

MathWorks
AUTOMOTIVE
CONFERENCE 2019

차량 모델의 매개변수화 및
제어 최적화 자동화

강효석 Ph.D



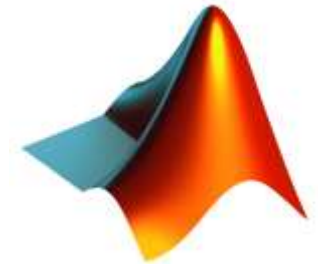
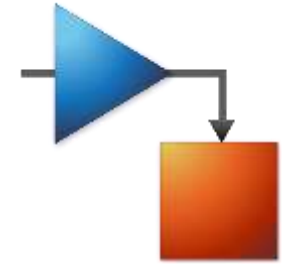
Problem - Design Electric Car

- System level architecture
- Control design and tuning



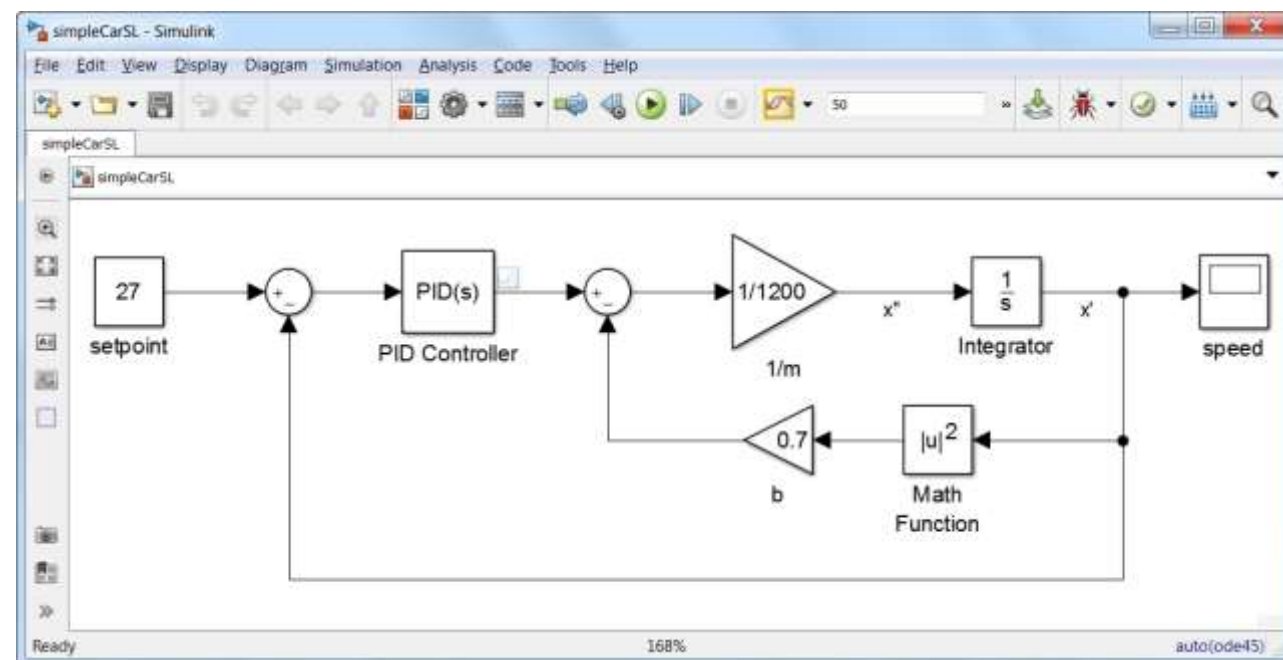
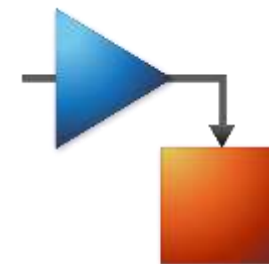
Approach

- Modeling and Simulation with Simulink
- The power of MATLAB
 - Performance optimization
 - Parameter estimation



Simulink

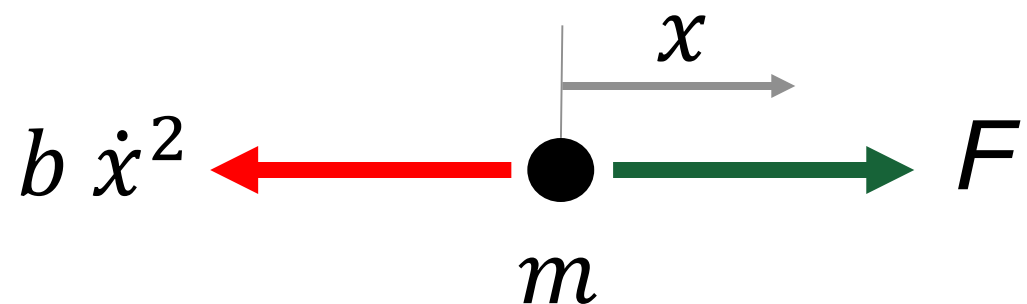
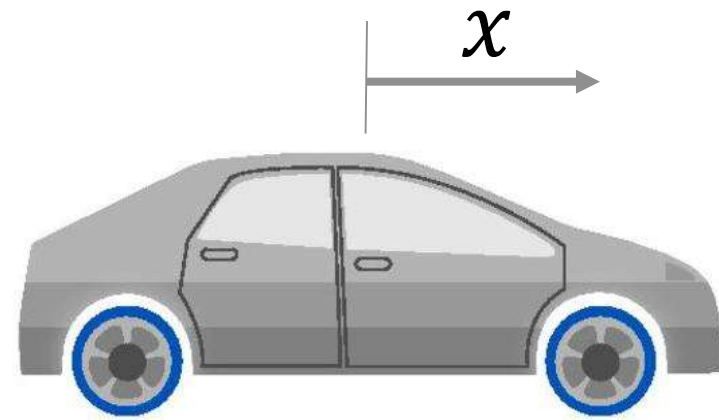
- Model and simulate dynamic systems
- Signal-based modeling
- Need equations



Dynamic System

Longitudinal Control of a Vehicle

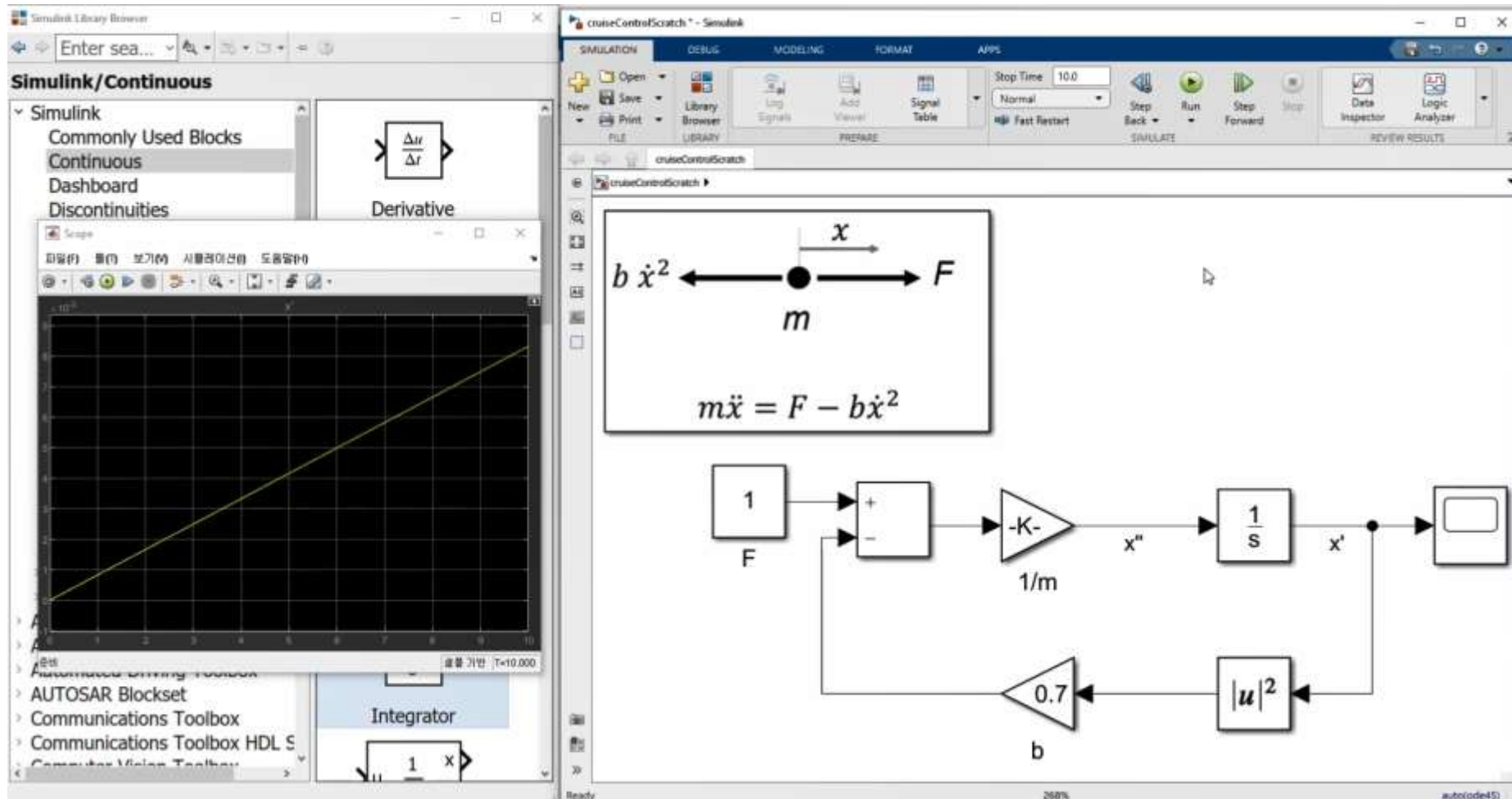
- Input & Output
 - F : Force(input)
 - \dot{x} : Speed(Output)
- Parameters
 - b : Air-drag parameter
 - m : Mass



$$m\ddot{x} = F - b\dot{x}^2$$

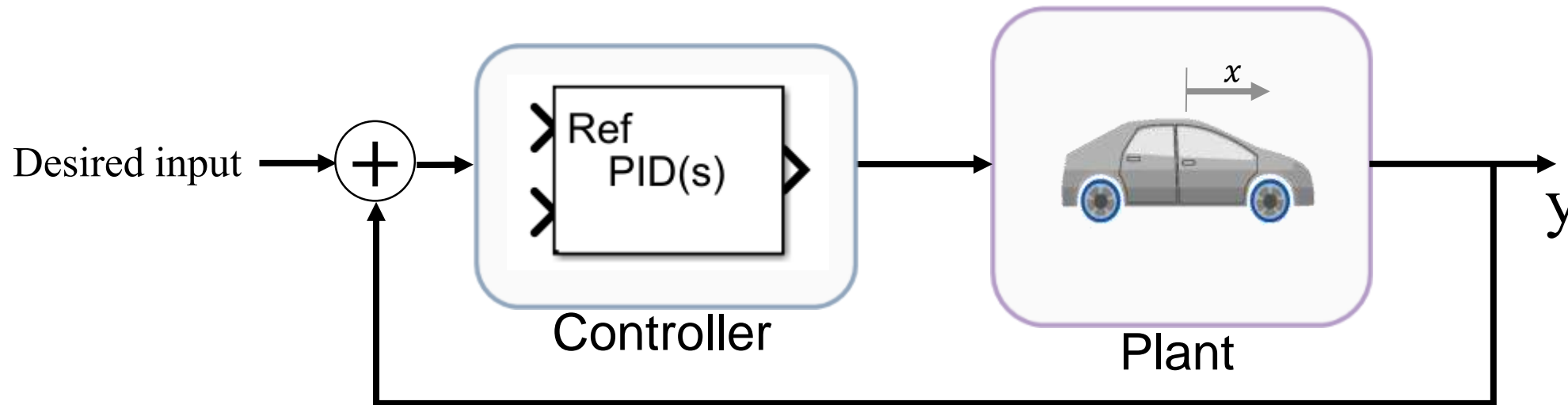
Dynamic System Modeling using Simulink

Longitudinal Control of a Vehicle



Dynamic System Modeling using Simulink

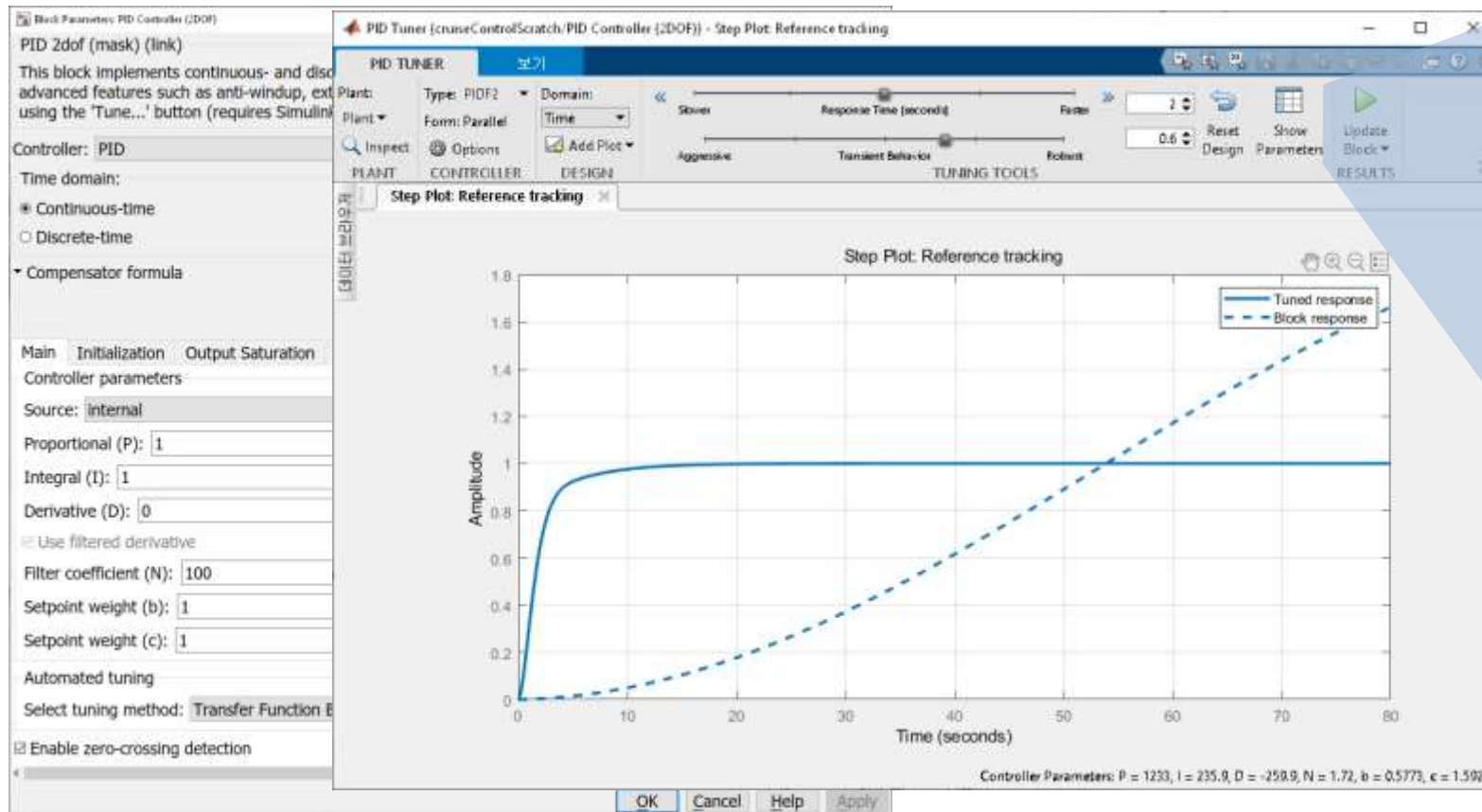
Longitudinal Control of a Vehicle



Simulating plant and controller **in one environment** allows you to **optimize system-level performance**

