MATLAB EXPO 2018

Modeling and Simulation of Physical Systems with Simscape

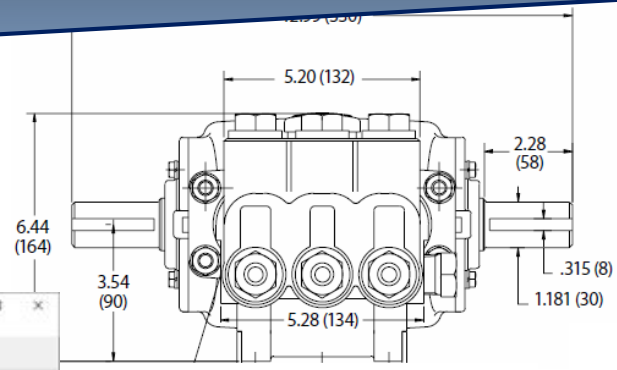
Paul Lambrechts
Tadele Shiferaw Tadele

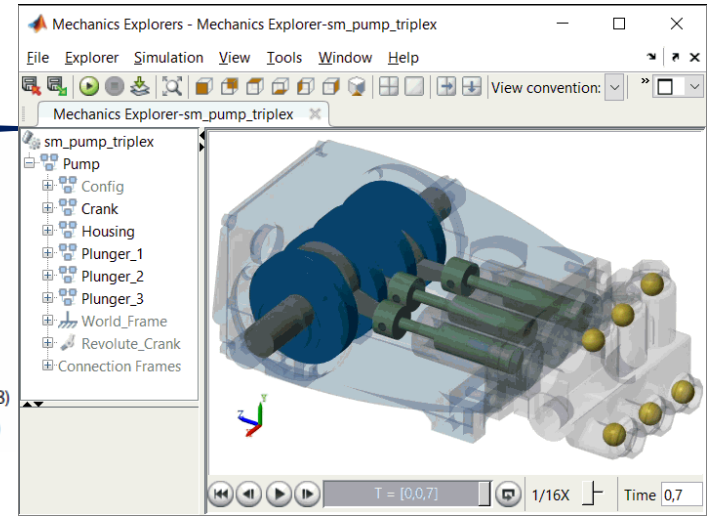
Modeling and Simulation of Physical Systems with Simscape

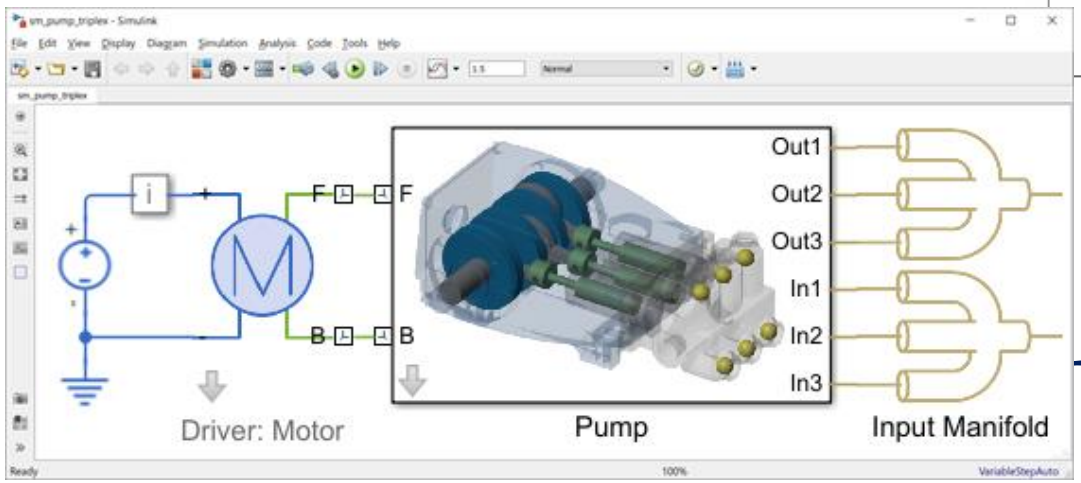
- What's physical modeling and why should I care?
- Working with a multi-domain physical model in Simscape
  - An electrically driven triplex plunger pump for a predictive maintenance study
- Extending the model to explore a new design element
  - Adding a battery model to the design
- Key take-aways of the session

Physical Modeling with Simscape is easy and accurate!

Use CAD import to obtain visualization and parameters

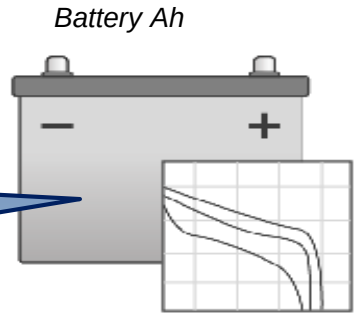


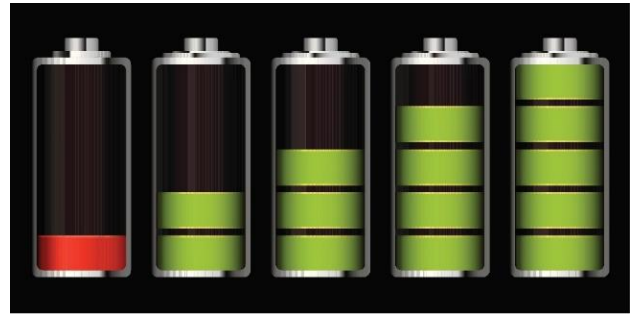




Extend and explore to create a multi-domain “digital twin”

Add new components to investigate innovative design





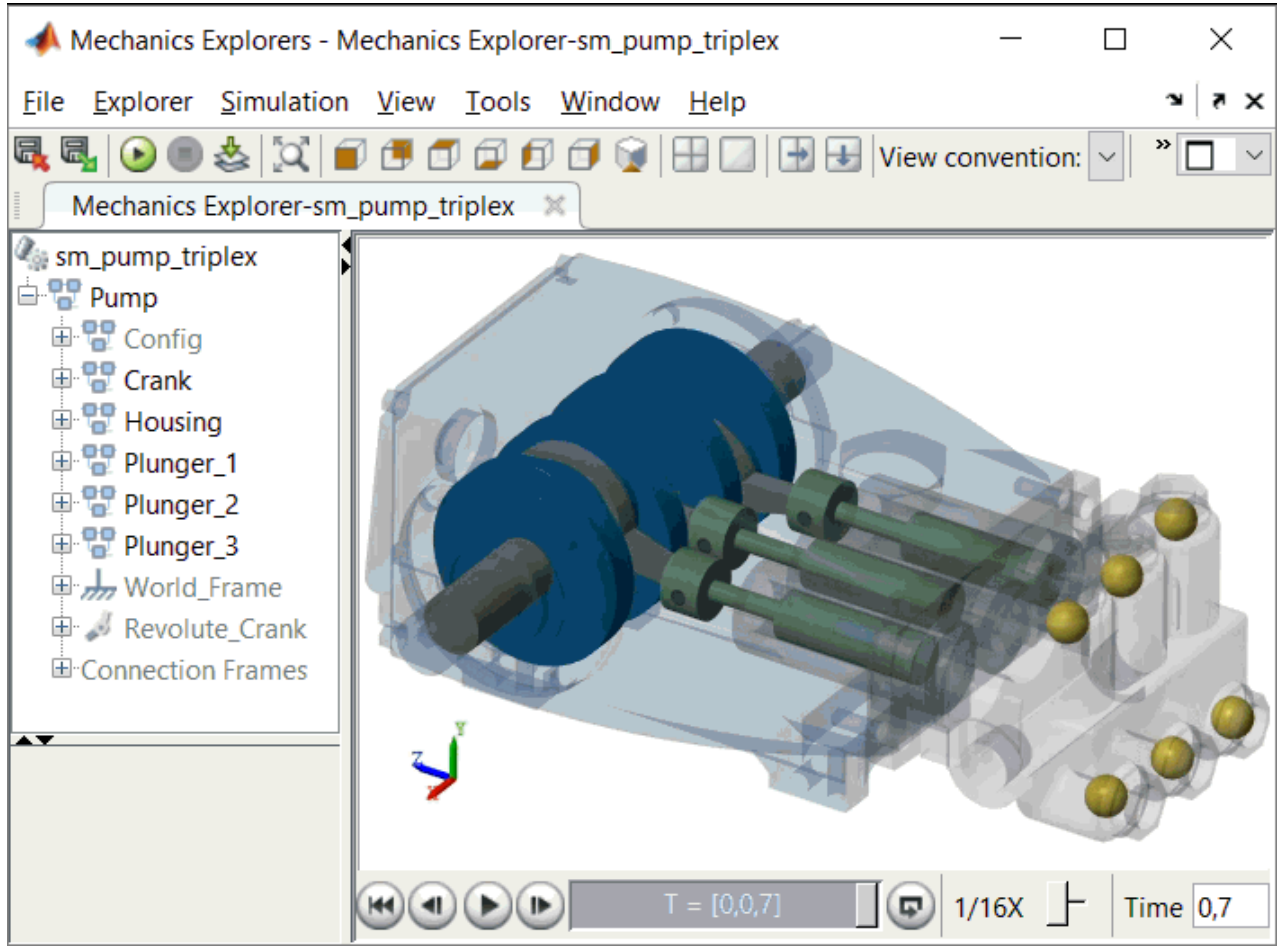
The Big Question?

Why

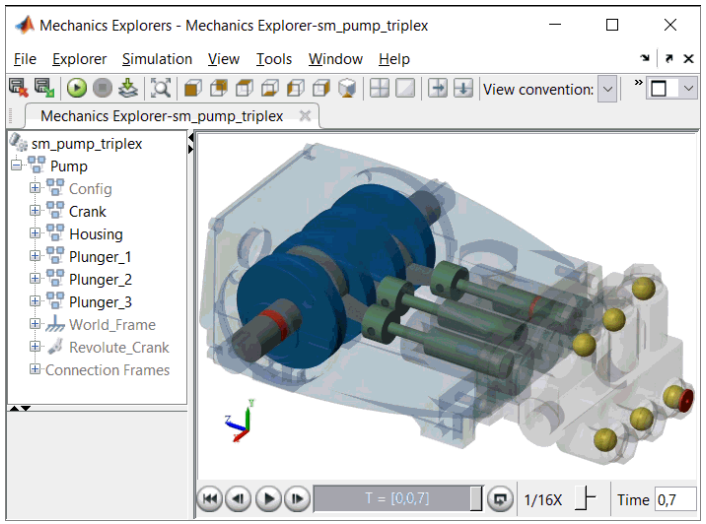
- Why Physical Modeling?
- Why in Simulink/Simscape?

