MathWorks
AUTOMOTIVE
CONFERENCE 2019

차량 모델의 매개변수화 및 제어 최적화 자동화

강효석 Ph.D

Problem - Design Electric Car

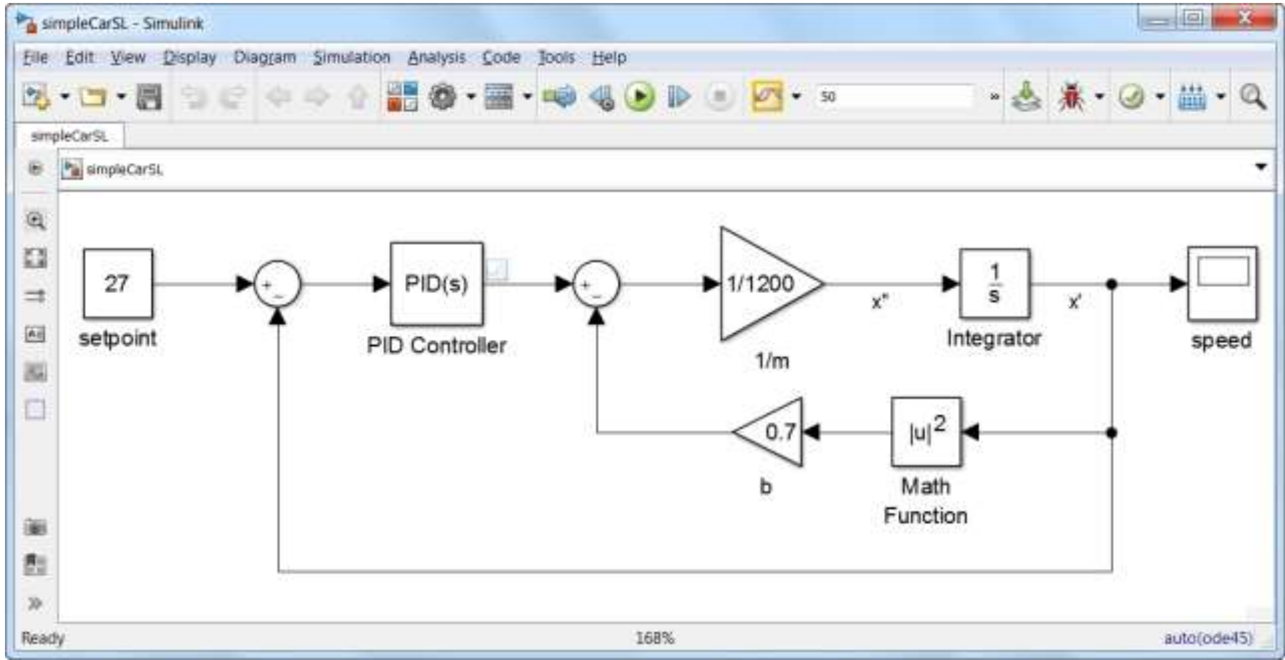
- System level architecture
- Control design and tuning

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

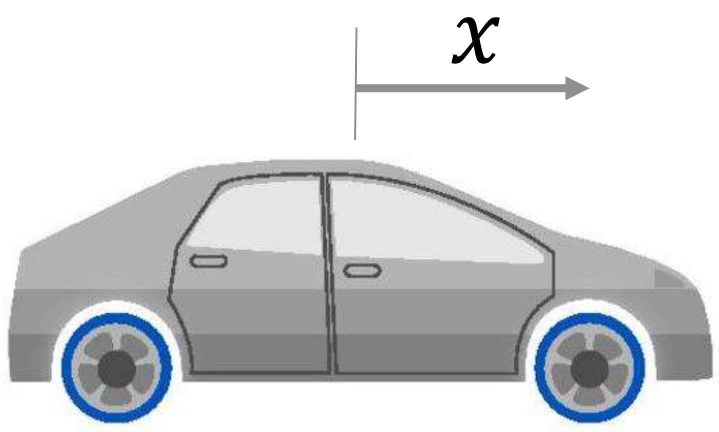


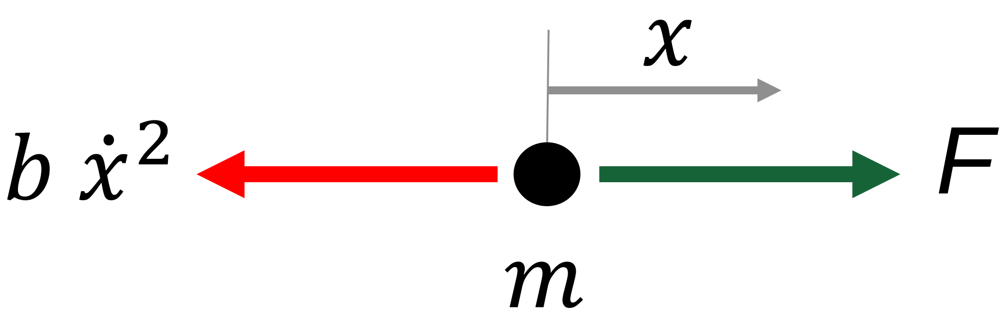
Dynamic System

Longitudinal Control of a Vehicle

- Input & Output
  - F: Force(input)
  - $\dot{x}$: Speed(Output)

