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High-Fidelity Transmission Simulation

for Vehicle Dynamics Simulations

Orang Vahid, PhD

Senior Modeling Engineer, Maplesoft

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Topics

- Introduction – Model Based Development
- The MapleSim Solution
- The Driveline Component Library
- Advantage of the Symbolic Technology
- MapleSim and VI-CarRealTime
- Summary

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Physical Model-Based Development

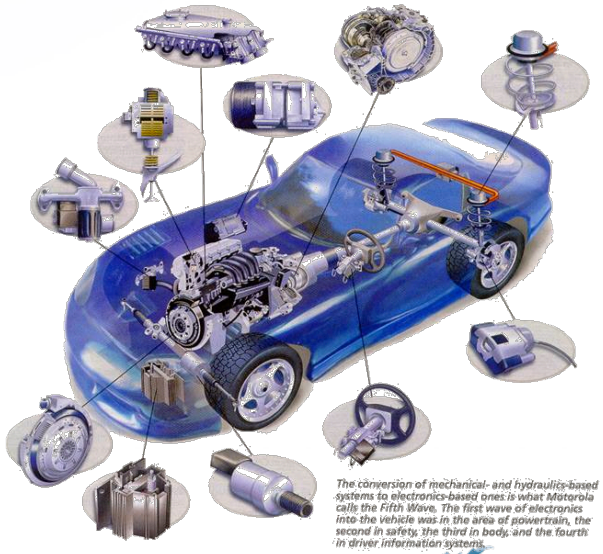
"Virtual" Prototyping through Model-based Design and Development plays an increasingly key role in powertrain design and development.

- Increasing adoption of MBD and simulation
  - Reduce prototyping cycles and costs
  - Increase end-user functionality, quality, safety and fuel-efficiency
  - Deterministic, repeatable testing platform

Modeling the whole vehicle provides greater insight into overall energy losses and how to reduce them

- Energy loss through individual subsystems
- Efficiency losses through interaction between subsystems

Greater demand for greater model fidelity…



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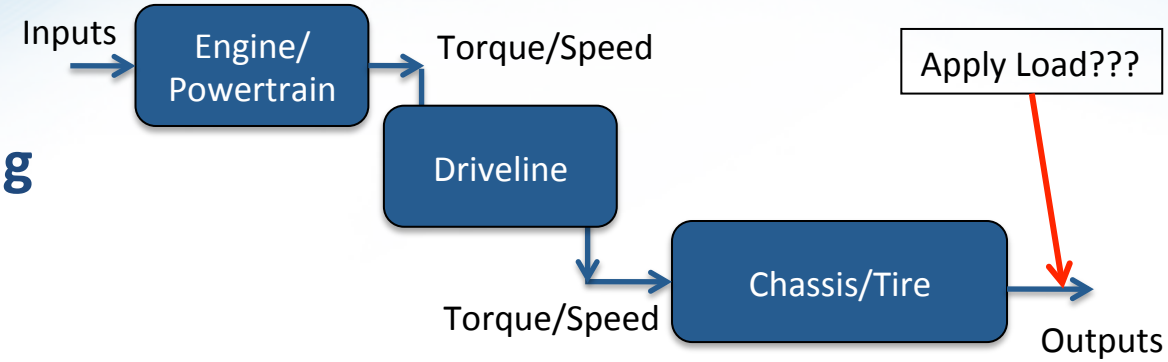
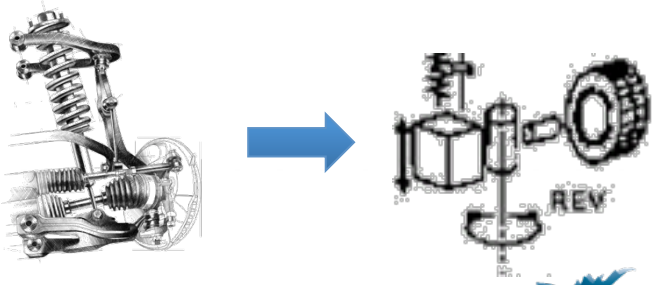
Emerging Challenges

