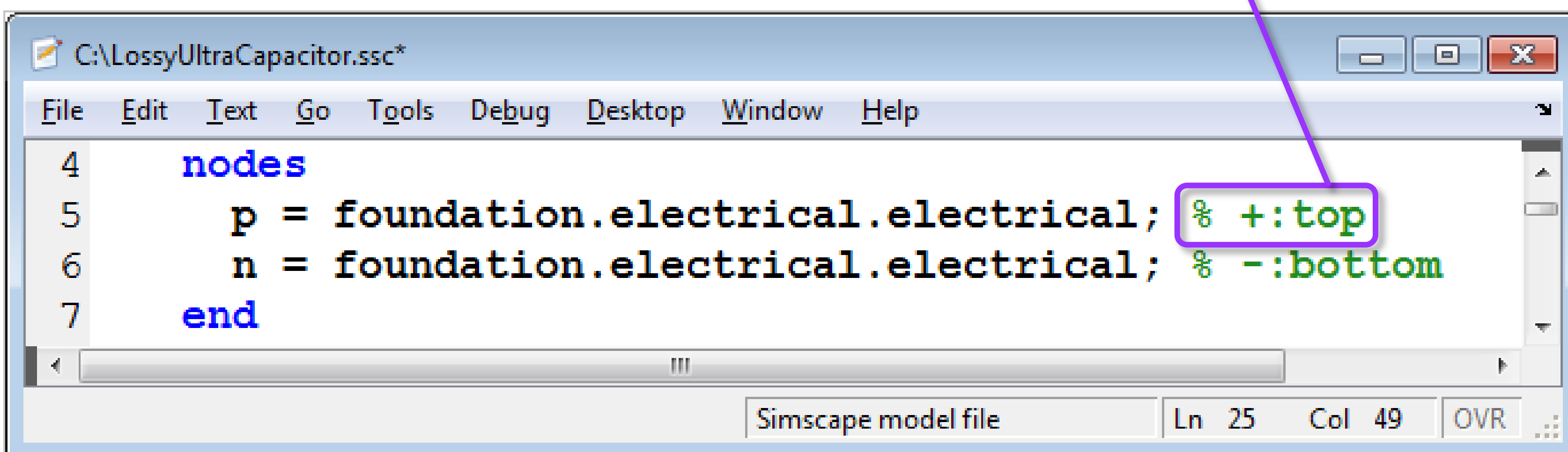
- Syntax closely follows MATLAB language
- Use MATLAB functions and expressions for typical physical modeling tasks like:
  - Analyze parameters
  - Perform preliminary computations
  - Initialize system variables



Simscape Language: Extend or Create Libraries

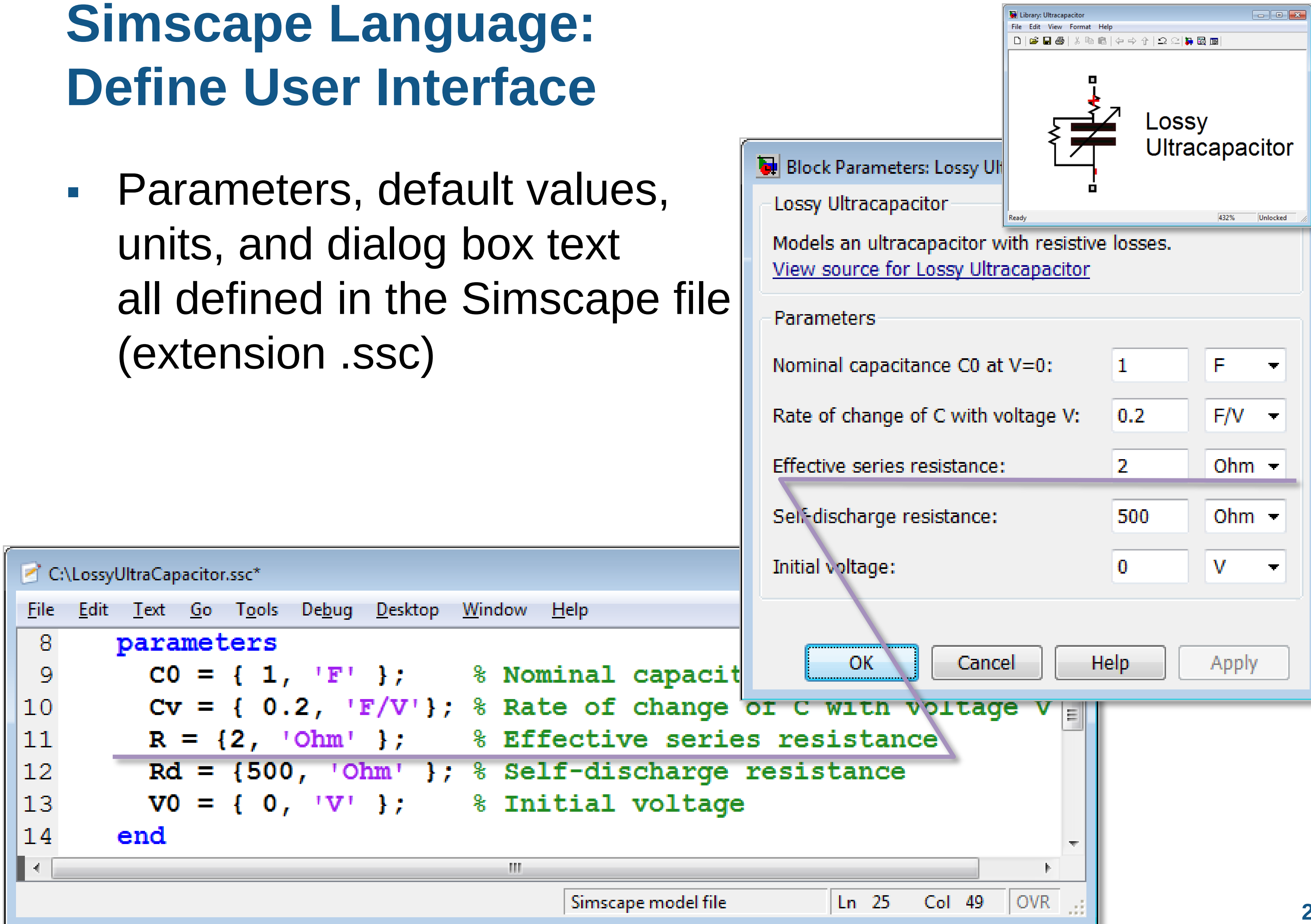
- Define the physical network ports for your Simscape block
  - Reuse existing physical domains to extend libraries
  - Define new physical domains





Simscape Language: Define User Interface

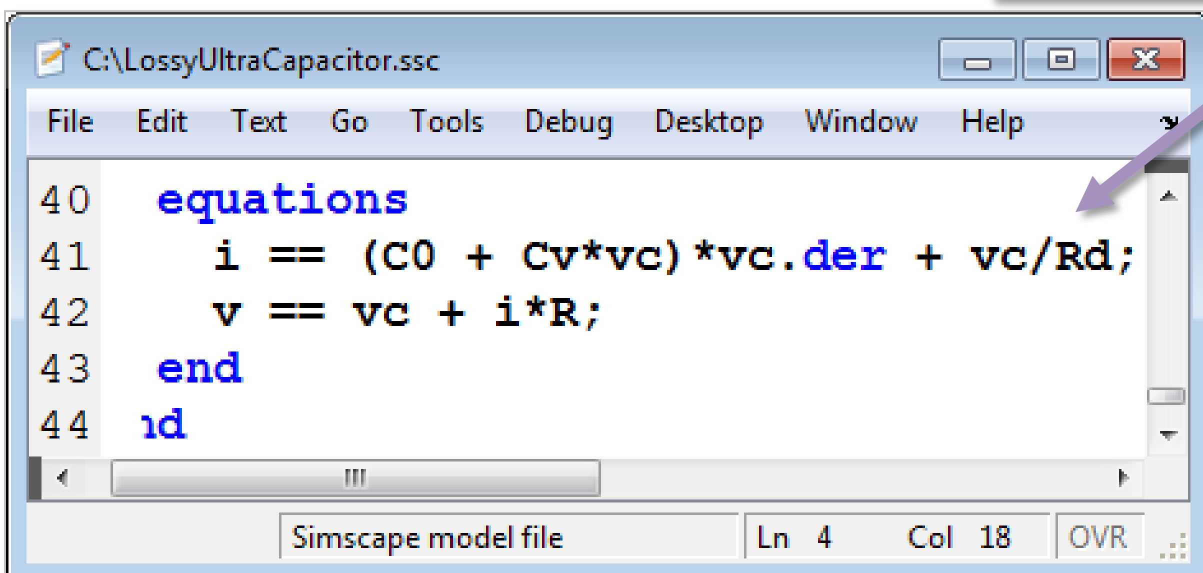
- Parameters, default values, units, and dialog box text all defined in the Simscape file (extension .ssc)



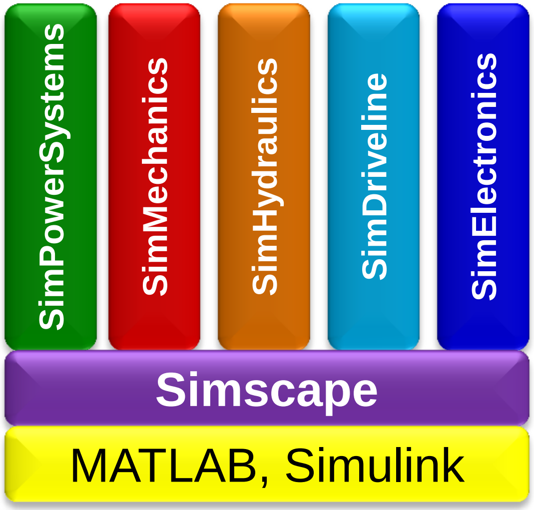
Simscape Language:
Define Reusable Components

- Equations defined in a text-based language
  - Symmetrical mathematical relationship (not inputs and outputs)

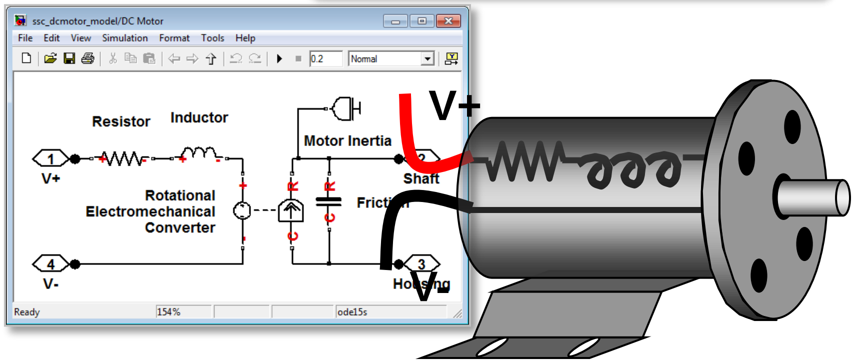
$$\mathrm{i} = (\mathrm{C}_0 + \mathrm{C}_\mathrm{v} v)\frac{dv}{dt} + \frac{v}{r_d}$$



Simscape Summary



- Physical modeling (acausal) of Multi-domain physical systems
  - Model system not equations

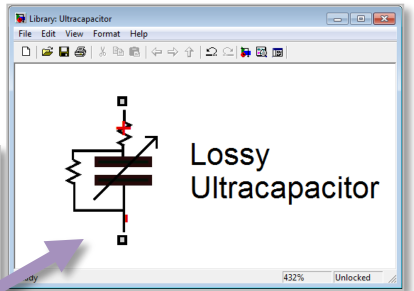


- Custom components/Domain using Simscape language

$$i = (C_0 + C_v v)\frac{dv}{dt} + \frac{v}{r_d}$$

C:\LossyUltraCapacitor.ssc

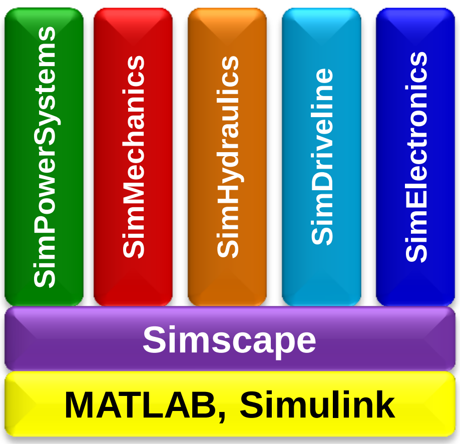
```
equations
  i == (C0 + Cv*vc)*vc.der + vc/Rd;
  v == vc + i*R;
end
end
```