Dynamic System Modeling using Simulink

Longitudinal Control of a Vehicle



Controller Parameters		
	Tuned	Block
P	1233.1678	1
I	235.8852	1
D	-259.8734	0
N	1.7204	100
b	0.57727	1
c	1.5922	1

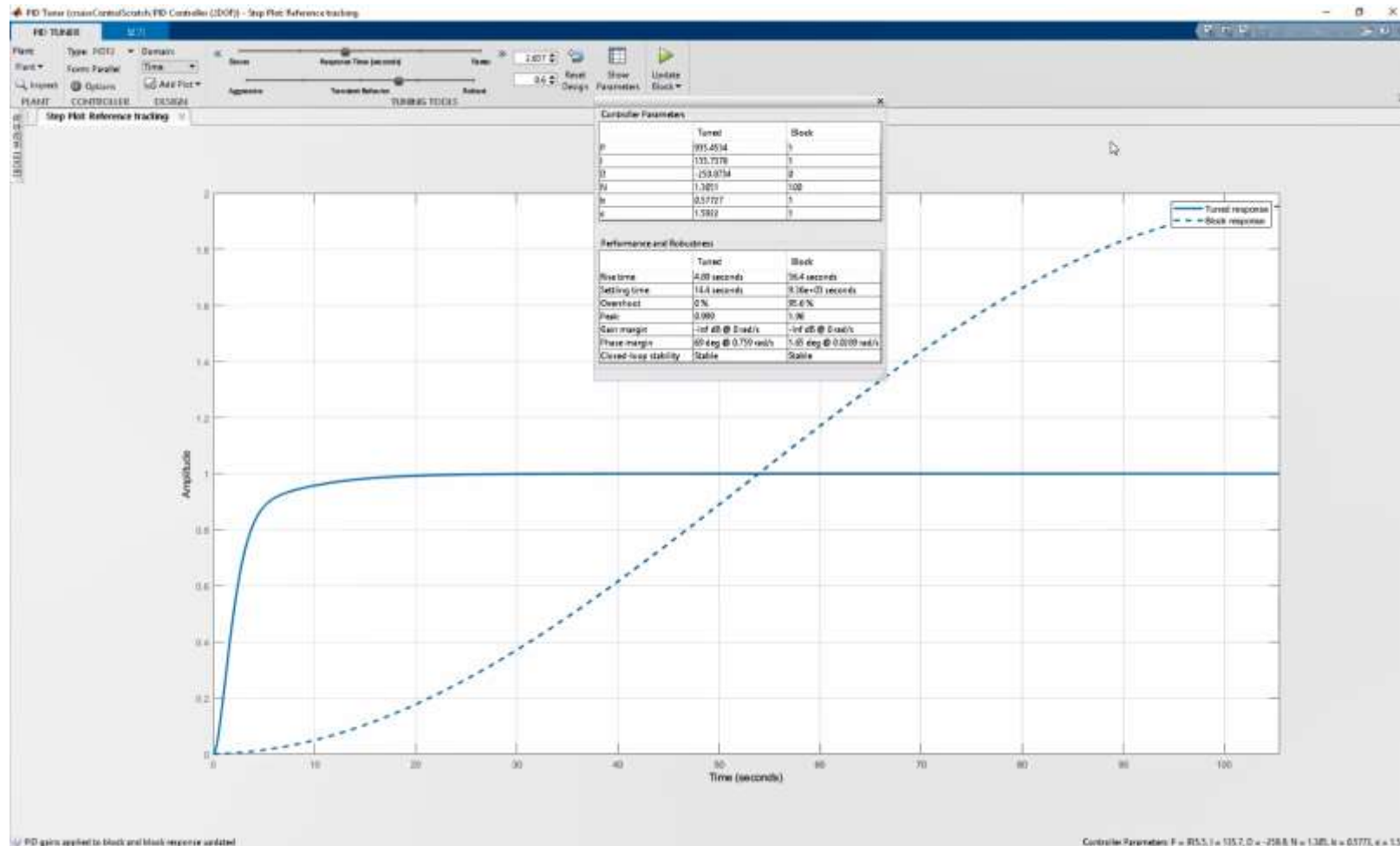
Performance and Robustness		
	Tuned	Block
Rise time	3.71 seconds	36.4 seconds
Settling time	10.9 seconds	9.36e+03 seconds
Overshoot	0 %	95.6 %
Peak	0.999	1.96
Gain margin	-Inf dB @ 0 rad/s	-Inf dB @ 0 rad/s
Phase margin	69 deg @ 1 rad/s	1.65 deg @ 0.0289 rad/s
Closed-loop stability	Stable	Stable

*PID Tuner App

*required Simulink Control Design

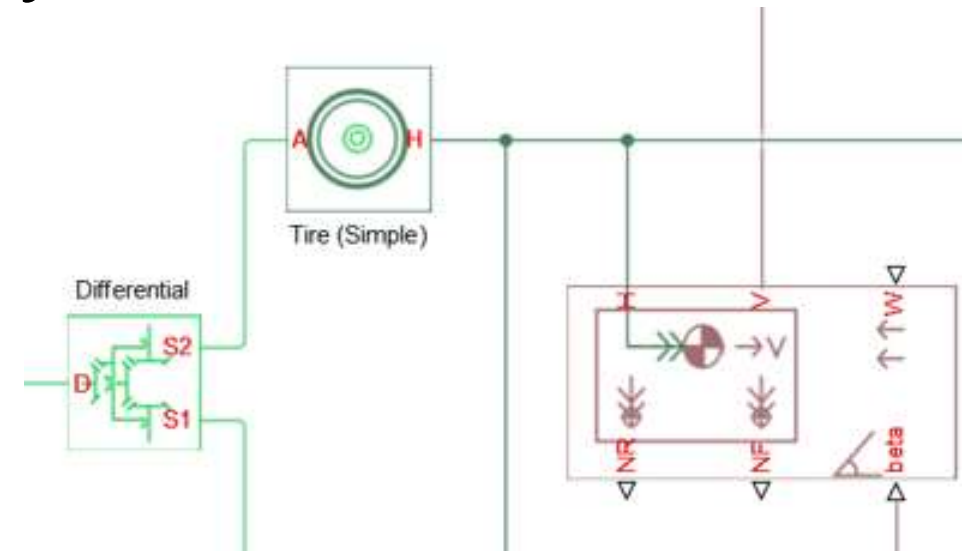
Dynamic System Modeling using Simulink

Longitudinal Control of a Vehicle



Simscape

- Model and simulate dynamic systems
- Network-based modeling
- Intuitive, reusable, less math
- Simscape Language



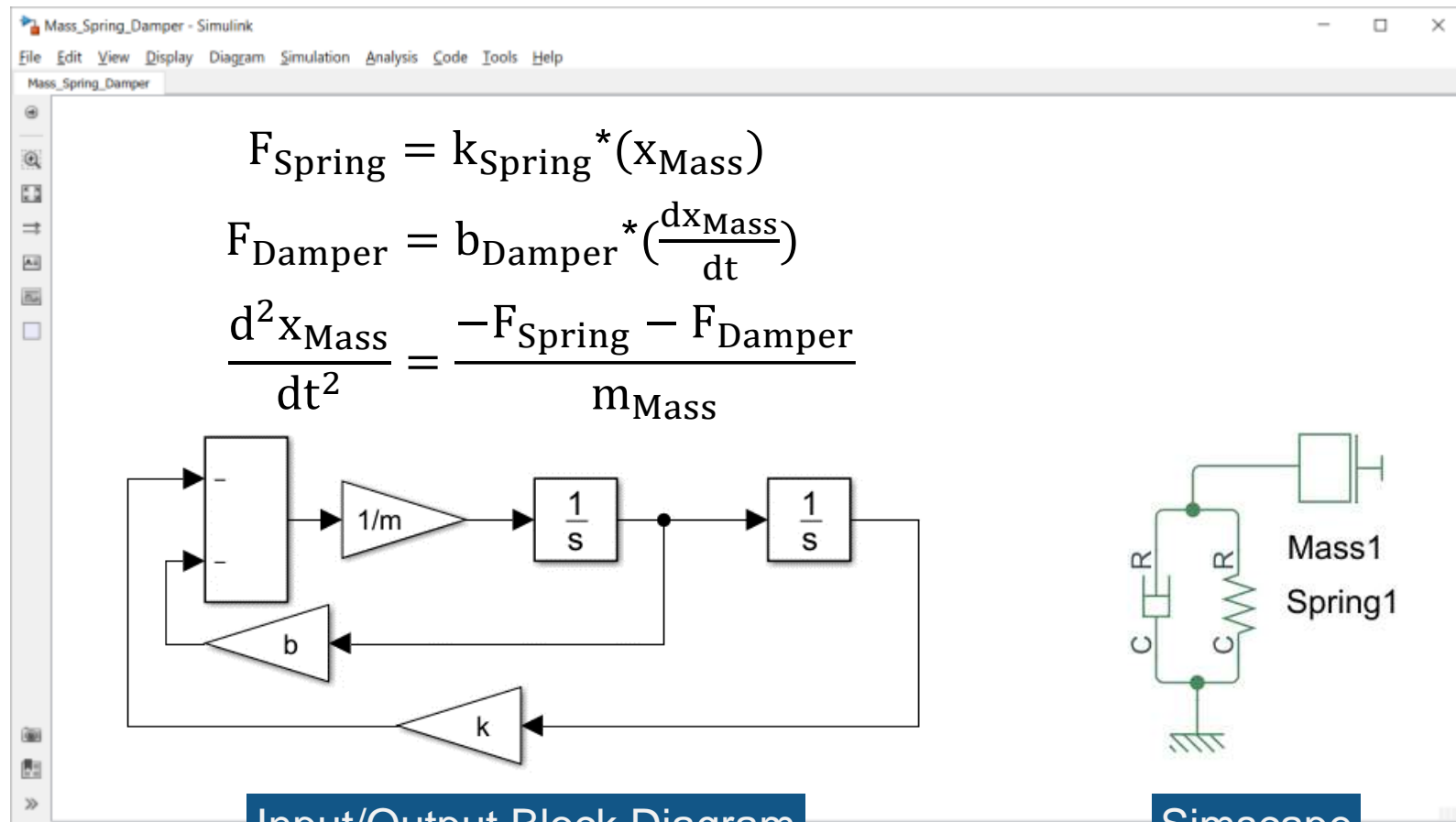
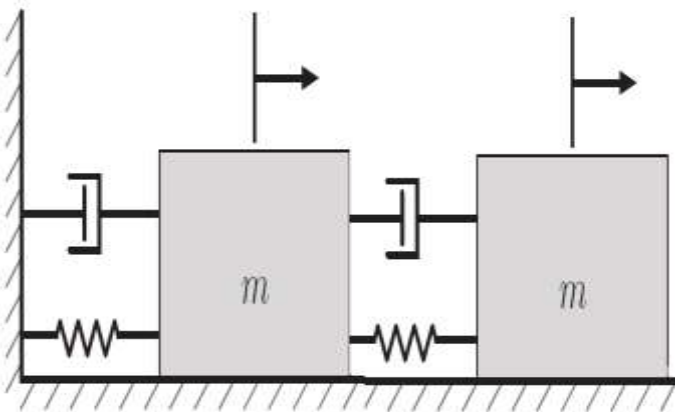
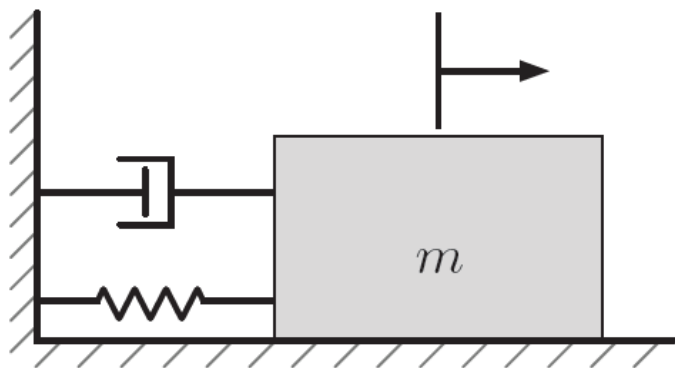
$$i = (C_0 + C_v v) \frac{dv}{dt} + \frac{v}{r_d}$$

```

Editor - C:\MyComponents\LossyUltraCapacitor.ssc
40 equations
41   i == (C0 + Cv*vc) *vc.der + vc/Rd;
42   v == vc + i*R;
43 end
  
```

Compare between Simulink and Simscape

Mass-Spring-Damper System



Input/Output Block Diagram

Simscape

Dynamic System Modeling using Simscape

Longitudinal Control of a Vehicle

The image shows the Simulink/Simscape software interface. On the left is the Simscape library browser, and on the right is the main workspace showing a diagram with two blocks: a 'Signal Converter' and a 'Local solver for Physical Networks'.