Scalability

Multi-domain Modeling



Real-time Performance



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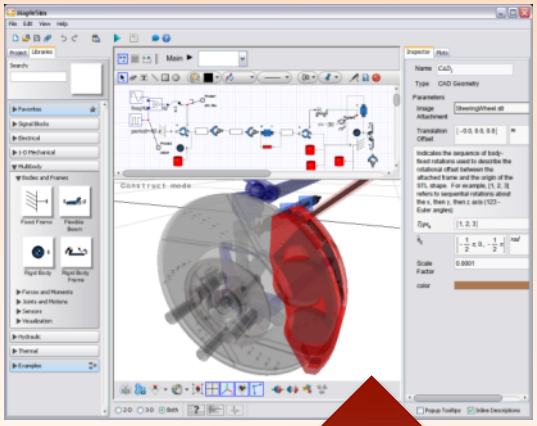
The MapleSim Solution

Multidomain physical modeling and simulation

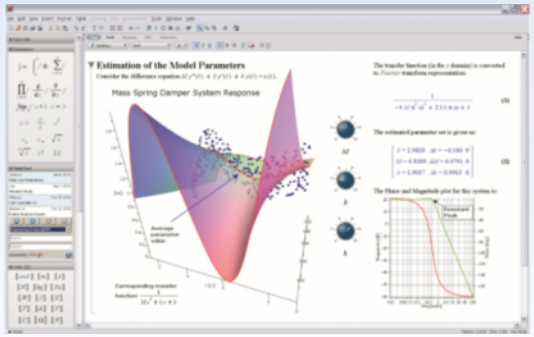


Control Design **Toolbox** | Tire Component Library | Driveline Component Library | More Libraries