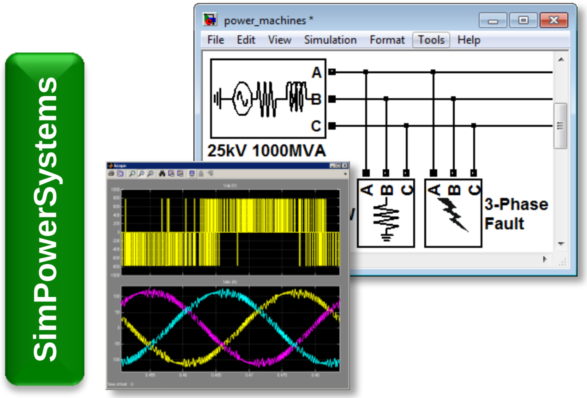


- Simulate plant and controller in one environment
  - Optimize entire system

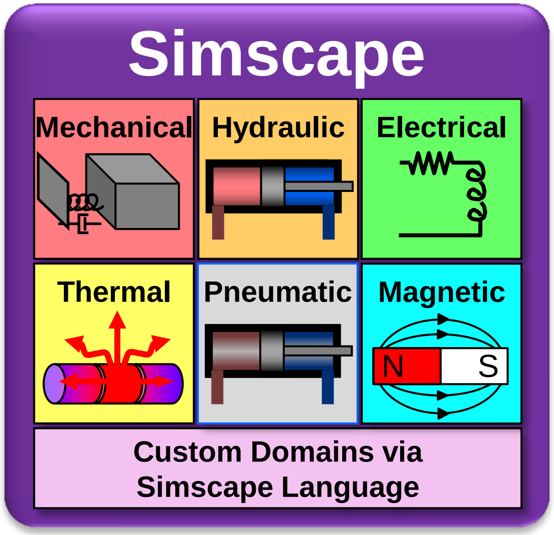
MathWorks

Physical Systems in Simulink

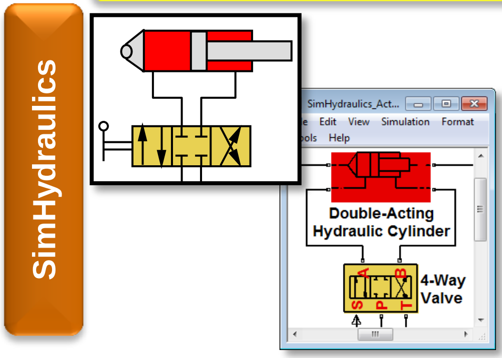




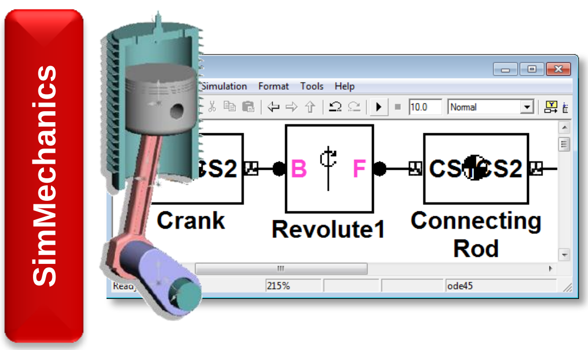
Electrical power systems



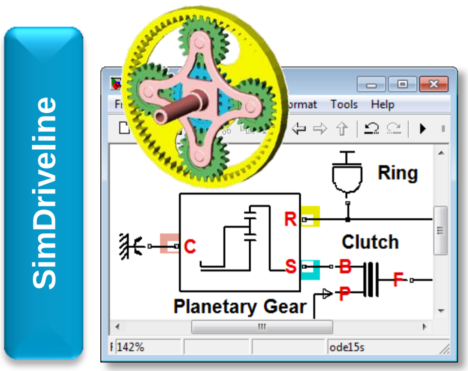
Multidomain physical systems



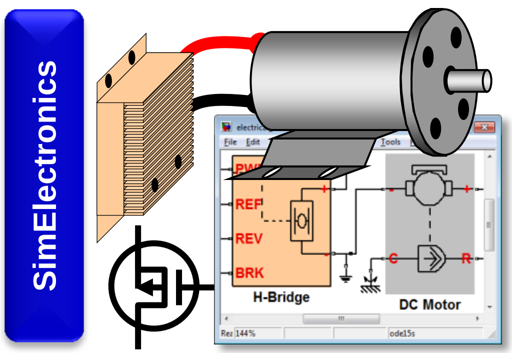
Fluid power and control



Multibody mechanics (3-D)

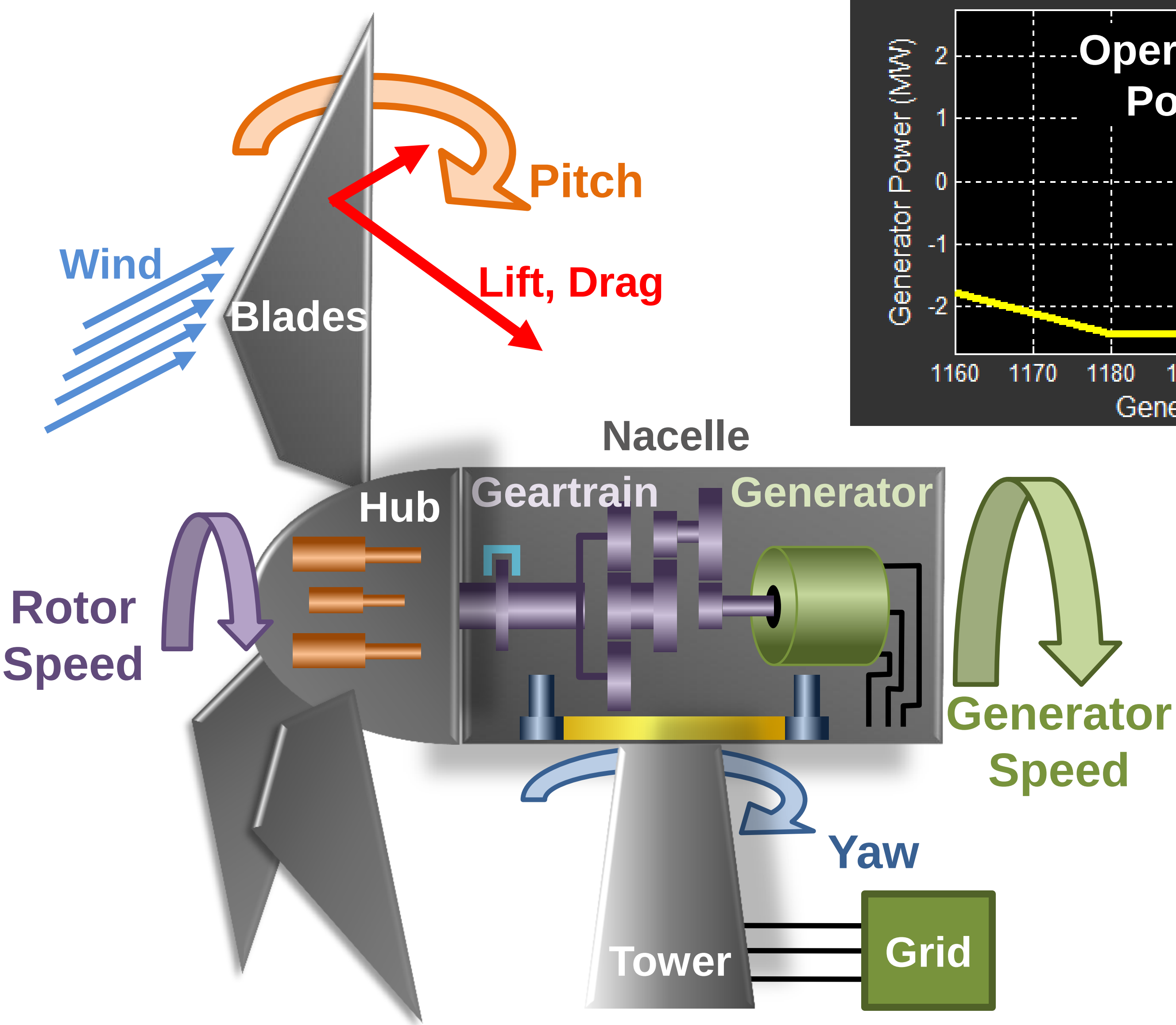


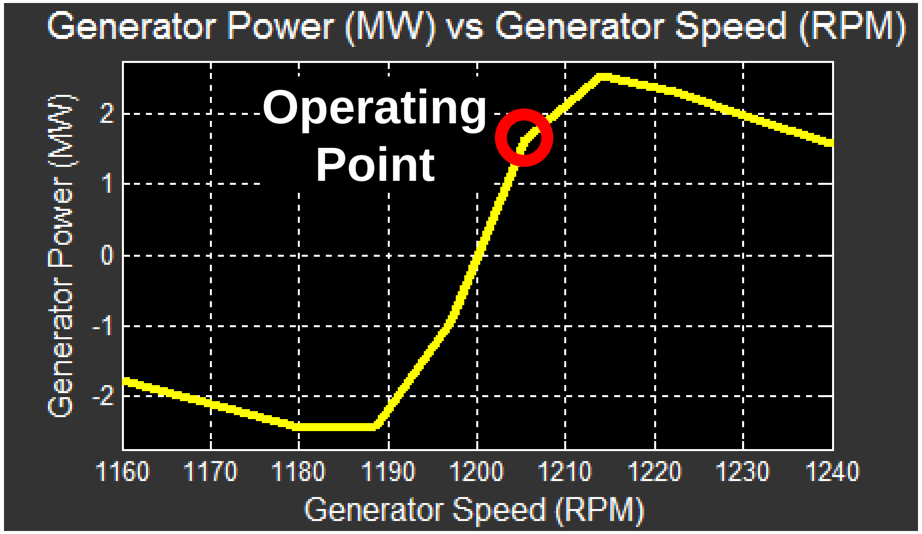
Mechanical systems (1-D)



Electromechanical and electronic systems

Wind Turbine Basics





<u>Primary Goal</u>

Spin at or near operating speed

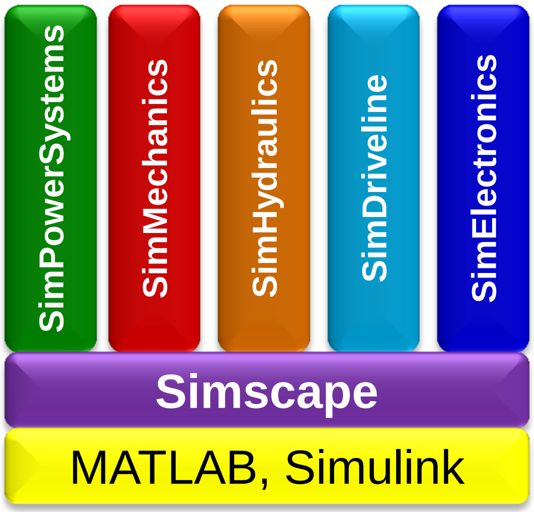
Wind Turbine Model

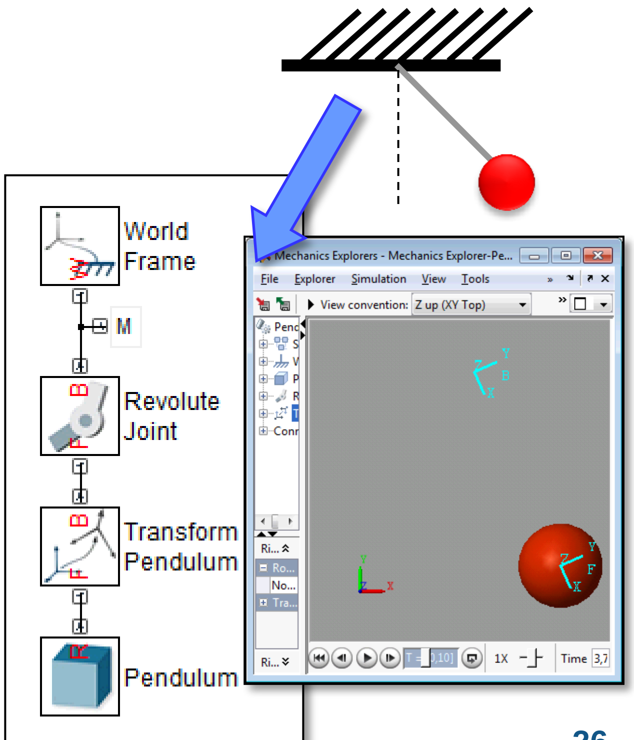
- Public domain model and supporting MATLAB scripts available at: http://www.mathworks.com/matlabcentral/fileexchange/25752-wind-turbine-model

- Simulation requires licenses for these tools:
  - MATLAB
  - Simulink
  - Simscape
  - Stateflow
  - Please request a trial license if needed to experiment with the model.