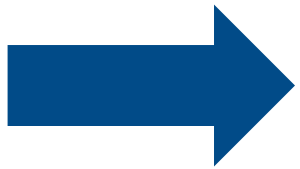
The CAT Triplex Plunger Pump

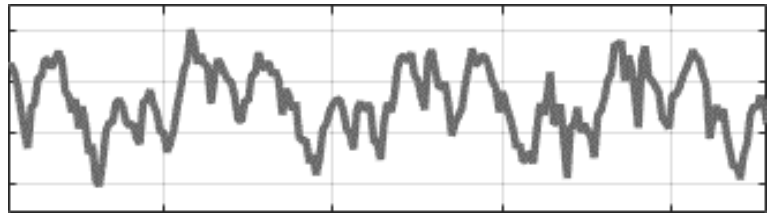
Predictive Maintenance?

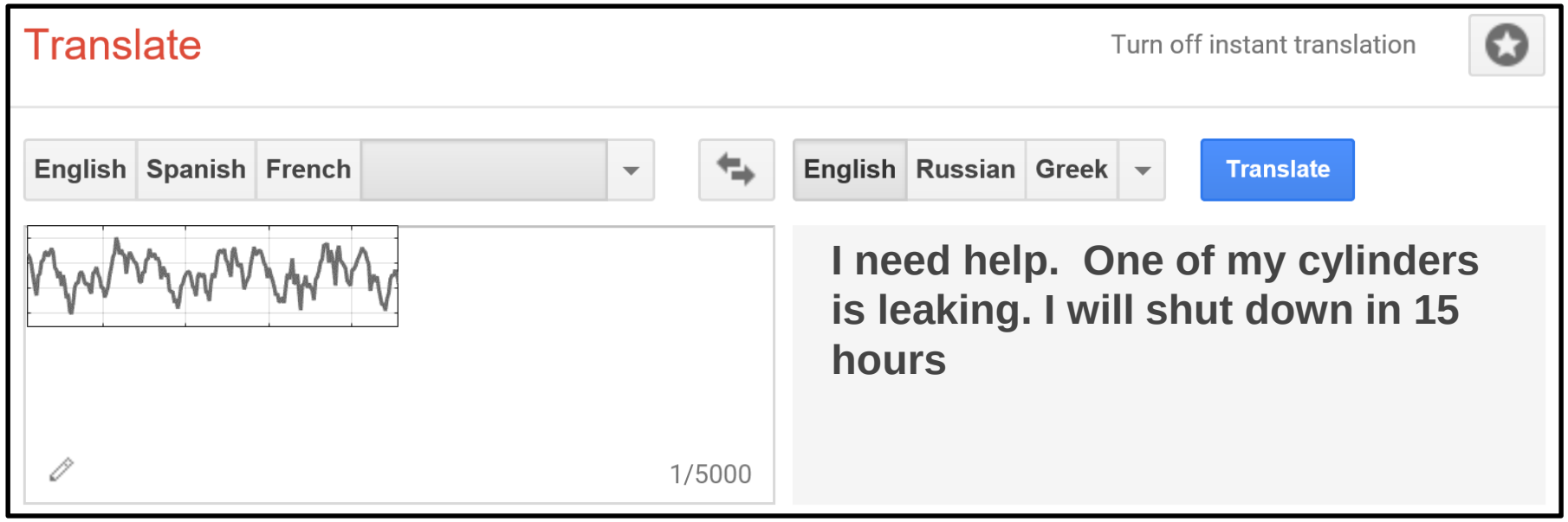


Pressure transducer is available



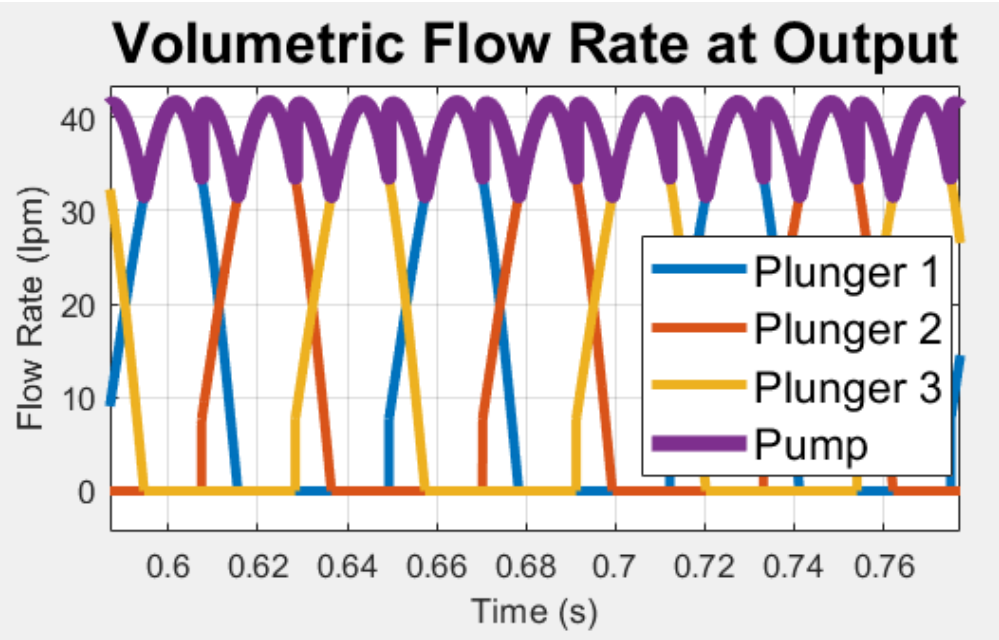


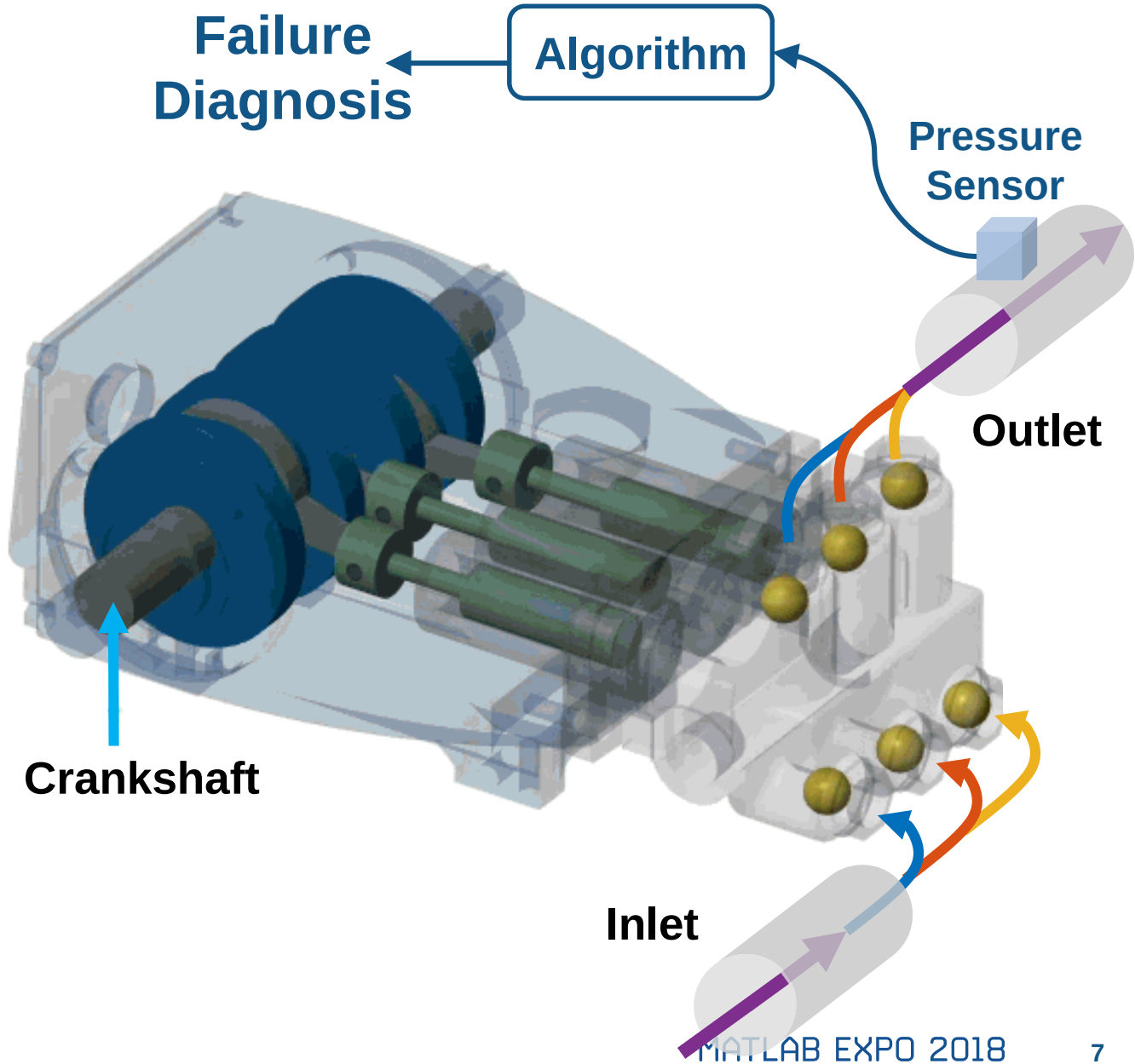


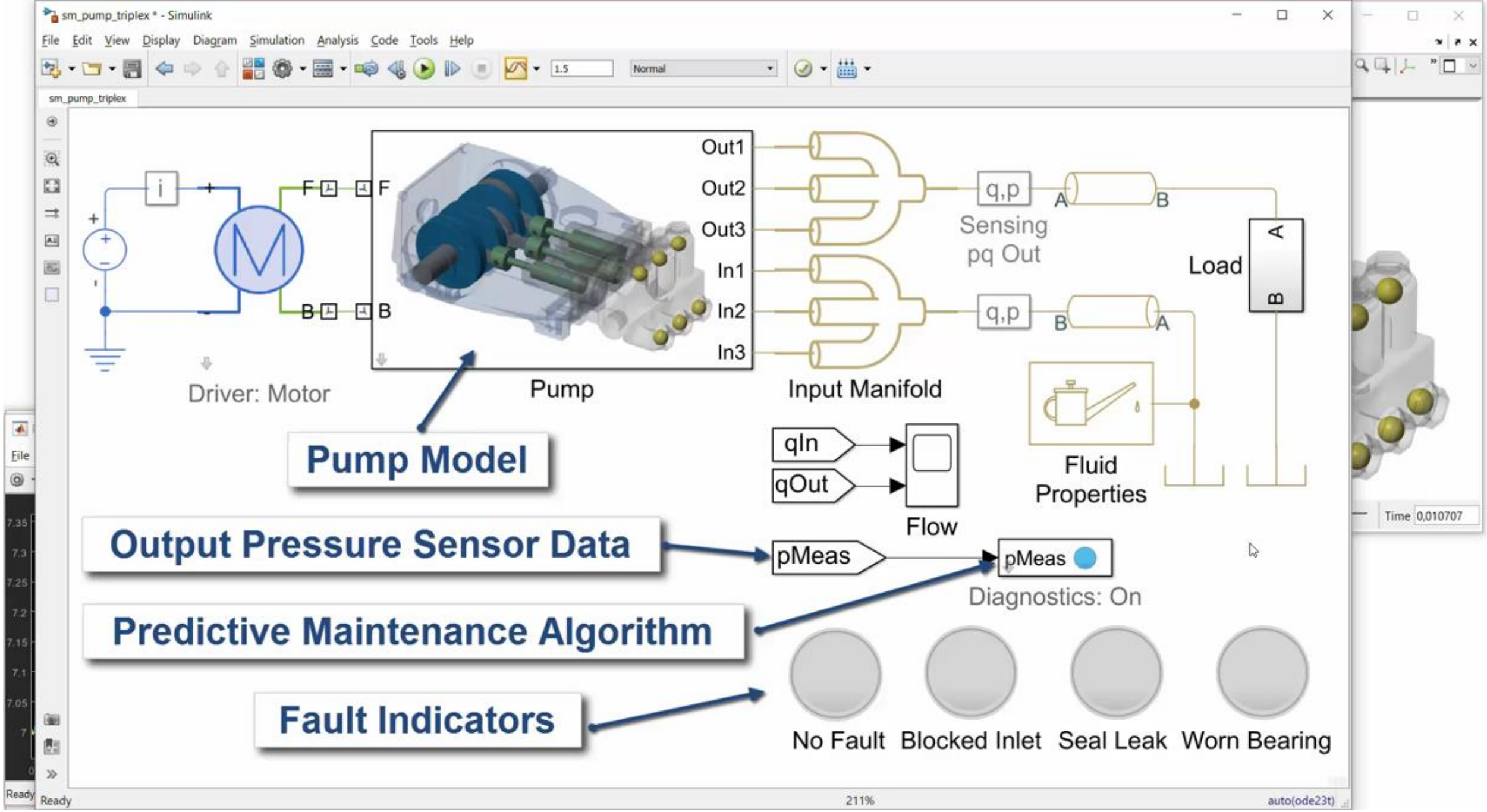


Triplex Pump

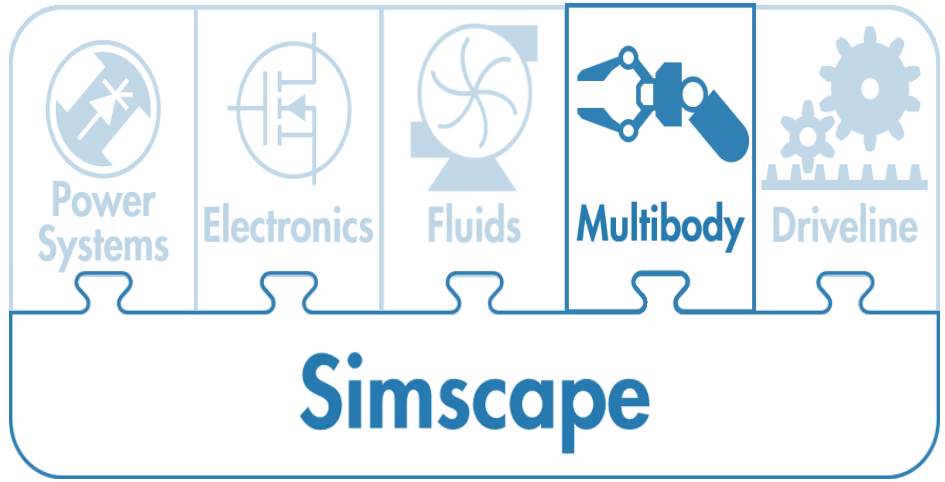
- Crankshaft drives three plungers
  - Each 120 degrees out of phase
  - One chamber always discharging
  - Smoother flow than single or duplex piston pumps



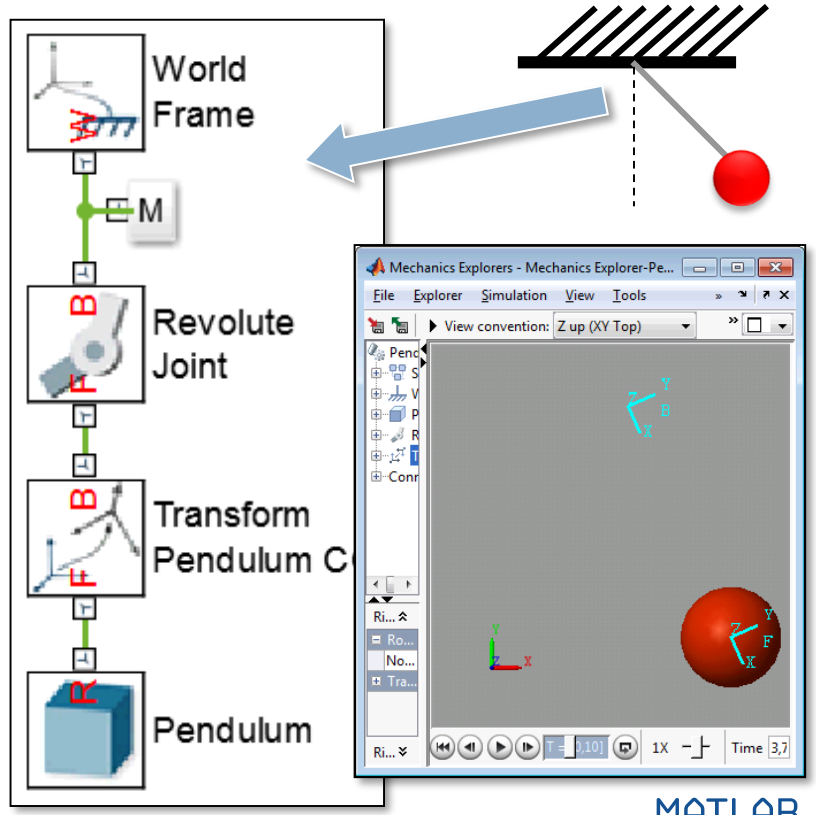



sm_pump_triplex * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
sm_pump_triplex
Out1
Out2
Out3
In1
In2
In3
F
B
Driver: Motor
Pump
Input Manifold
q,p
Sensing
pq Out
Load
A
B
Fluid
Properties
qIn
qOut
Flow
pMeas
Diagnostics: On
Pump Model
Output Pressure Sensor Data
Predictive Maintenance Algorithm
Fault Indicators
No Fault
Blocked Inlet
Seal Leak
Worn Bearing
Ready
211%
auto(ode23t)
Time 0,010707

Introduction to Simscape Multibody