MapleSim Connector

- dSPACE
- LabVIEW
- NI VeriStand
- MATLAB & SIMULINK
- Automation Studio
- VI grade — engineering software & services
- modeLisar — Functional Mock-up Interface

Analysis environment



Global Optimization | MapleNet | GRIDComputing

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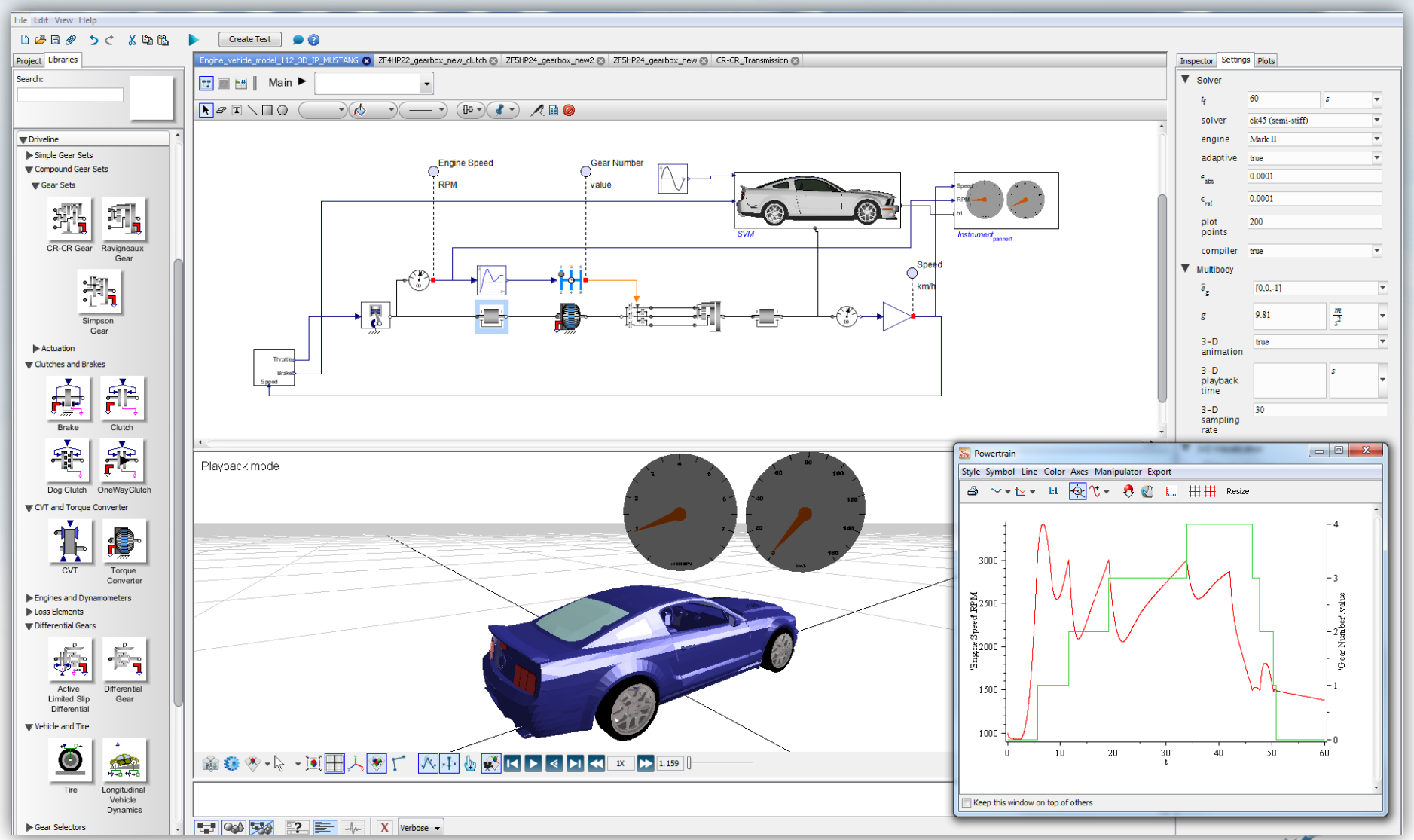
MapleSim Modeling Environment