Introduction to SimMechanics

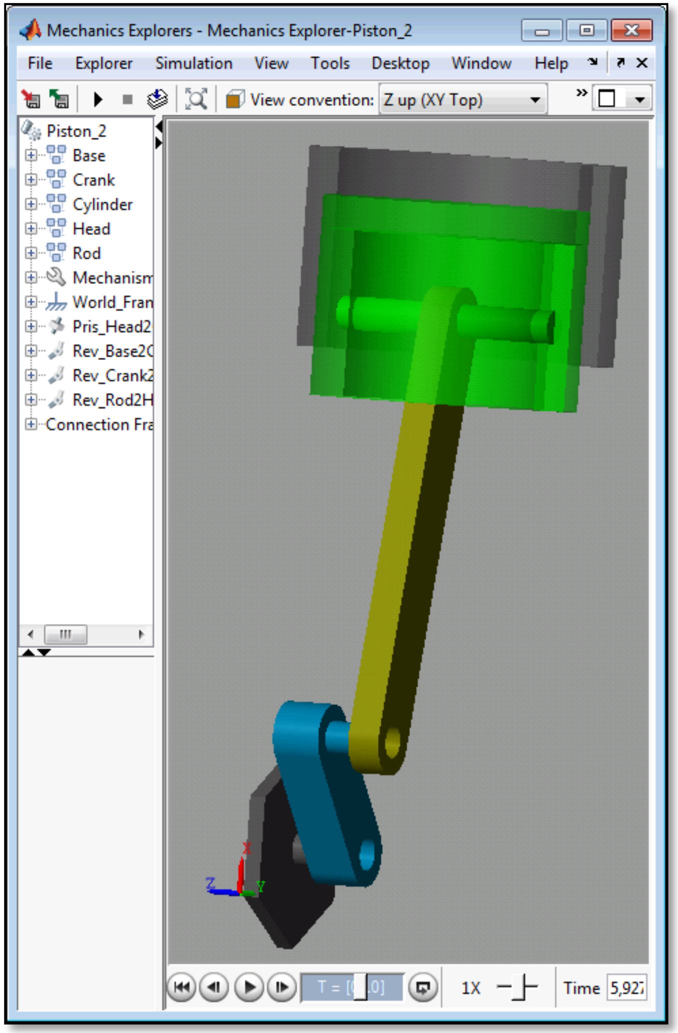
- Enables multibody simulation of 3D mechanical systems
- Construct model using bodies, joints, and forces
  - Model matches structure of system
  - No need to derive and program equations
- Primary uses
  - System-level analysis
  - Control development in Simulink





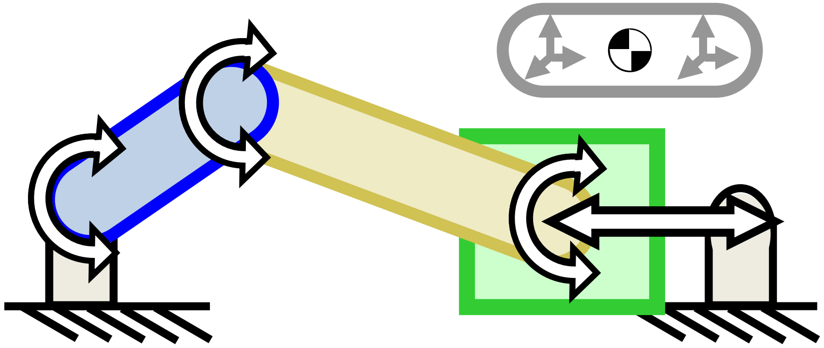
SimMechanics Key Features

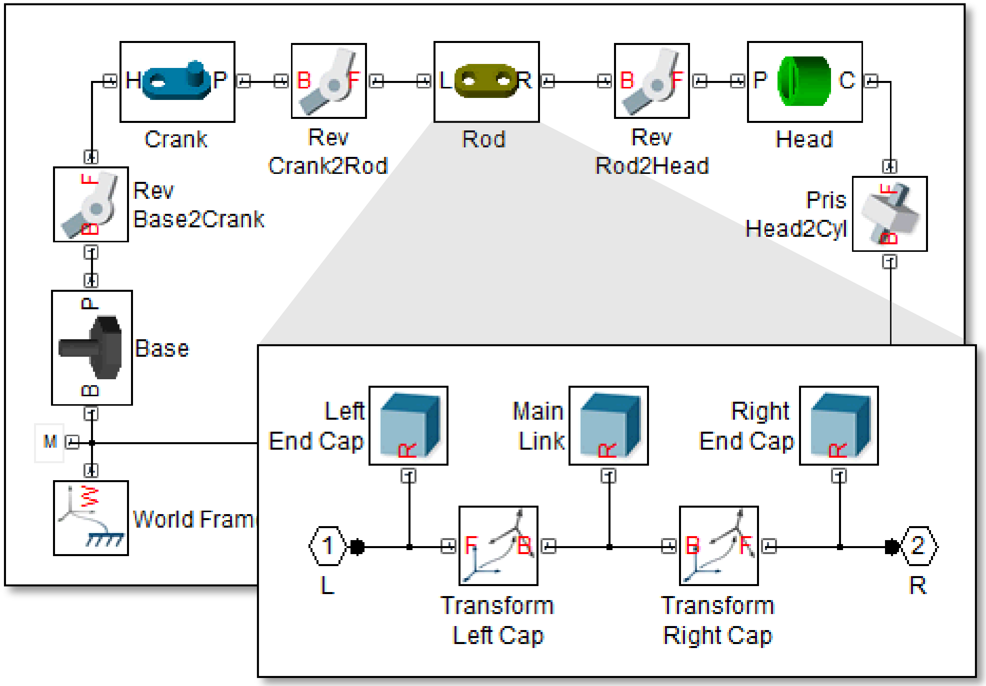
- Rigid body definition using standard geometry and custom extrusions defined in MATLAB
  - Mass and inertia tensor calculation
  - Easily reuse models in other designs
- 3D animation of simulation results
- Connect to control algorithms and other physical domains



Modeling 3D Mechanical Systems

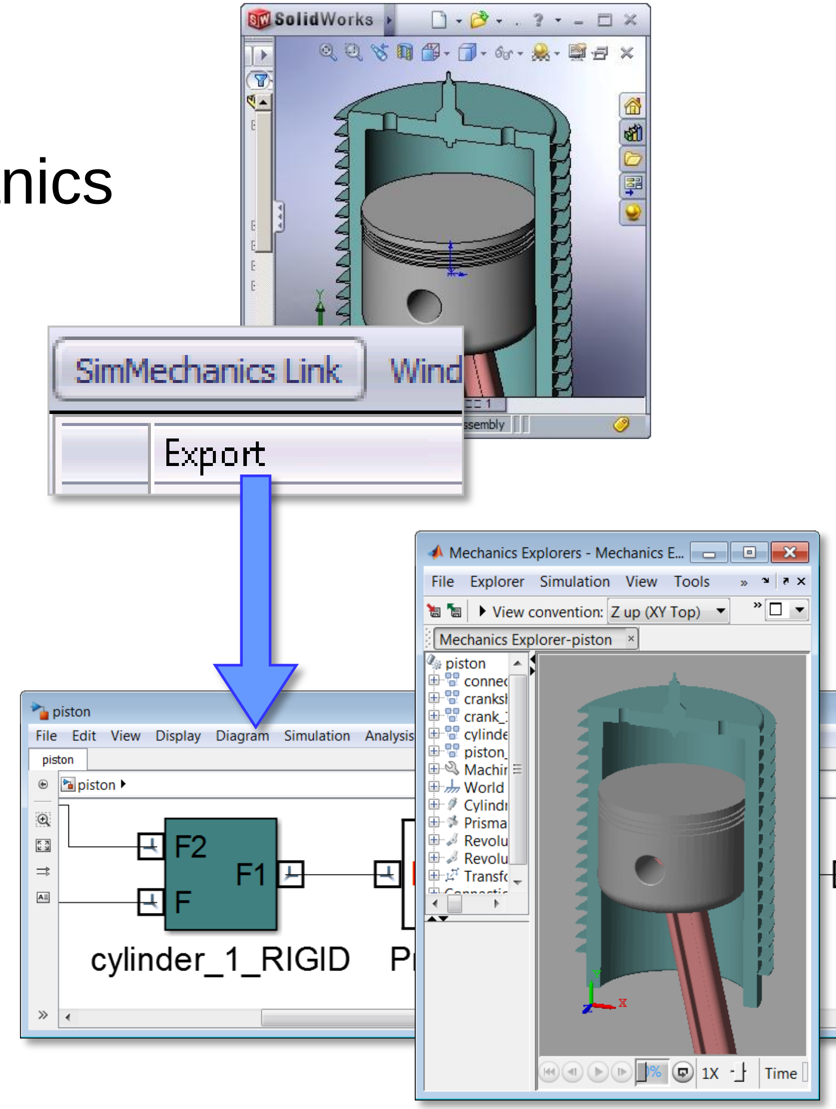
- Build a model whose structure represents the system:
  - Parts (mass, inertia)
  - Coordinate systems
  - Joints and constraints
- Parameterize model using MATLAB variables
- Save subsystems for reuse in other models
- Connect directly to Simscape and Simulink



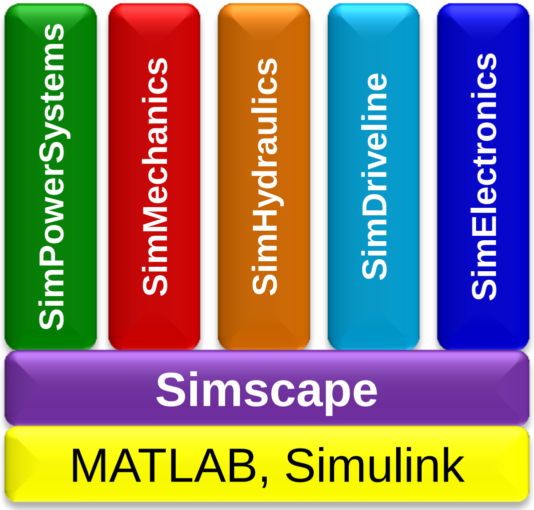


Import CAD Data Using SimMechanics Link

- Automatically create SimMechanics models from a CAD assembly
  - Converts mass and inertia to rigid bodies
  - Converts mate definitions to joints
  - Creates STL files for use with SimMechanics visualization
- Directly connects SolidWorks, ProEngineer and Inventor
- Public API for other CAD tools
- Free download from **www.mathworks.com**
  - Requires MATLAB

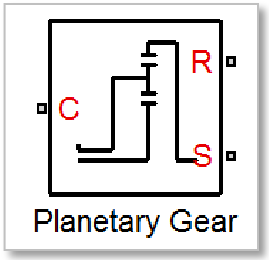


Introduction to SimDriveline

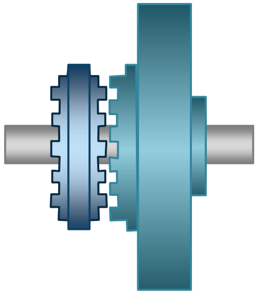


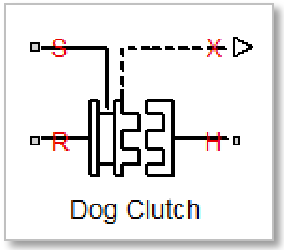
- Enables physical modeling (acausal) of mechanical powertrain systems