- Parameters
  - b: Air-drag parameter
  - m: Mass

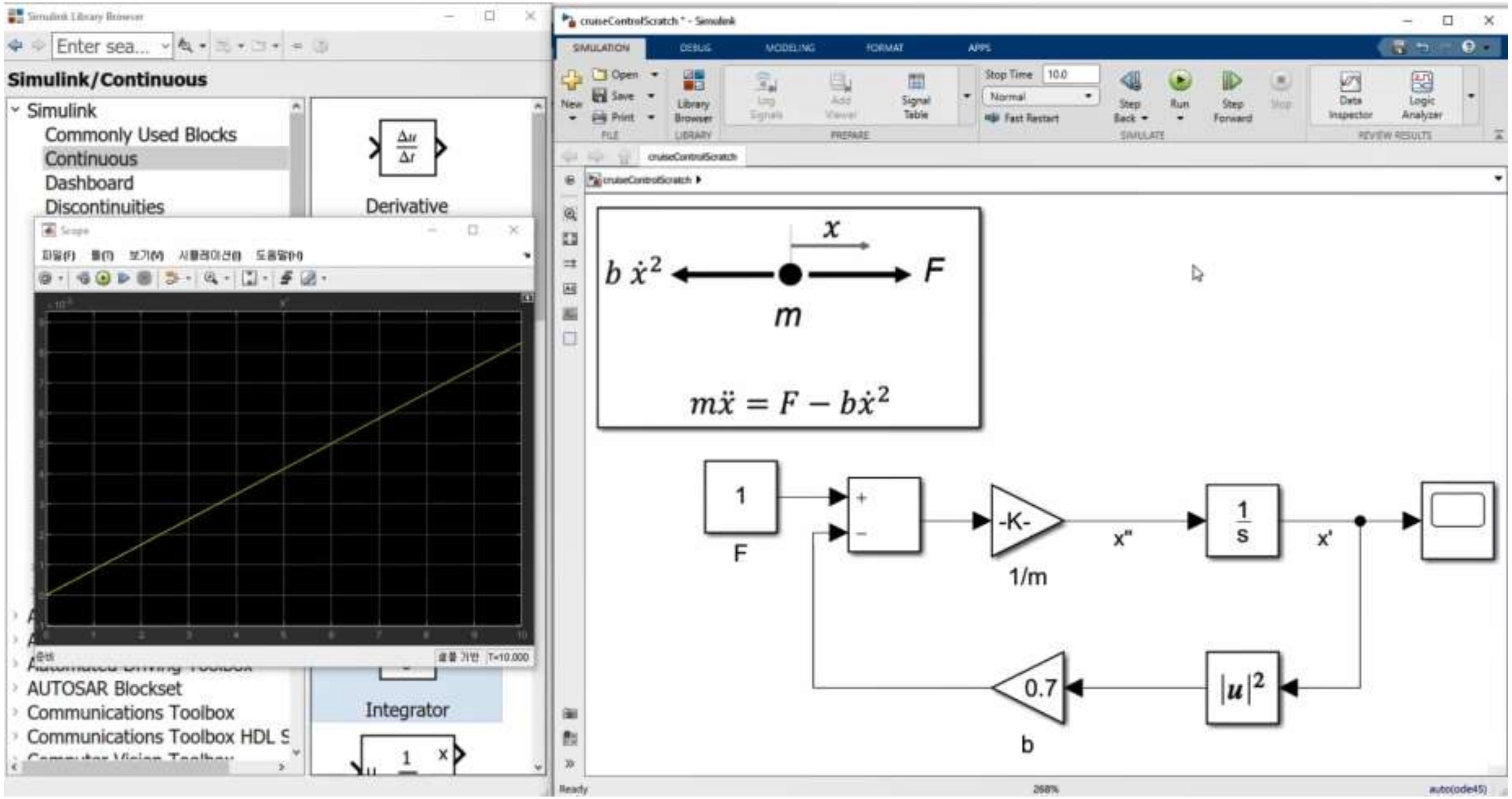




$$m\ddot{x} = F - b\dot{x}^2$$

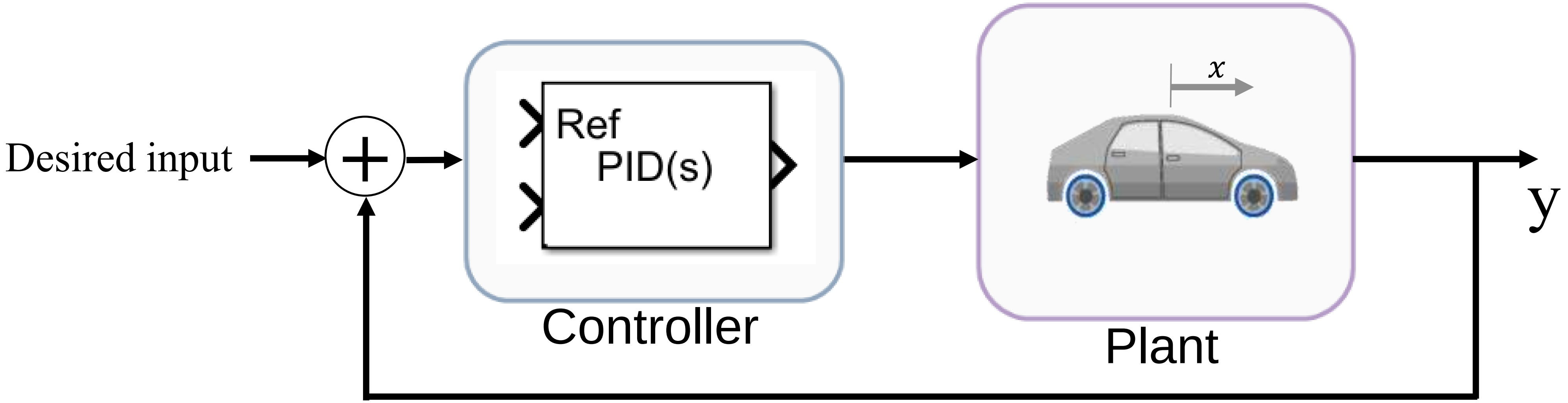
Dynamic System Modeling using Simulink

Longitudinal Control of a Vehicle



Dynamic System Modeling using Simulink

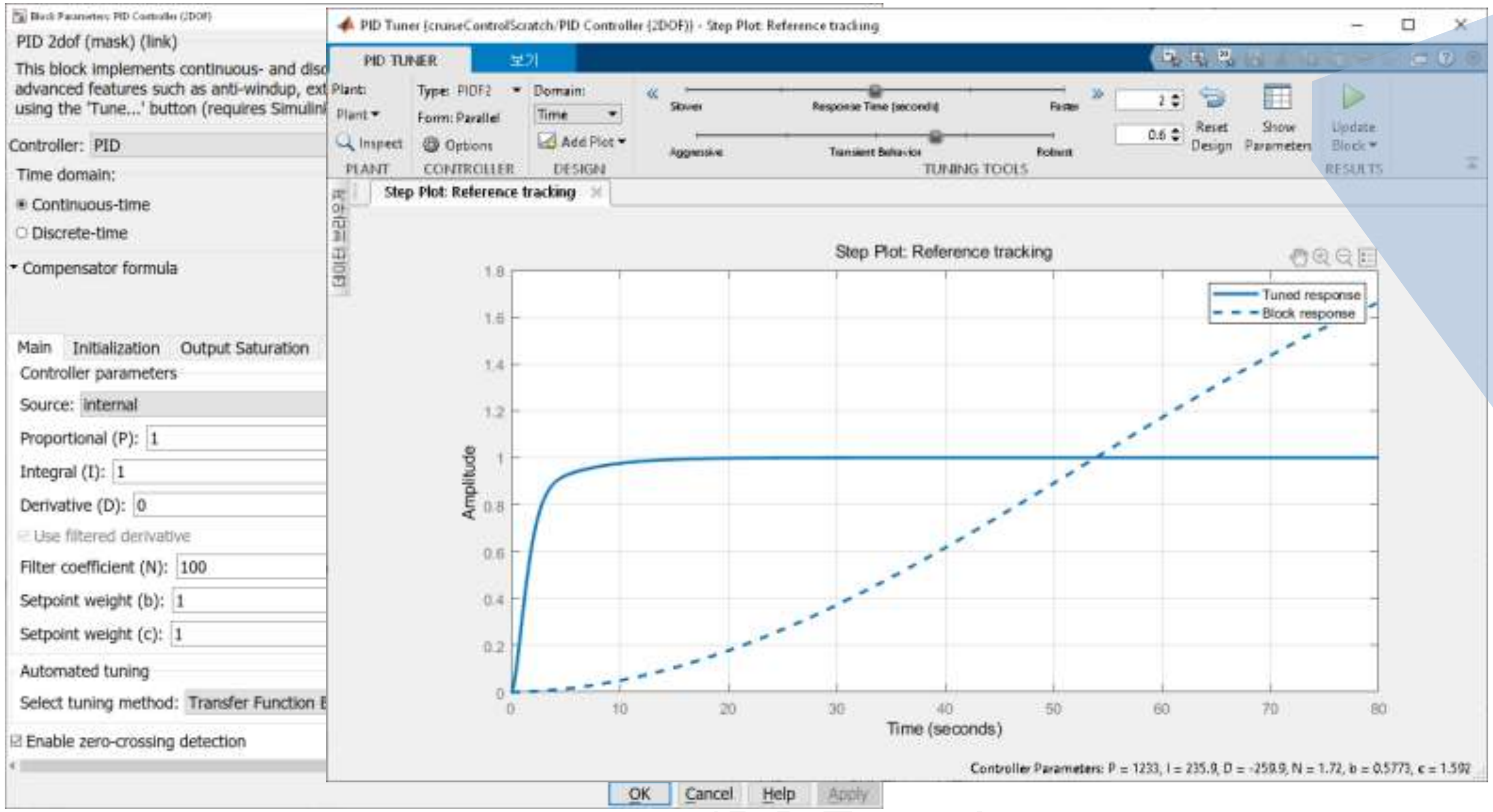
Longitudinal Control of a Vehicle



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

Dynamic System Modeling using Simulink

Longitudinal Control of a Vehicle



*PID Tuner App

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

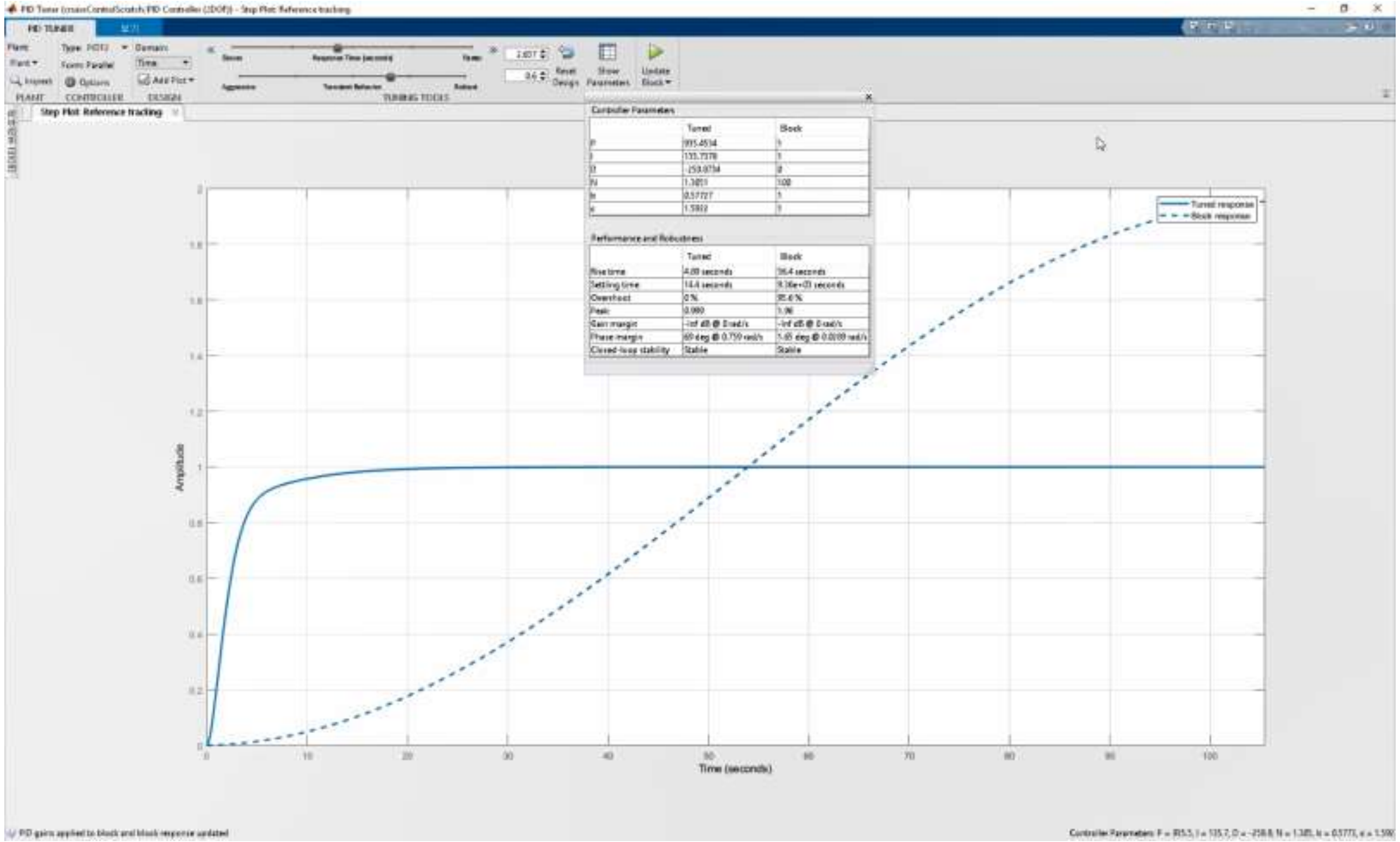
Performance and Robustness

	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

*required Simulink Control Design

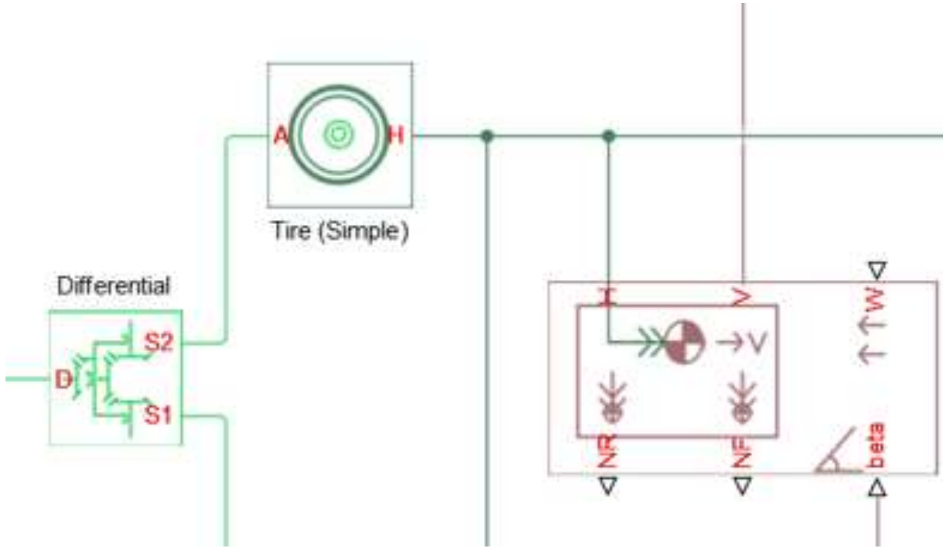
Dynamic System Modeling using Simulink

Longitudinal Control of a Vehicle



Simscape

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



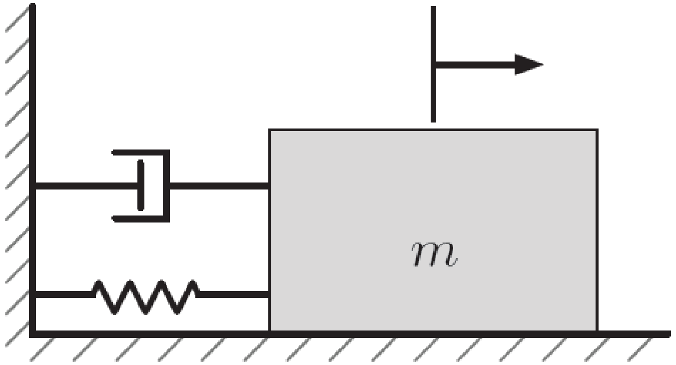
$$i = (C_0 + C_v v)\frac{dv}{dt} + \frac{v}{r_d}$$

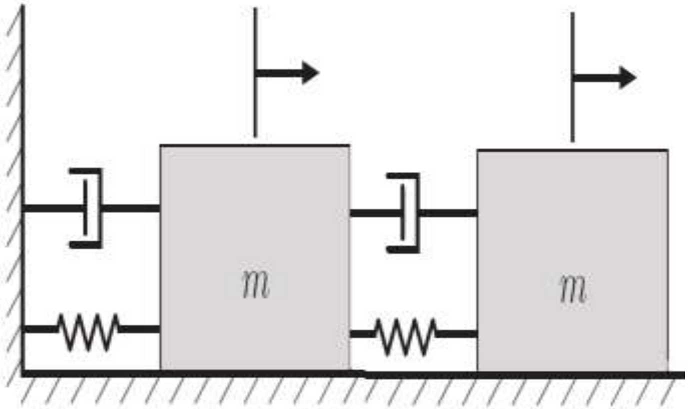
Editor - C:\+MyComponents\LossyUltraCapacitor.ssc

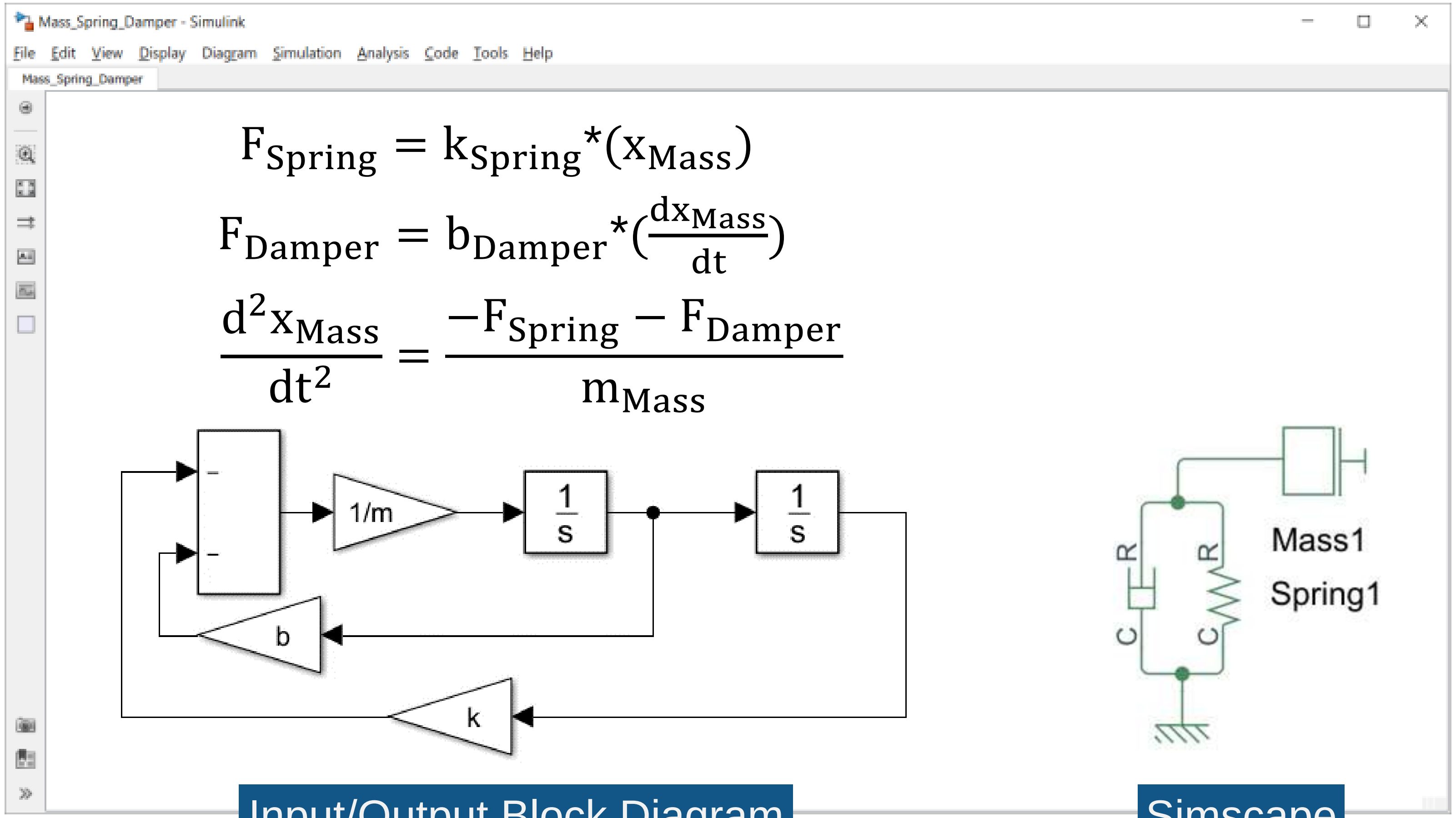
```
equations
  i == (C0 + Cv*vc)*vc.der + vc/Rd;
  v == vc + i*R;
end
```