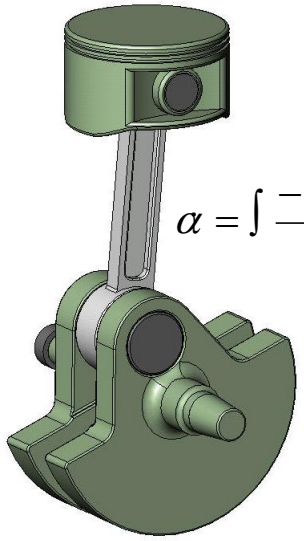
- Enables multibody simulation of 3D mechanical systems
- Construct model using bodies, joints, and forces
  - Model matches structure of system
  - No need to derive and program equations
- Primary uses
  - System-level analysis
  - Control development in Simulink
  - Predictive Maintenance study



Modeling Dynamic Systems: two approaches

First-Principles Modeling

Use an understanding of the system's physics to derive a mathematical representation



$$\alpha = \int \frac{-L_2 \sin(\alpha) + nw_2(-\sin(\alpha-\gamma))\sin(\gamma) - ne(-\sin(\alpha-\gamma))\cos(\alpha-\gamma)\alpha^2 - n\cos(\alpha-\gamma)\gamma^2}{1 - ne\sin^2(\alpha-\gamma)} \, d\gamma$$

Modeling Dynamic Systems: two approaches

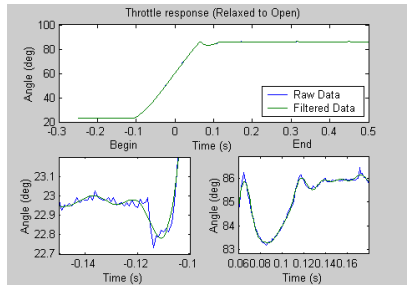
First-Principles Modeling

Use an understanding of the system's physics to derive a mathematical representation

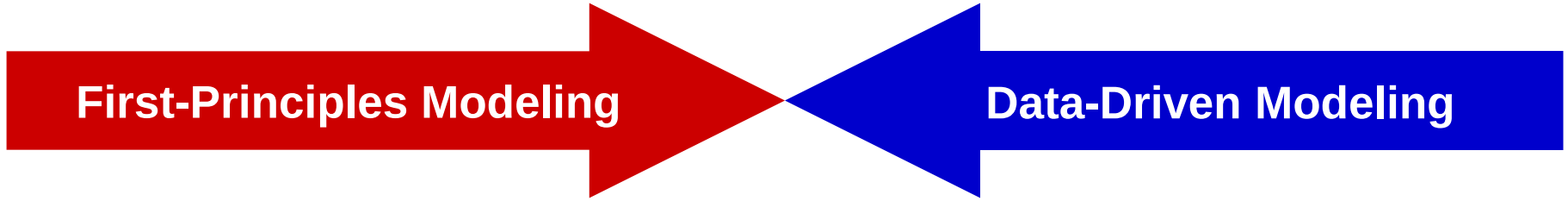
$$H(s) = \begin{bmatrix} \dfrac{s+1}{s^3+3s^2+2} \\ \dfrac{s^2+3}{s^2+s+1} \end{bmatrix}$$