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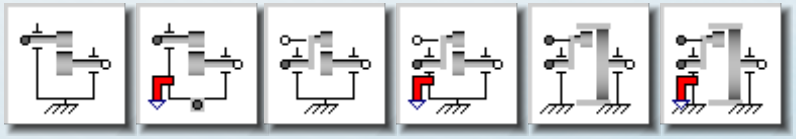
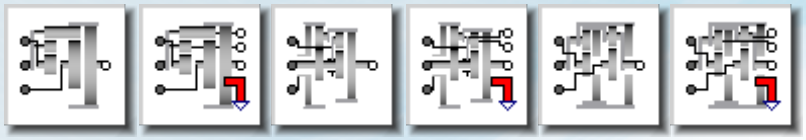
Driveline Component Library

Simple Gear Sets

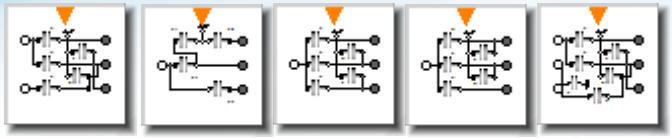


Planetary Gear Sets

Compound Gear Sets

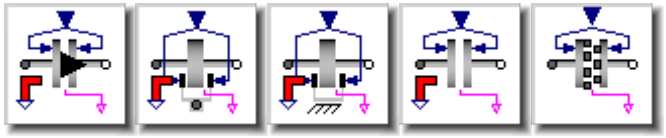


Actuation Components

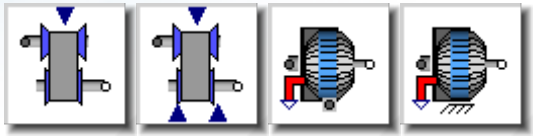


Differentials

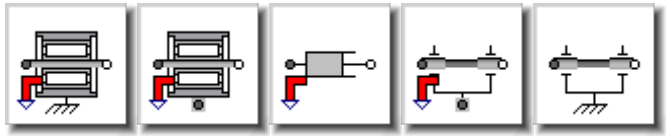
Brakes and Clutches



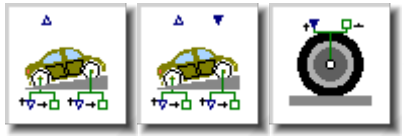
CVT and Torque Converter



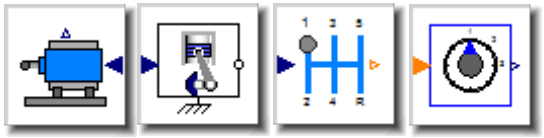
Loss Components



Vehicle Dynamics



Dyno, Engine, Gear Shifter



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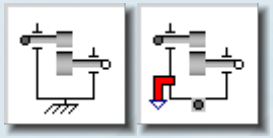
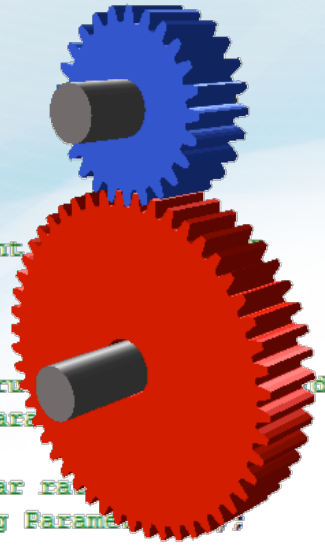
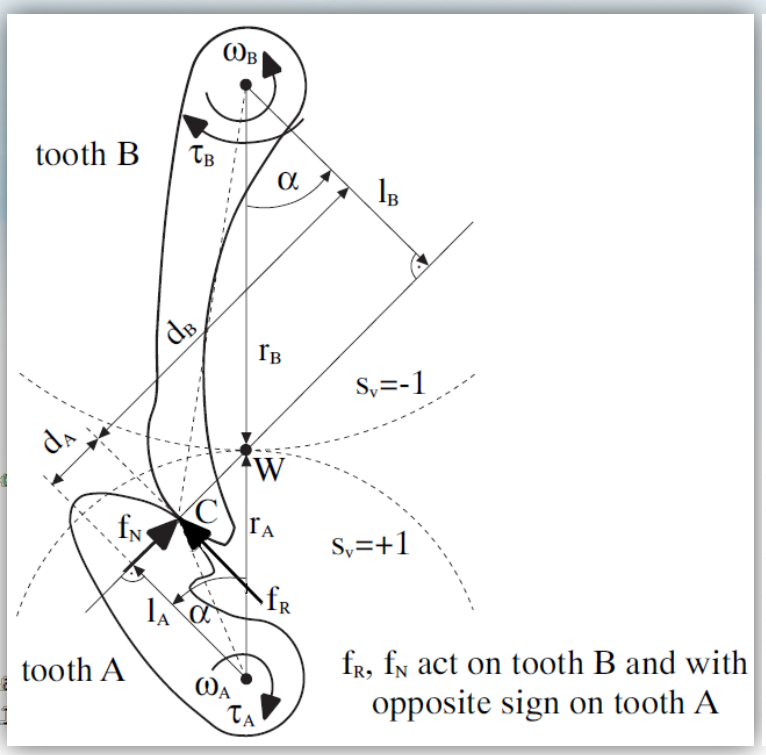
Modeling Gear Sets