Compare between Simulink and Simscape

Mass-Spring-Damper System





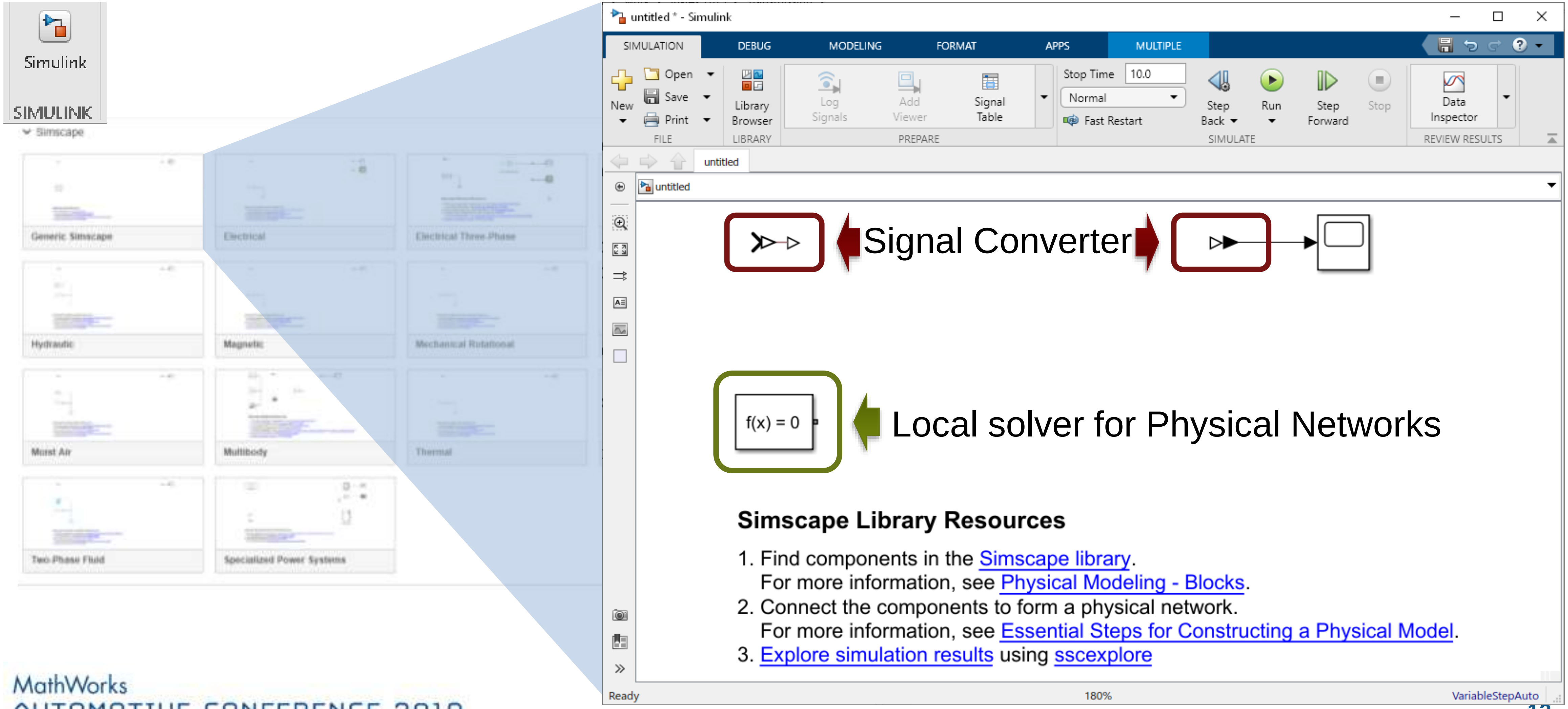


Input/Output Block Diagram

Simscape

Dynamic System Modeling using Simscape

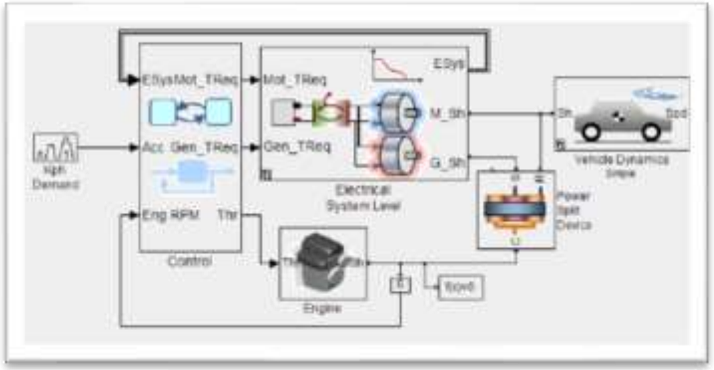
Longitudinal Control of a Vehicle

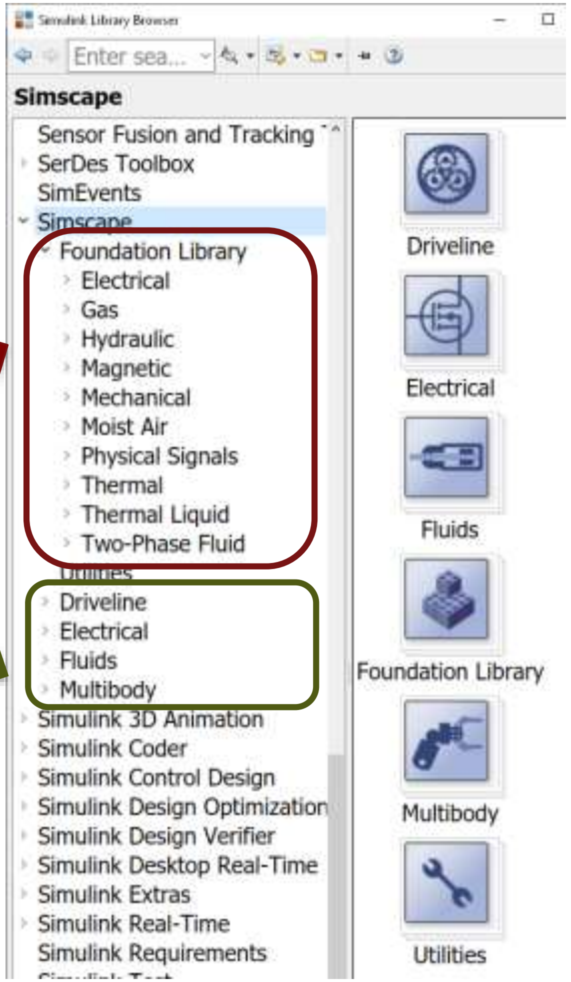


Dynamic System Modeling using Simscape

Longitudinal Control of a Vehicle

Foundation physical modeling blocks in more than 10 different physical domains

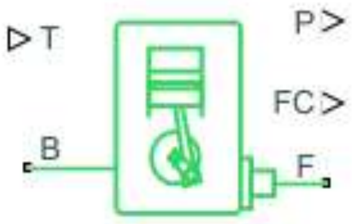




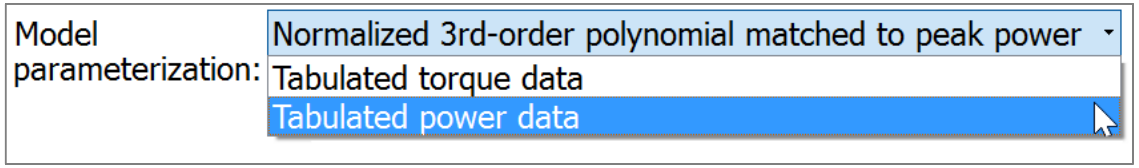
Simscape Driveline Component Models

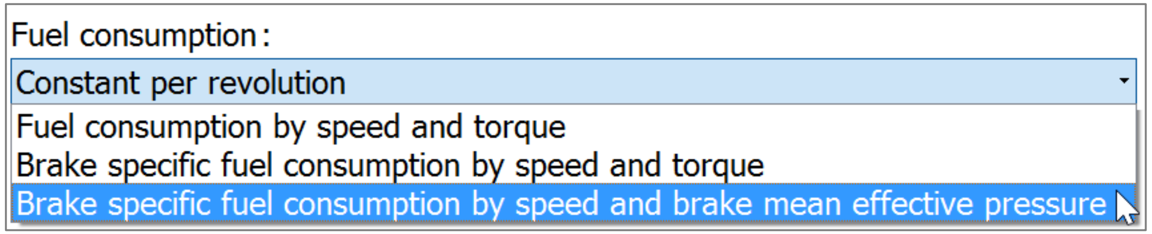
Engines, Shafts, Gears, Clutches, Tires

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

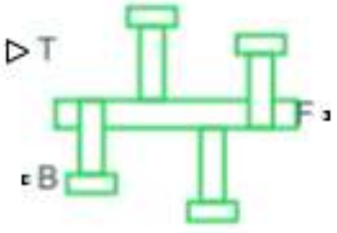


Generic Engine

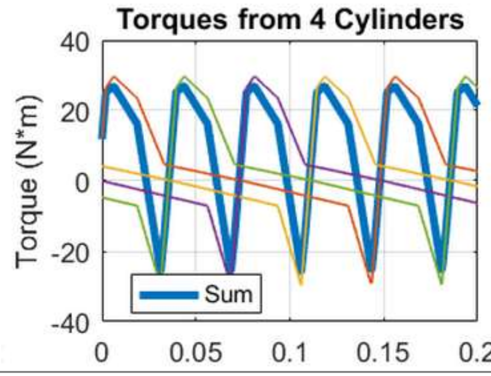


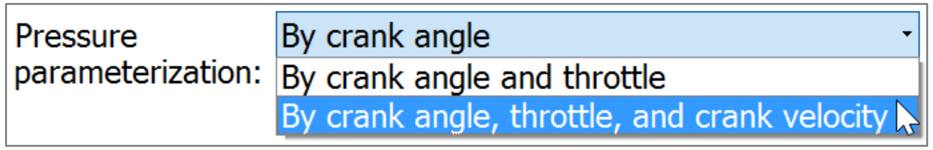


- Crank-Angle Resolved
  - Torque varies during piston cycle
  - Excite vibrations in drivetrain



Piston Engine



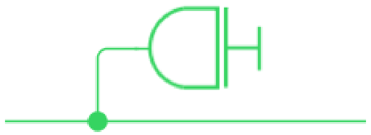


Simscape Driveline Component Models

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

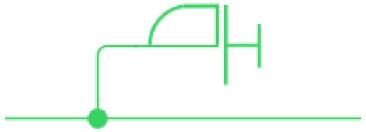
- Rigid
  - Ideal rigid shaft

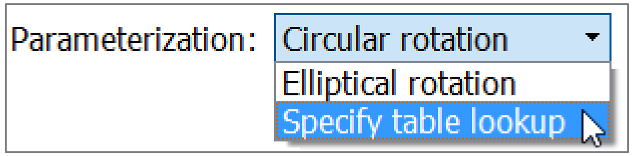
Inertia



- Unbalanced
  - Shaft inertia varies with rotation angle

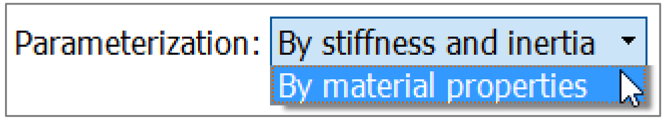
Unbalanced Load





- Flexible
  - Inertia with torsional flexibility

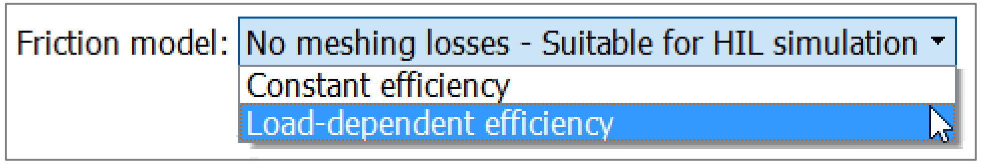
Flexible Shaft



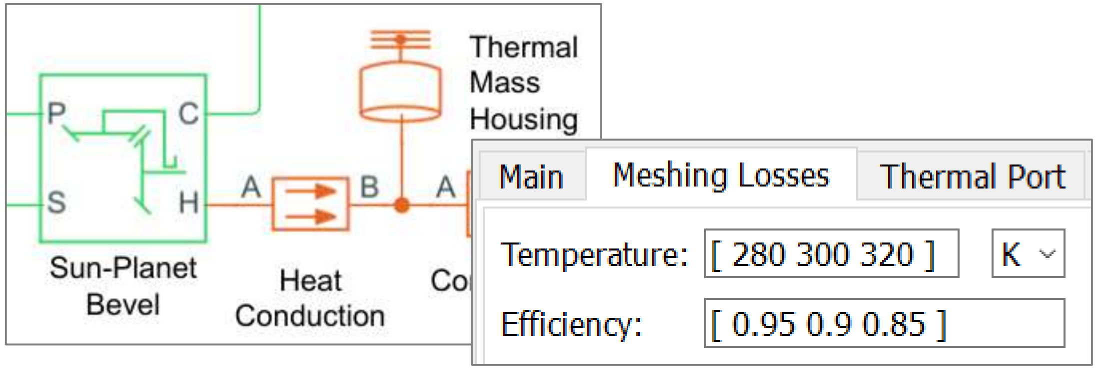
Simscape Driveline Component Models

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

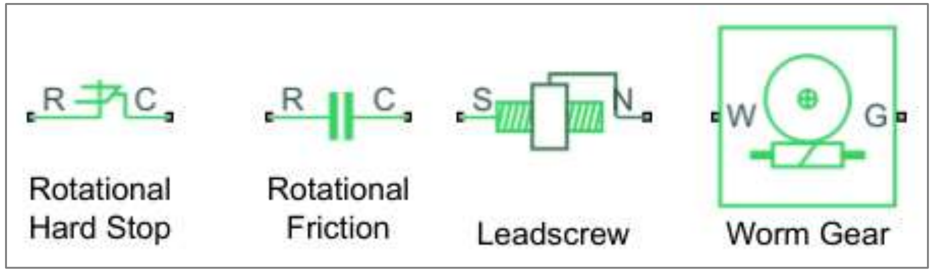
- Loss models
  - Valid for all shaft speeds and loads



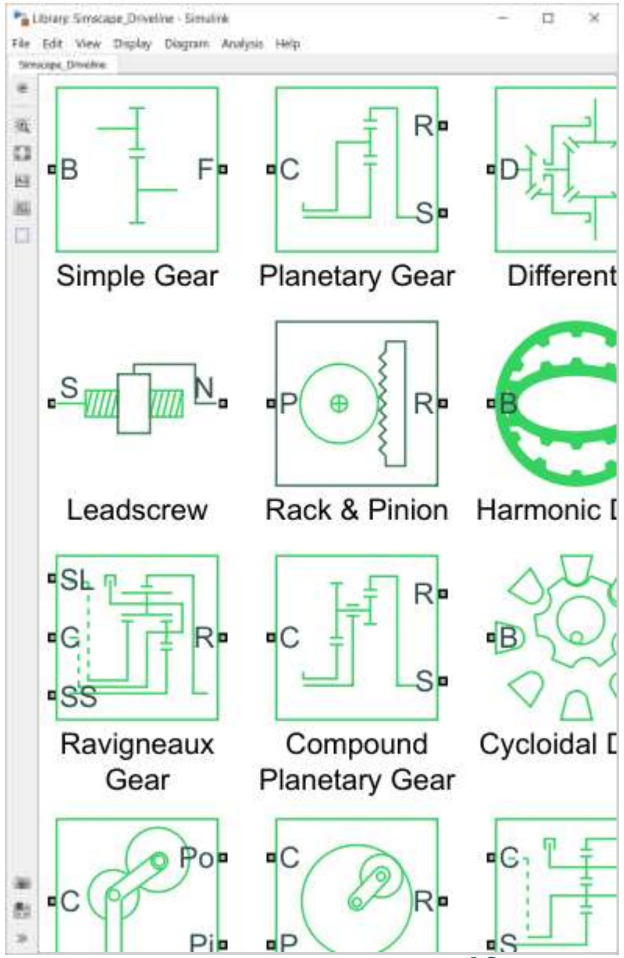
- Temperature effects
  - Heat transfer
  - Modified behavior



- Nonlinearities
  - Backlash
  - Friction
  - Self-locking

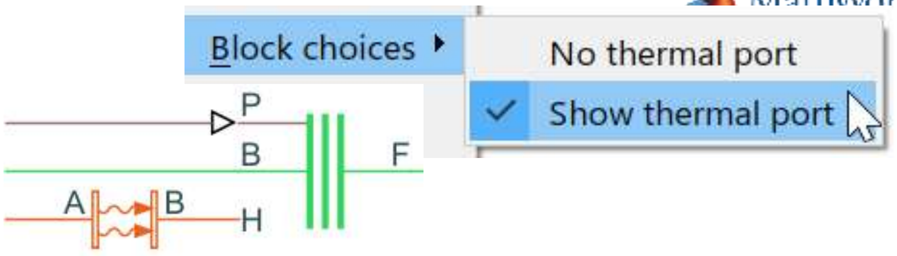


Subset of libraries

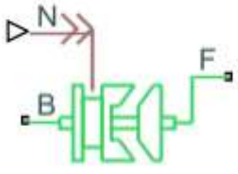


Simscape Driveline Component Models

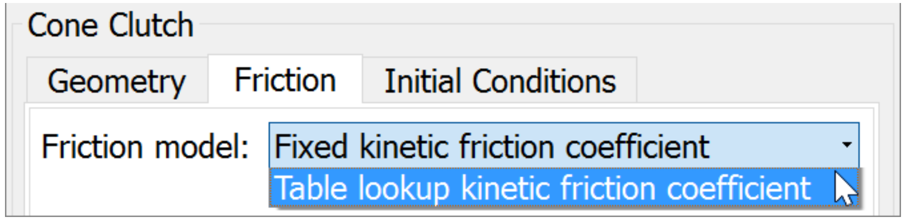
Engines, Shafts, Gears, **Clutches**, Tires



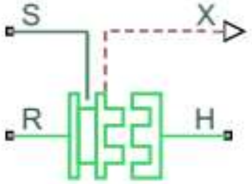
- Friction clutches
  - Customize friction model



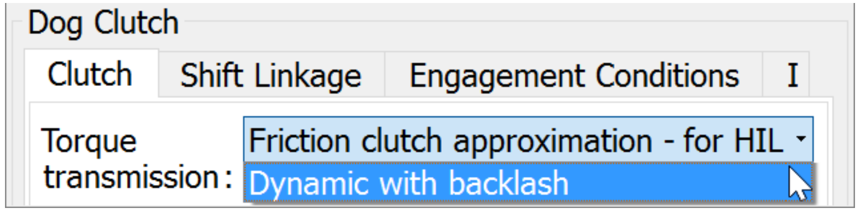
Cone Clutch



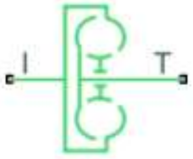
- Positive contact clutches
  - Backlash
  - Suitable for HIL