Data-Driven Modeling

Use system test data to derive a mathematical representation



Both have Advantages & Disadvantages



Advantages:
- Insight in behavior
- Physical parameters

Disadvantages:
- Friction and turbulence?
- Time consuming
- Requires expertise

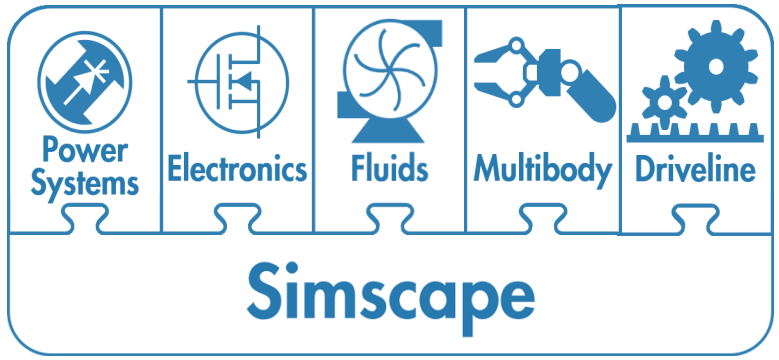
Advantages:
- Fast
- Accurate

Disadvantages:
- Requires plant
- Requires data acquisition system

Tools that span both modeling approaches
Enhance Advantages, Reduce Disadvantages

First-Principles

Simulink



Partial Differential Equation (FEM)

Symbolic Math

Simulink Design Optimization

Data-Driven

System Identification

Machine Learning

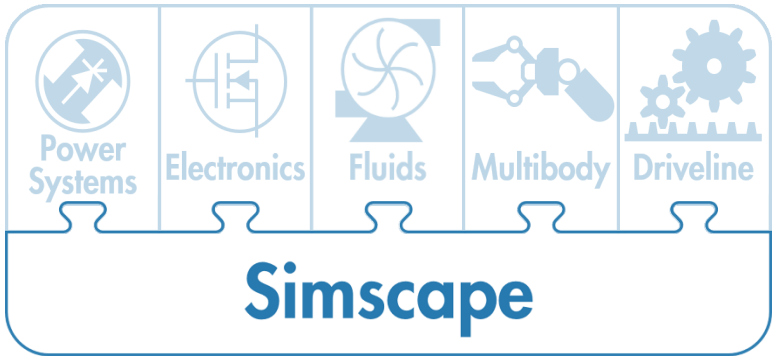
Test & Measurement Tools

Tools that span both modeling approaches
Enhance Advantages, Reduce Disadvantages