Simple Gear Sets

- Basic Gear







Pelchen C., Schweiger C., Otter M.
Modeling and Simulating the Efficiency of Gearboxes and of Planetary Gearboxes
2nd International Modelica Conference, Proceedings, pp. 257-266

```
model BasicGear "Mass-less gear element
  import Modelica.Blocks.Types;

  parameter Boolean ideal=true "= tru                    deal,
  annotation(Dialog(tab="Modeling Para

  parameter Real ratio(start=1) "Gear ra
  annotation(Dialog(tab="Engineering Parame

  parameter DataSourceMode4 datasourcemode=DataSourceMode4.Via
  annotation(Dialog(tab="Modeling Parameters",enable=not ideal

  parameter String fileName="DataFileName" "Enter the file (complete path) where matrix is stored"
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  parameter Real columns[1, :]=[2, 3] "Data columns used"
  annotation(Dialog(tab="Engineering Parameters",enable=not ideal and (datasourcemode==DataSourceMode4.OnFile or data

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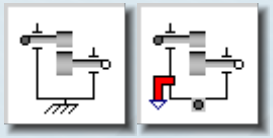
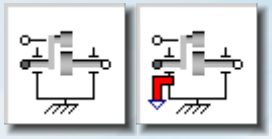
Modeling Gear Sets

Simple Gear Sets

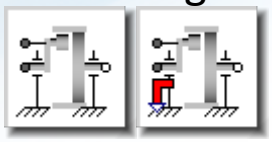
- Basic Gear



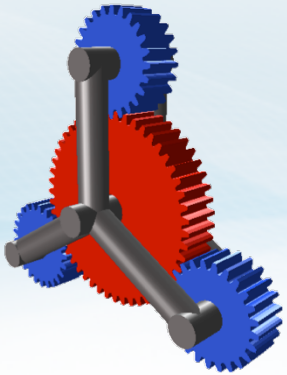