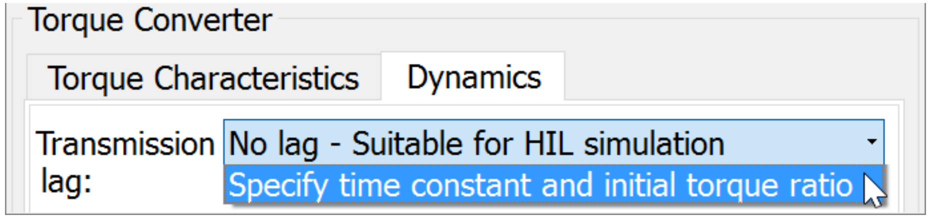
Dog Clutch



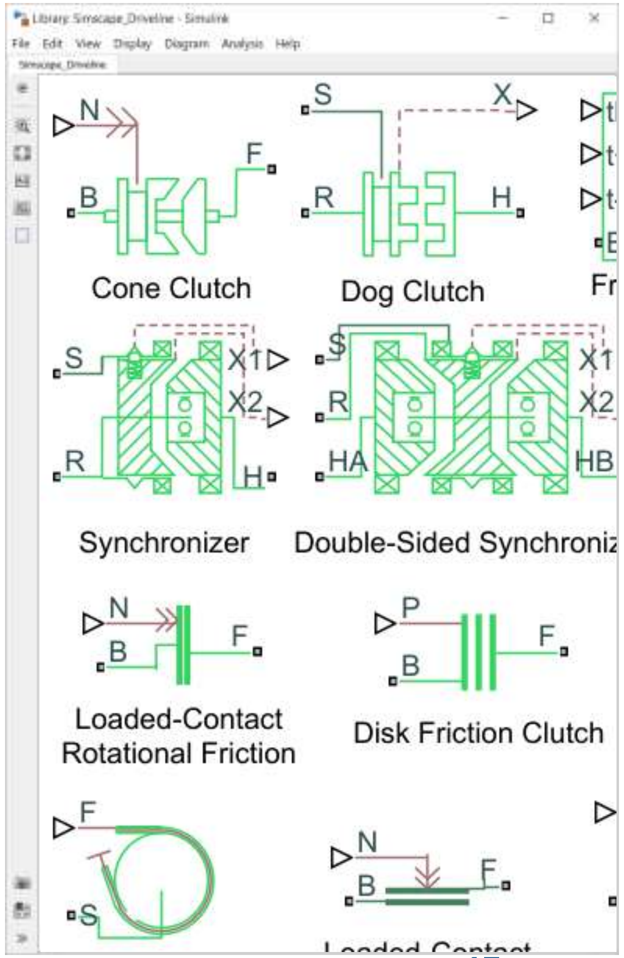
- Fluid couplings
  - Valid for all speeds and shaft loads



Torque Converter



Subset of libraries

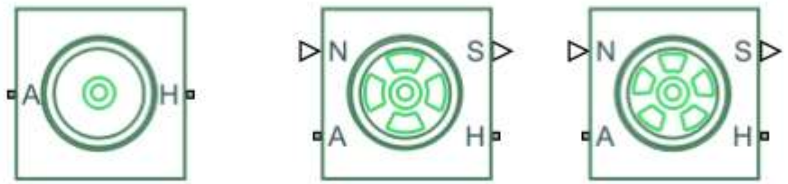


Simscape Driveline Component Models

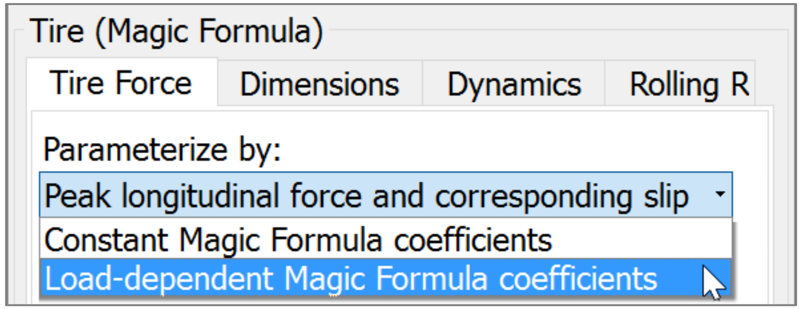
Engines, Shafts, Gears, Clutches, **Tires**

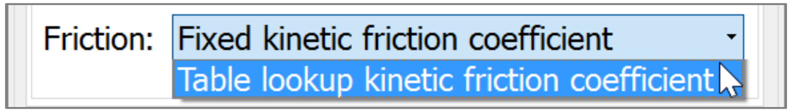
- With and without slip
  - Various options for friction coefficients

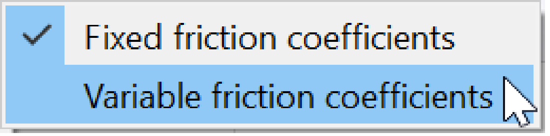
No Slip | With Slip



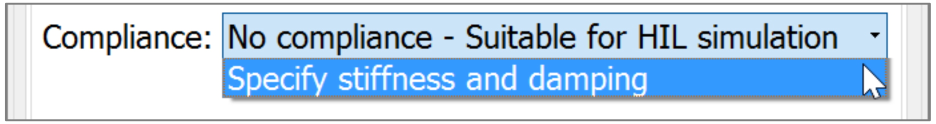
Tire (Simple) | Tire (Friction Parameterized) | Tire (Magic Formula)

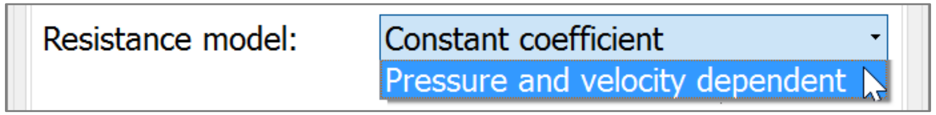




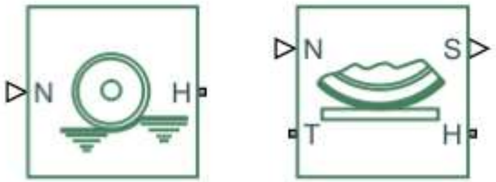


- Adjustable effects
  - Compliance
  - Rolling resistance





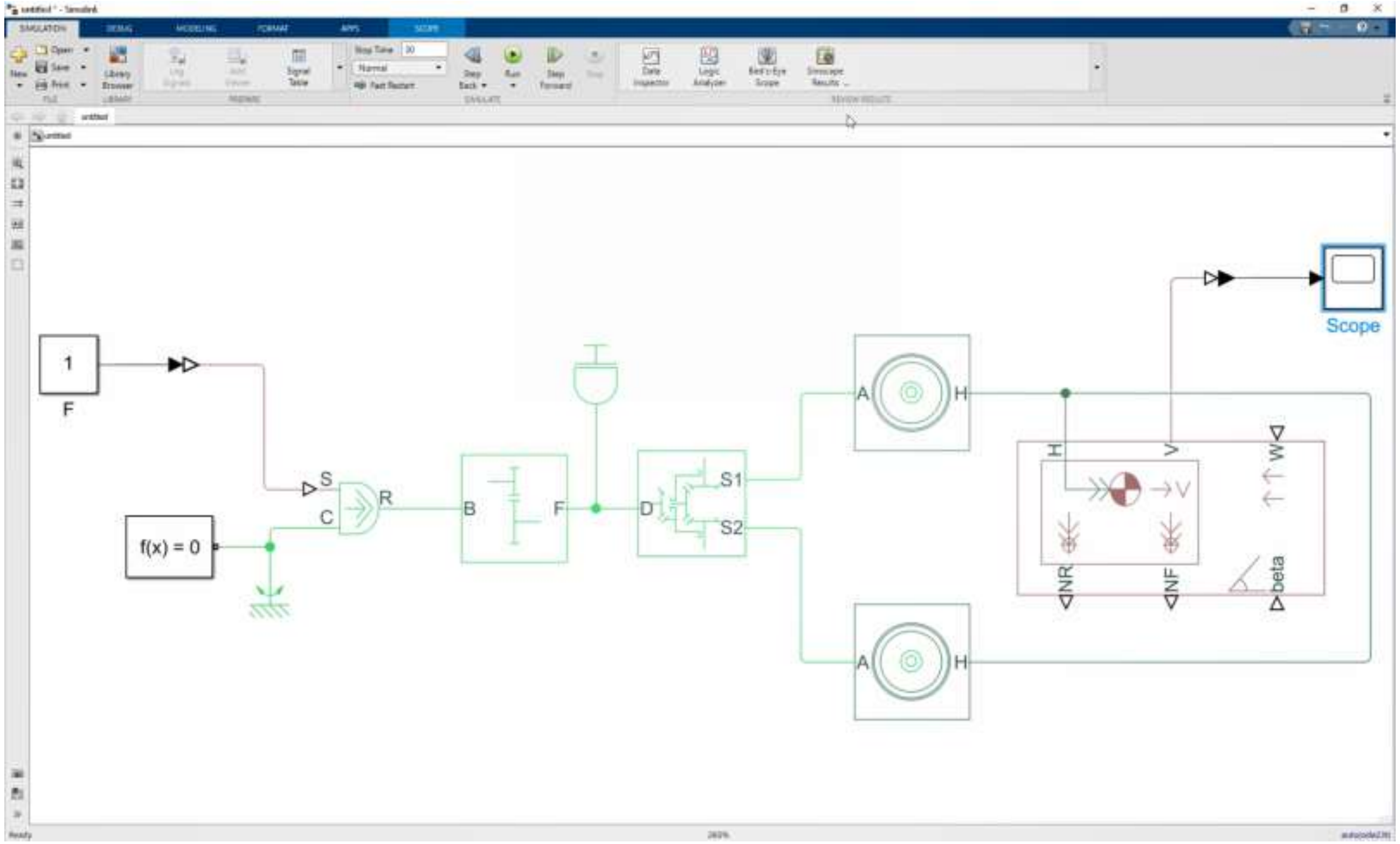
- Custom models
  - Construct models to meet your exact requirements



Rolling Resistance | Tire-Road Interaction (Magic Formula)