First-Principles

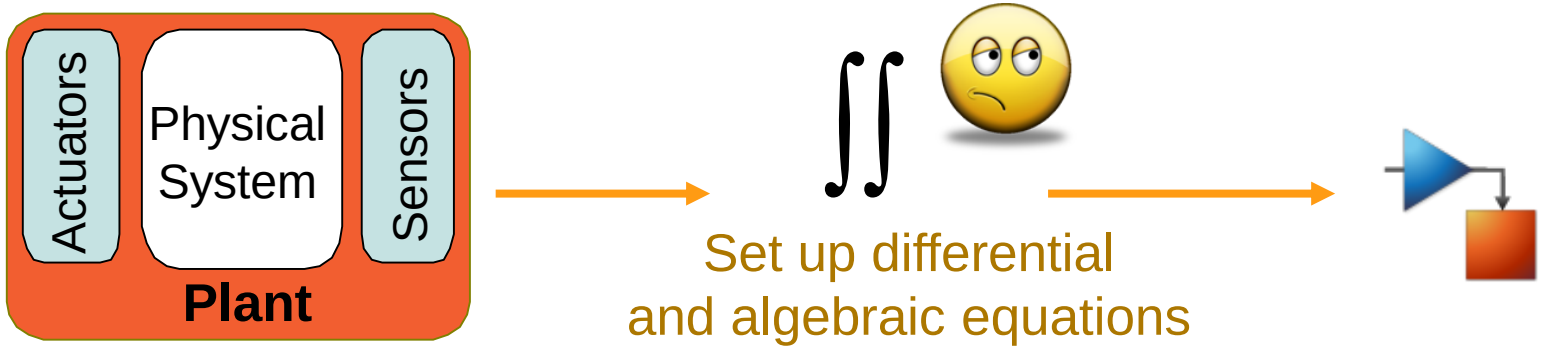
Data-Driven

Simulink

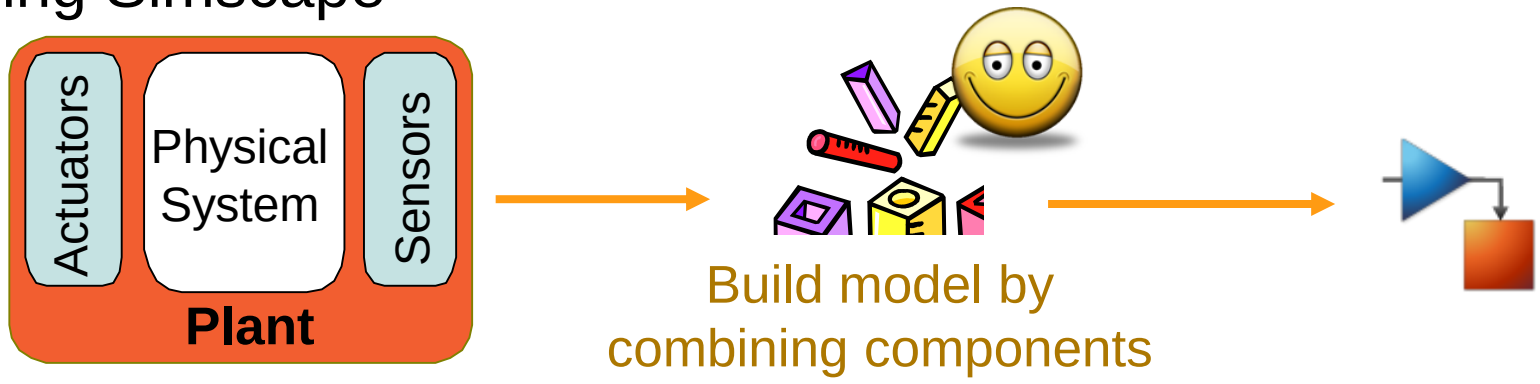


First-Principles Modeling in Simulink

- Traditional process

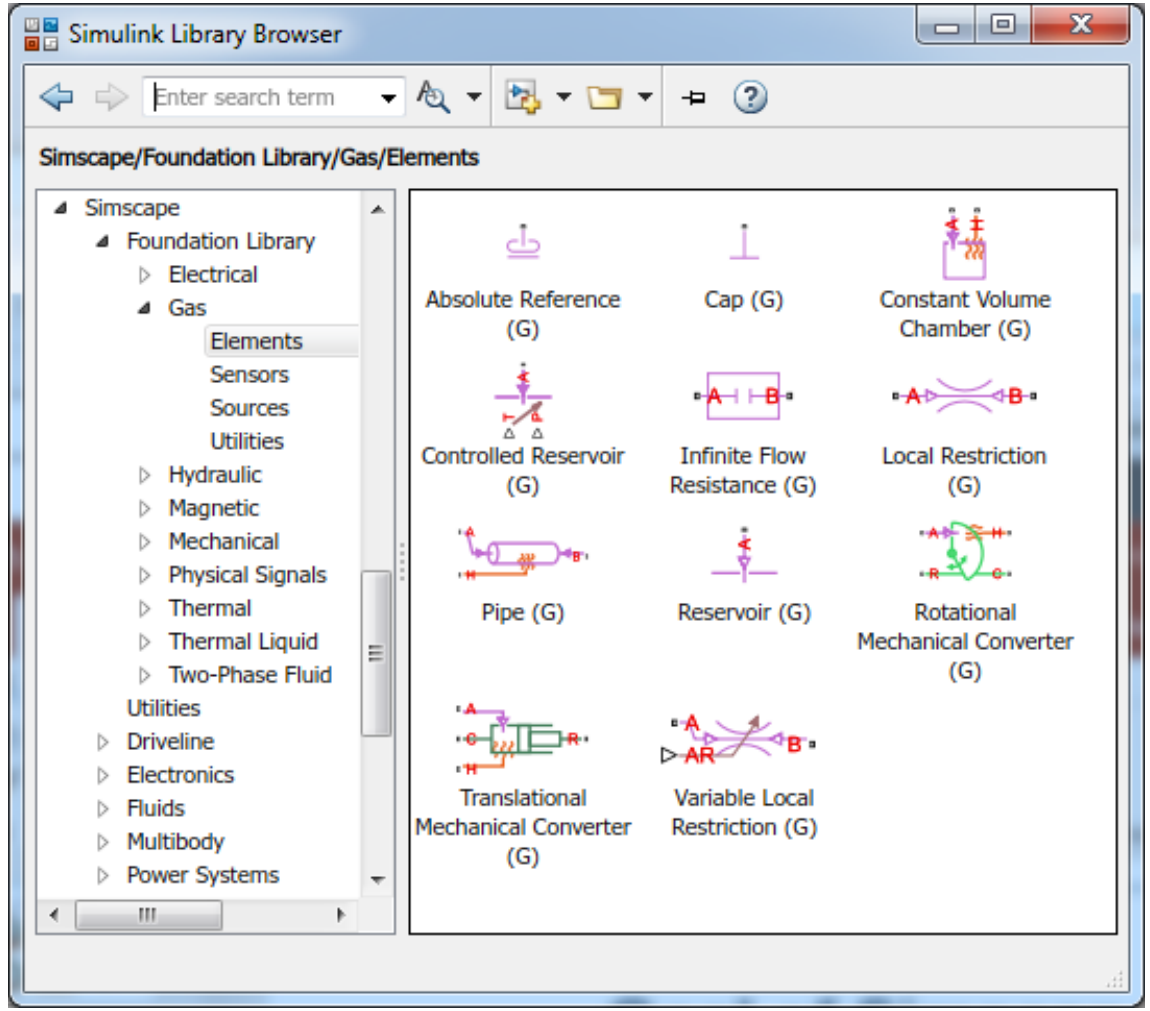


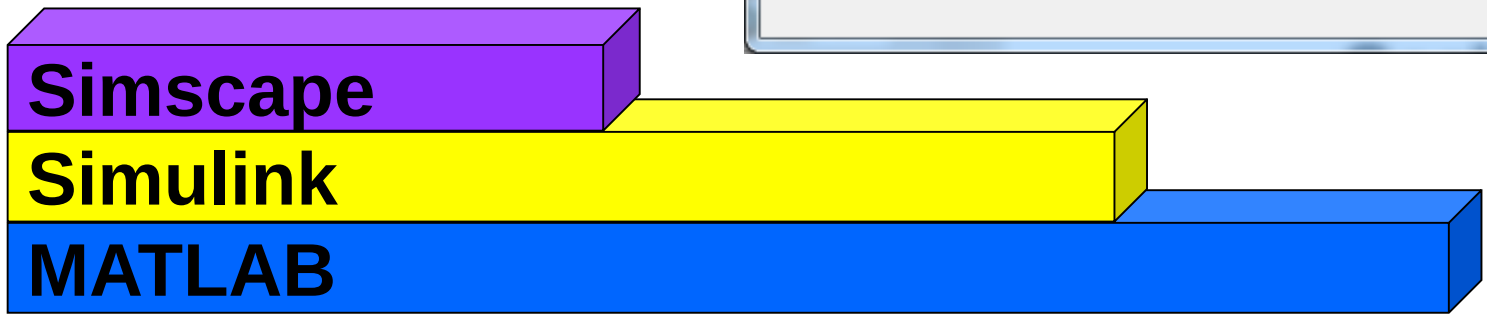
- Using Simscape



Goal of Simscape

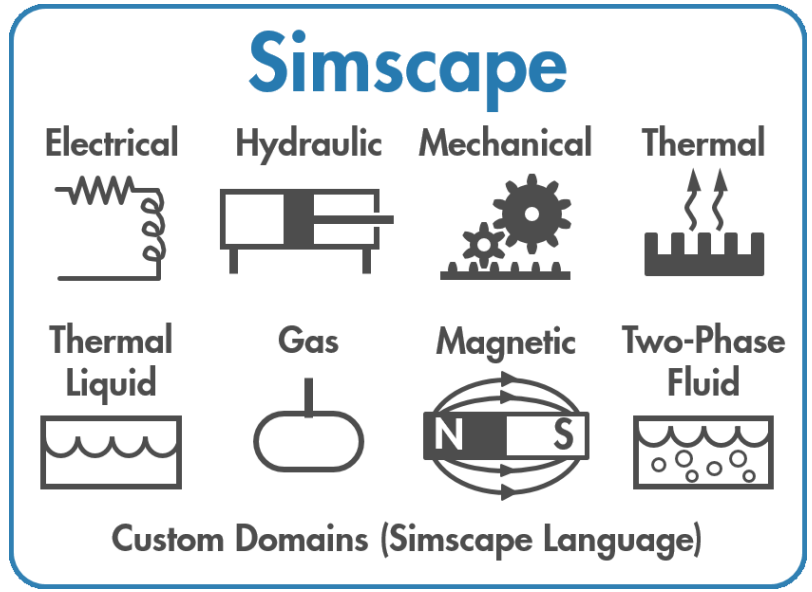
- As easy to use as Simulink; but easier to use for creating a model of a physical system





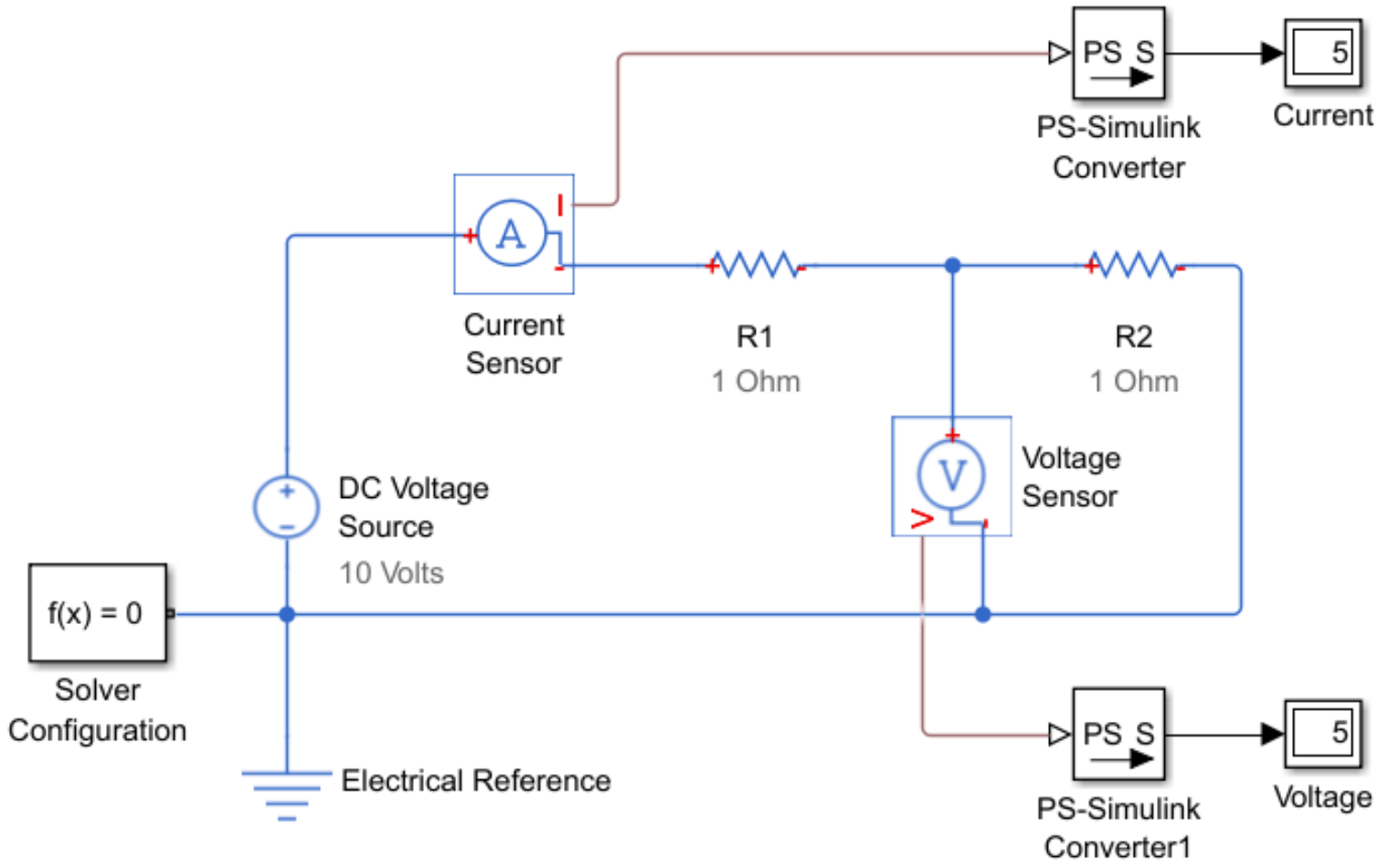
Simscape: modeling in multiple domains

- Use Fundamental Analogy between Physical Domains



Domain	Across Variable	Through Variable
Mechanical	Velocity Angular Velocity	Force Torque
Hydraulic	Pressure	Flow Rate
Electrical	Voltage	Current
Magnetic	MMF	Flux
Thermal	Temperature	Heat Flow
Thermal Fluids	Pressure Temperature	Mass Flow Rate Energy Flow

How things are measured

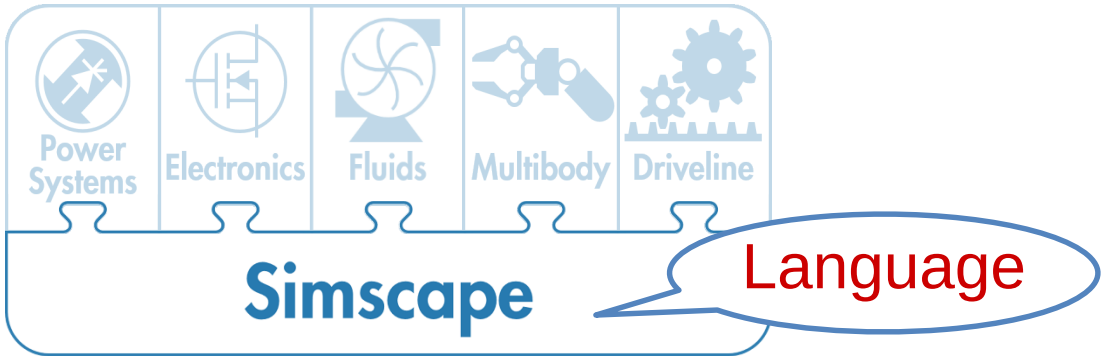


Tools that span both modeling approaches
Enhance Advantages, Reduce Disadvantages