Signal Converter

Local solver for Physical Networks

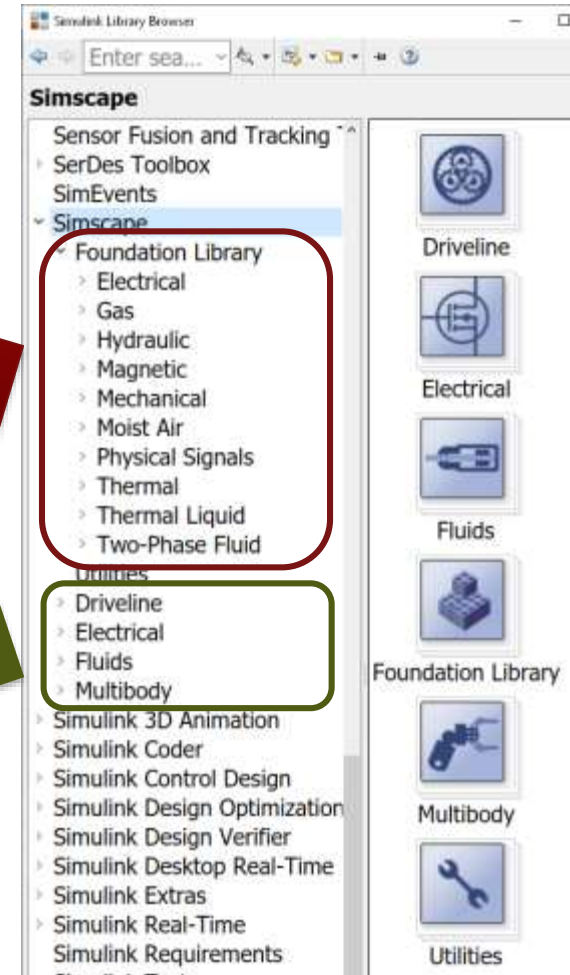
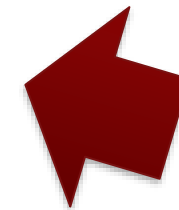
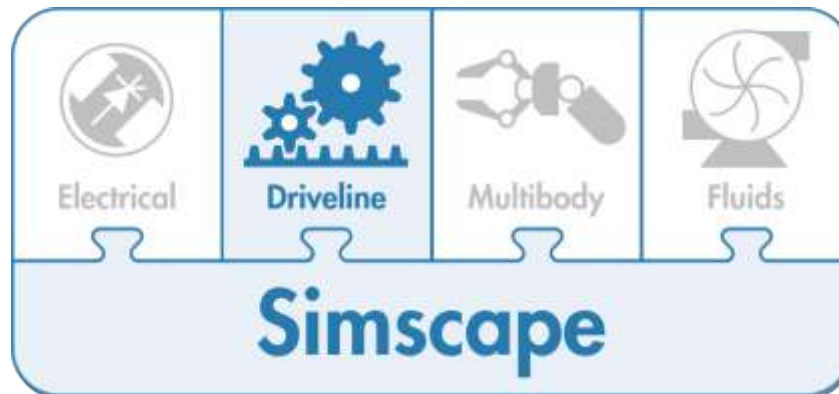
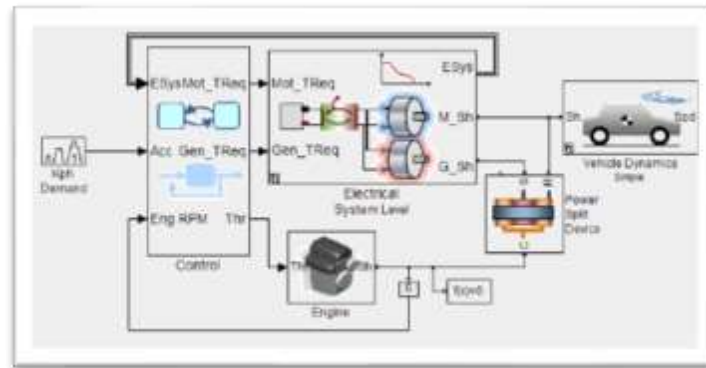
Simscape Library Resources

1. Find components in the [Simscape library](#).
For more information, see [Physical Modeling - Blocks](#).
2. Connect the components to form a physical network.
For more information, see [Essential Steps for Constructing a Physical Model](#).
3. [Explore simulation results](#) using [sscexplore](#)

Dynamic System Modeling using Simscape

Longitudinal Control of a Vehicle

Foundation physical modeling blocks in more than 10 different physical domains

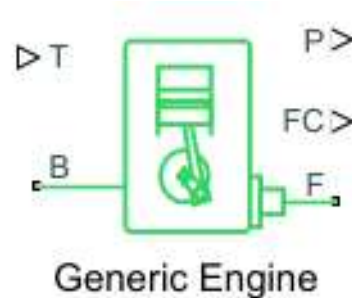


Simscape Driveline Component Models

Engines, Shafts, Gears, Clutches, Tires

- Mean-Value

- Torque averaged over piston cycle
- Use for engine sizing and throttle transients



Model parameterization:

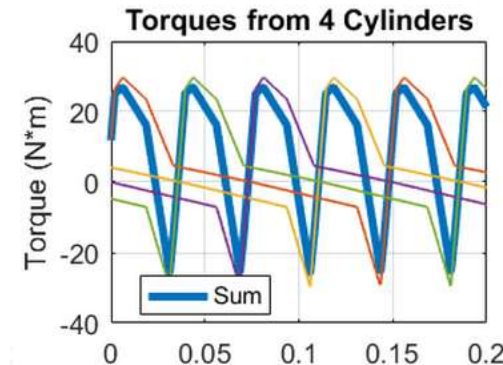
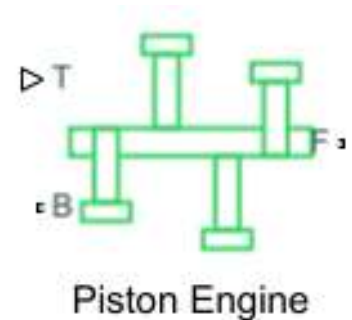
- Normalized 3rd-order polynomial matched to peak power
- Tabulated torque data
- Tabulated power data**

Fuel consumption:

- Constant per revolution
- Fuel consumption by speed and torque
- Brake specific fuel consumption by speed and torque
- Brake specific fuel consumption by speed and brake mean effective pressure**

- Crank-Angle Resolved

- Torque varies during piston cycle
- Excite vibrations in drivetrain



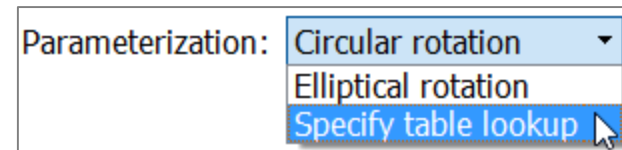
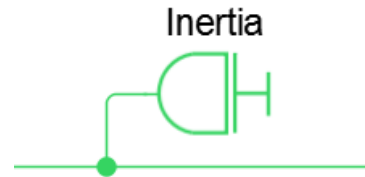
Pressure parameterization:

- By crank angle
- By crank angle and throttle
- By crank angle, throttle, and crank velocity**

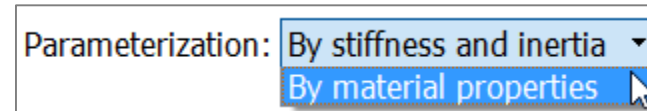
Simscape Driveline Component Models

Engines, **Shafts**, Gears, Clutches, Tires

- Rigid
 - Ideal rigid shaft
- Unbalanced
 - Shaft inertia varies with rotation angle
- Flexible
 - Inertia with torsional flexibility



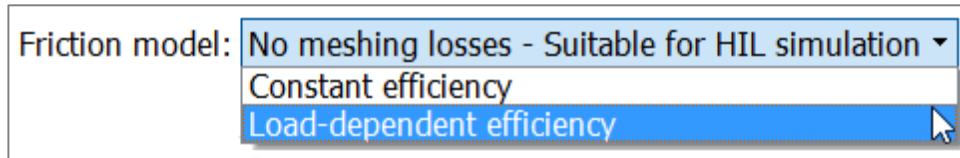
Flexible Shaft



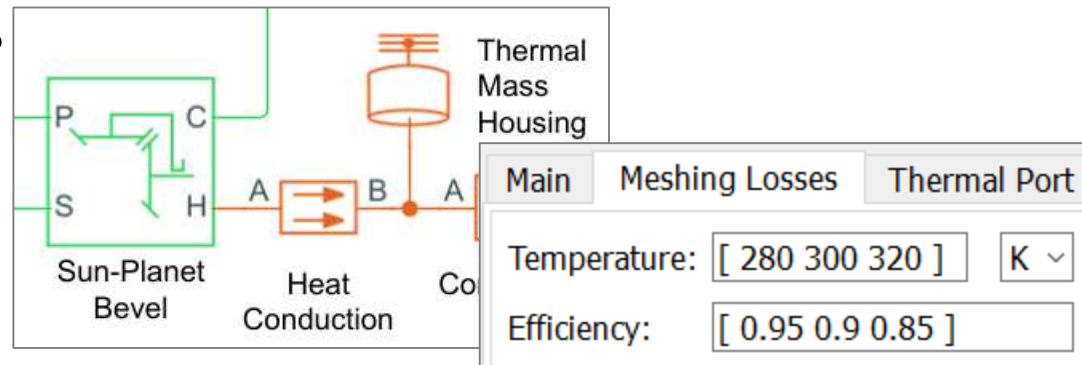
Simscape Driveline Component Models

Engines, Shafts, **Gears**, Clutches, Tires

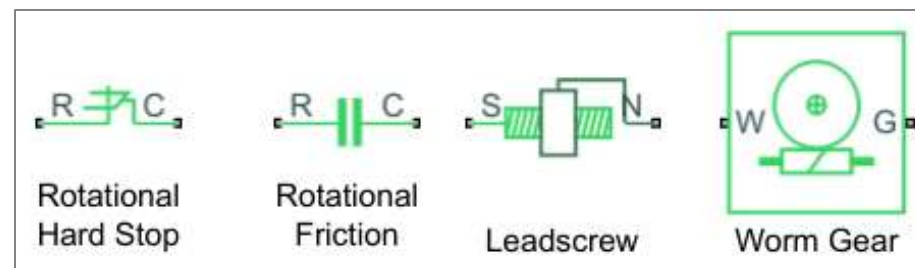
- Loss models
 - Valid for all shaft speeds and loads



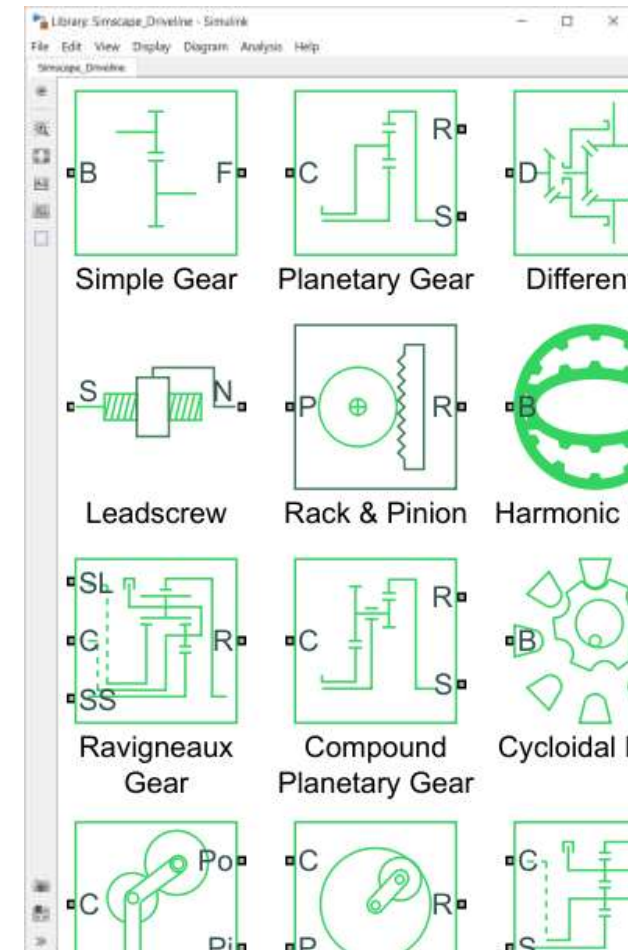
- Temperature effects
 - Heat transfer
 - Modified behavior



- Nonlinearities
 - Backlash
 - Friction
 - Self-locking

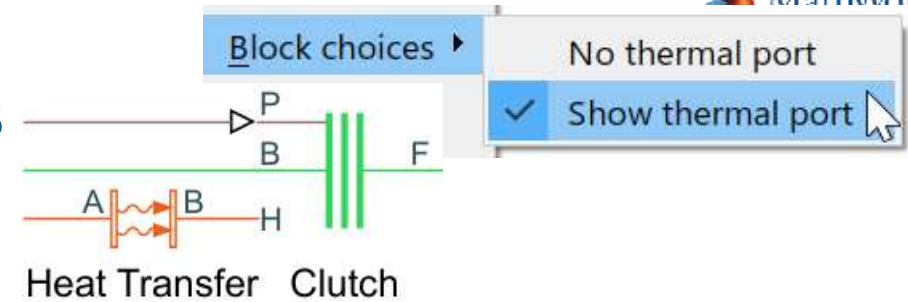


Subset of libraries



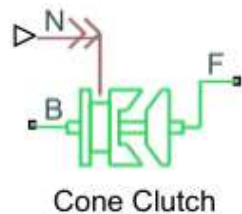
Simscape Driveline Component Models

Engines, Shafts, Gears, **Clutches**, Tires



- Friction clutches

- Customize friction model



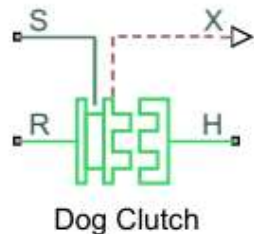
Cone Clutch

Geometry Friction Initial Conditions

Friction model: Fixed kinetic friction coefficient
 Table lookup kinetic friction coefficient

- Positive contact clutches

- Backlash
- Suitable for HIL



Dog Clutch

Clutch Shift Linkage Engagement Conditions I

Torque transmission: Friction clutch approximation - for HIL
 Dynamic with backlash