- Planet Planet Gear

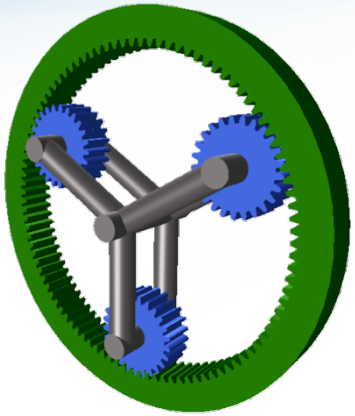


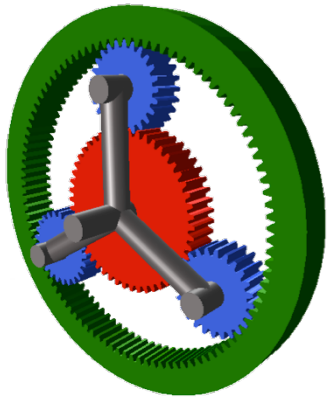
- Planet Ring Gear



Planetary Gear







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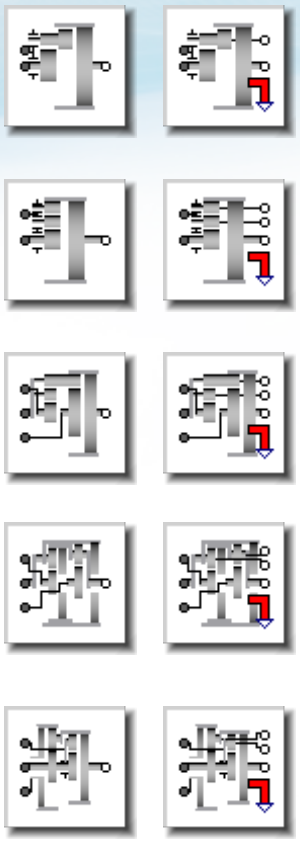
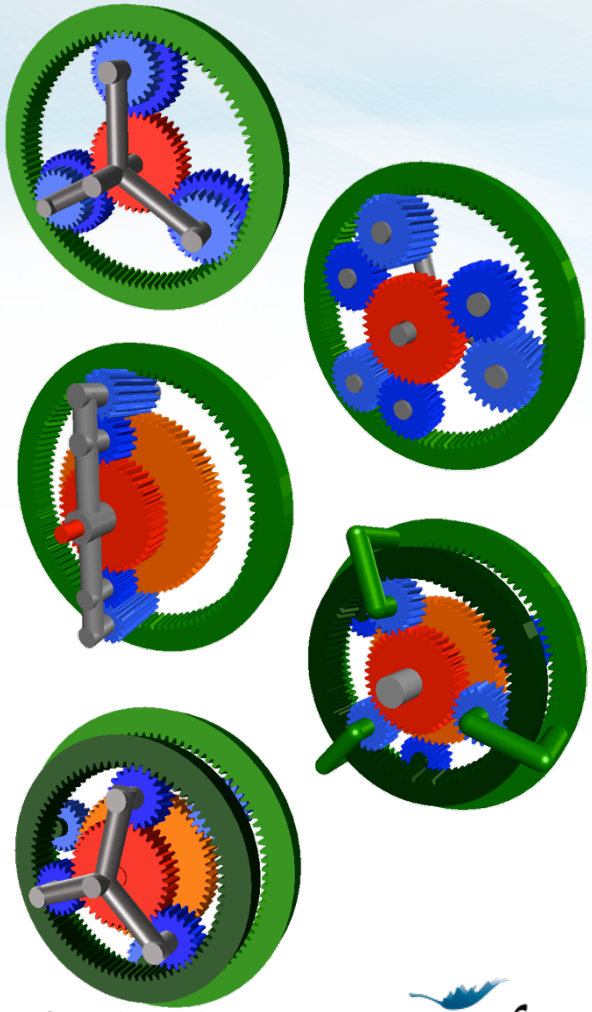
Driveline Component Library

Compound Gear Sets

Gear Sets:

- Dual-Ratio Planetary Gear
- Counter-Rotating Planetary Gear
- Ravigneaux Gear Set
- CR-CR Gear Set
- Simpson Gear Set





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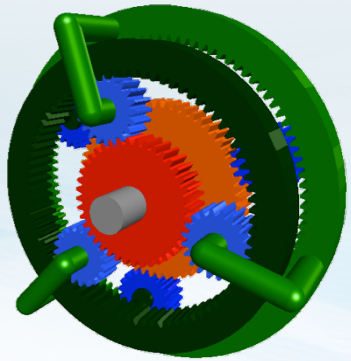
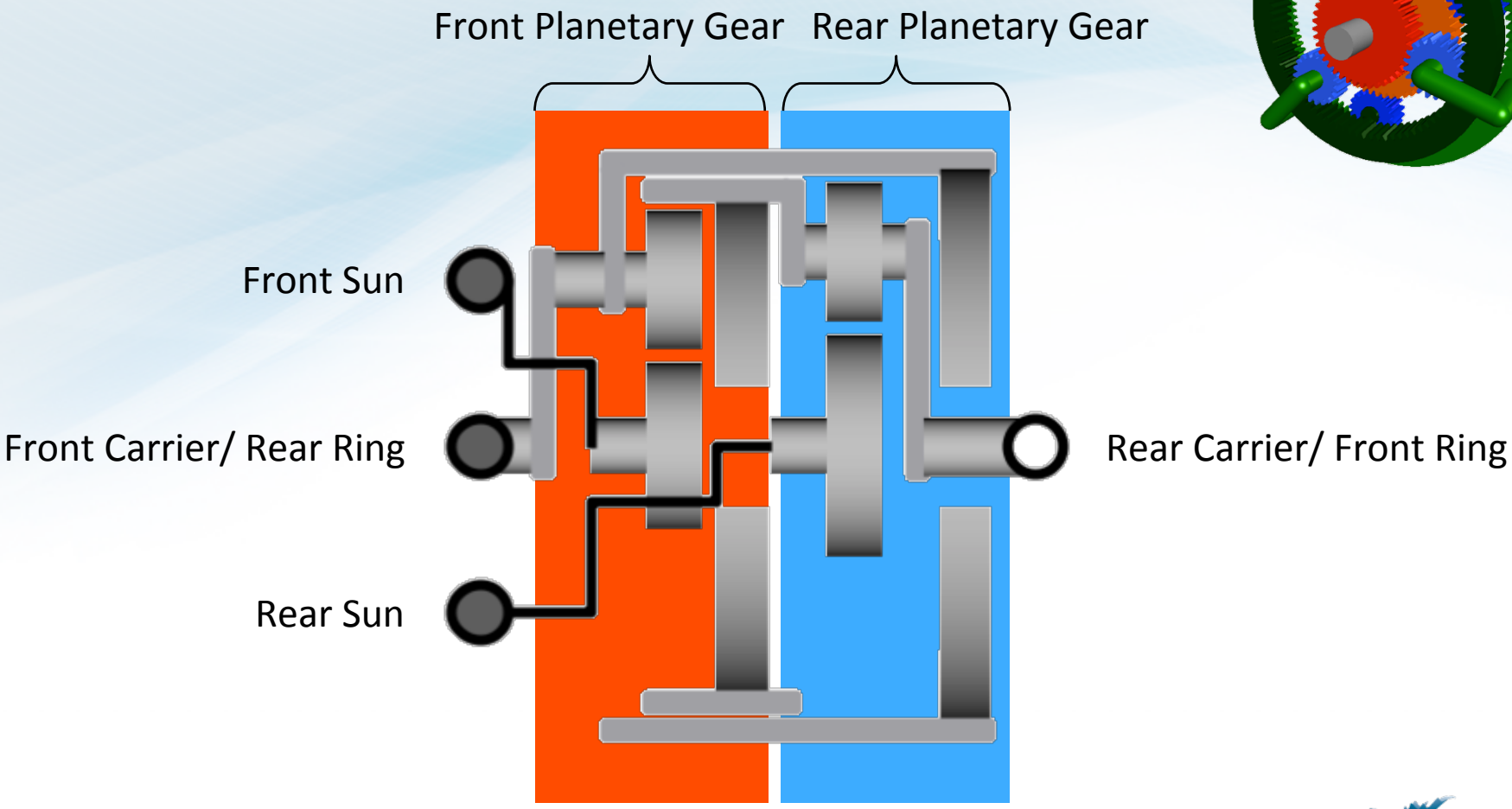