- Provides rotational and translational component models
  - Gears, clutches, vehicle components
  - Create custom components via Simscape language



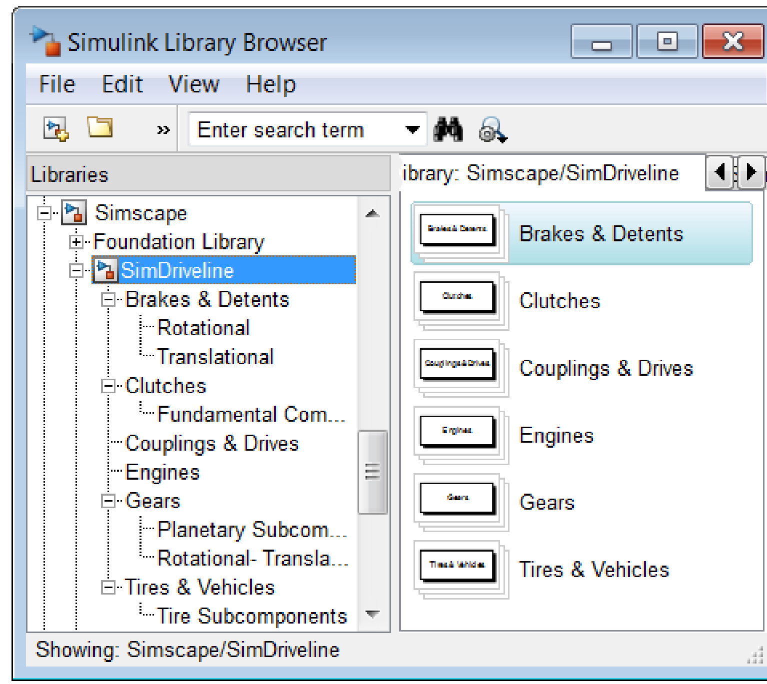
- Primary uses
  - System-level analysis of mechanical transmission systems
  - Control development in Simulink





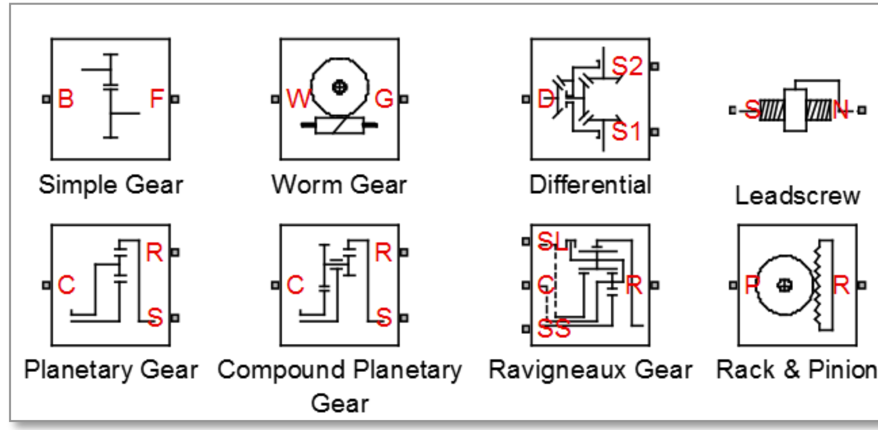
SimDriveline Key Features

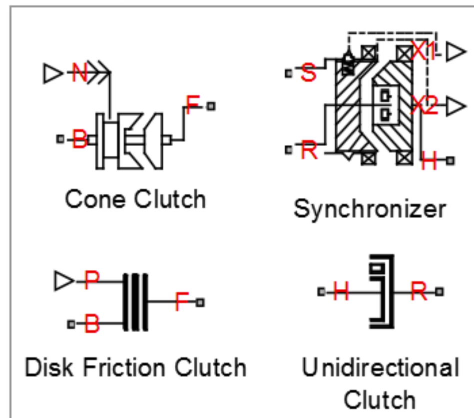
- Common gear models with meshing and viscous losses
- Clutch models
  - Cone, disk friction, and dog clutch
- Vehicle component models,
  - Engine, tire, torque converter, and vehicle dynamics
- Extend component libraries using the Simscape language
- Support for C-code generation from SimDriveline models (with Simulink Coder™)

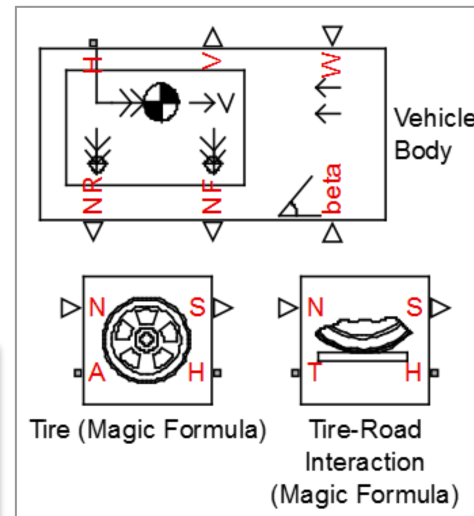


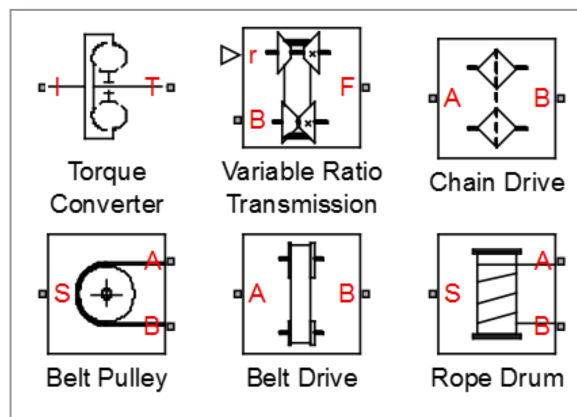
Model 1-Dimensional Mechanical Systems

- More than 35 component models of varying fidelity
  - Gears
  - Clutches
  - Couplings/drives
  - Vehicle components
- Configure models to meet your needs
- Connect to Simscape and other libraries to include other effects



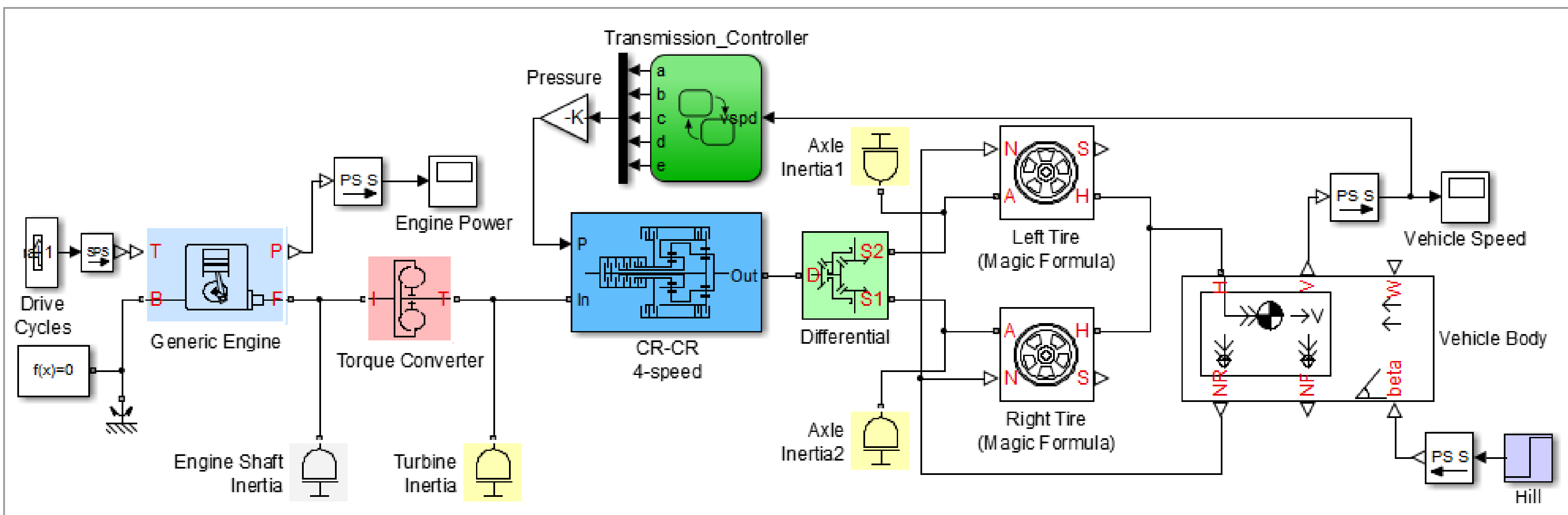






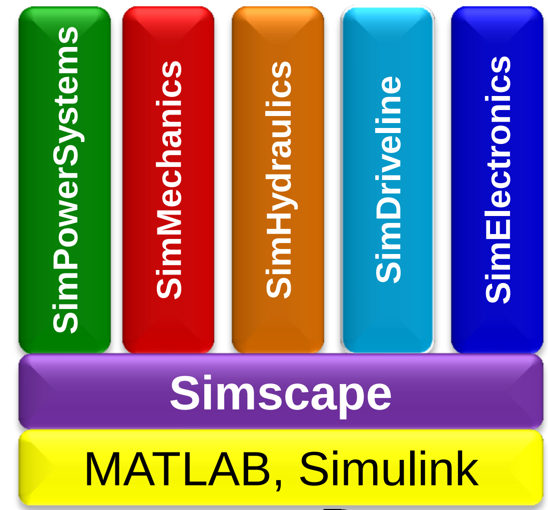
Quickly Build Drivetrain Systems

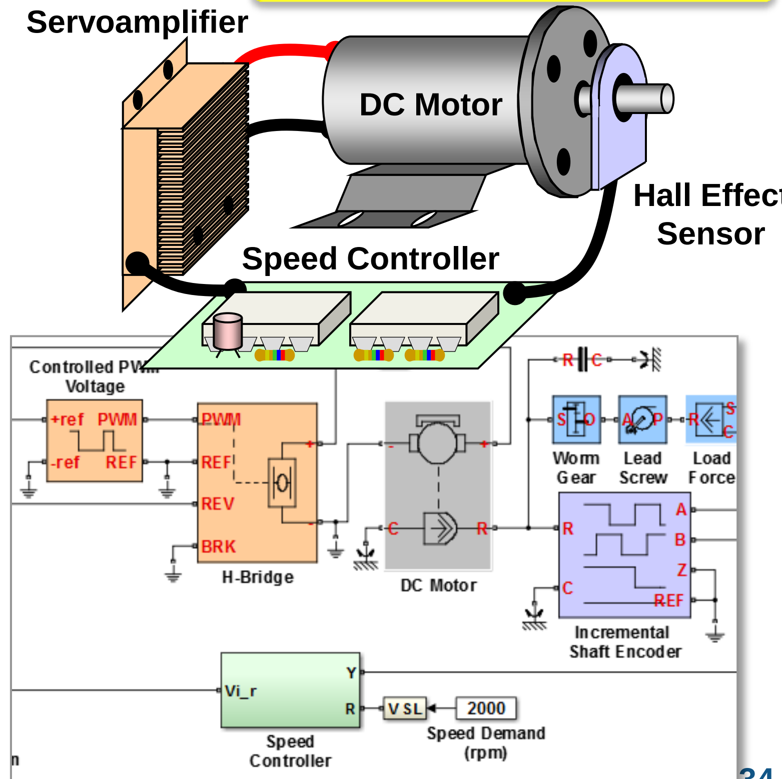
- Model topology reflects physical structure of system
  – Save subsystems for reuse in other models
- Connect directly to Simulink and Stateflow
- Parameterize models using MATLAB