- Fluid couplings

- Valid for all speeds and shaft loads

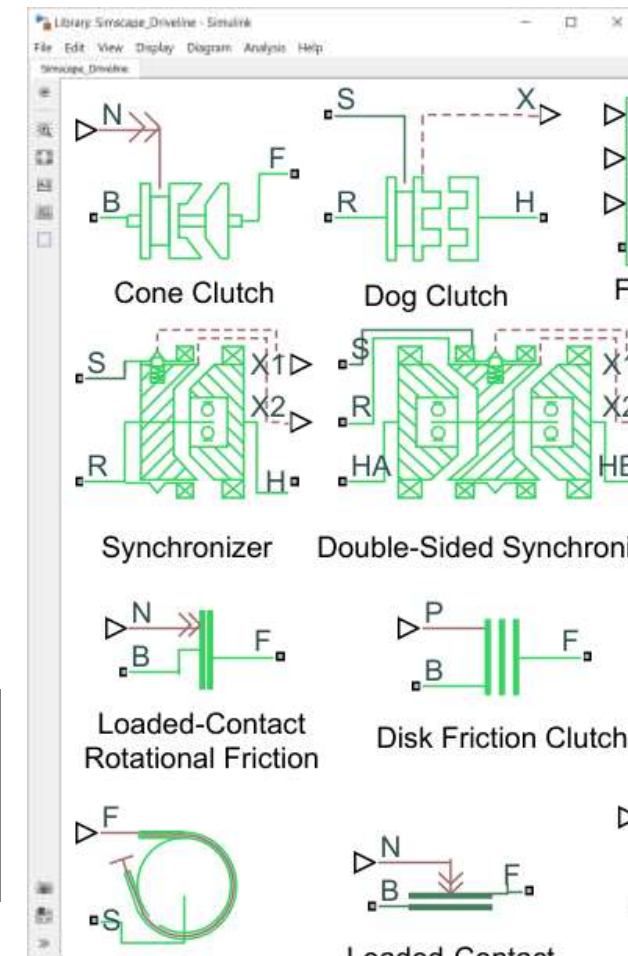


Torque Converter

Torque Characteristics Dynamics

Transmission lag: No lag - Suitable for HIL simulation
 Specify time constant and initial torque ratio

Subset of libraries



Simscape Driveline Component Models

Engines, Shafts, Gears, Clutches, Tires

- With and without slip

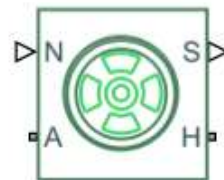
- Various options for friction coefficients

No Slip

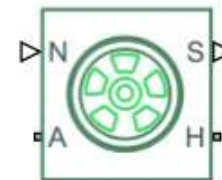


Tire (Simple)

With Slip



Tire
(Friction Parameterized)



Tire
(Magic Formula)

Tire (Magic Formula)

Tire Force Dimensions Dynamics Rolling R

Parameterize by:

- Peak longitudinal force and corresponding slip
- Constant Magic Formula coefficients
- Load-dependent Magic Formula coefficients

Friction: Fixed kinetic friction coefficient

- Table lookup kinetic friction coefficient

- Adjustable effects

- Compliance
- Rolling resistance

Compliance: No compliance - Suitable for HIL simulation

- Specify stiffness and damping

Resistance model: Constant coefficient

- Pressure and velocity dependent

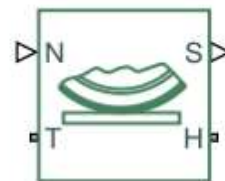
- Fixed friction coefficients
- Variable friction coefficients

- Custom models

- Construct models to meet your exact requirements



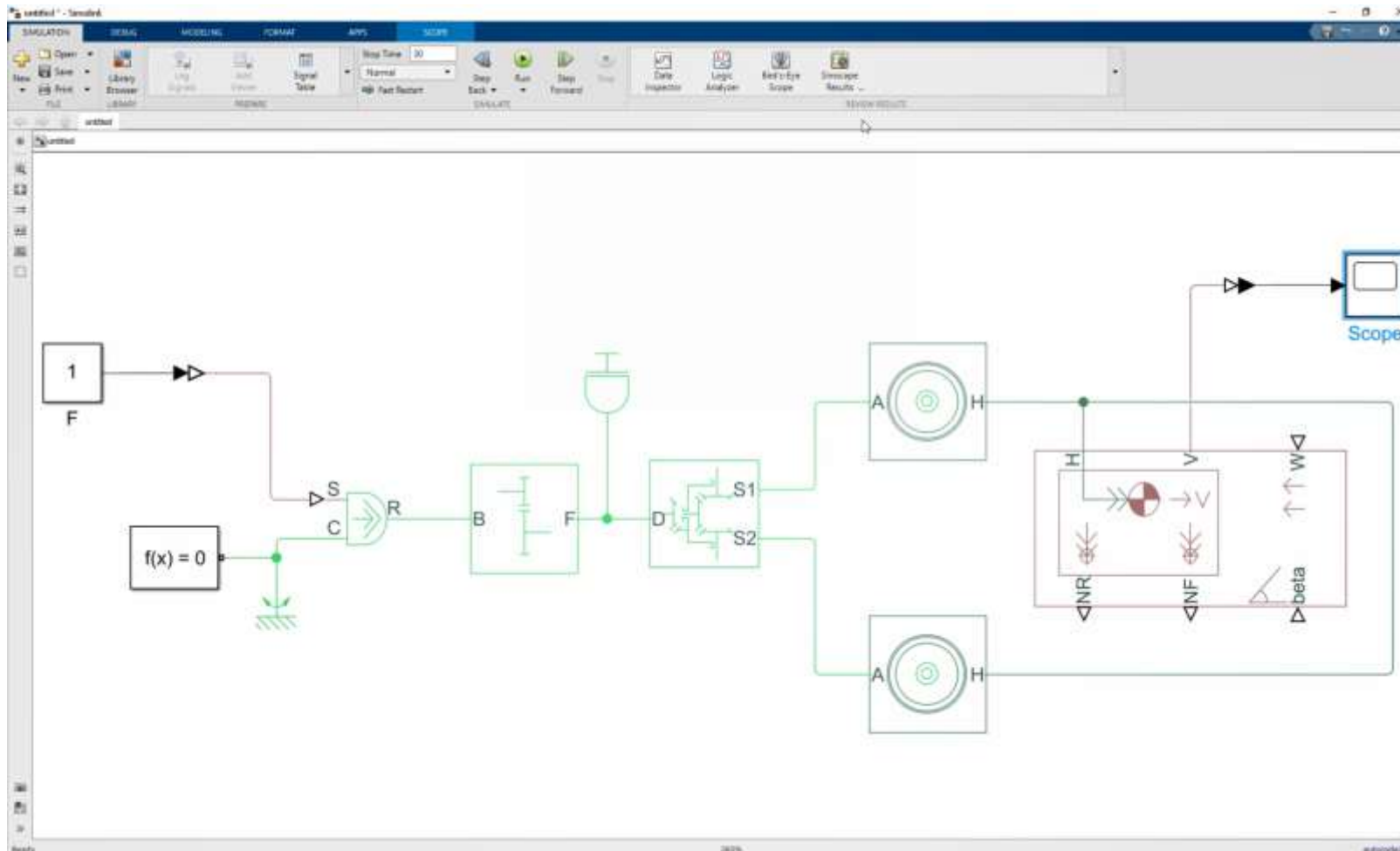
Rolling Resistance



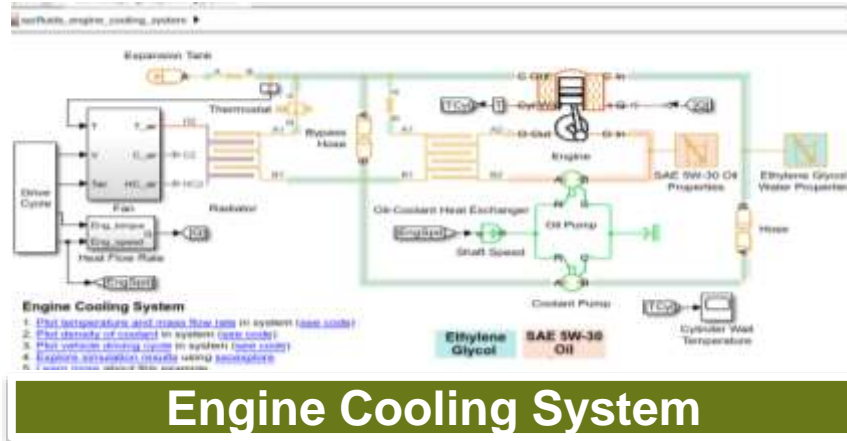
Tire-Road Interaction
(Magic Formula)