Dynamic System Modeling using Simscape

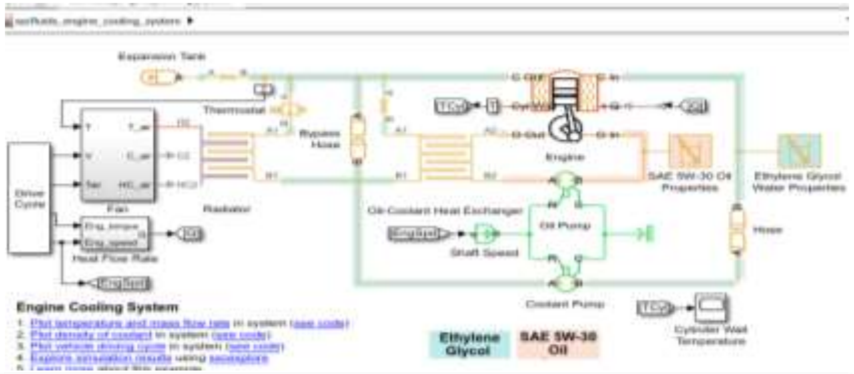
Longitudinal Control of a Vehicle



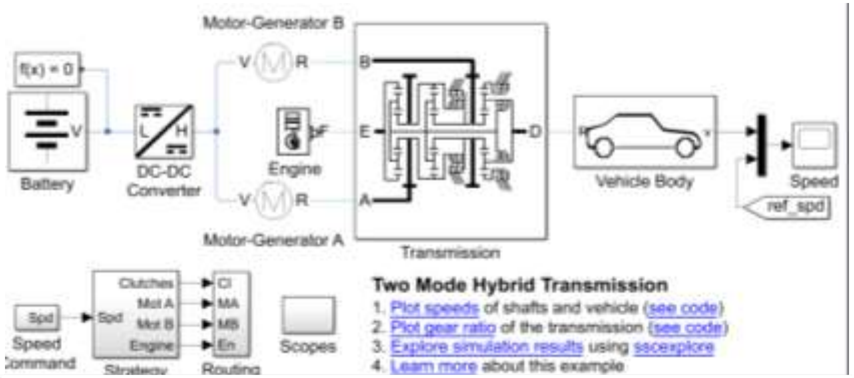
Dynamic System using Simscape

Electrical | Driveline | Multibody | Fluids

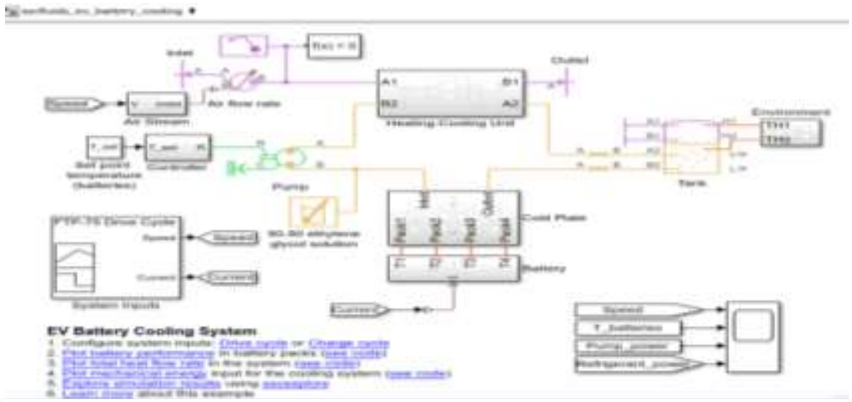
Simscape



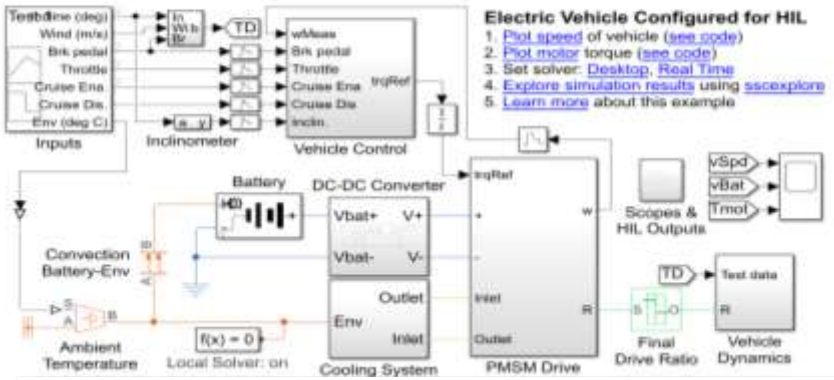
Engine Cooling System



Two Mode Hybrid Transmission



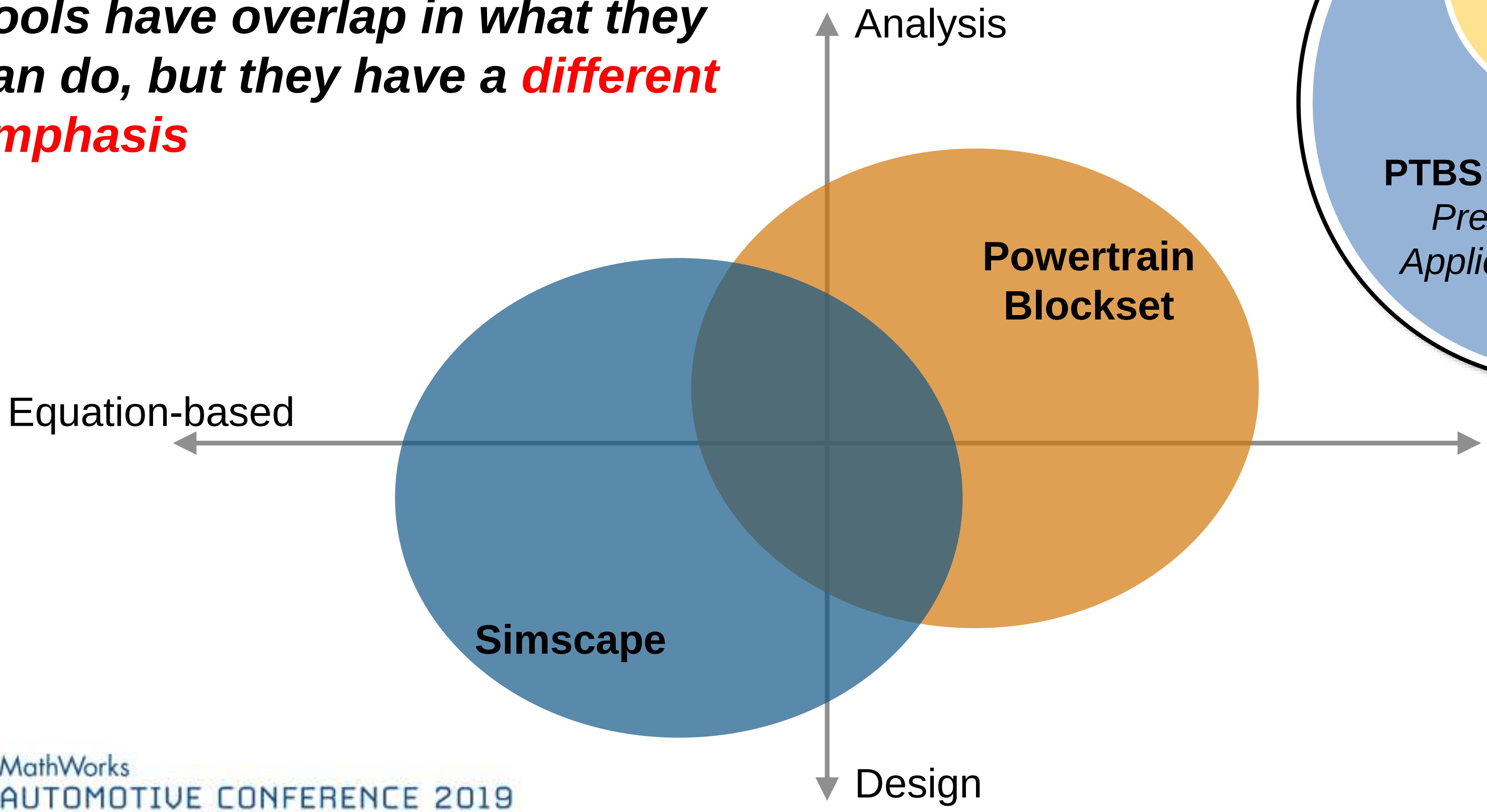
Battery Cooling System

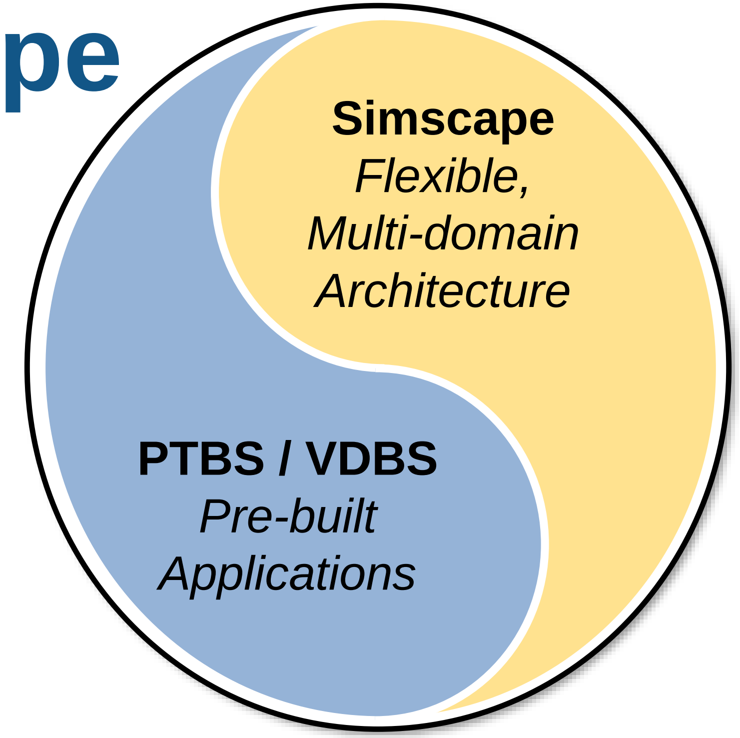


EV configure for HIL

Powertrain Blockset and Simscape

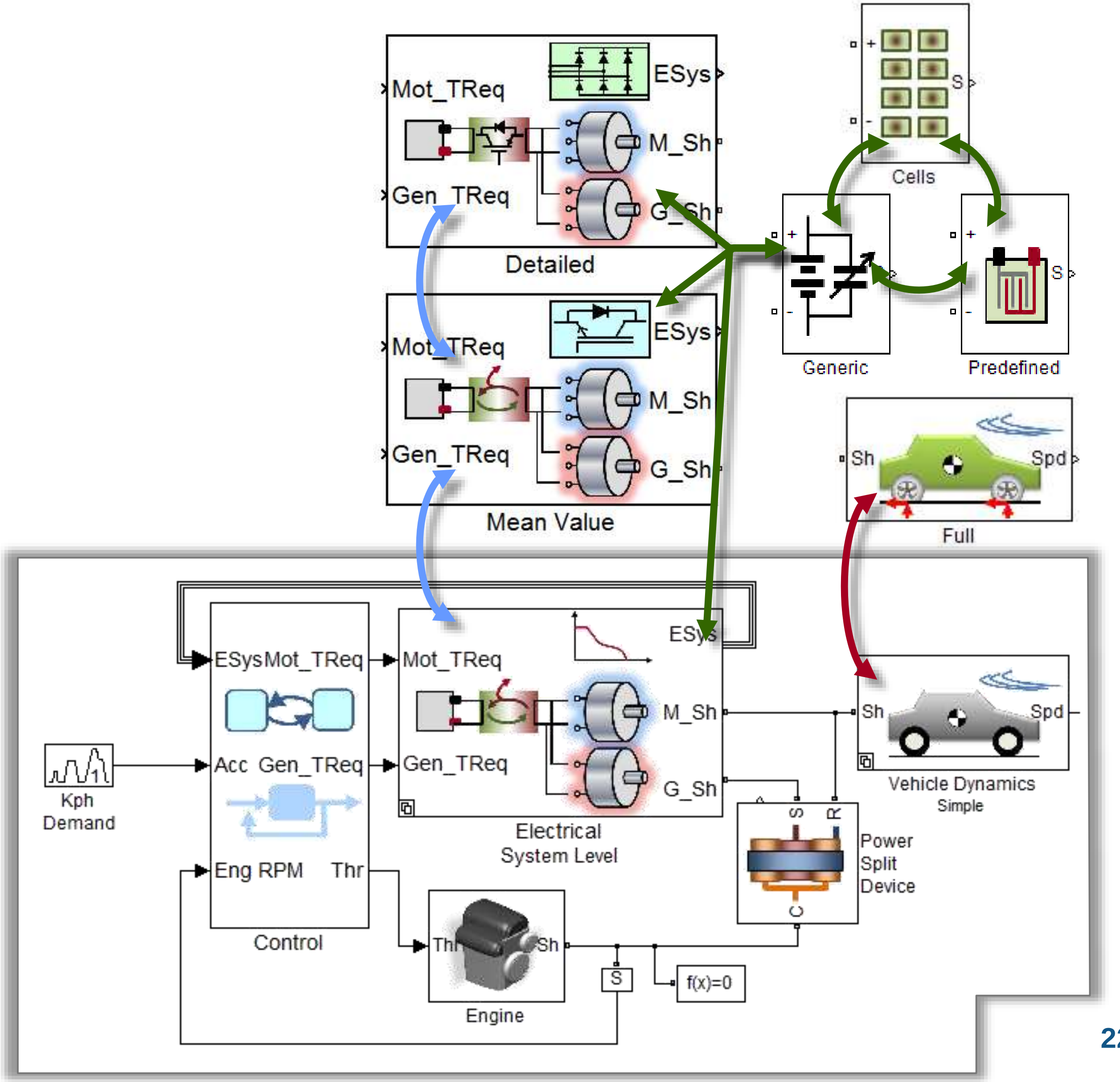
Tools have overlap in what they can do, but they have a different emphasis



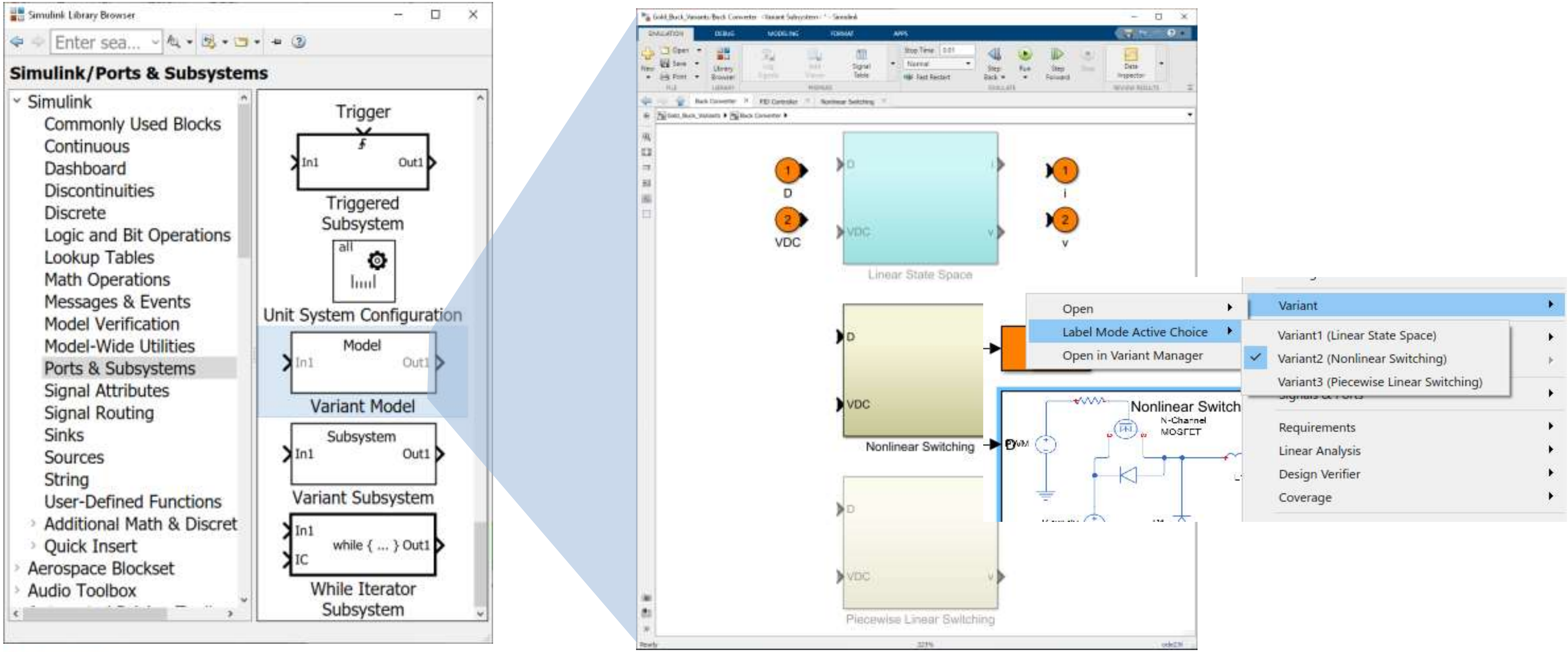


Hybrid Electrical Vehicle Model Balance Fidelity and Speed

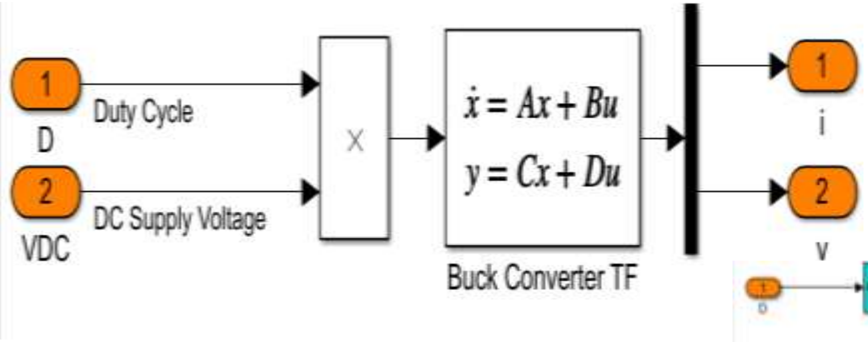
- Electrical
  - System Level
    - Test integration, optimize system
  - Mean Value
    - Three-phase electrical system
  - Detailed
    - Test power quality
- Battery
  - Generic, predefined, and custom models
- Vehicle
  - Inertial & Aero Effects
  - Tire models