Introduction to SimElectronics

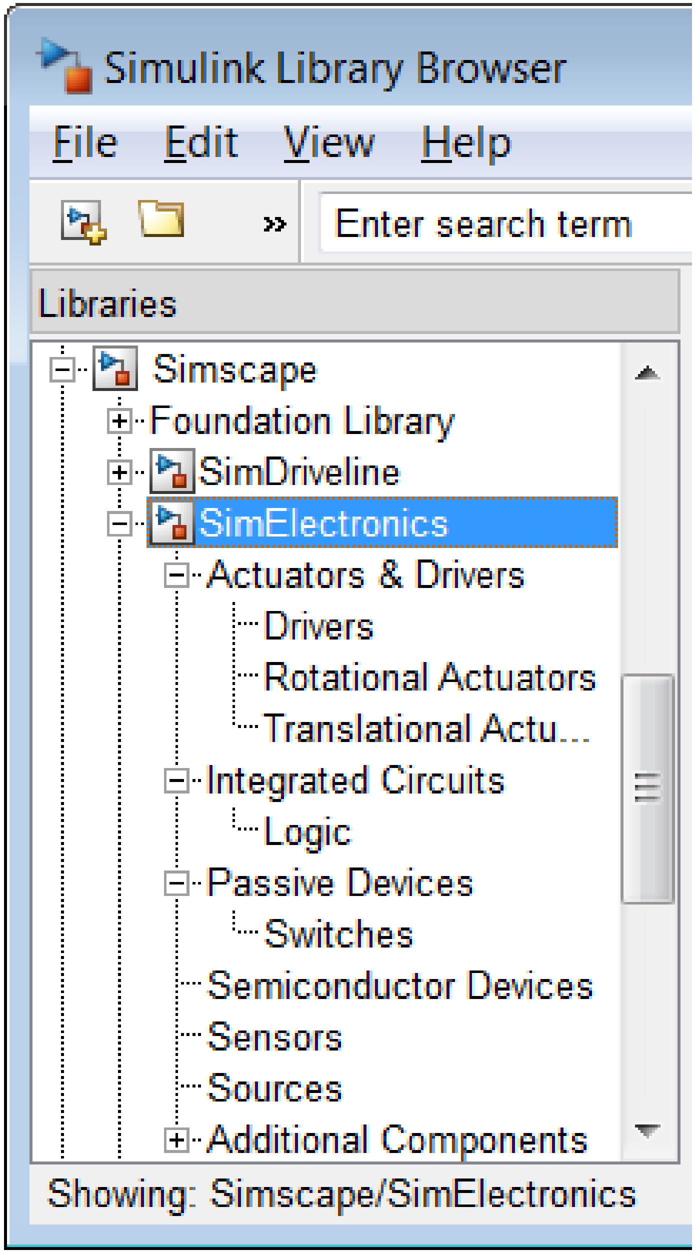
- Enables physical modeling (acausal) for electronic and mechatronic systems
- Provides sensor, actuator, and semiconductor models
- Supports algorithm and control system development in Simulink





SimElectronics
Key Features

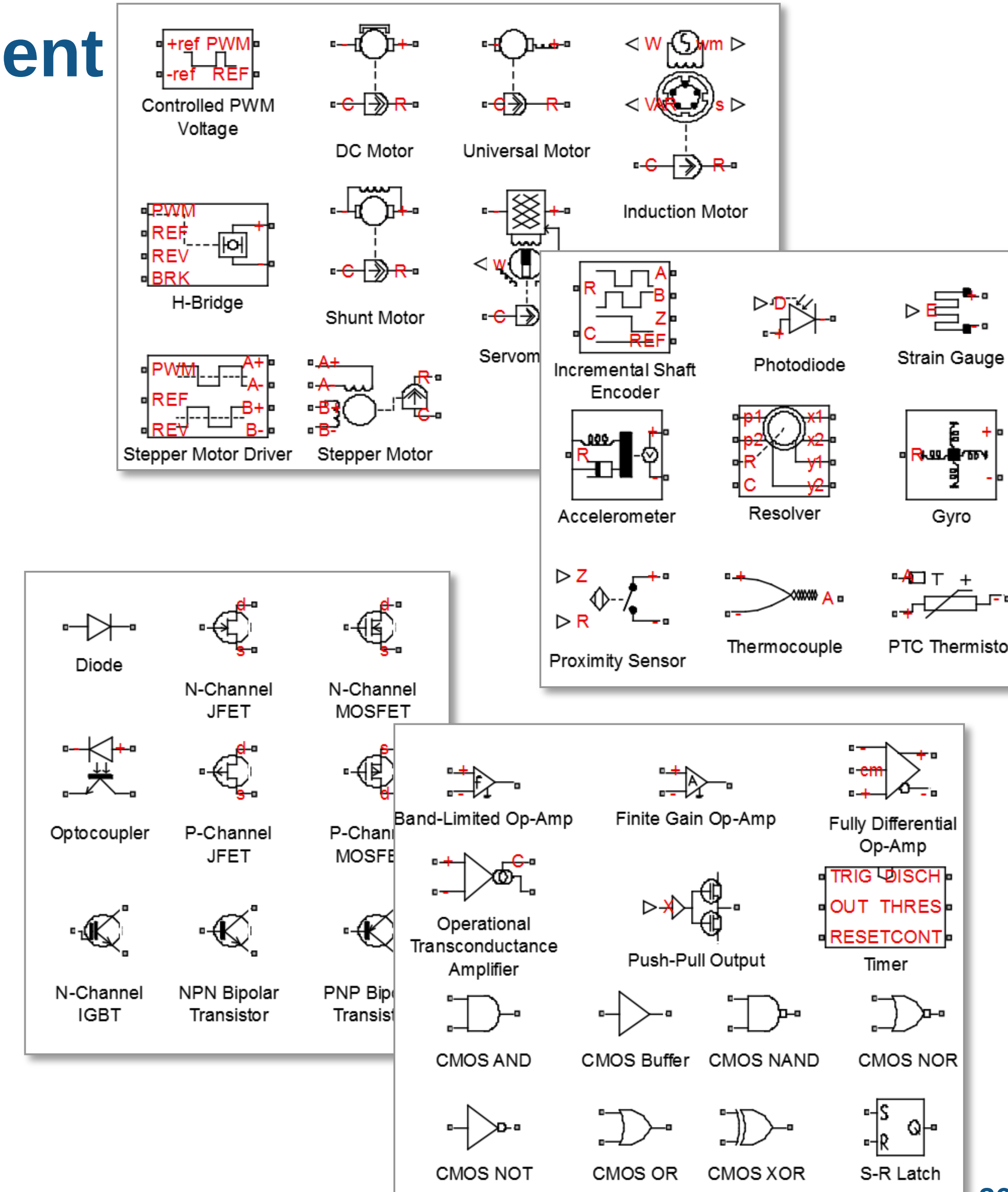
- Provides sensor, actuator, and semiconductor models
- Enter parameters values directly from data sheets
- Model temperature dependence heat production, and device temperature
- Linearize for control design or small signal analysis
- Convert to C code
  - Accelerate simulation
  - Create standalone executables



Extensive Component Libraries

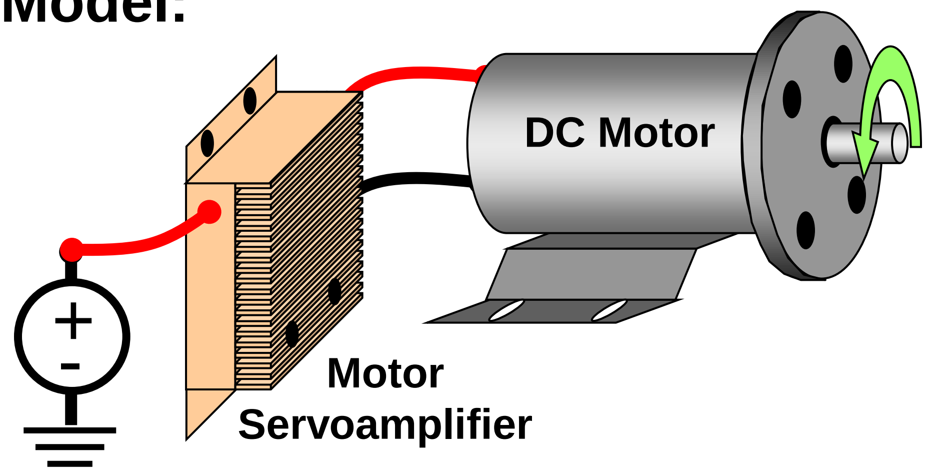
- More than 90 component models
  - Actuators, drivers
  - Sensors
  - Semiconductors
  - Integrated circuits

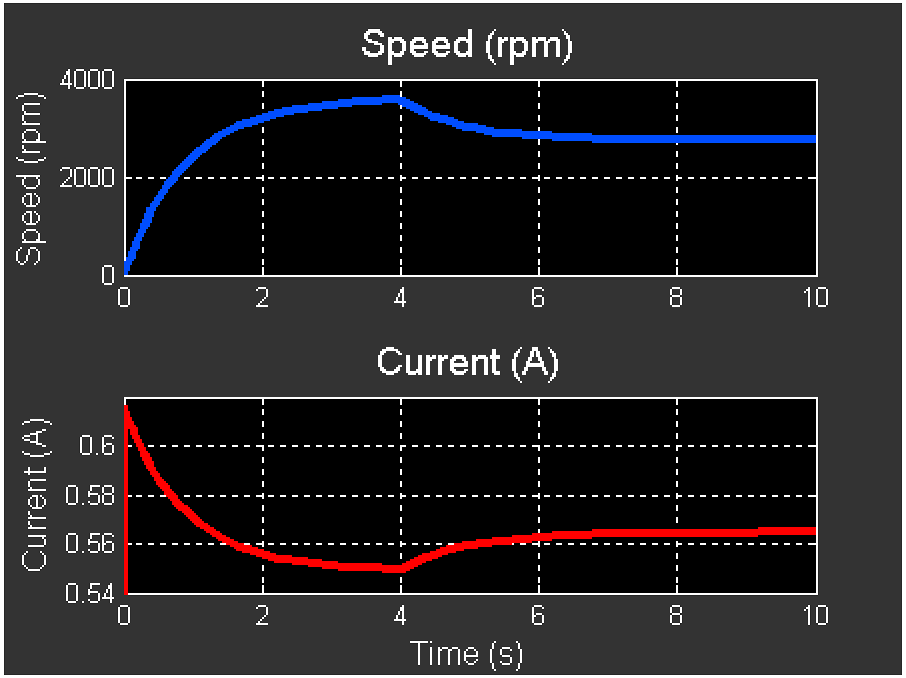
- Models look like schematics
  - Easy to read and interpret



Demo SimElectronics: Controlled DC Motor

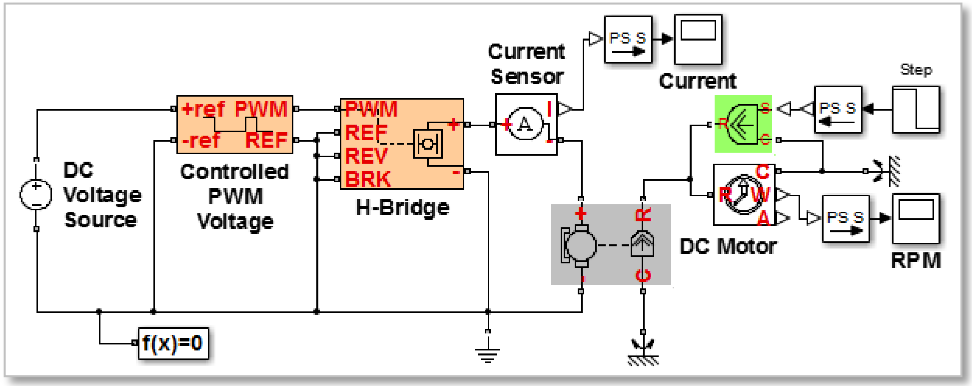
Model:





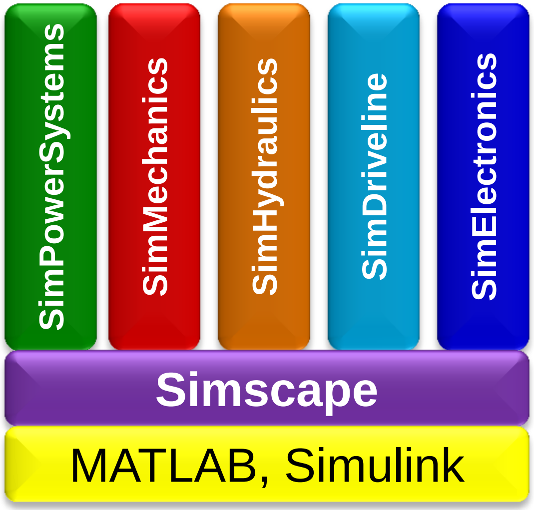
Problem: Model a DC motor with a configurable PWM controller in the Simulink environment