Dynamic System Modeling using Simscape

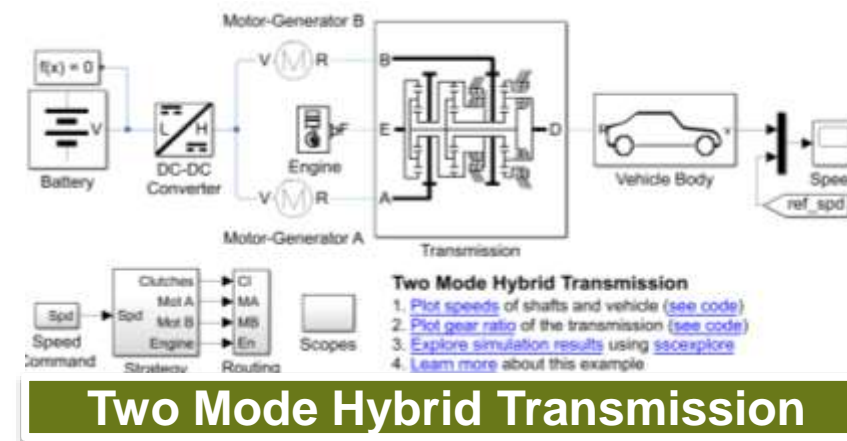
Longitudinal Control of a Vehicle



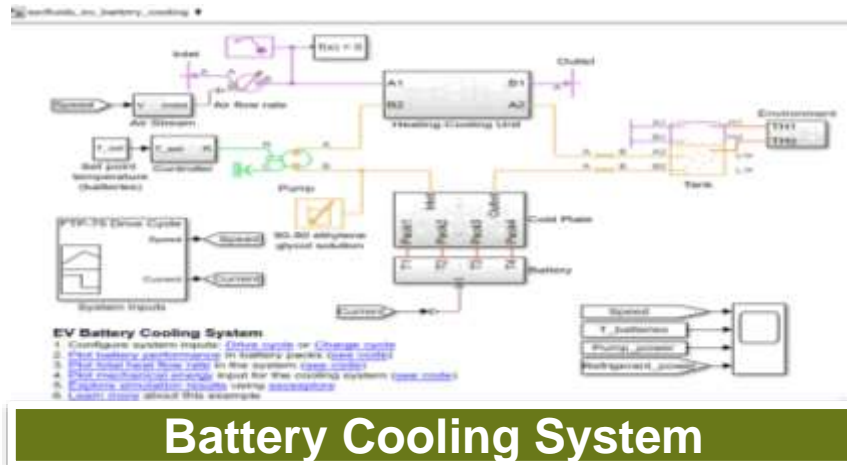
Dynamic System using Simscape



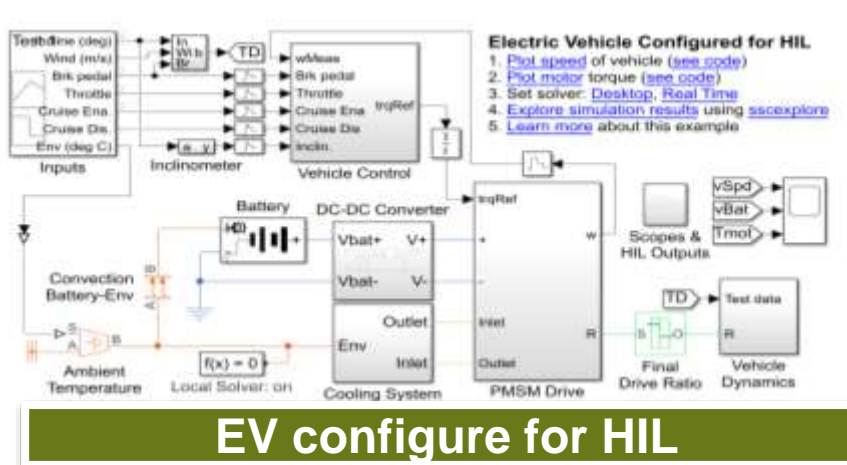
Engine Cooling System



Two Mode Hybrid Transmission



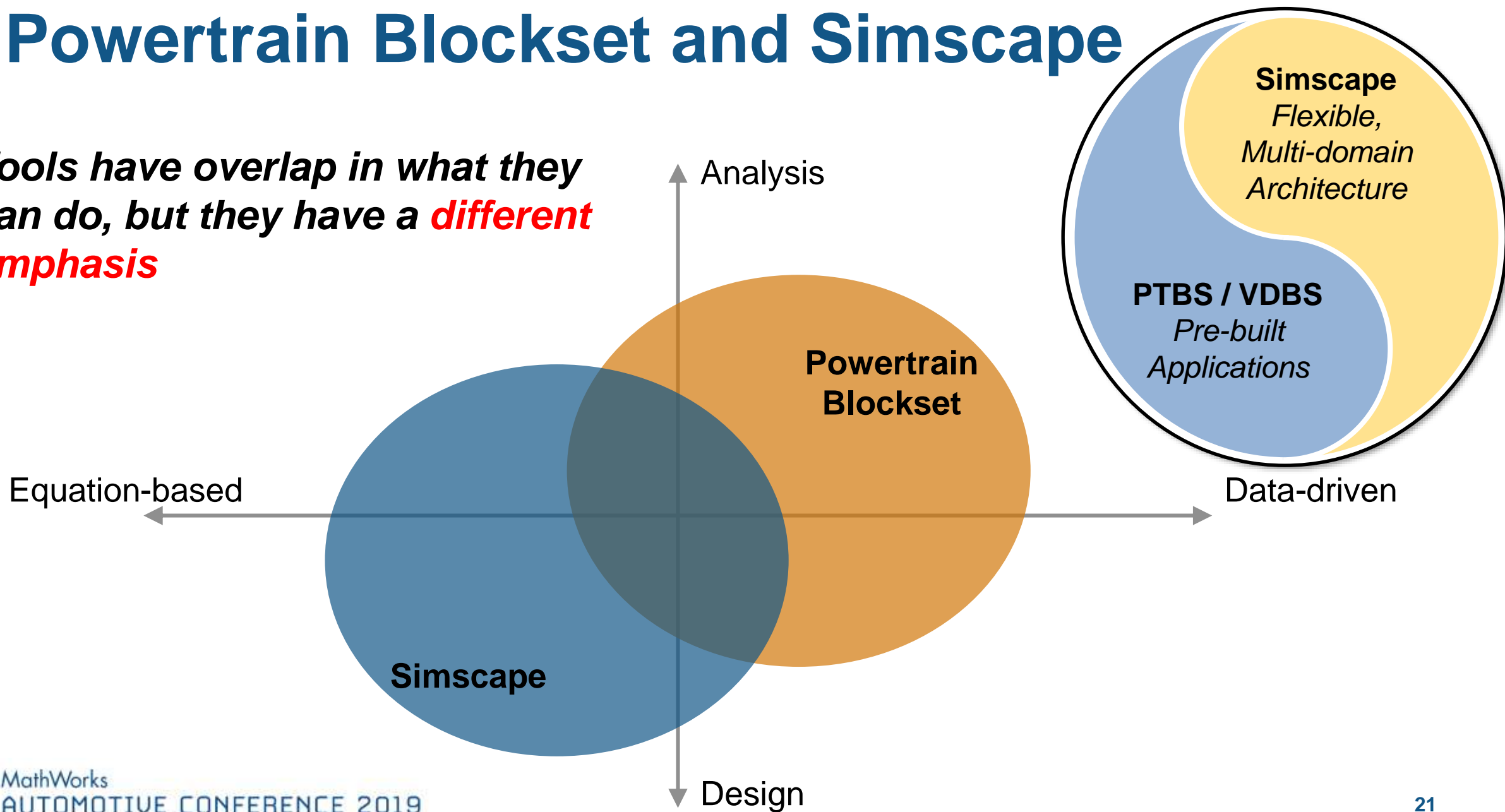
Battery Cooling System



EV configure for HiL

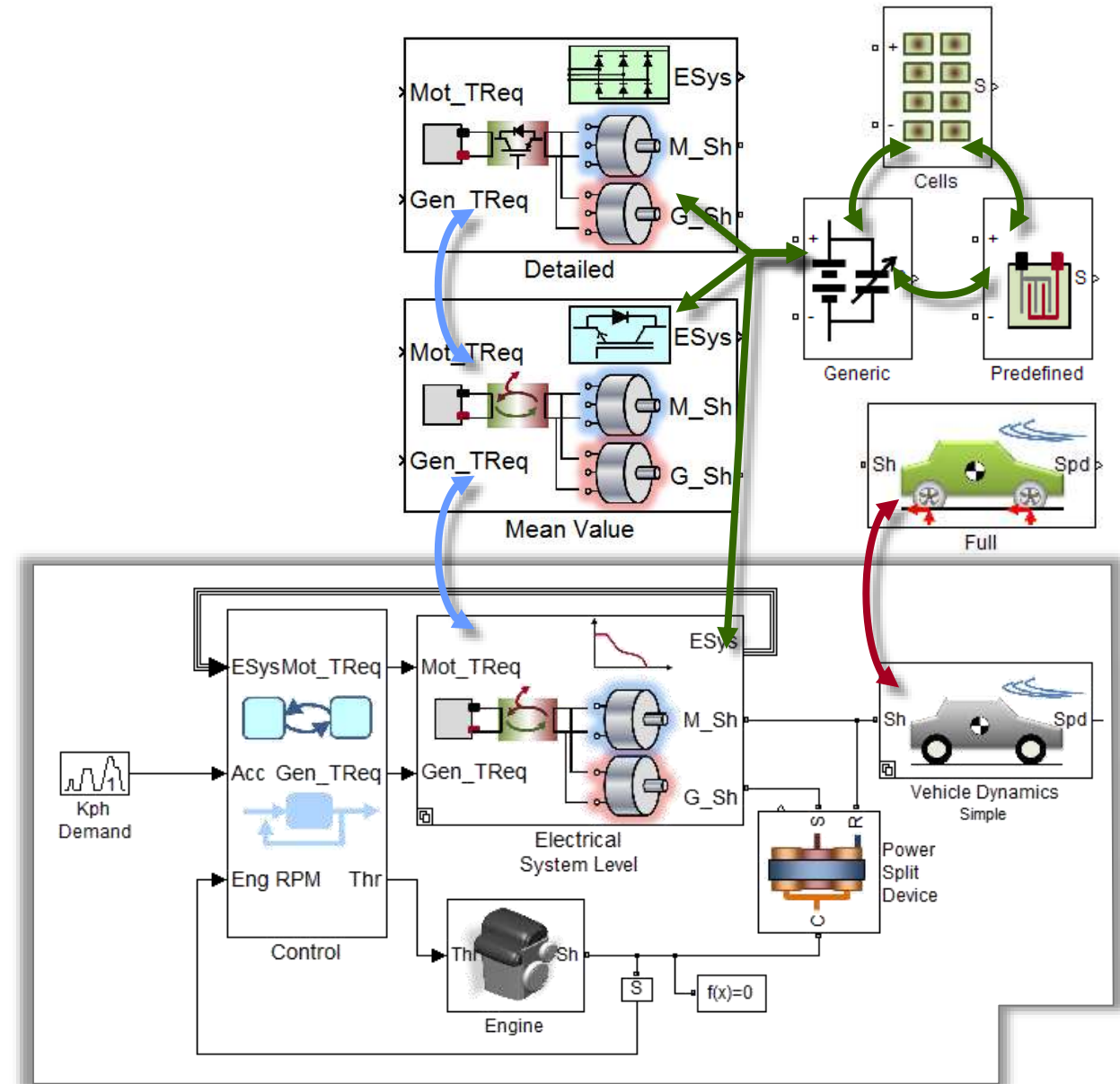
Powertrain Blockset and Simscape

Tools have overlap in what they can do, but they have a *different emphasis*

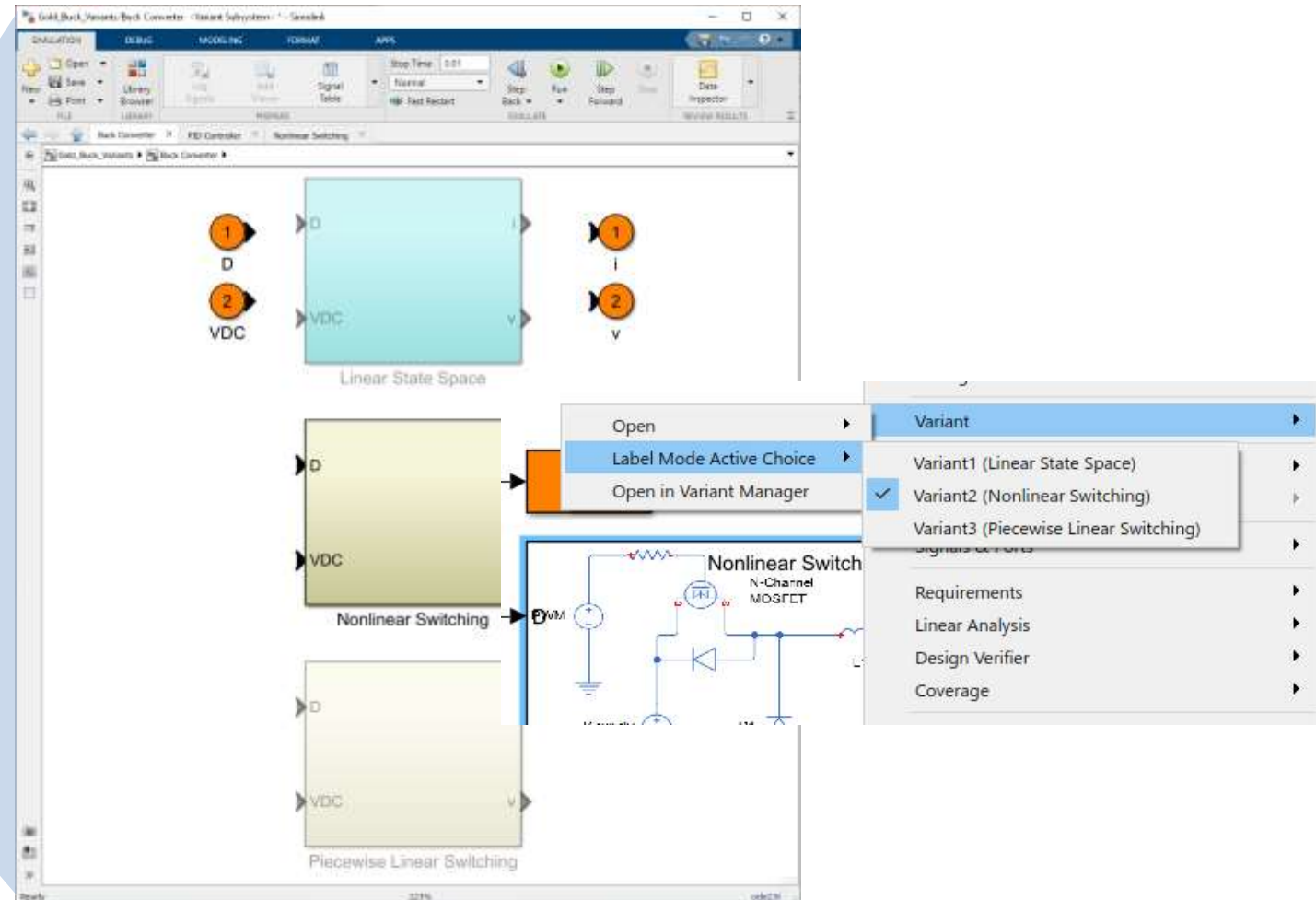
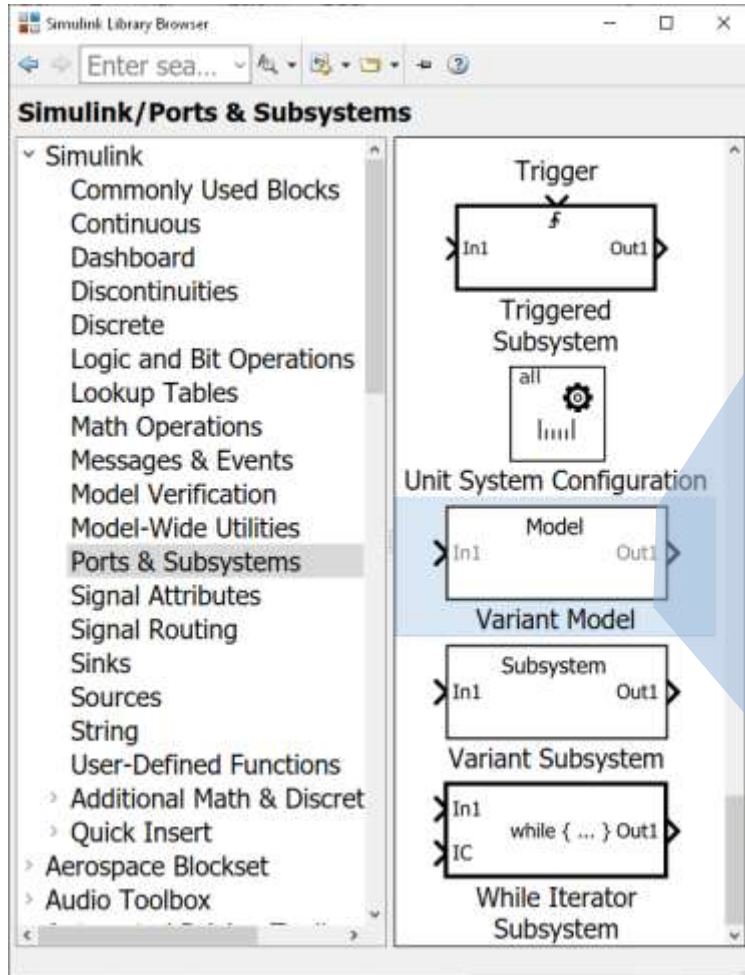


Hybrid Electrical Vehicle Model Balance Fidelity and Speed

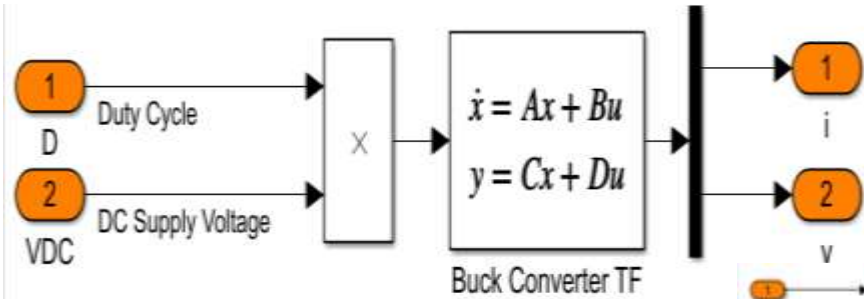
- **Electrical**
 - System Level
 - Test integration, optimize system
 - Mean Value
 - Three-phase electrical system
 - Detailed
 - Test power quality
- **Battery**
 - Generic, predefined, and custom models
- **Vehicle**
 - Inertial & Aero Effects
 - Tire models



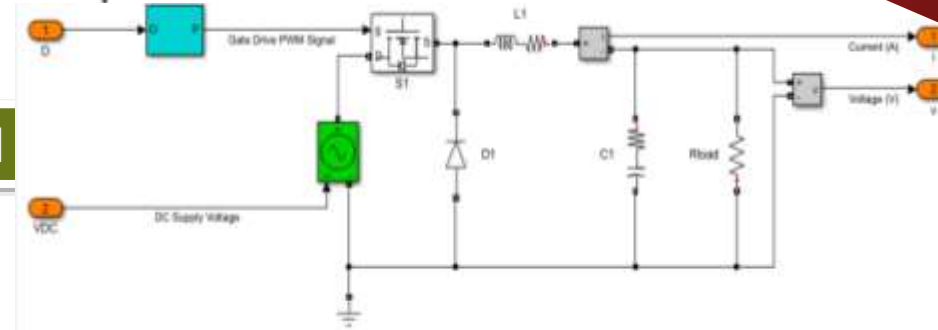
Model Fidelity



Buck Converter Modeling about Various Fidelity

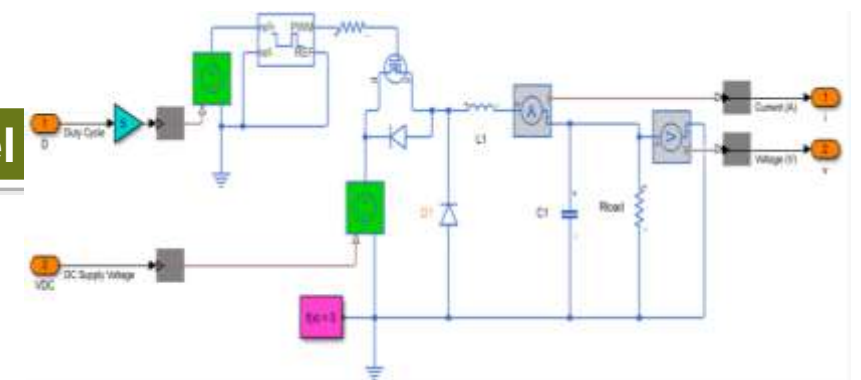
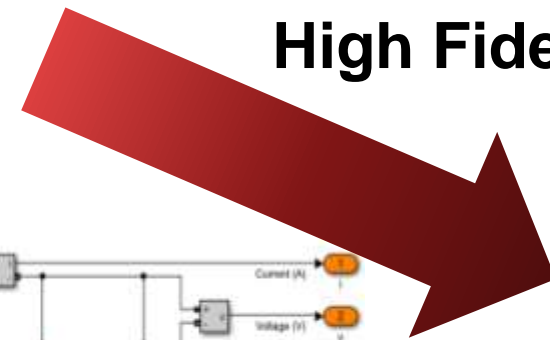