First-Principles

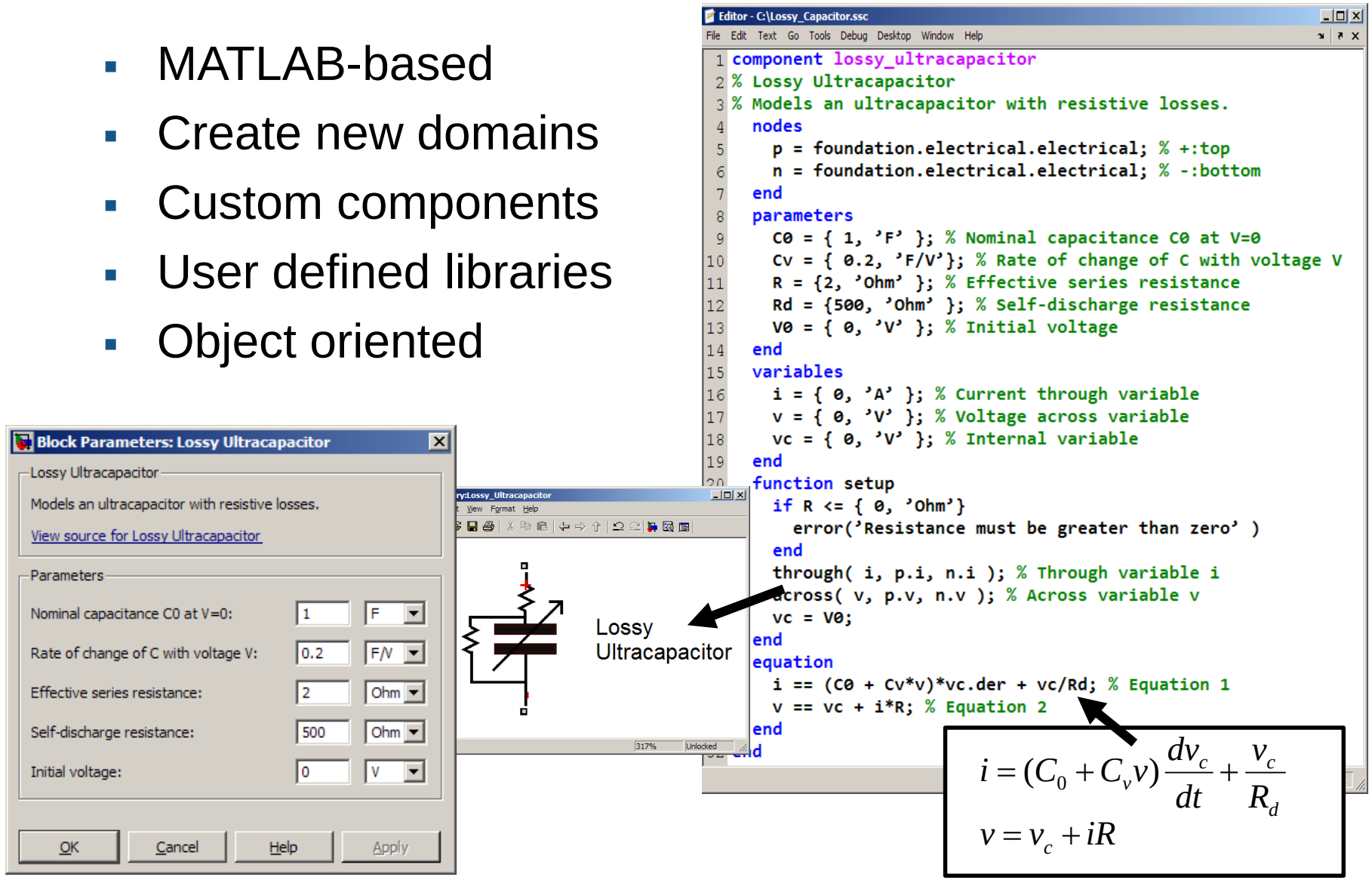
Data-Driven

Simulink



Simscape Language

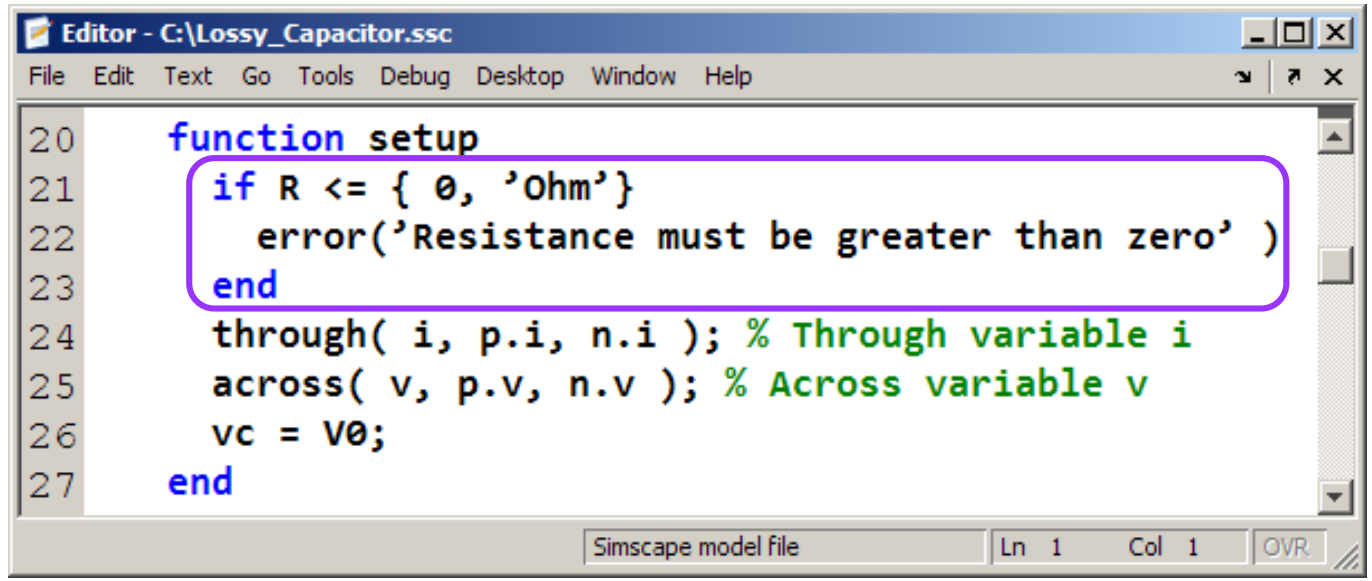
- MATLAB-based
- Create new domains
- Custom components
- User defined libraries
- Object oriented



Simscape Language: setup

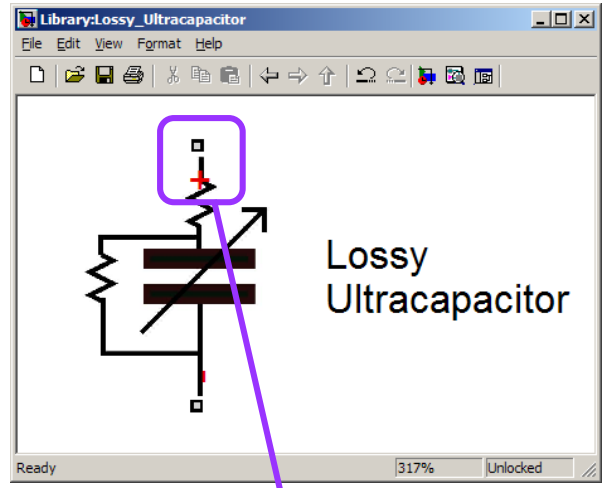
- Syntax closely follows MATLAB language

- Use MATLAB functions and expressions
  - Analyze parameters
  - Perform preliminary computations
  - Initialize system variables



Simscape Language: nodes

- Define the physical network ports
- Reuse existing physical domains to extend an existing library
- Define new physical domains to create a new library



Editor - C:\Lossy_Capacitor.ssc

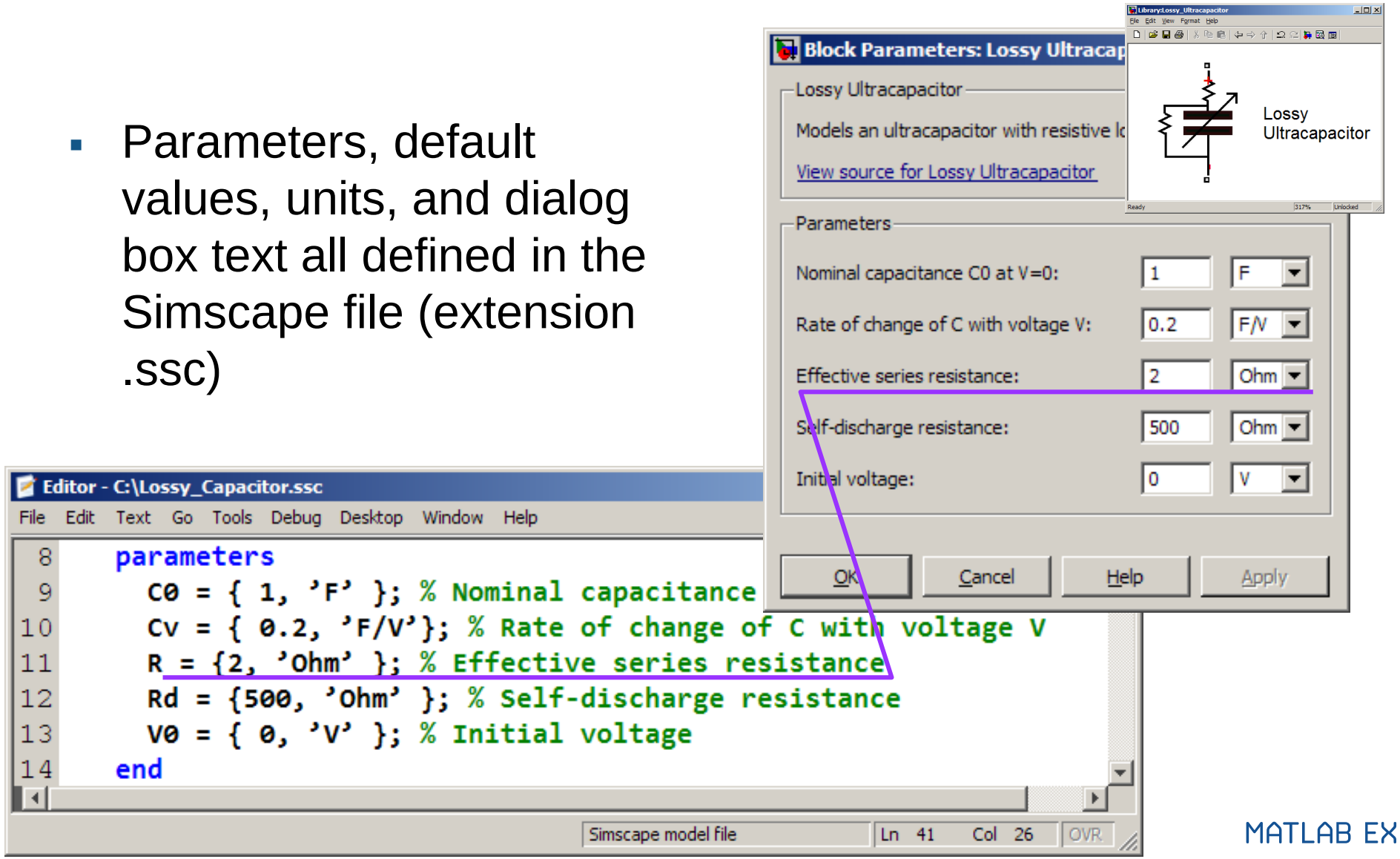
File Edit Text Go Tools Debug Desktop Window Help

```
4    nodes
5      p = foundation.electrical.electrical; % +:top
6      n = foundation.electrical.electrical; % -:bottom
7    end
```