Model Fidelity

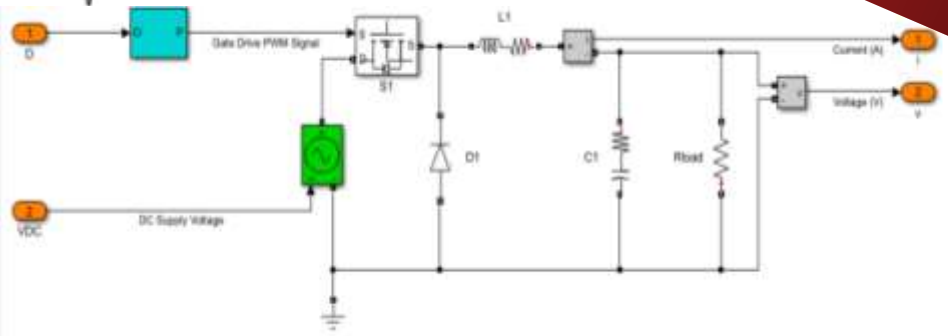


Buck Converter Modeling about Various Fidelity

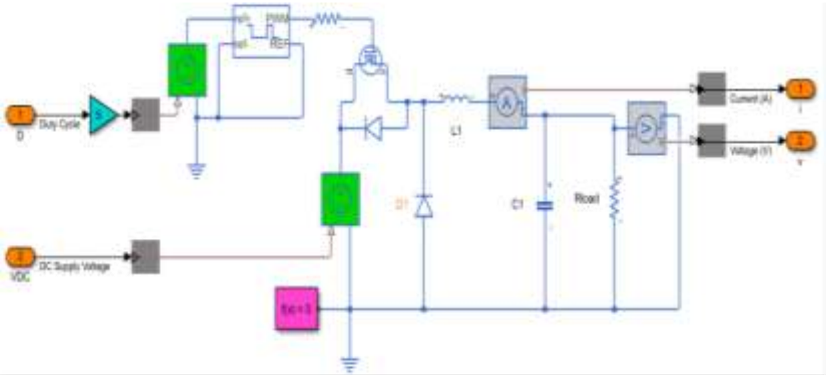


Linear State Space Model

High Fidelity



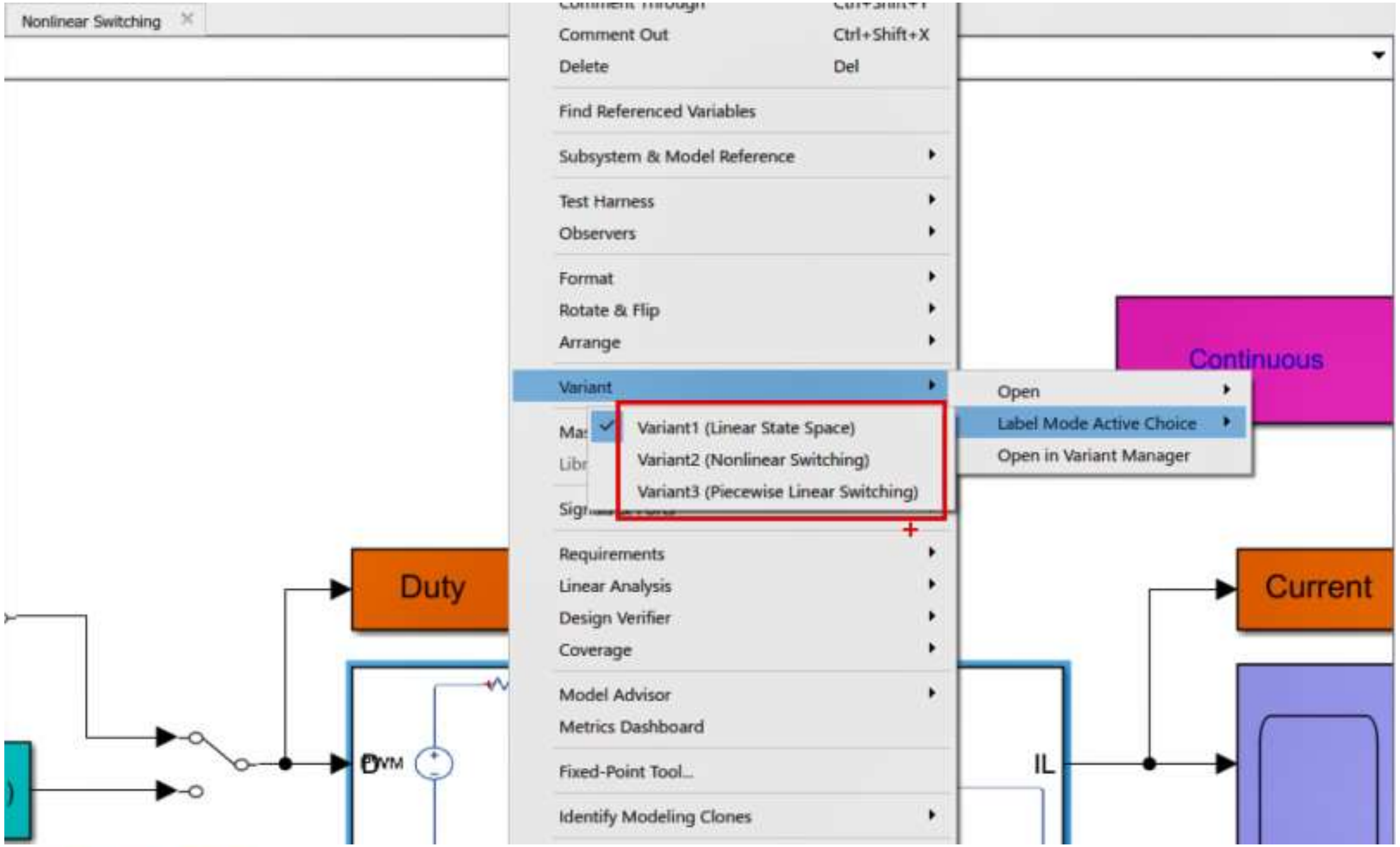
Piecewise Linear Switching Model



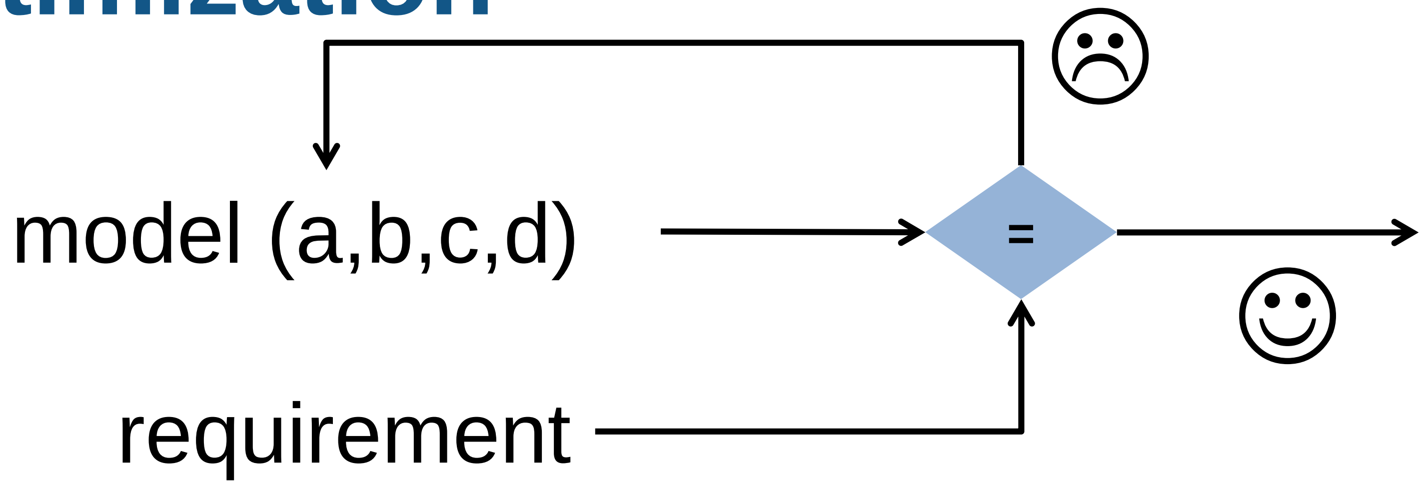
Nonlinear Switching Model

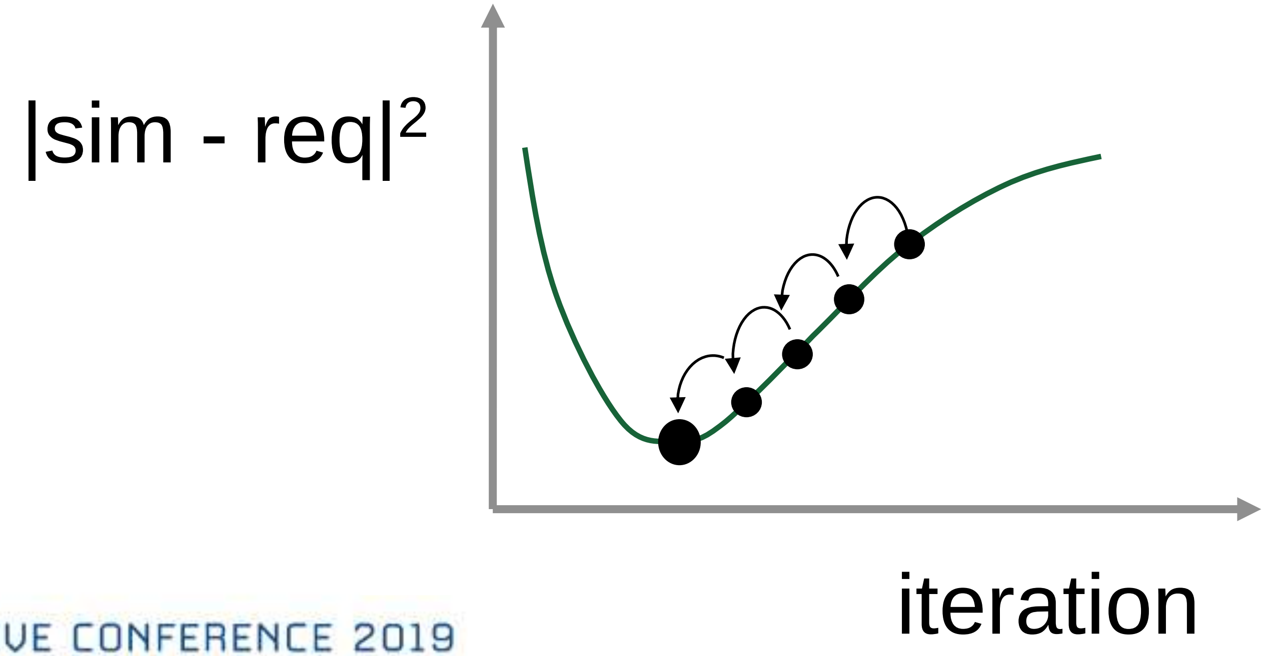
High Speed

Buck Converter Modeling about Various Fidelity



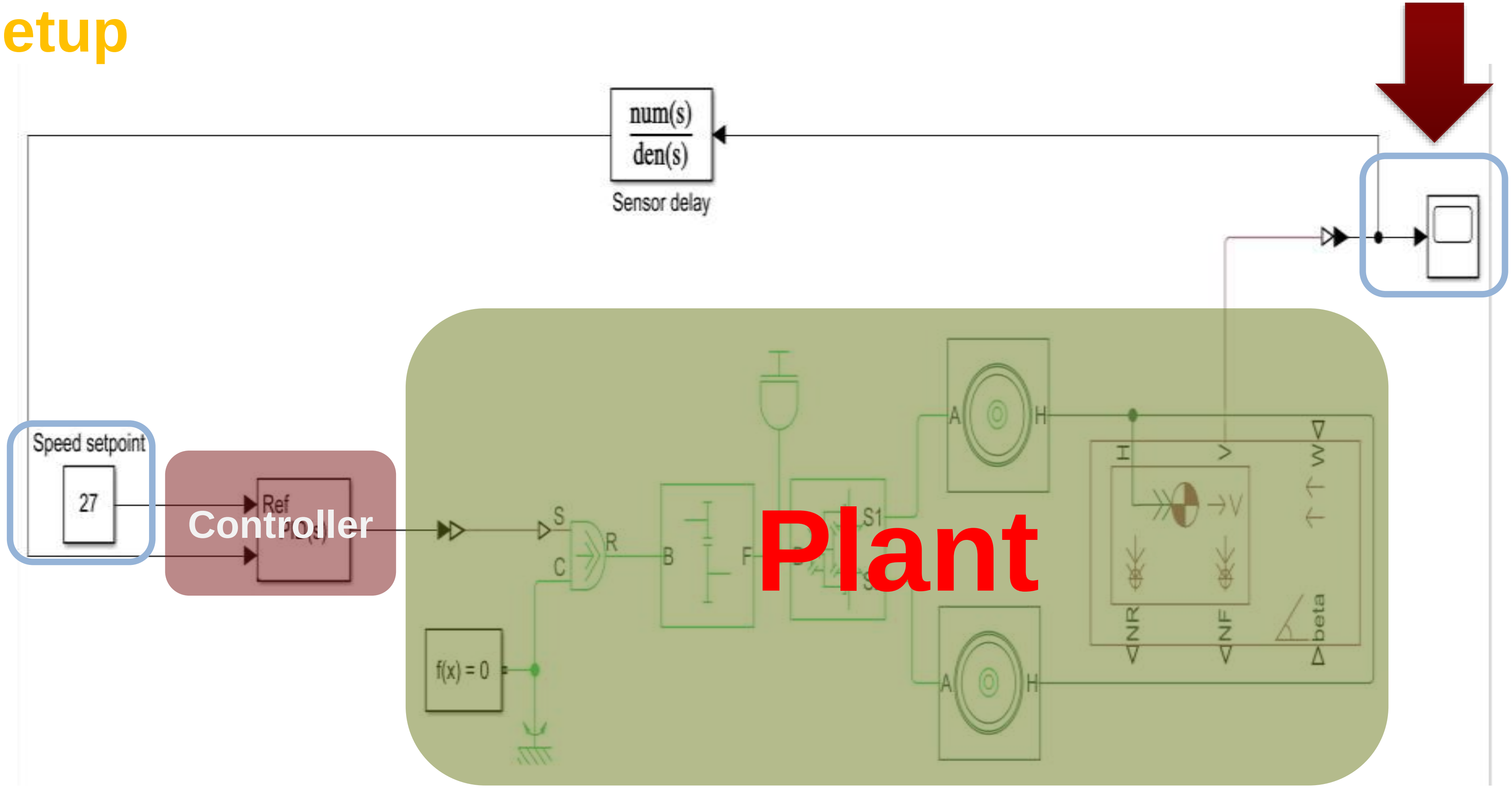
Response Optimization





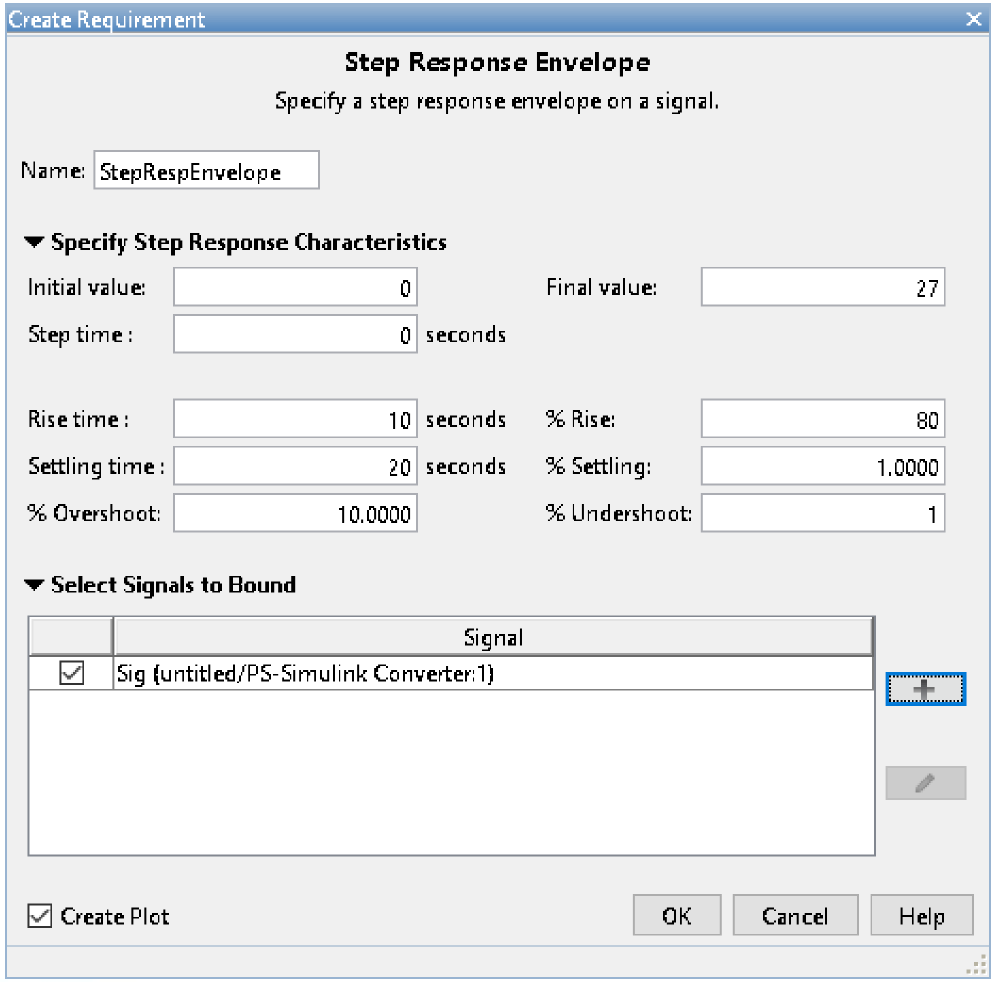
Response Optimization

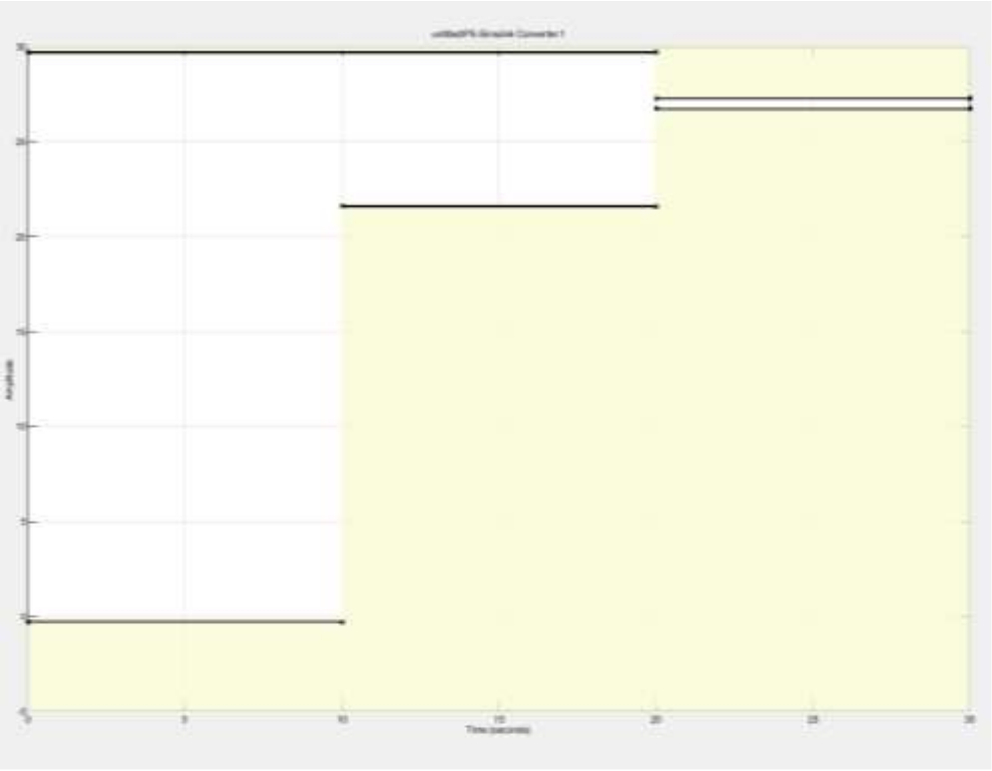