Linear State Space Model



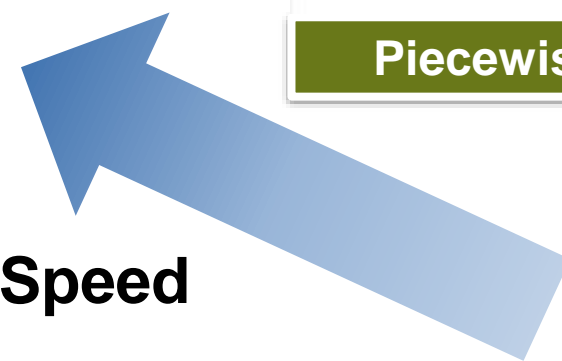
Piecewise Linear Switching Model

High Fidelity

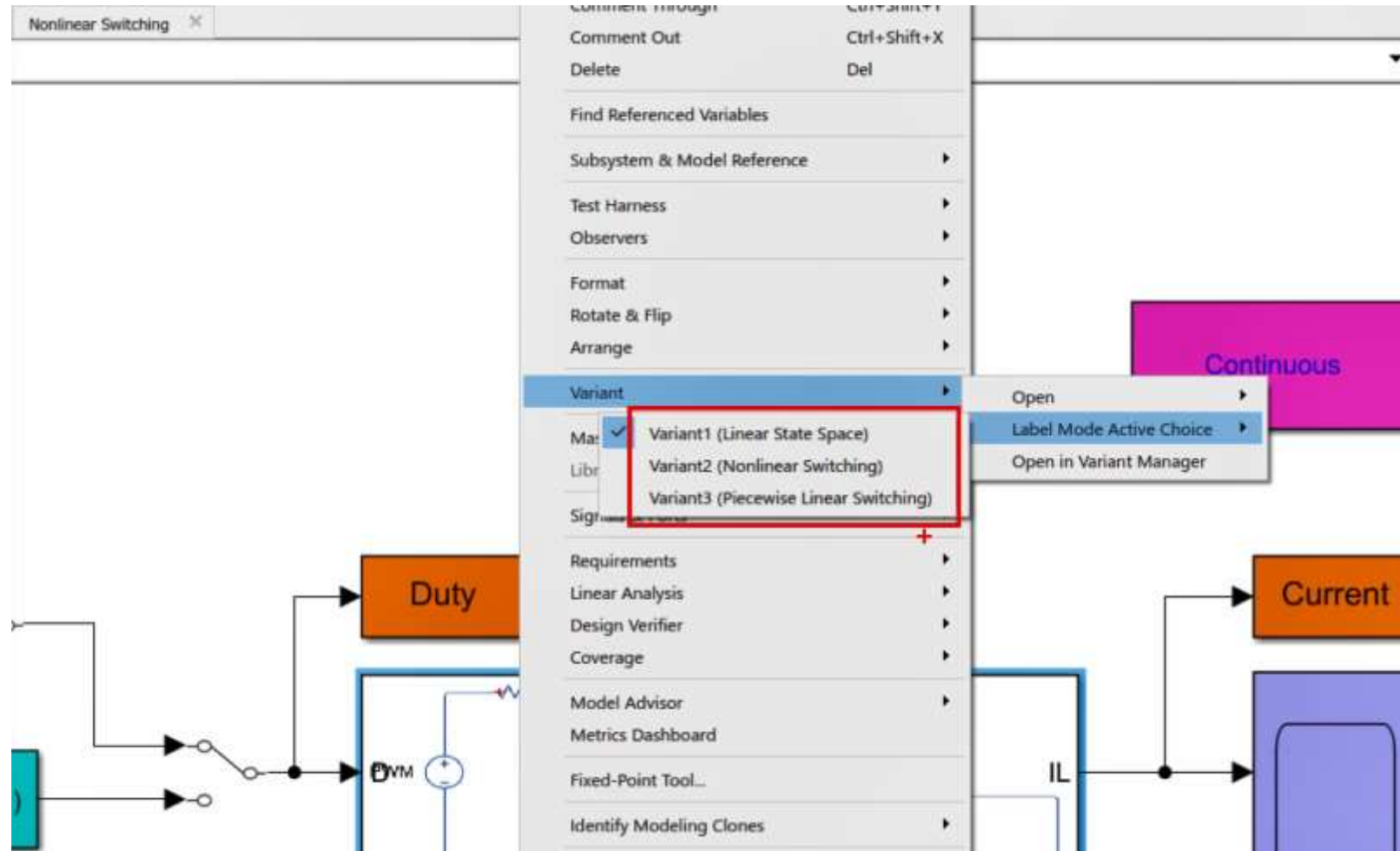


Nonlinear Switching Model

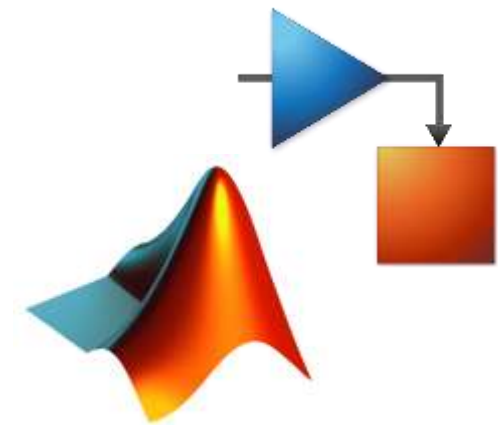
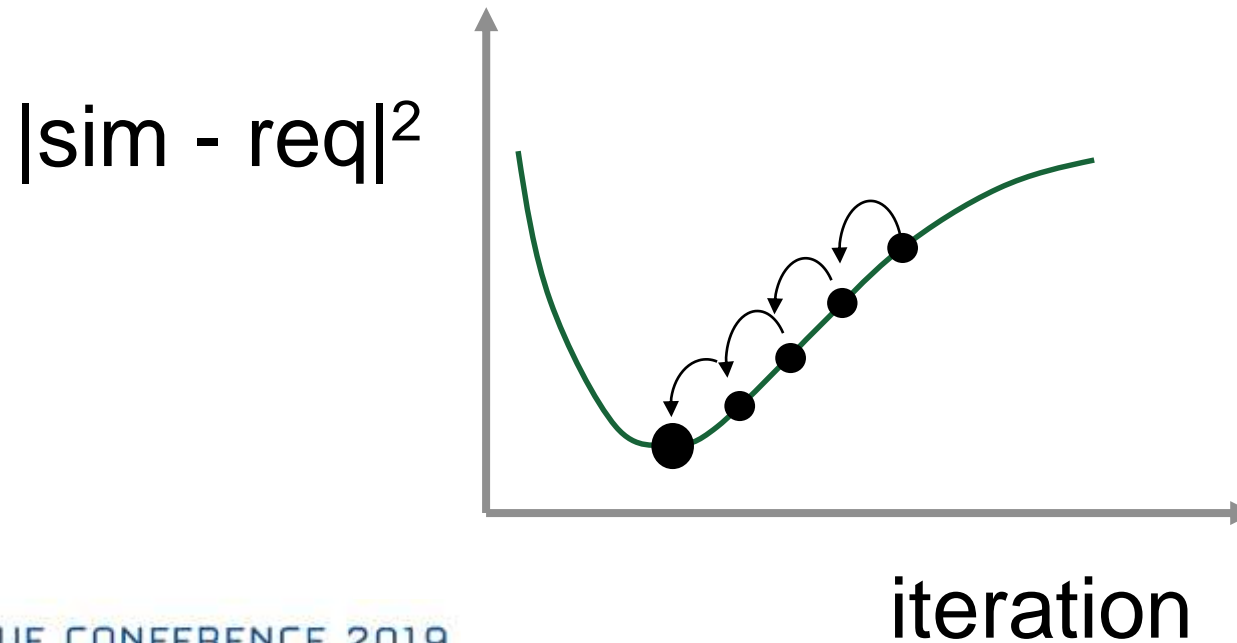
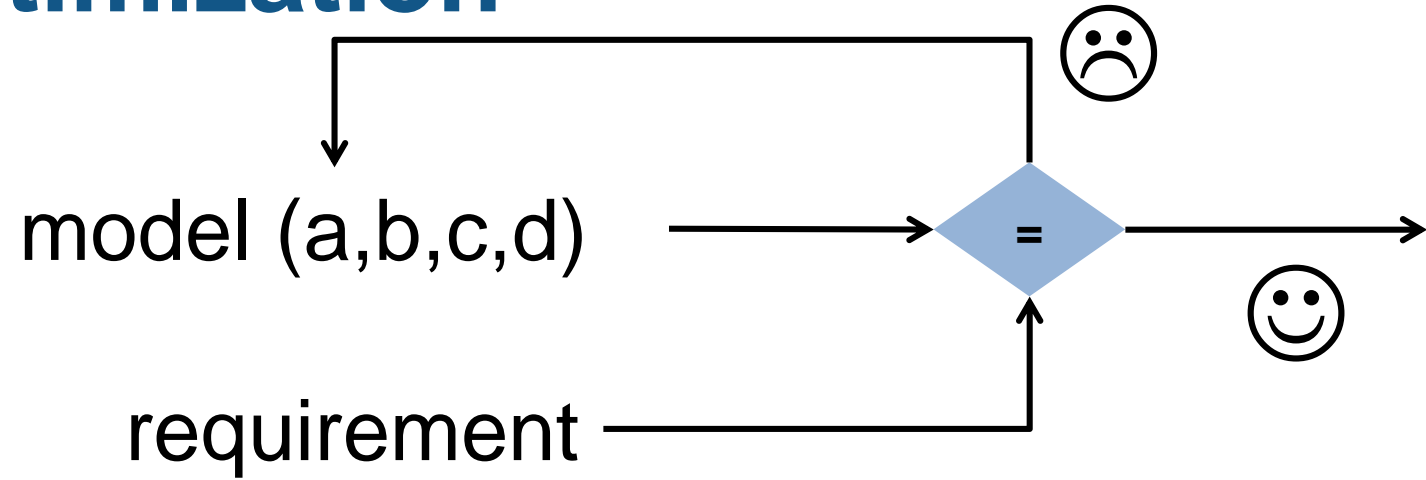
High Speed



Buck Converter Modeling about Various Fidelity

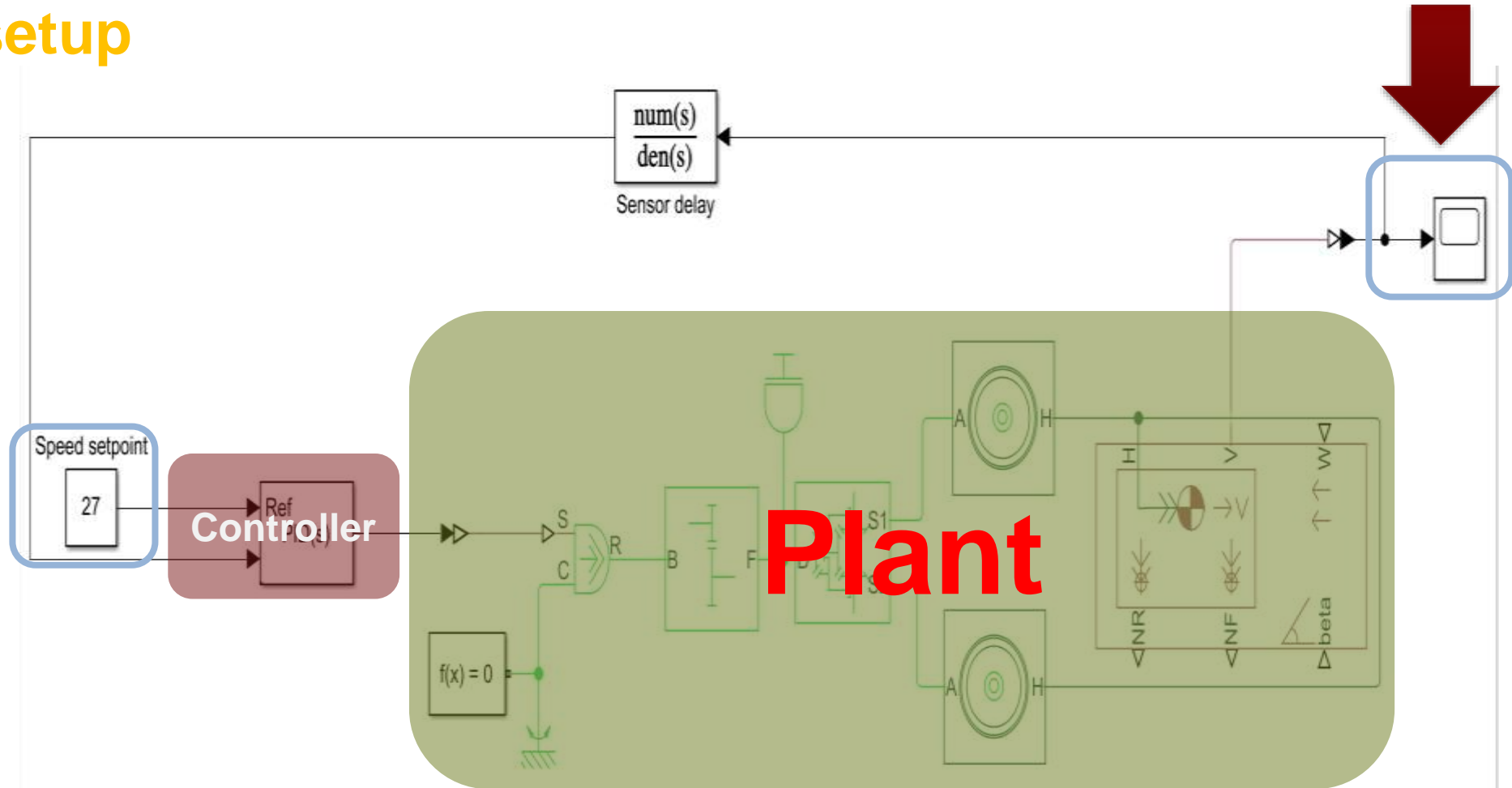


Response Optimization



Response Optimization

Model setup



Response Optimization Requirement

Create Requirement

Step Response Envelope

Specify a step response envelope on a signal.