Simscape model file Ln 4 Col 1 OVR

Simscape Language: parameters

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

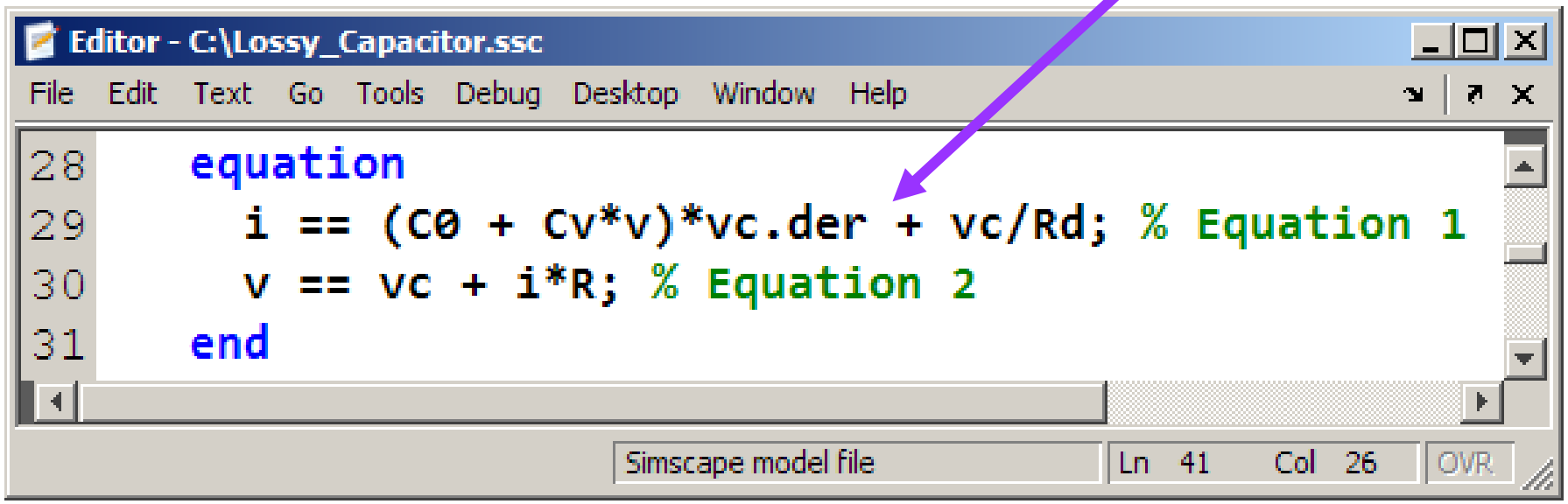


Simscape Language: equation

- Equations defined implicitly means no pre-defined inputs and outputs

$$i = (C_0 + C_v v)\frac{dv_c}{dt} + \frac{v}{R_d}$$

$$v = v_c + iR$$



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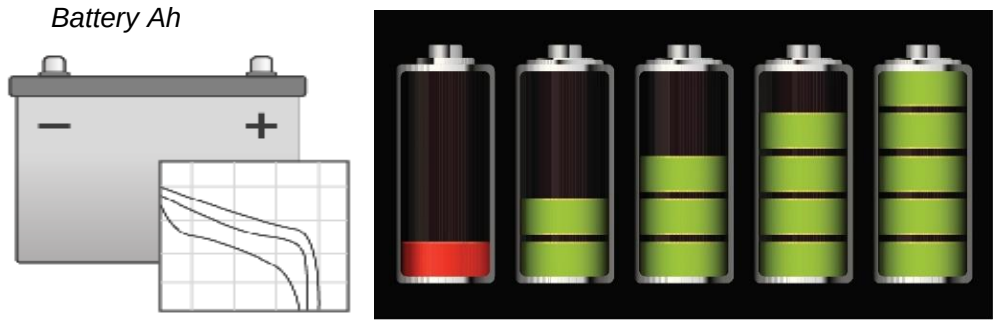
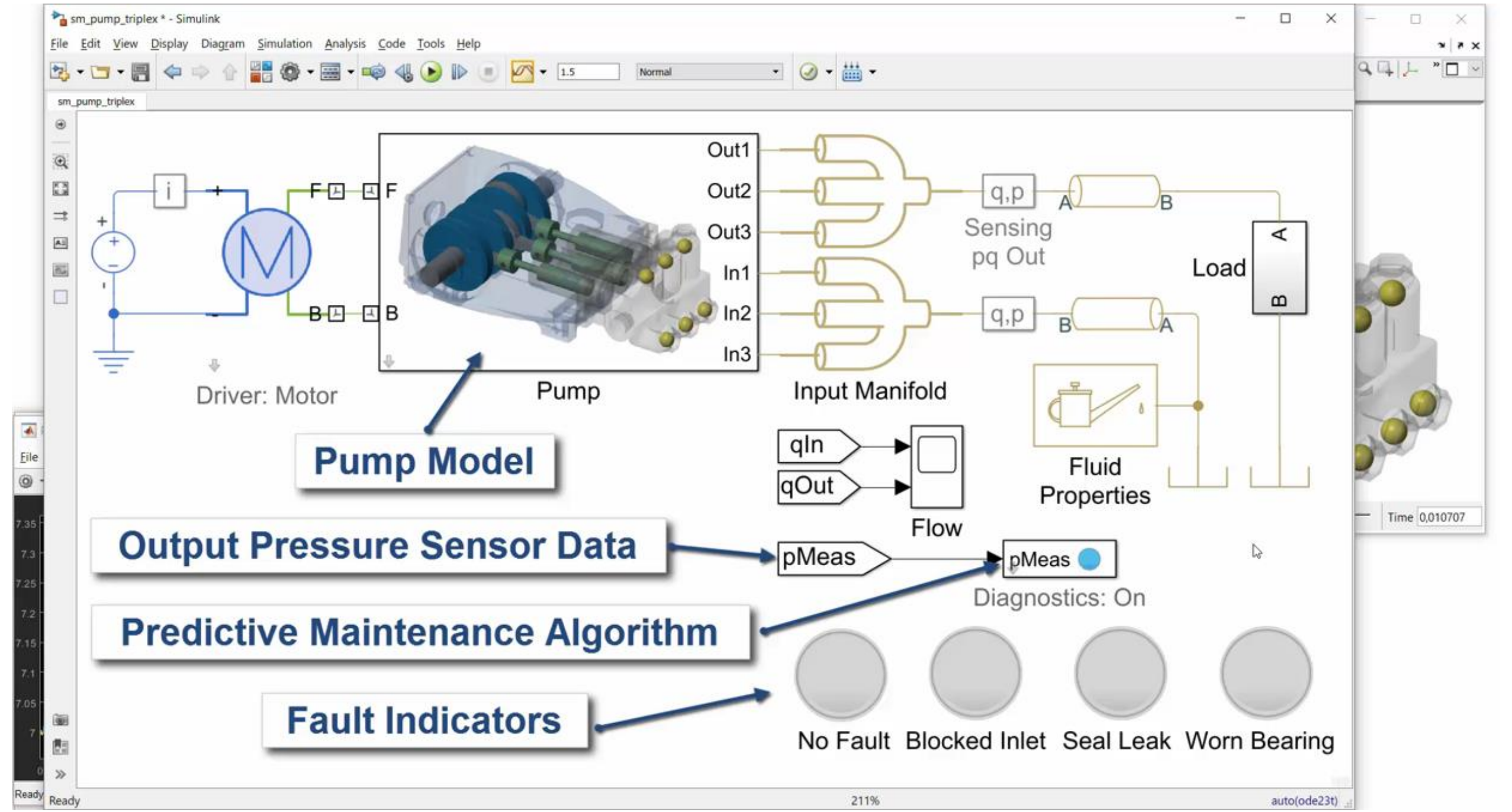


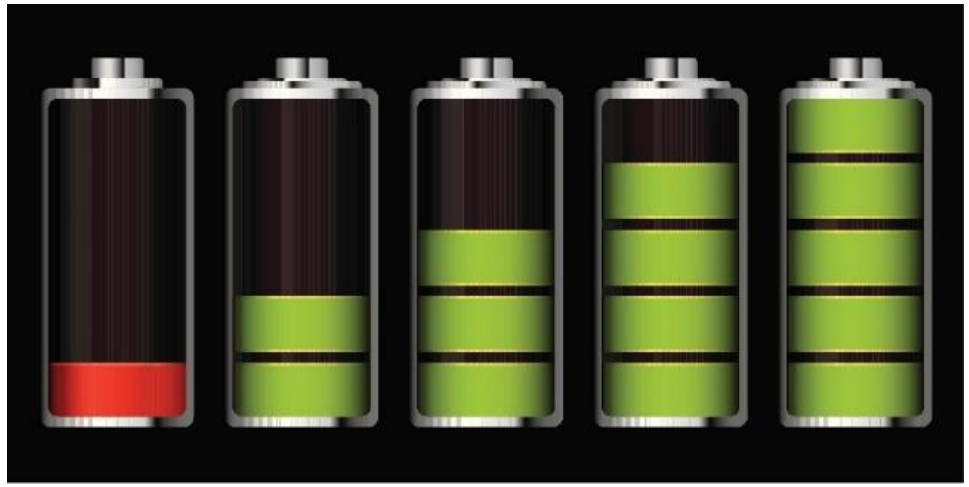

sm_pump_triplex * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
sm_pump_triplex
Out1
Out2
Out3
In1
In2
In3
F
B
Driver: Motor
Pump
Input Manifold
q,p
Sensing
pq Out
Load
Fluid
Properties
qIn
qOut
Flow
pMeas
Diagnostics: On
Pump Model
Output Pressure Sensor Data
Predictive Maintenance Algorithm
Fault Indicators
No Fault
Blocked Inlet
Seal Leak
Worn Bearing
Ready
211%
auto(ode23t)
Time 0,010707

Battery Management System

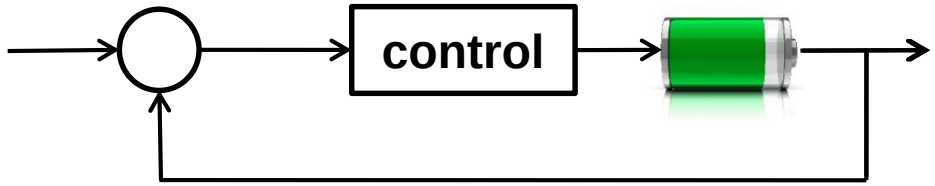
- BMS is necessary
  - Safety
  - Performance
  - Durability

Battery Management System

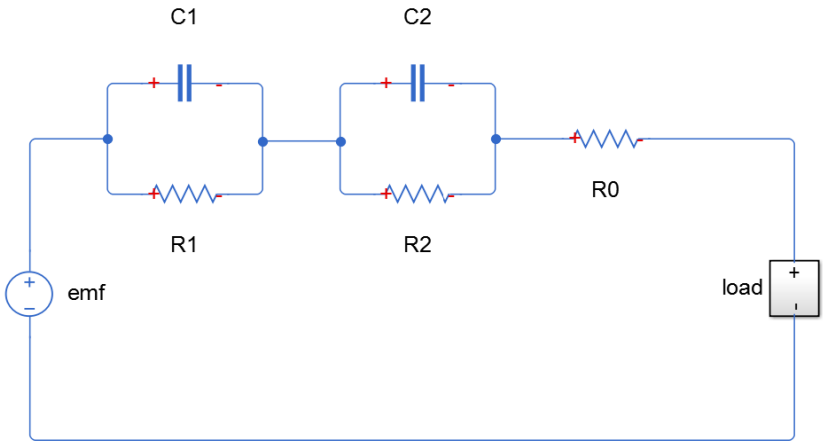
- BMS includes
  - Monitoring :
    - State of Charge (SoC)
    - State of Health (SoH)
  - Control:
    - Charging
    - Temperature
    - Current