Model setup



Response Optimization

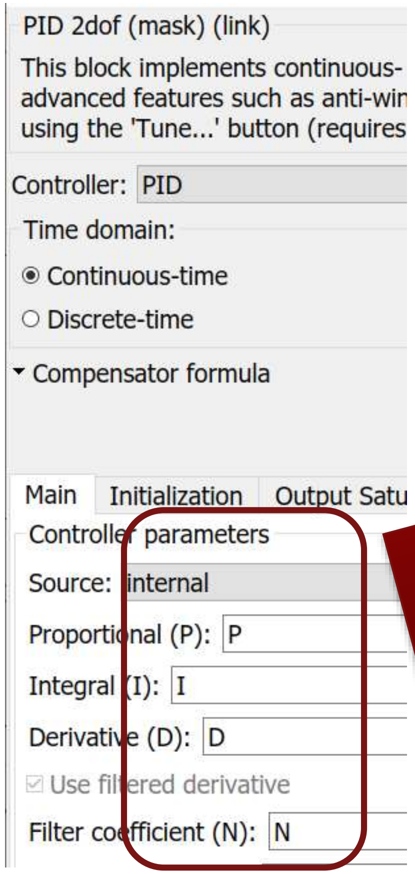
Requirement

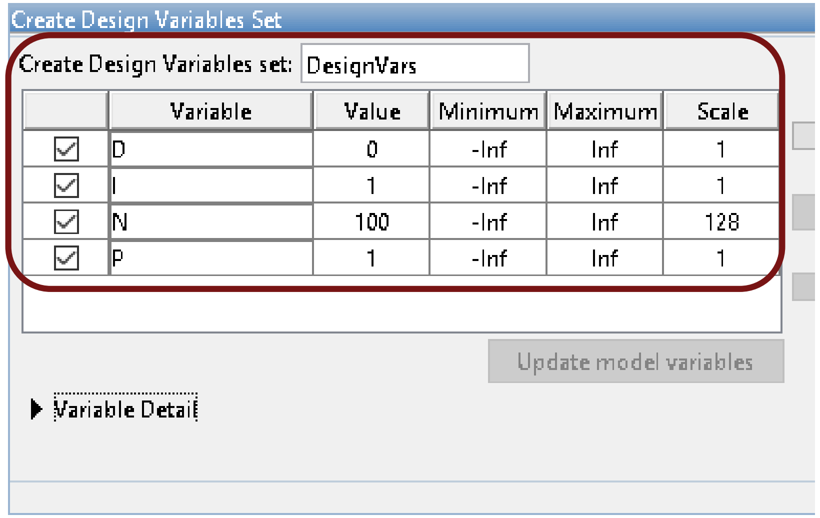




Response Optimization

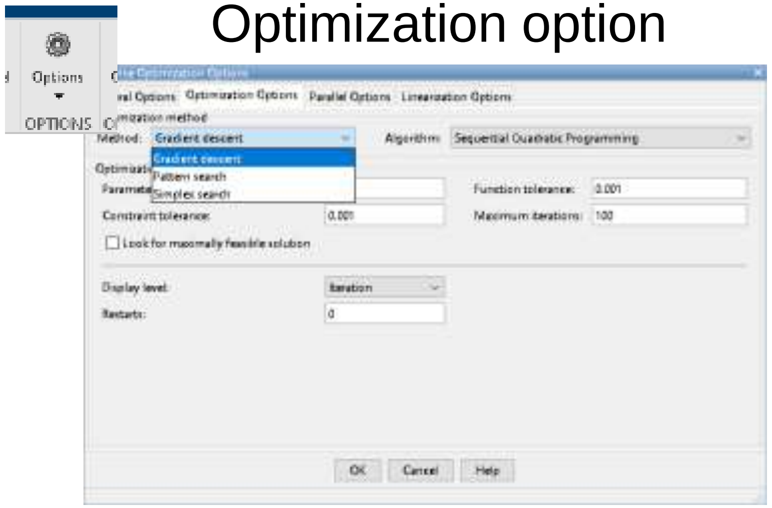
Parameterization & Optimization

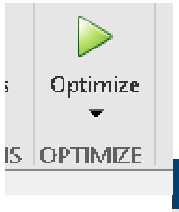


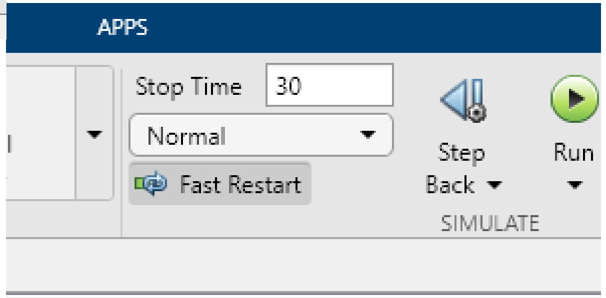


Choose Design variables

Optimization option







Simulation speed up

Response Optimization

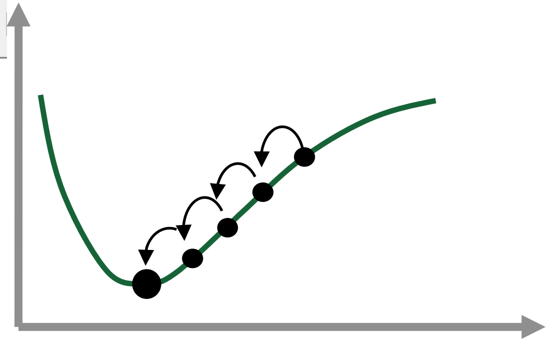
Optimization Progress Report

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

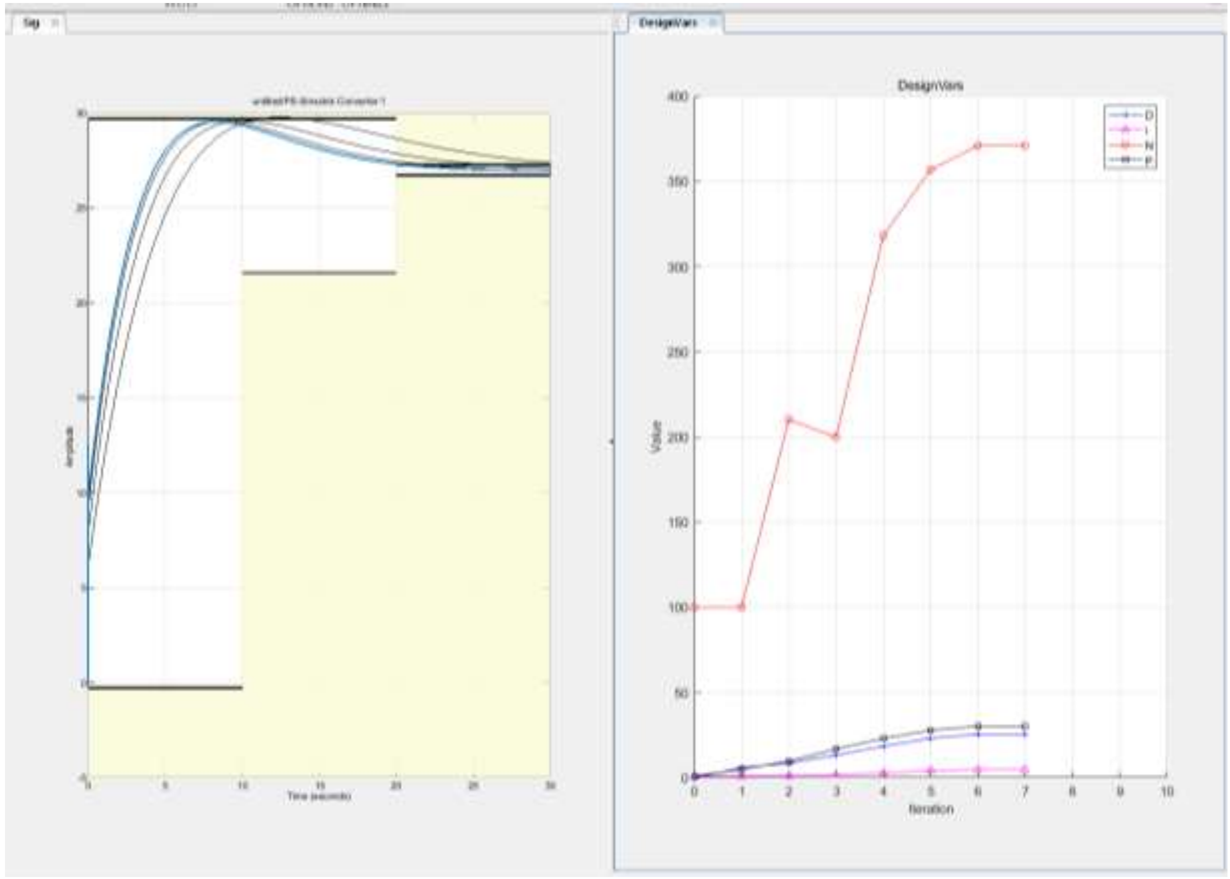
Optimization started 28-Oct-2019 21:33:07