Name:

▼ Specify Step Response Characteristics

Initial value: Final value:

Step time: seconds

Rise time: seconds % Rise:

Settling time: seconds % Settling:

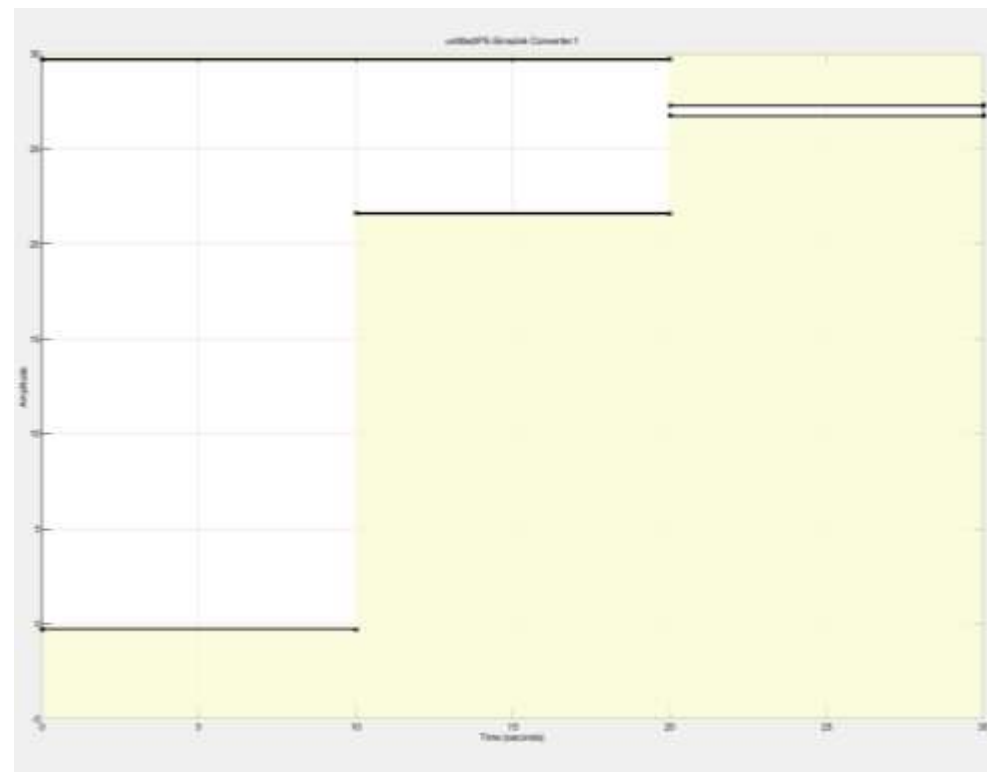
% Overshoot: % Undershoot:

▼ Select Signals to Bound

	Signal
<input checked="" type="checkbox"/>	Sig {untitled/PS-Simulink Converter:1}

Create Plot

OK Cancel Help



Response Optimization

Parameterization & Optimization

PID 2dof (mask) (link)

This block implements continuous-advanced features such as anti-windup using the 'Tune...' button (requires

Controller: PID

Time domain:

- Continuous-time
- Discrete-time

▼ Compensator formula

Main Initialization Output Saturation

Controller parameters

Source: internal

Proportional (P): P

Integral (I): I

Derivative (D): D

Use filtered derivative

Filter coefficient (N): N

Create Design Variables Set

Create Design Variables set: DesignVars

	Variable	Value	Minimum	Maximum	Scale
<input checked="" type="checkbox"/>	D	0	-Inf	Inf	1
<input checked="" type="checkbox"/>	I	1	-Inf	Inf	1
<input checked="" type="checkbox"/>	N	100	-Inf	Inf	128
<input checked="" type="checkbox"/>	P	1	-Inf	Inf	1

Update model variables

▶ Variable Detail

Choose Design variables

Optimization option

Options Optimization Options Parallel Options Linearization Options

OPTIONS Optimization method: Gradient descent Algorithm: Sequential Quadratic Programming

Optimization method: Gradient descent

Parameter: Pattern search Function tolerance: 0.001

Parameter: Complex search Constraint tolerance: 0.001 Maximum iterations: 100

Look for maximally feasible solution

Display level: Iteration

Restarts: 0

OK Cancel Help

Optimize

OPTIMIZE

APPS

Stop Time 30

Normal

Fast Restart

Step Back Run

SIMULATE

Simulation speed up

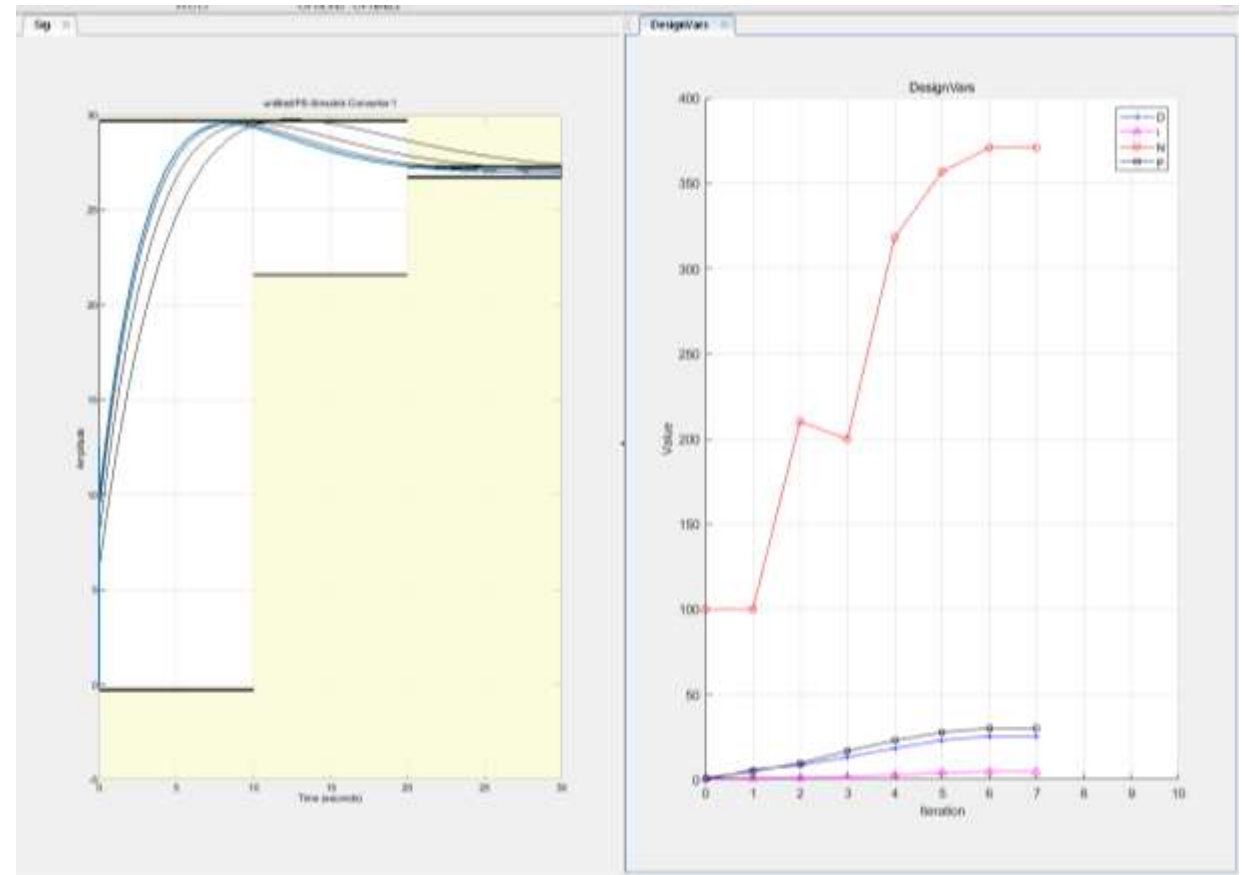
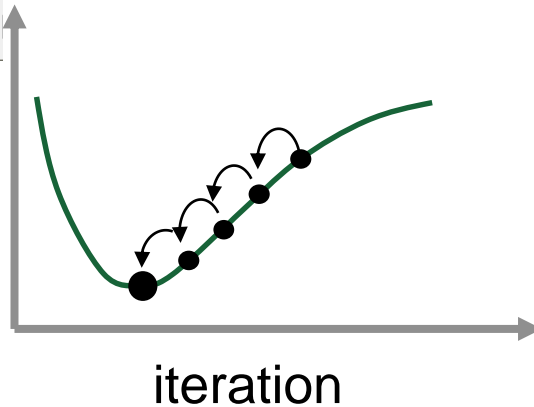
Response Optimization

Optimization Progress Report

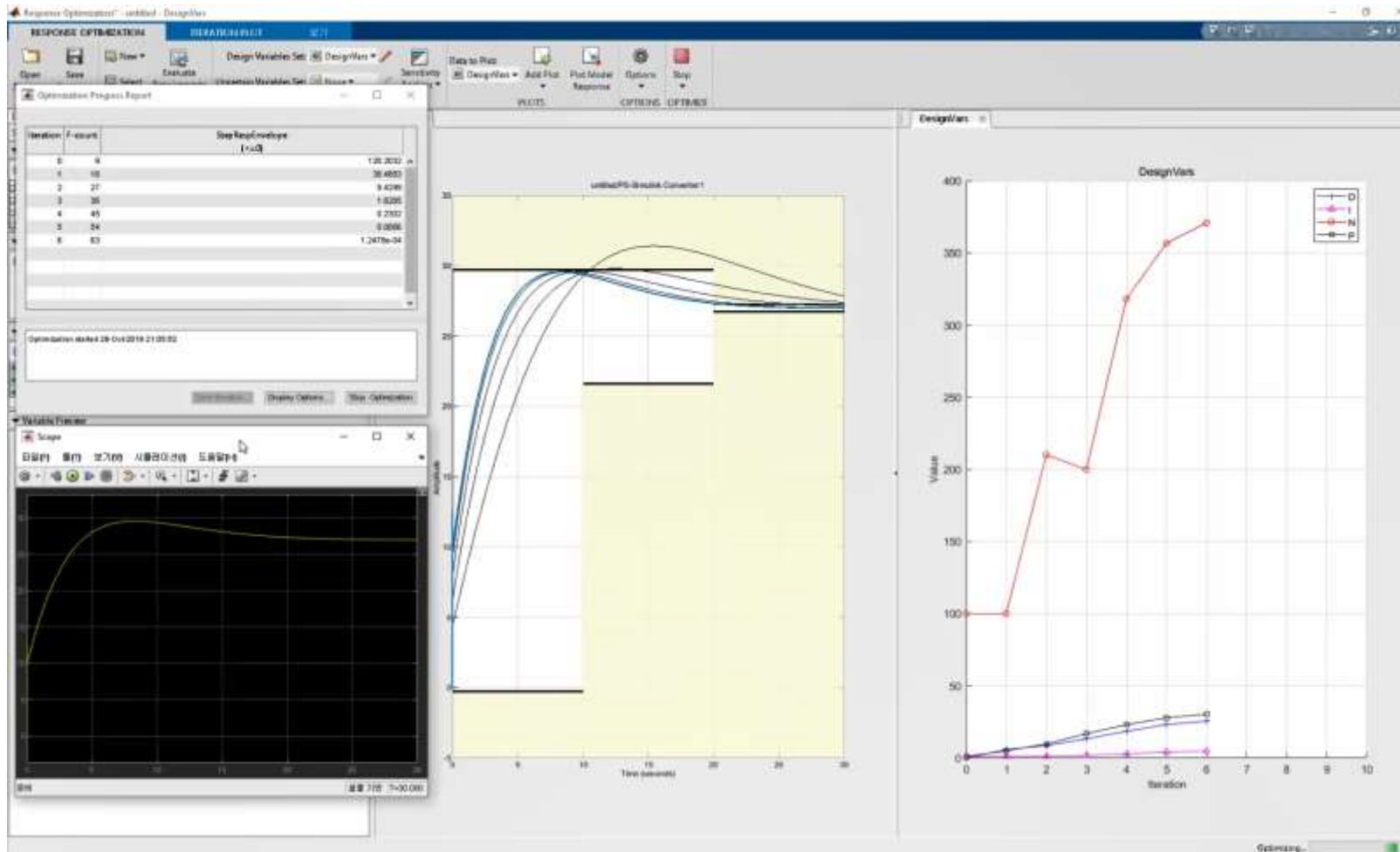
Iteration	F-count	StepRespEnvelope (<=0)
0	9	120.2032
1	18	38.4883
2	27	9.4299
3	36	1.6285
4	45	0.2302
5	54	0.0066
6	63	1.2478e-04
7	68	1.2478e-04

Optimization started 28-Oct-2019 21:33:07
 Optimization converged, 28-Oct-2019 21:37:15