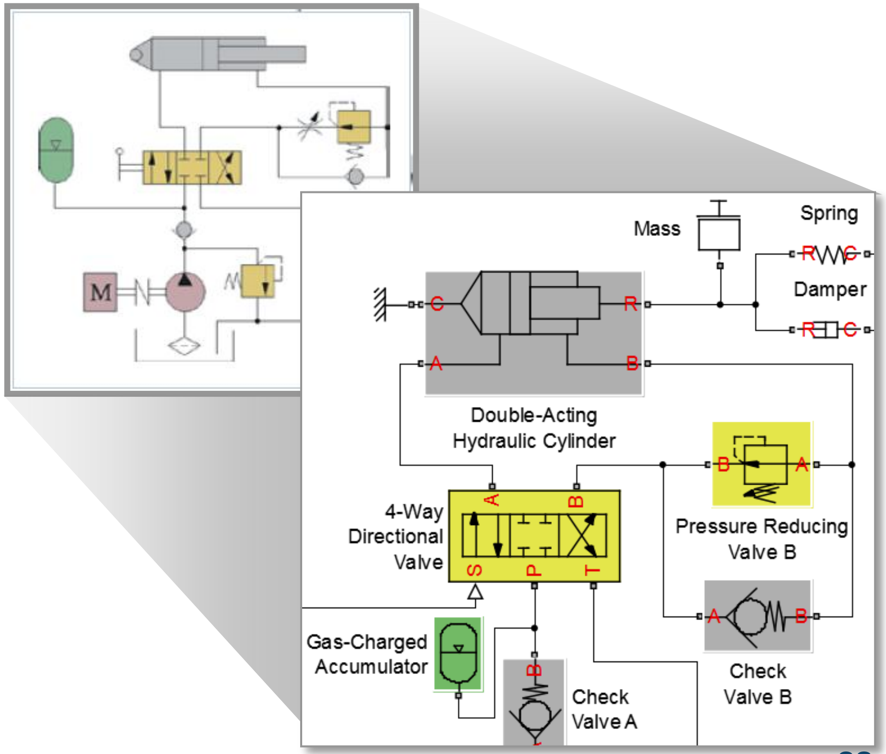
Solution: Use SimElectronics to model the mechatronic system



Introduction to SimHydraulics

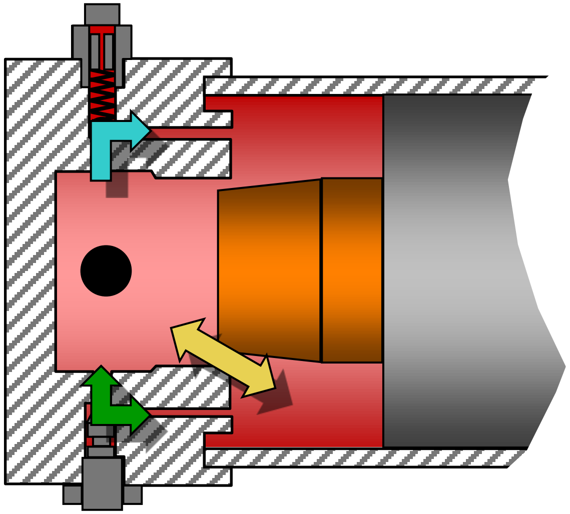
- Enables physical modeling (acausal) of hydraulic systems
- Enables engineers to build simulation models that look like hydraulic circuit diagrams
- Used by system engineers and control engineers to design and test hydraulic systems

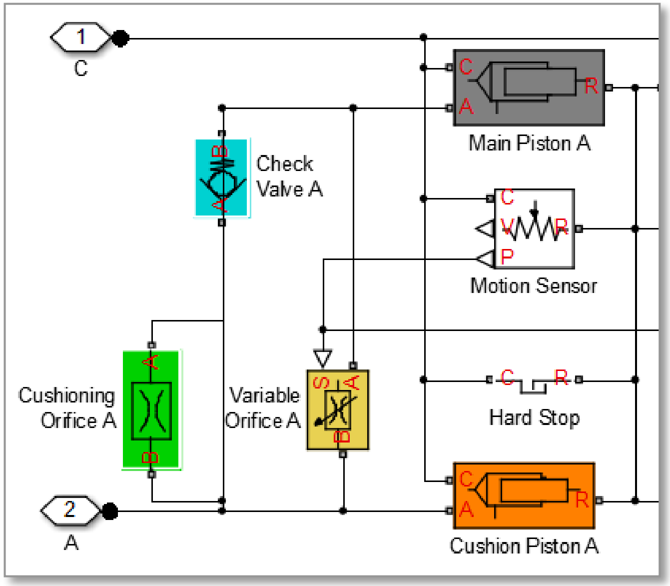




SimHydraulics Key Features

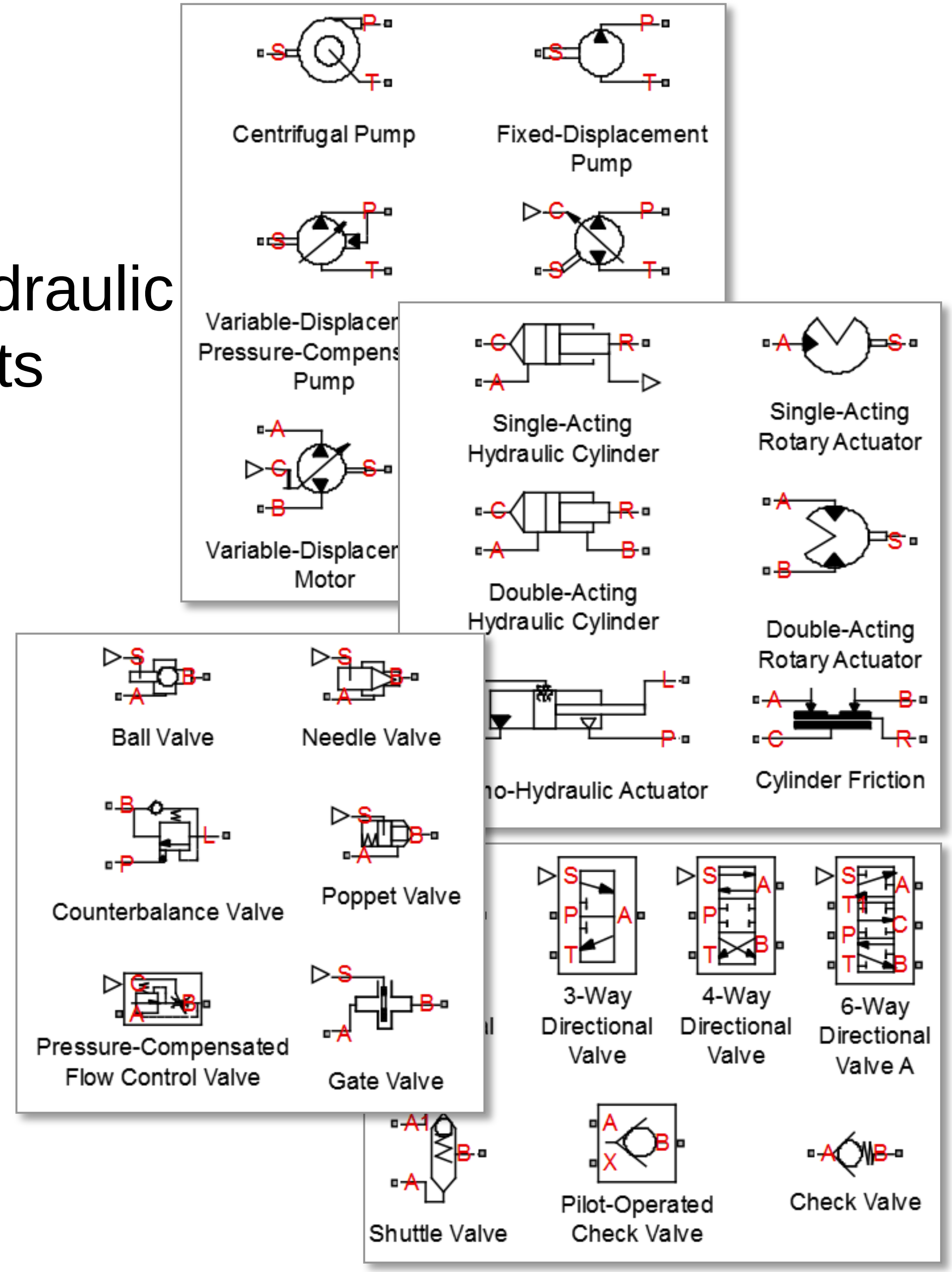
- Extensive component library enables modeling of custom components
- Parameterization methods allow multiple options for setting parameters
- Customizable library of common hydraulic fluids
- Steady-state capabilities of Simscape enable efficient simulation





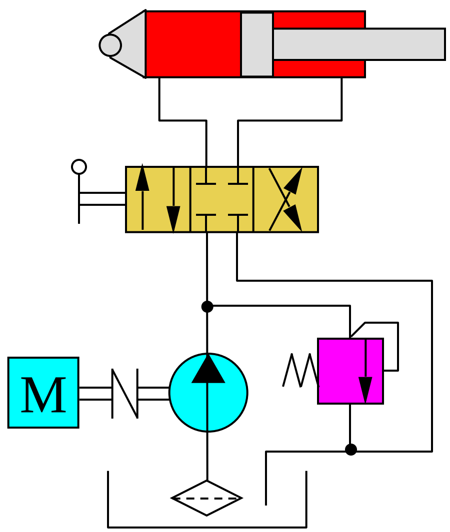
Extensive Component Libraries

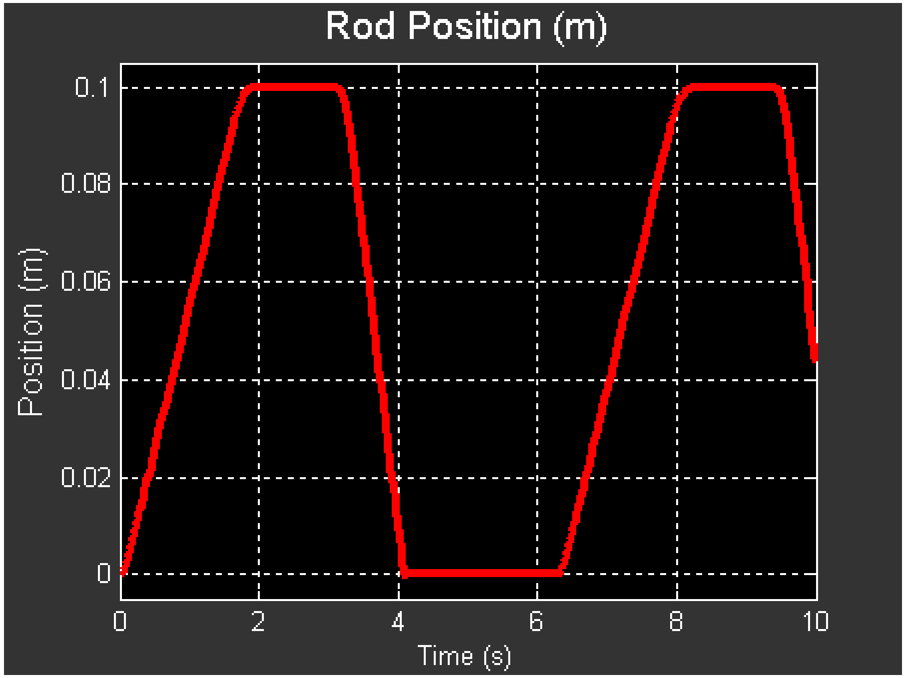
- More than 80 models of hydraulic and mechanical components
  - Pumps and motors
  - Actuators
  - Valves (directional, check, pressure compensation, etc.)
  - Accumulators
- Hydraulic blocks use images in compliance with ISO 1219 Fluid Power Standard
  - Easily understood by hydraulics engineers