Optimization converged, 28-Oct-2019 21:37:15

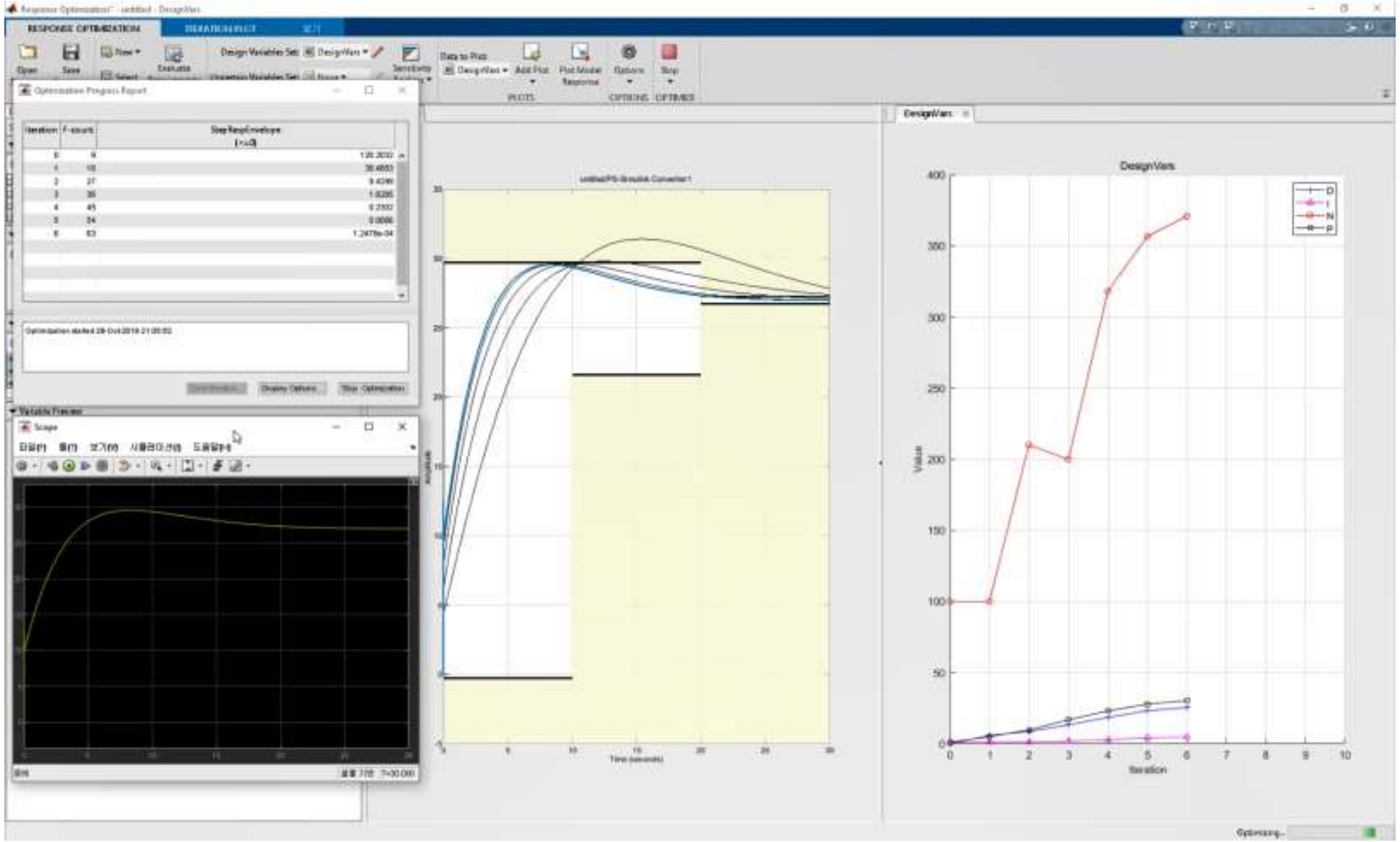
$|sim - req|^2$



iteration

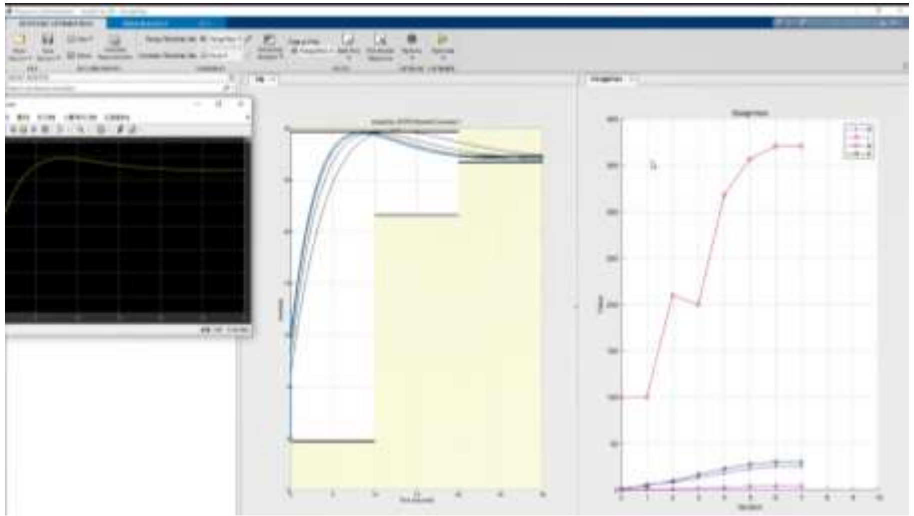


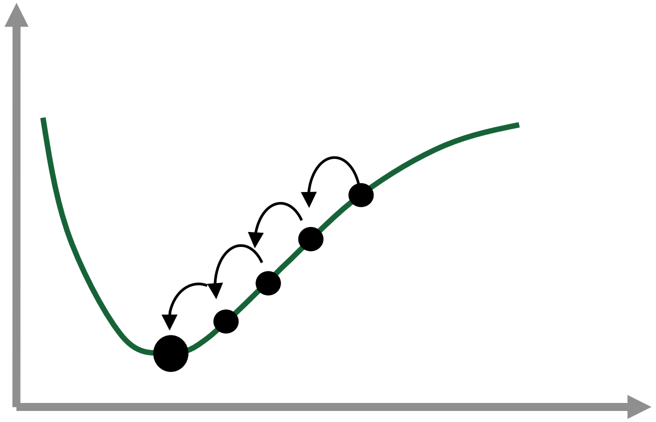
Response Optimization



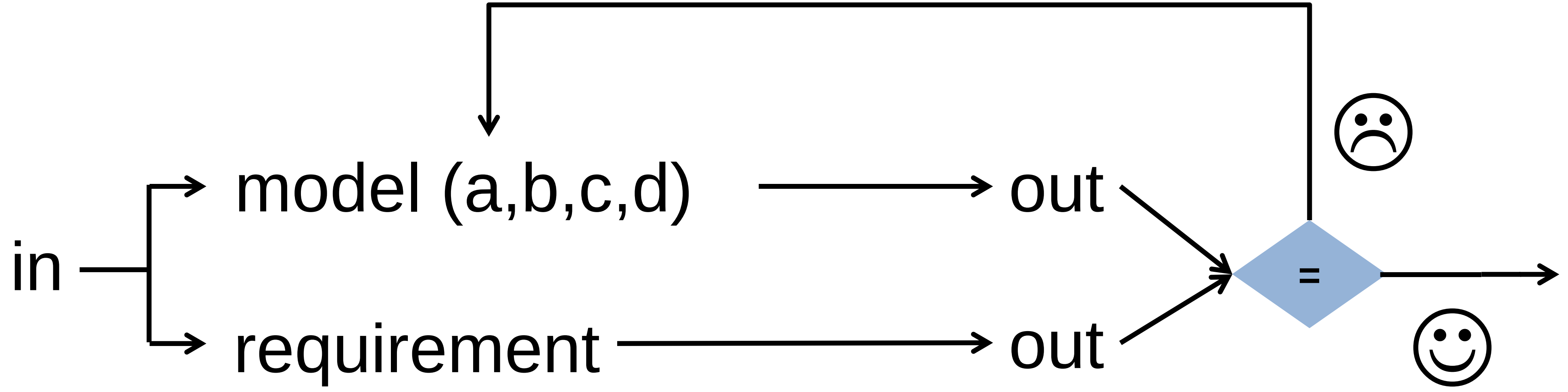
Response Optimization

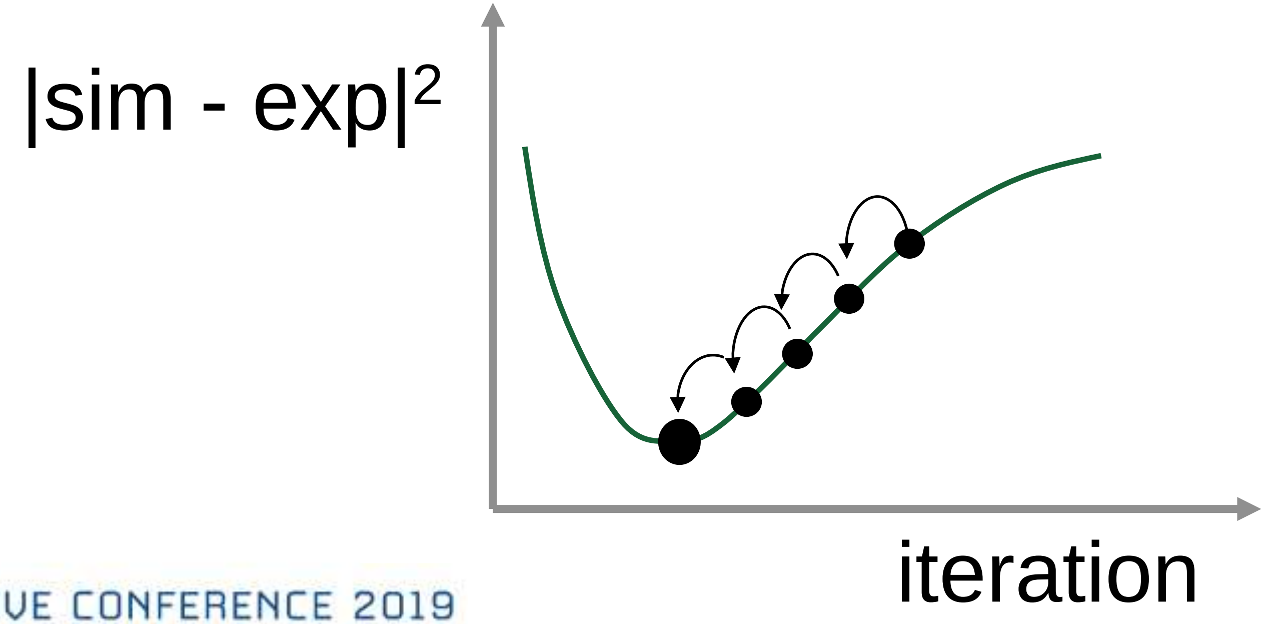
- Optimization + Simulation
- Fully non-linear plant
- Parallelizable
- Applicable to any parameter
  - Controller
  - Plant

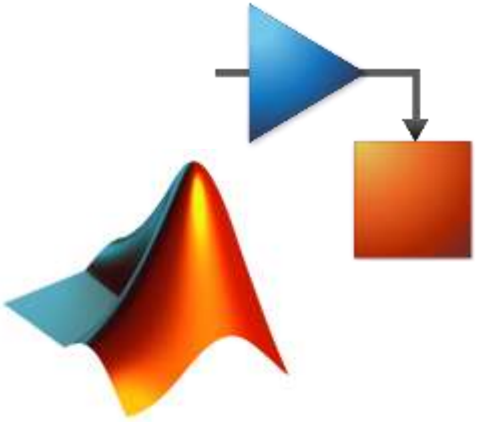




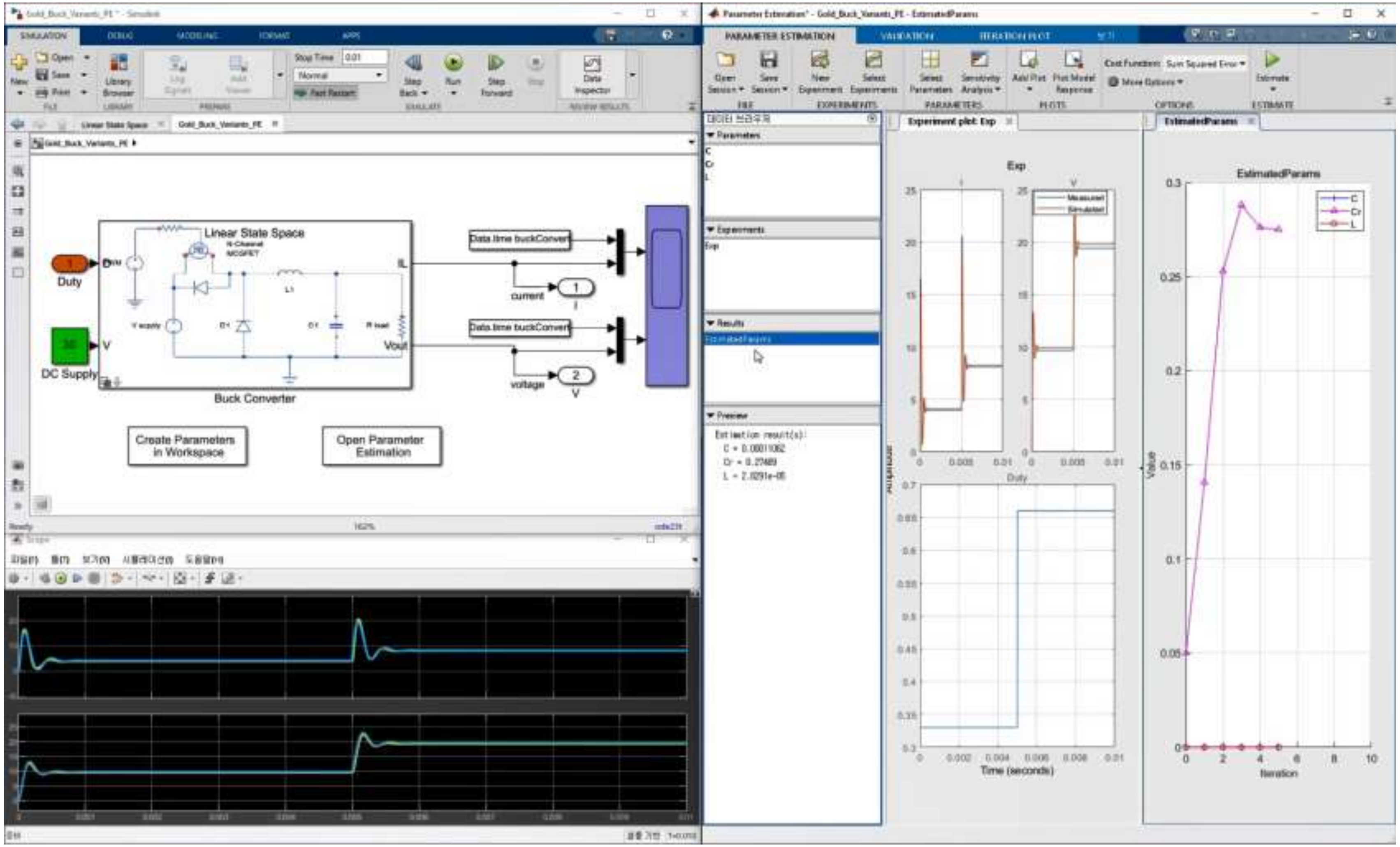
Parameter Estimation



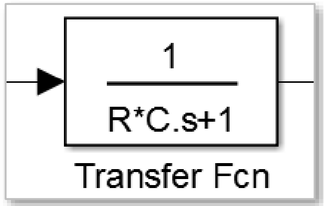


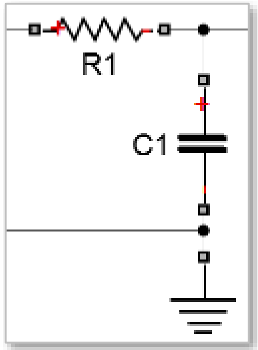


Parameter Estimation

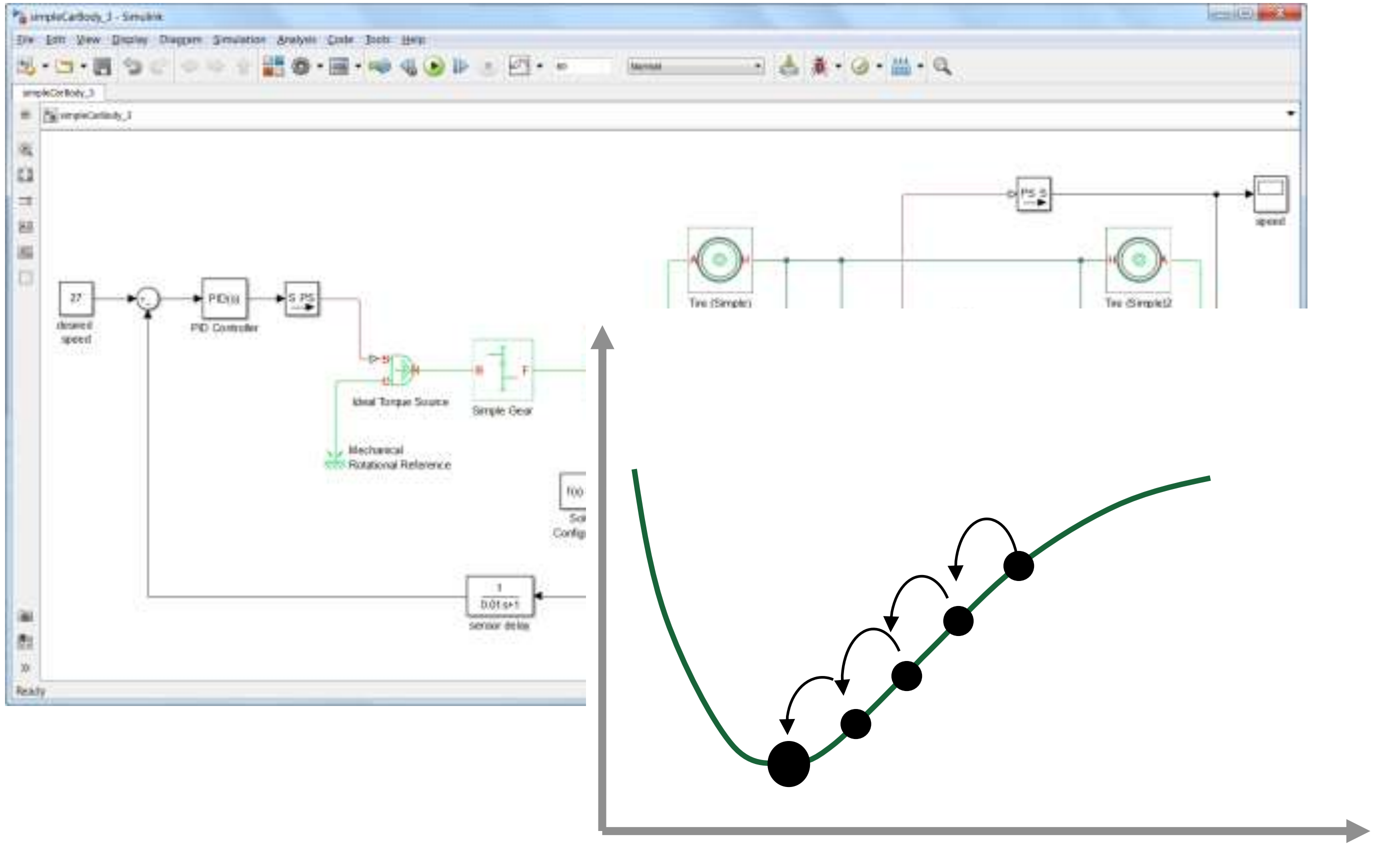


Key Takeaways





- Simulink and Simscape
  – Signal- and network-based multi-domain modeling



- The Power of MATLAB
  – Response Optimization
  – Parameter Estimation

Thank You