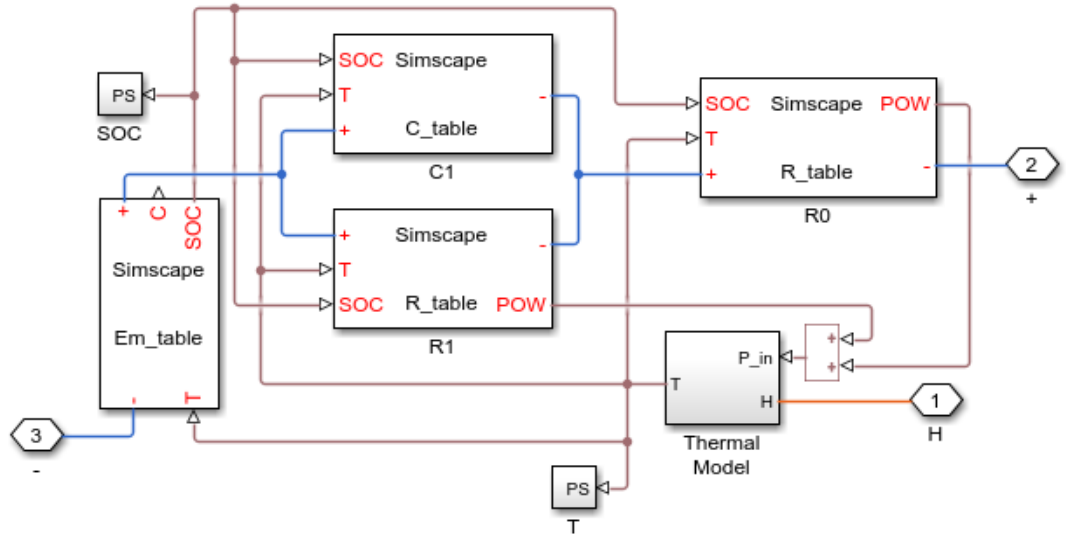


Competent Battery Model



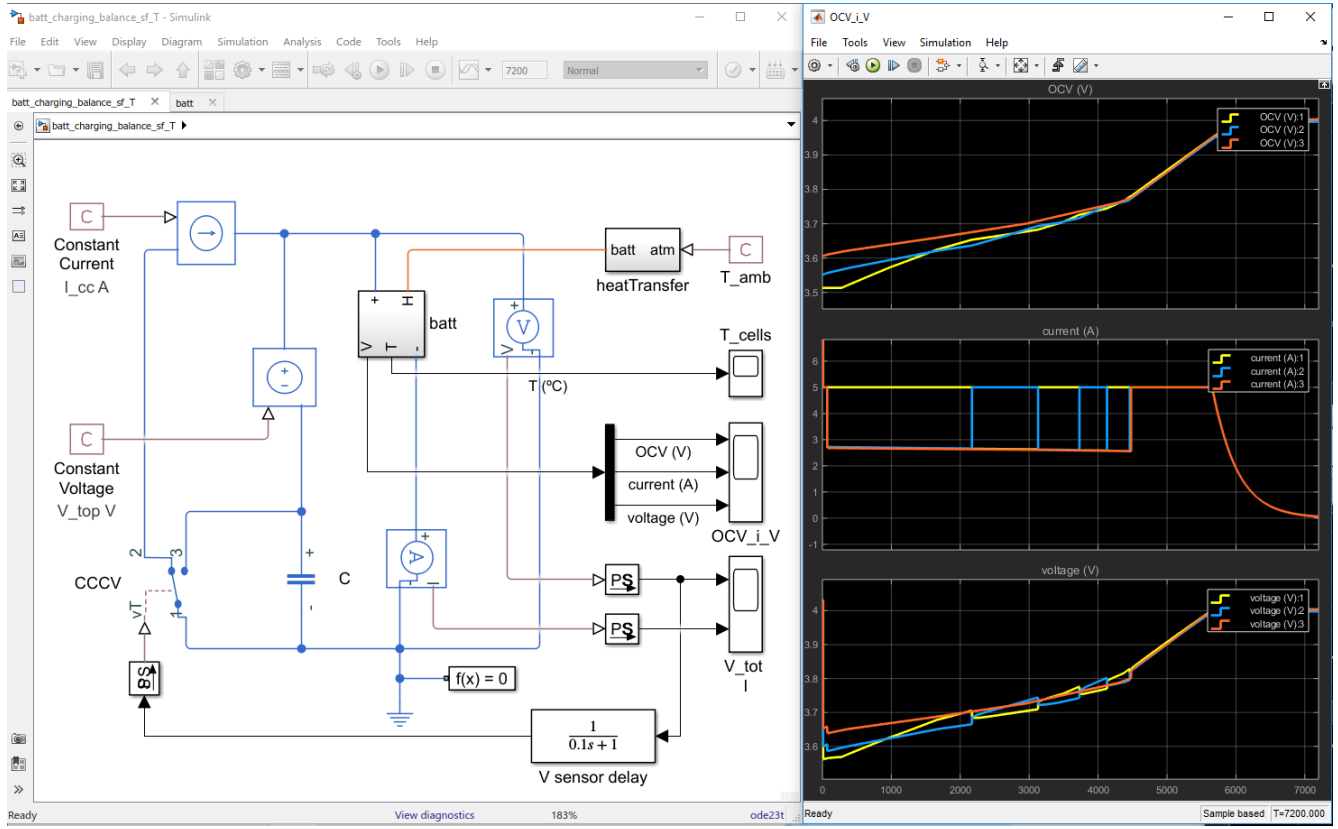
- Battery Modeling
  - Equivalent Circuit Model
  - Parameter Estimation





Battery Management System

- Charging Control:
  - CCCV Charging method
  - Cell Balancing Ensure all cells have equivalent SoC during charging.



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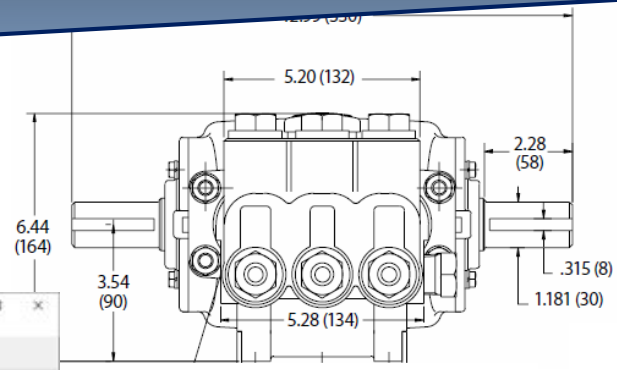
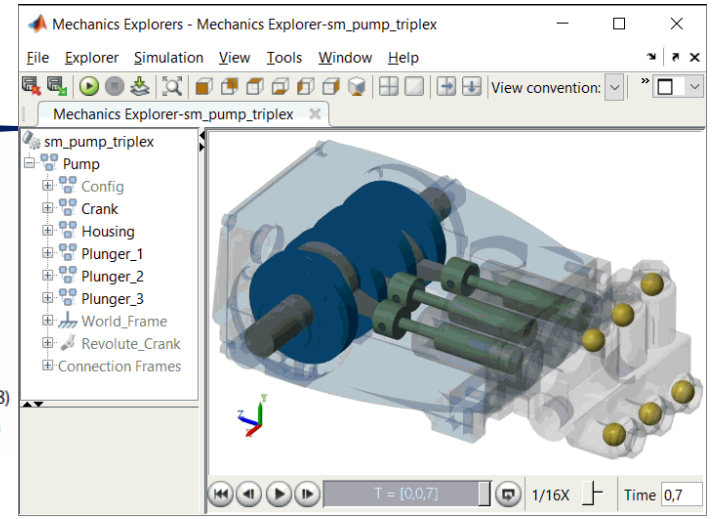
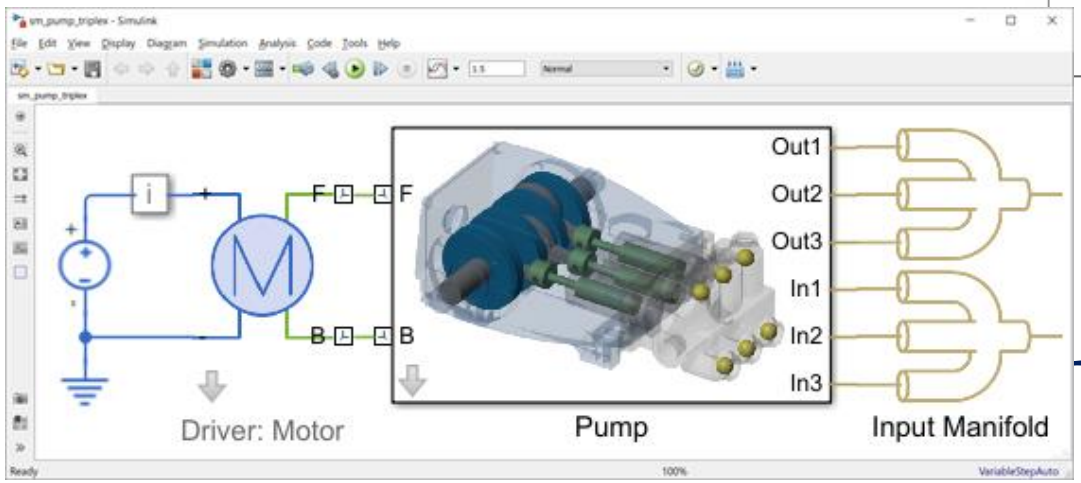


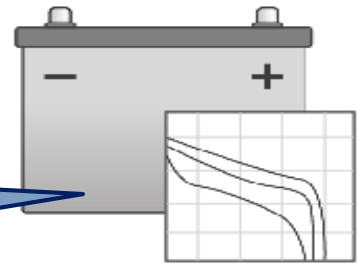


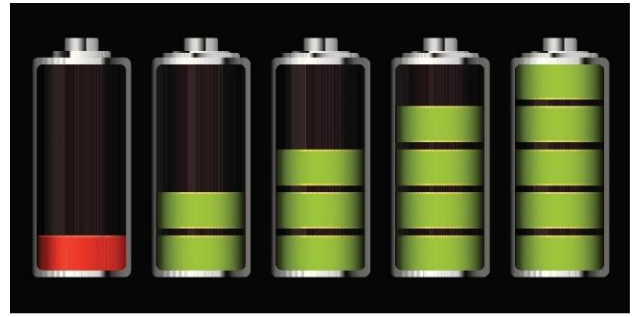


Extend and explore to create a multi-domain “digital twin”

Add new components to investigate innovative design

Battery Ah





Physical Modeling Training

- Simscape
- Multibody
- Fluids
- Electrical Power
- Driveline

Exhibition
MathWorks Training Booth

Thank you for attending…

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