Hydraulic Actuation System

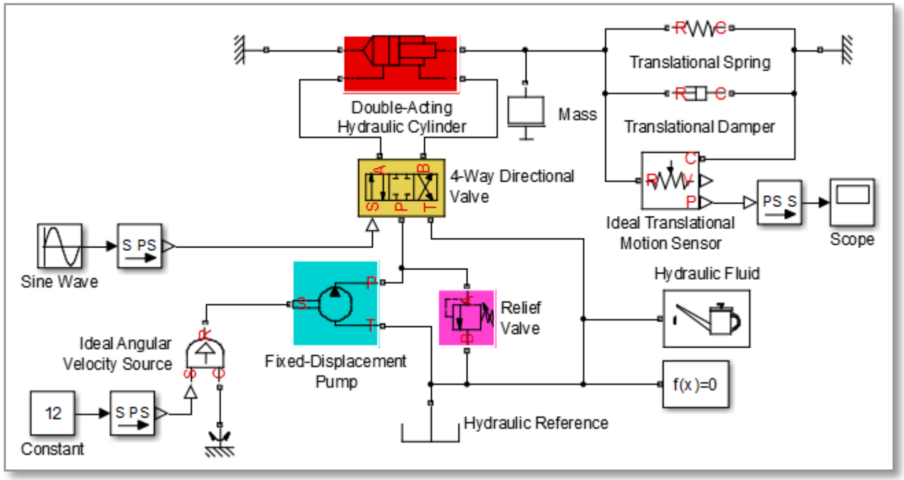
Model:



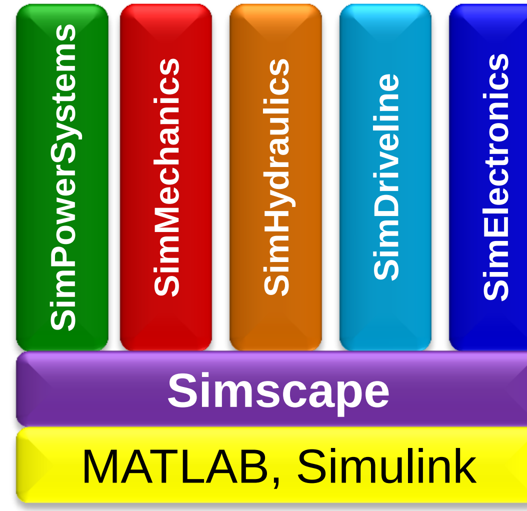


Problem: Model a hydraulic actuation system within the Simulink environment

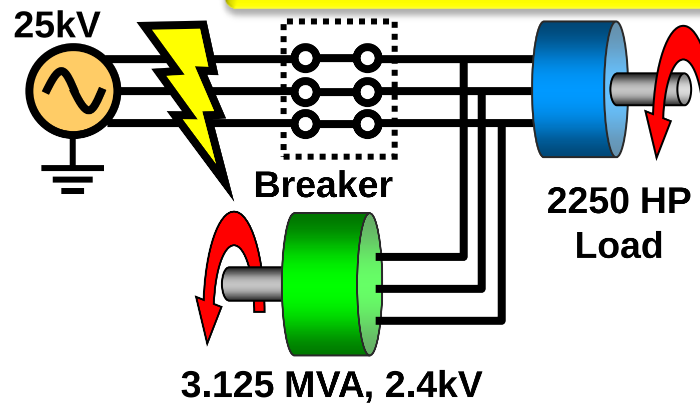
Solution: Use SimHydraulics to model the hydraulic system



Introduction to SimPowerSystems

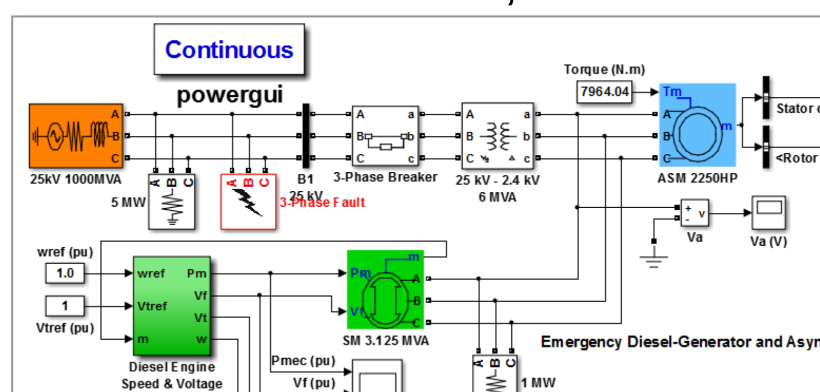


- Enables physical modeling (acausal) of electrical power systems and electric drives



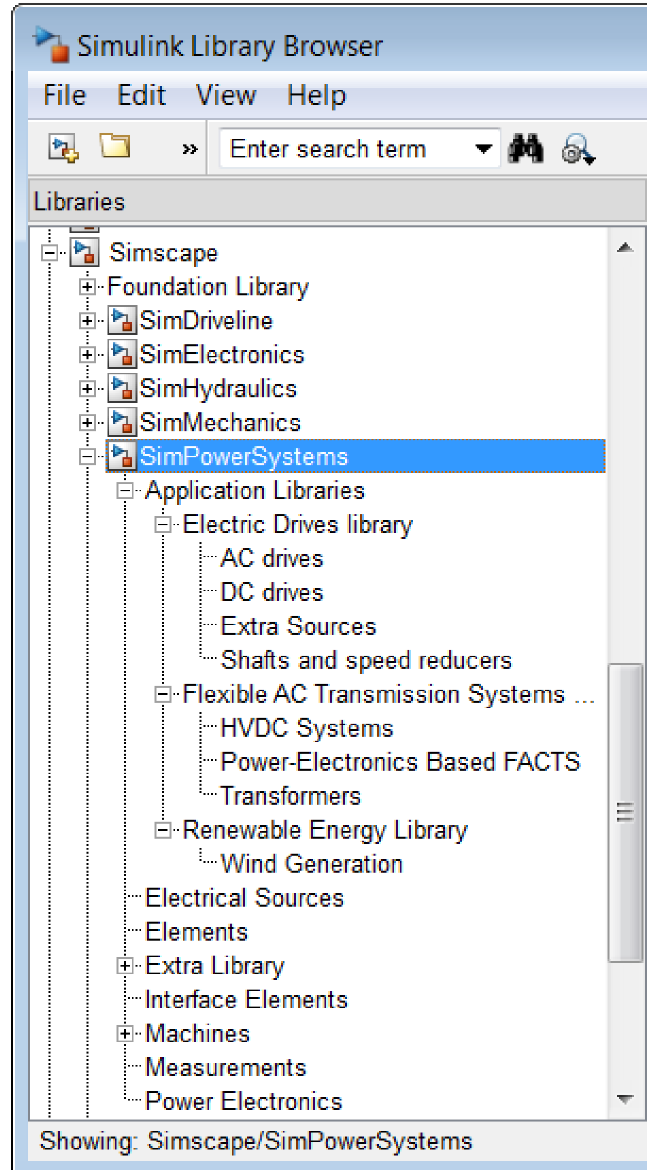
- Electrical system topology represented by schematic circuit

- Used by electrical, system and control engineers to develop plant models and test control systems



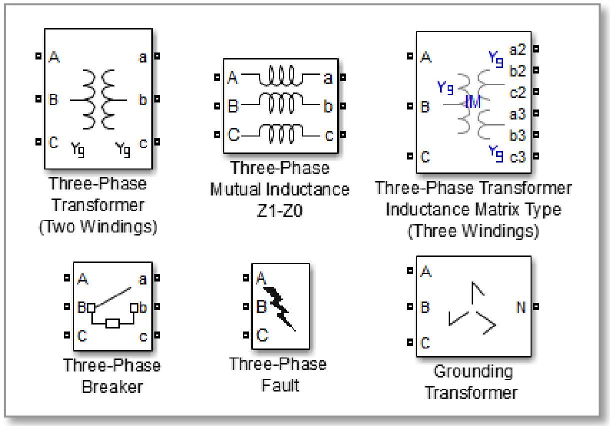
SimPowerSystems Key Features

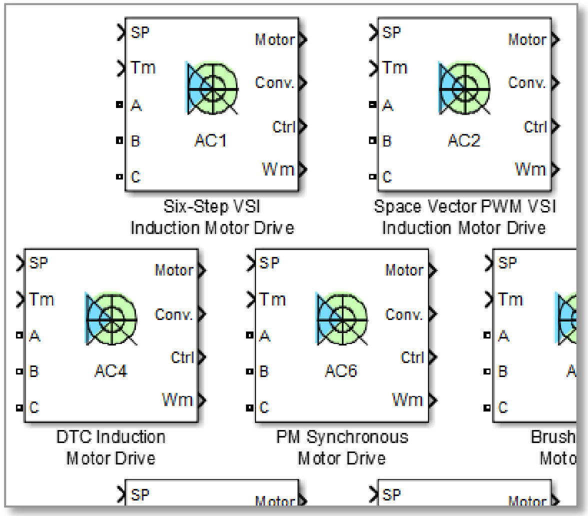
- Comprehensive block libraries for building power system models
- Detailed models of common AC and DC electric drives
- Different simulation modes to speed model execution
- Ideal switching algorithm, enabling fast simulation of power electronics
- PowerGUI provides convenient tools for common analysis tasks
- Extensive set of demonstration circuits and systems

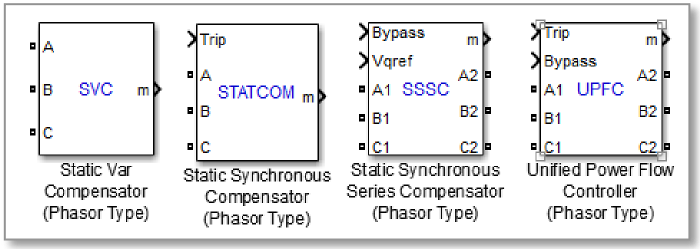


Quickly Build Electrical Systems

- Build models that look like an electrical schematic:
  - Three-phase components
  - Detailed electric drive models
  - Flexible AC Transmission Systems (FACTS)
- Parameterize model using MATLAB® variables
- Connect to Simulink with sources and sensors
- Save subsystems for reuse in other models or libraries