$$|\text{sim} - \text{req}|^2$$

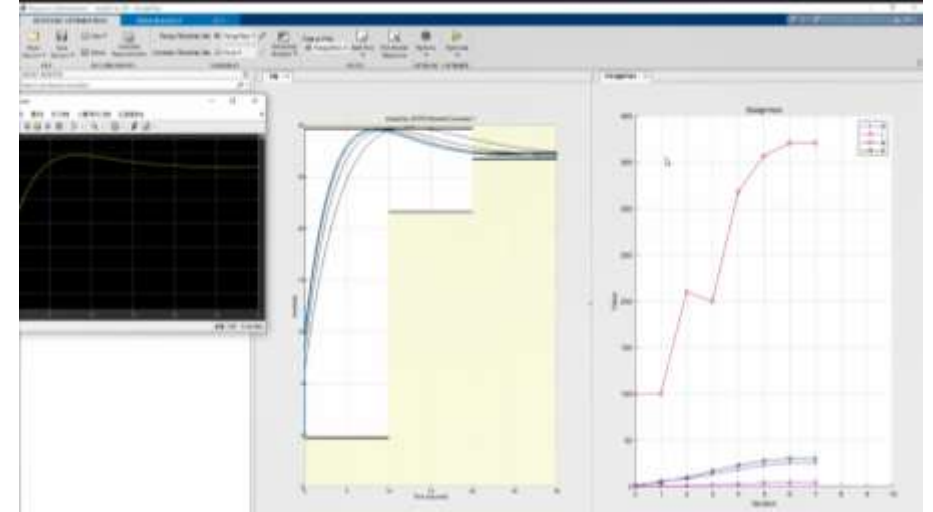


Response Optimization

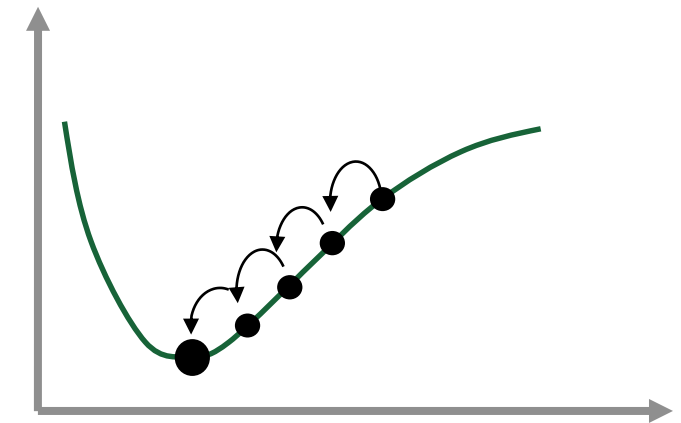


Response Optimization

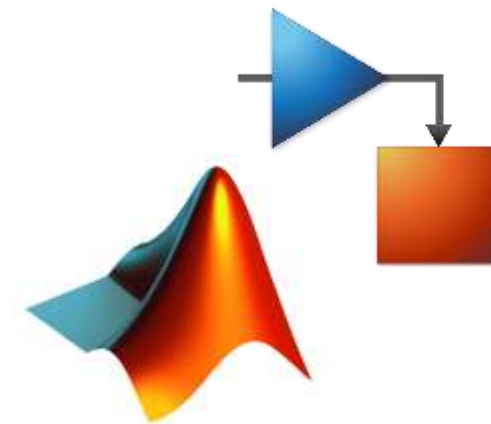
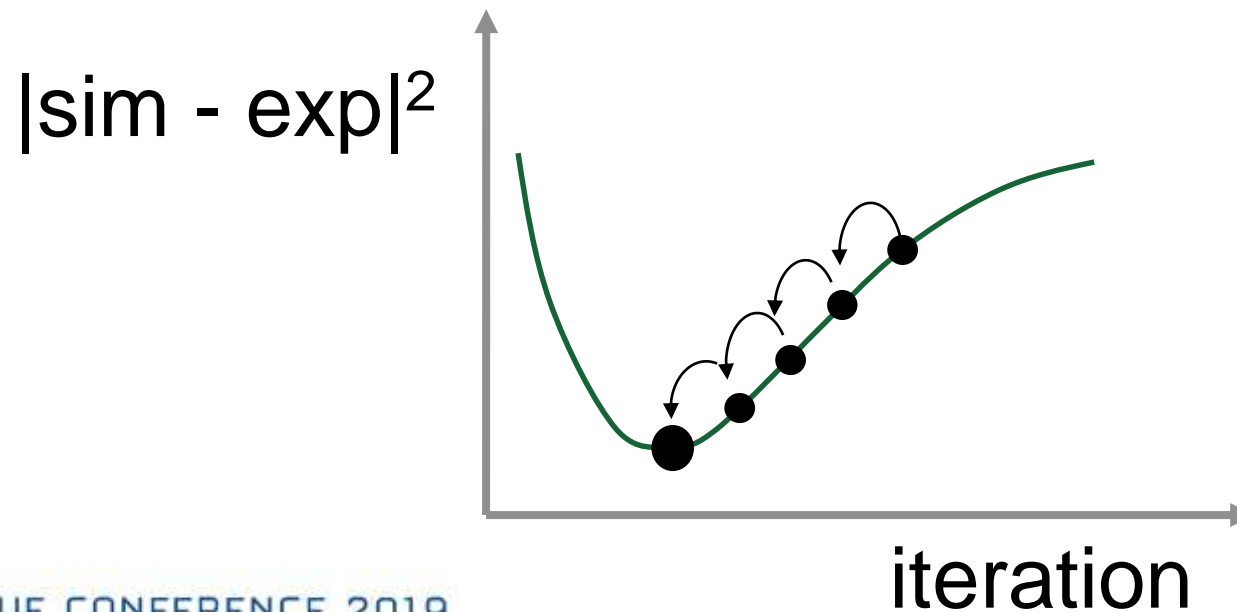
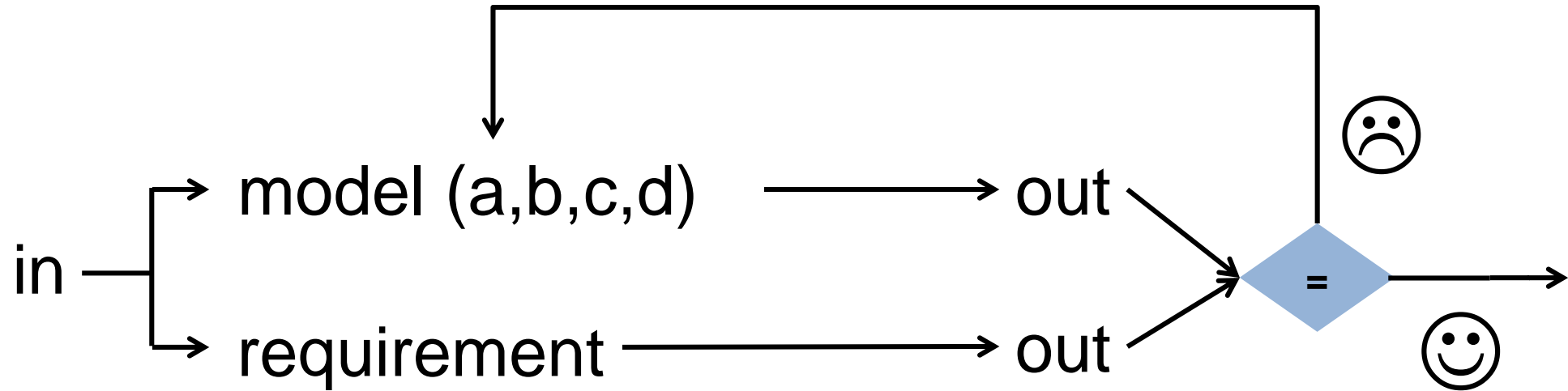
- Optimization + Simulation
- Fully non-linear plant
- Parallelizable
- Applicable to any parameter
 - Controller
 - Plant



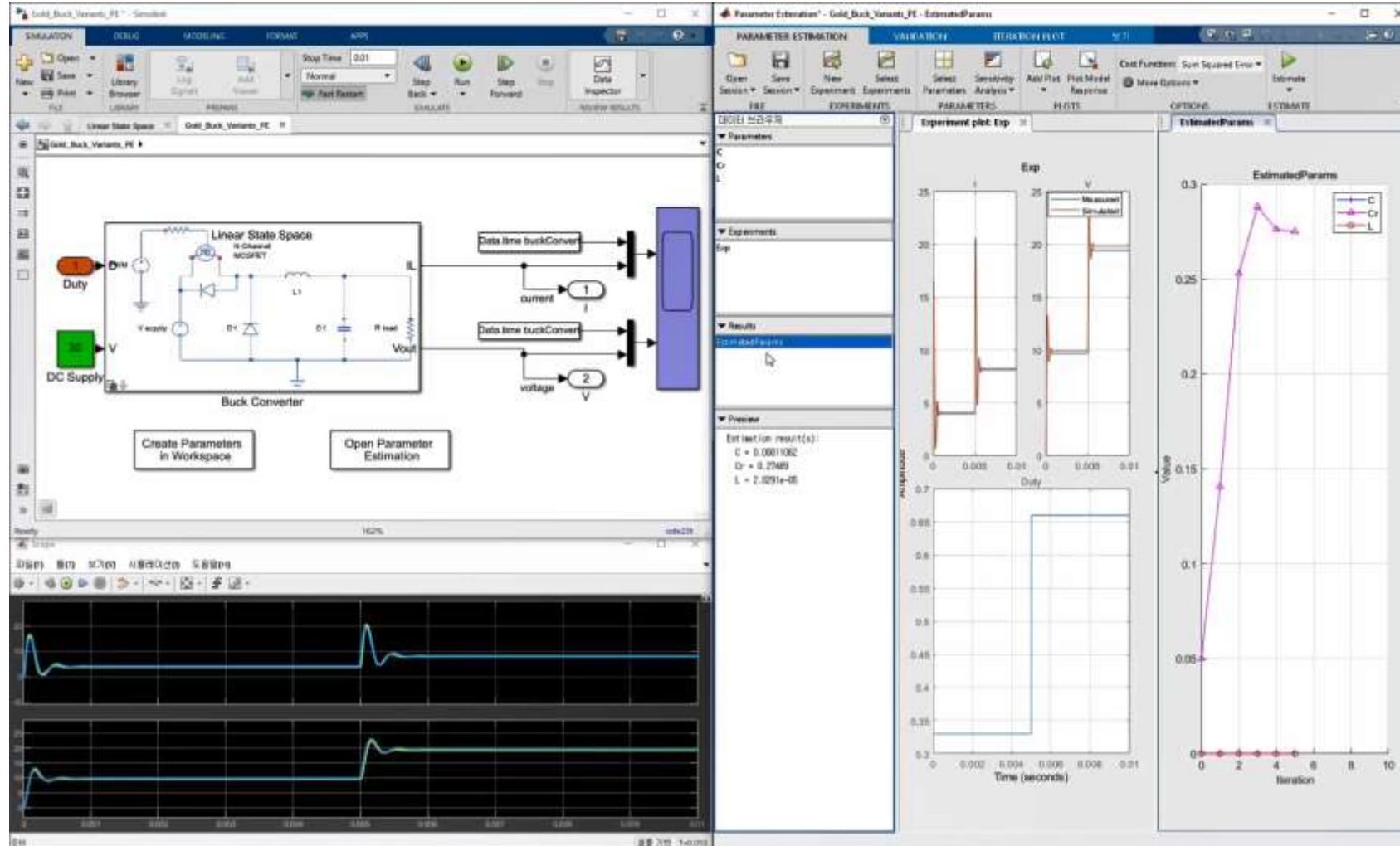
$$|\text{sim} - \text{req}|^2$$



Parameter Estimation

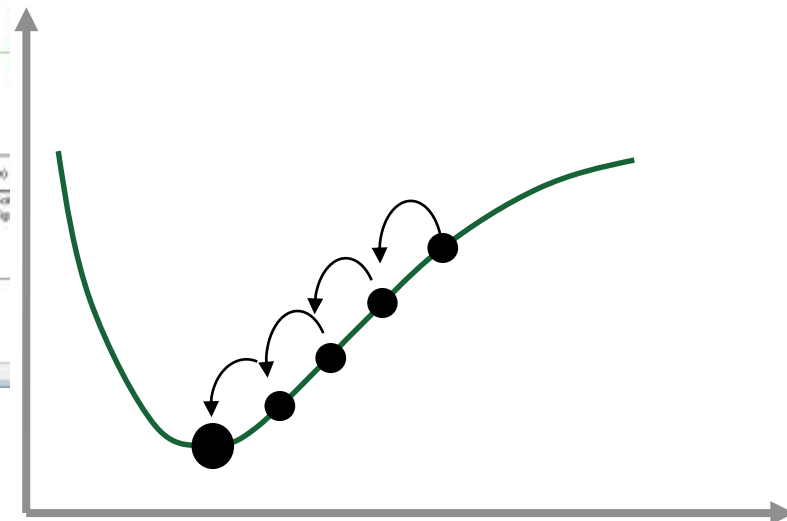
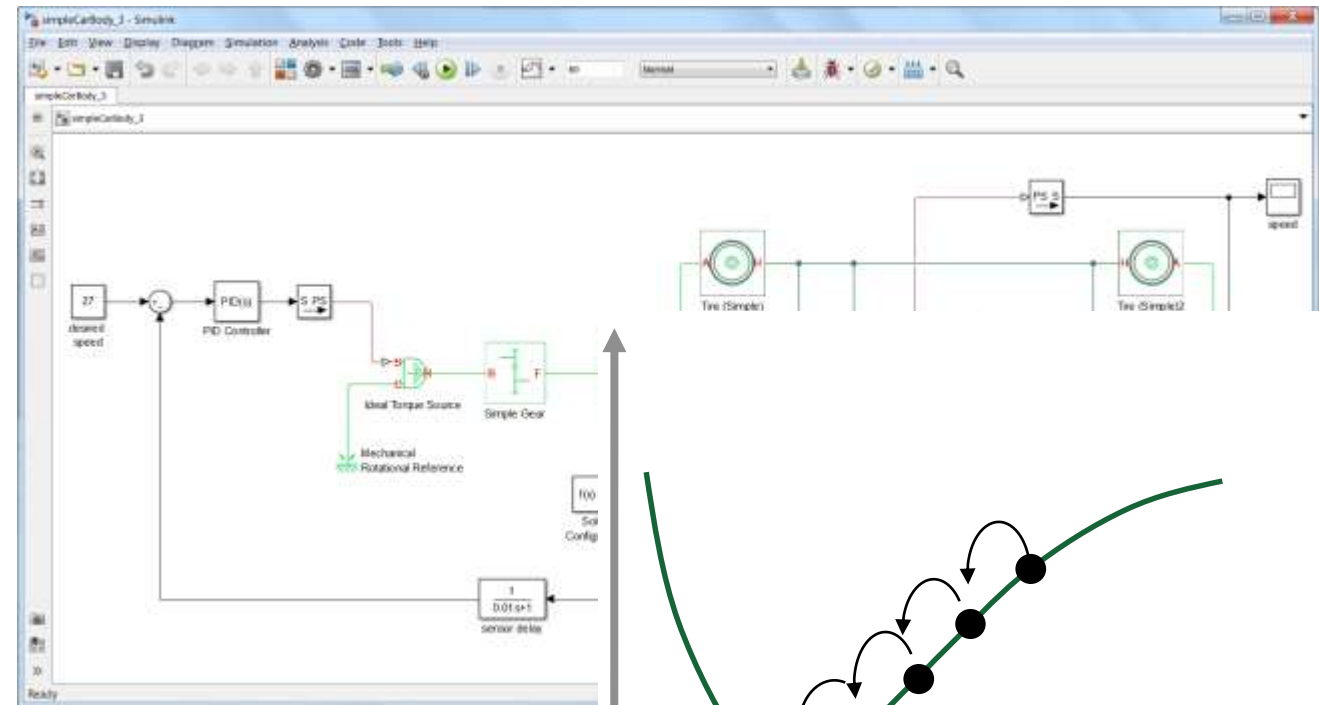
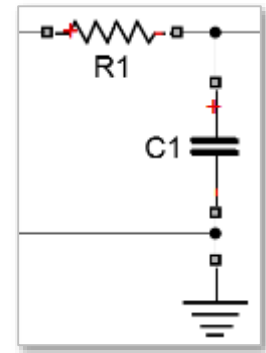
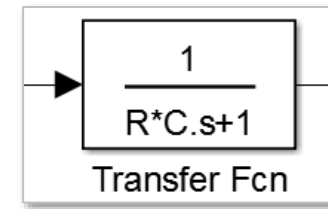


Parameter Estimation



Key Takeaways

- Simulink and Simscape
 - Signal- and network-based multi-domain modeling
- The Power of MATLAB
 - Response Optimization
 - Parameter Estimation



Thank You