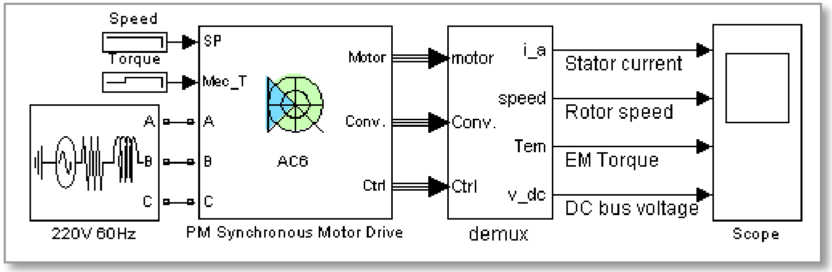


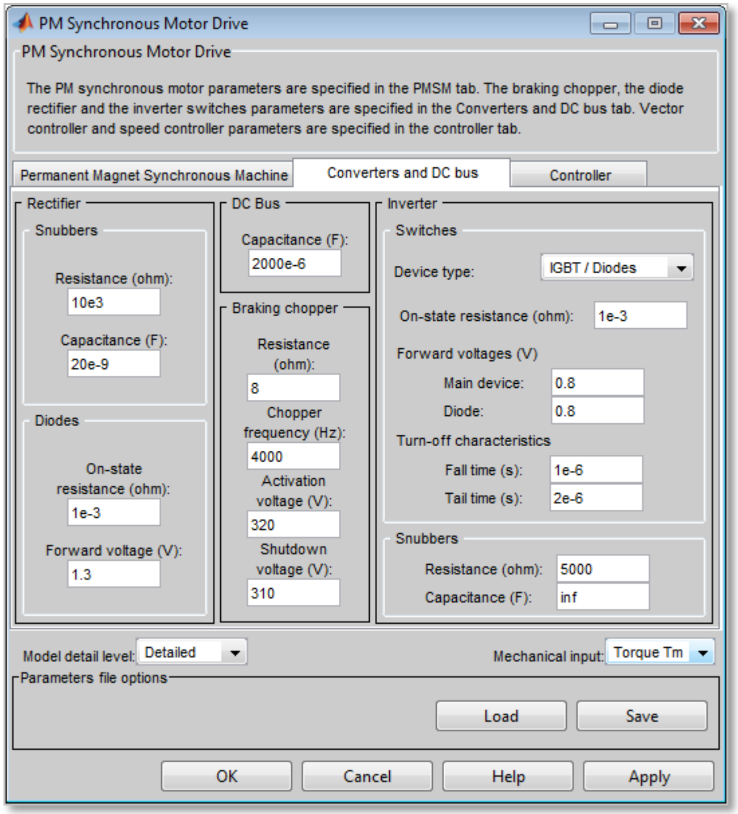




Model Electric Drives

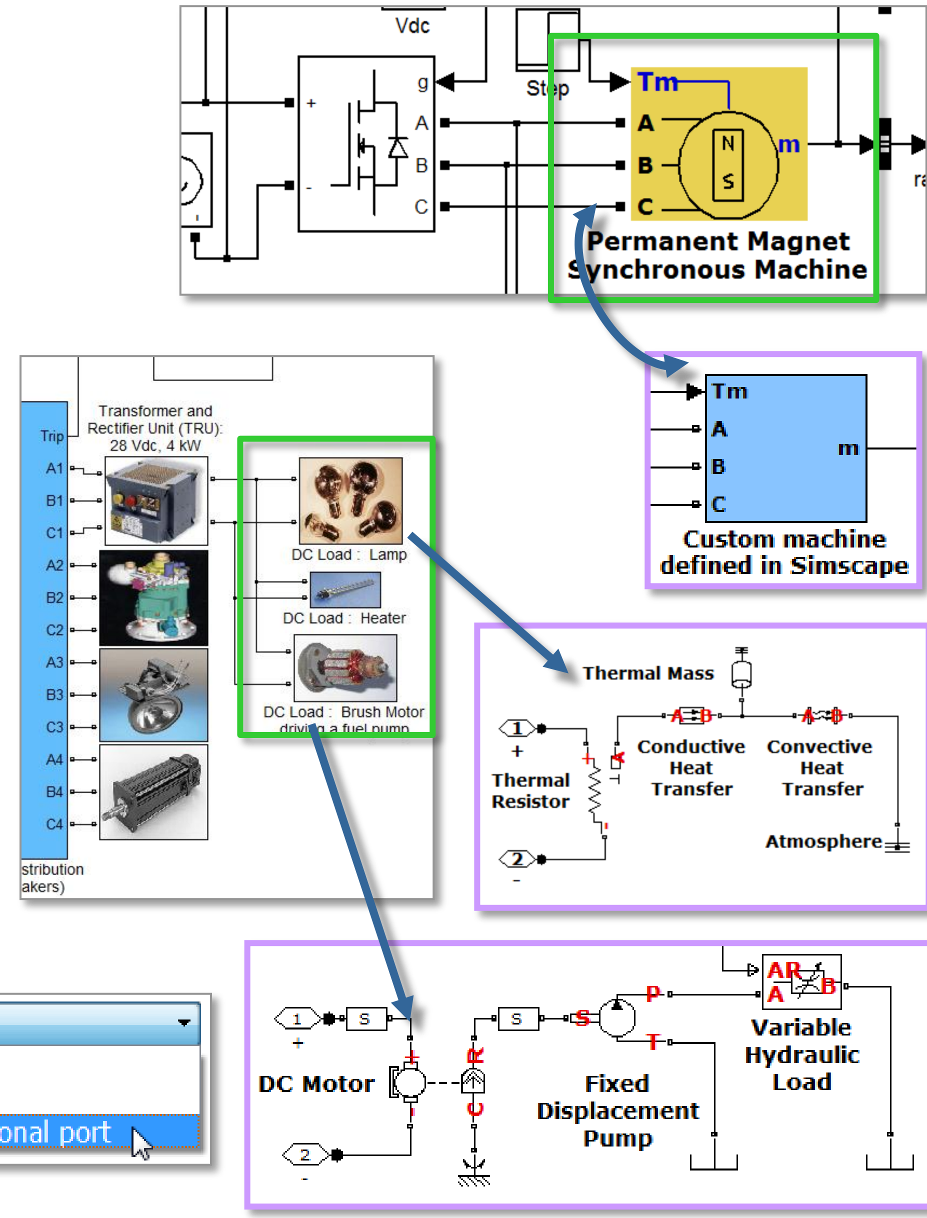
- Combine power electronics, machine, and control algorithm
  - GUI to assign key parameters
  - Common strategies for speed and torque control
  - Adjustable level of fidelity (detailed, averaged)
- Common machine types can be used as motors or generators:
  - Permanent magnet
  - Synchronous, asynchronous
  - Induction
  - Single phase or 3-phase

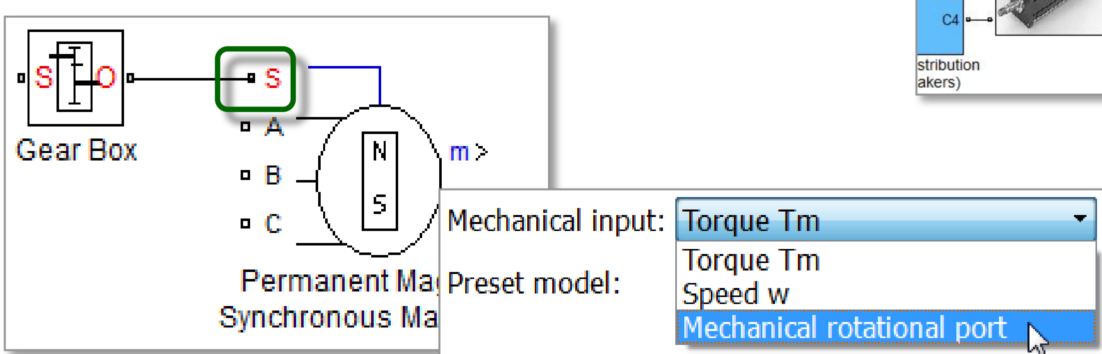




Connecting to Simscape

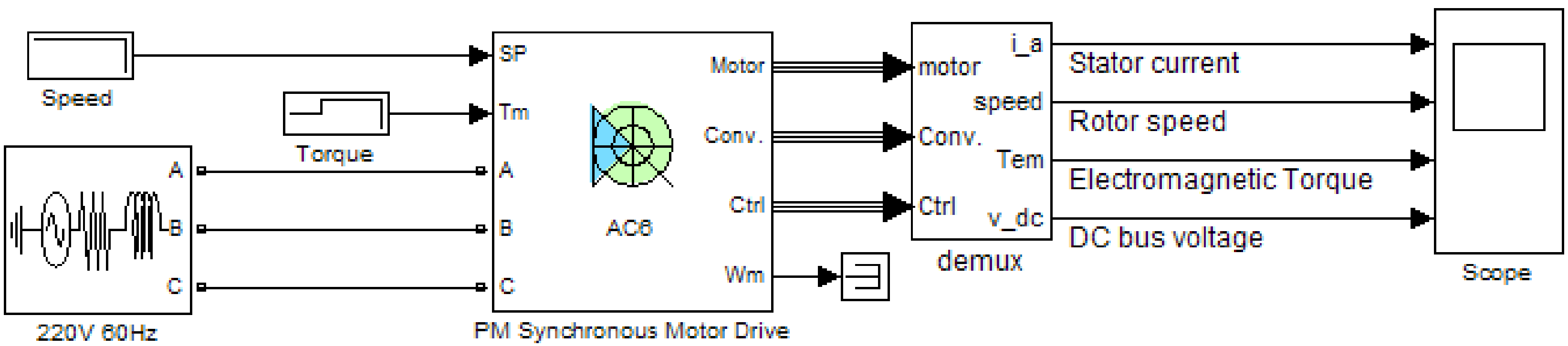
- Electrical connection via interface blocks
  - Add custom components using Simscape language
  - Include other domains
- Mechanical ports
  - Synchronous, asynchronous, DC, and PMS machines

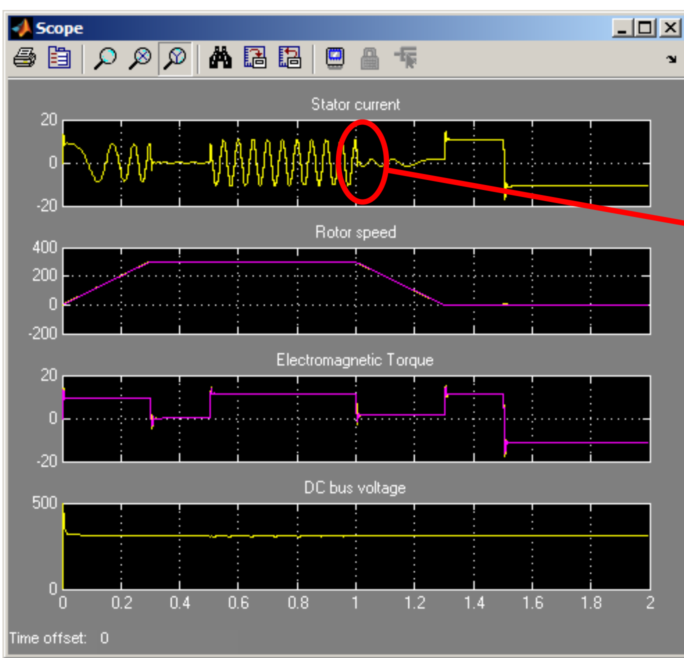


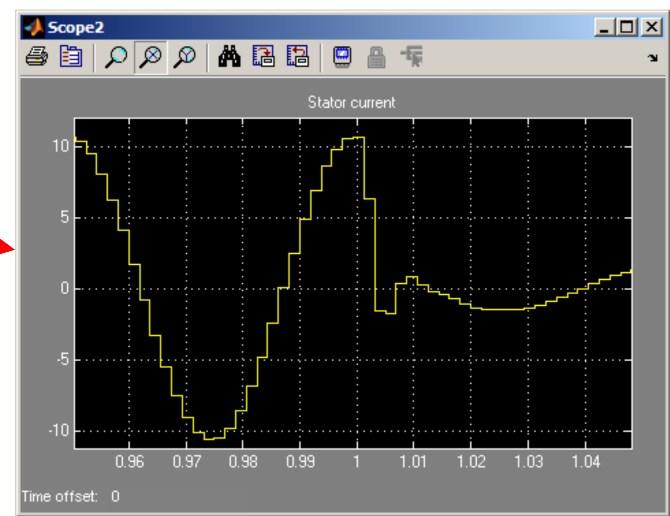


SimPowerSystems Demonstration

PM Synchronous Motor Drive (`ac6_example.mdl`)



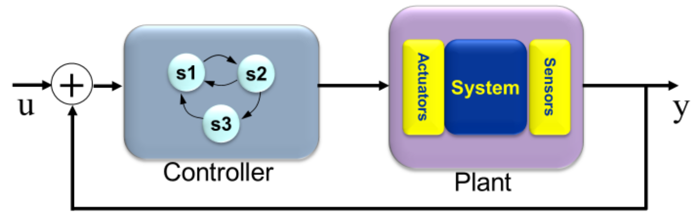




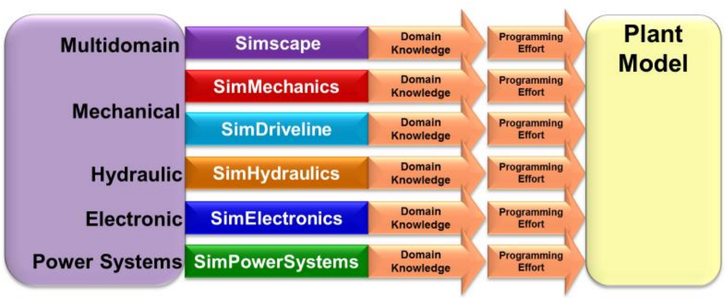
Discrete solver provides fast, accurate results.

Key Takeaways

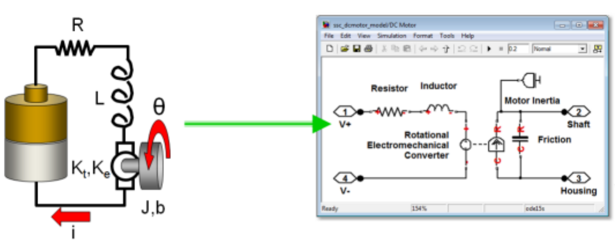
- **Optimize system performance**
  - Develop in a single environment



- **Multi-domain Physical System**



- **Eases process of modeling physical systems**



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