Driveline Component Library

Compound Gear Sets

CR-CR Gear Set





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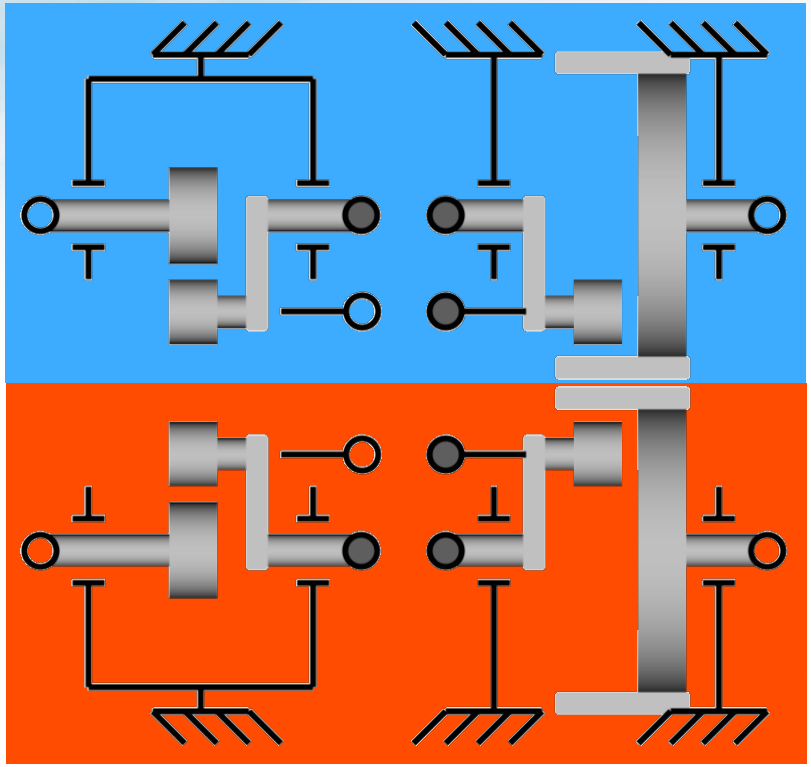
Driveline Component Library

Compound Gear Sets

CR-CR Gear Set



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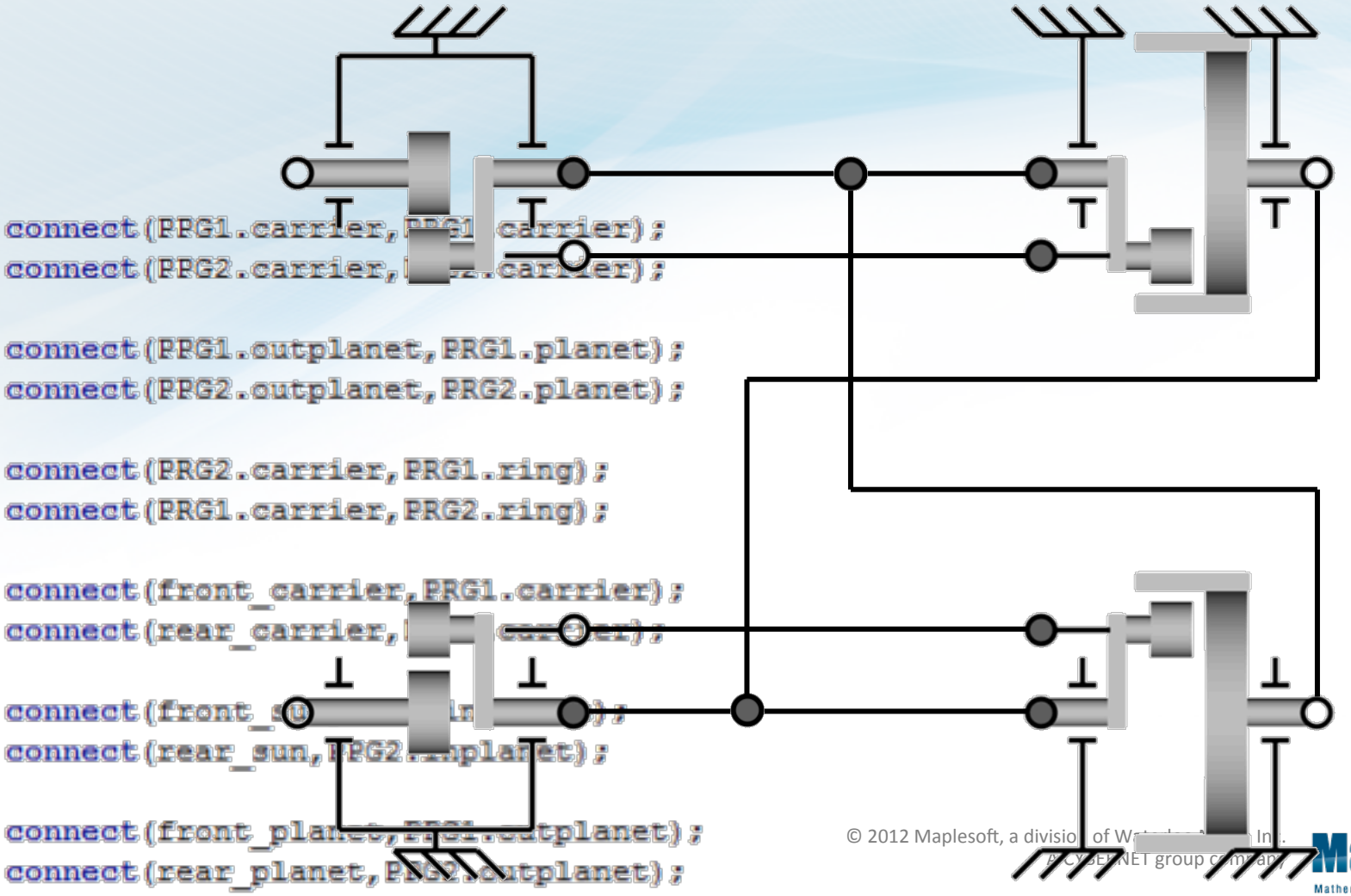
Driveline Component Library

Compound Gear Sets

CR-CR Gear Set



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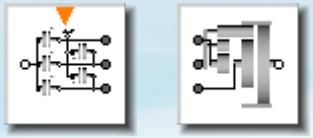
Modeling Transmissions

Actuation Components

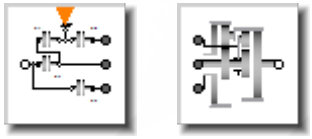
Transmissions:

- Ravigneaux 4-Speed

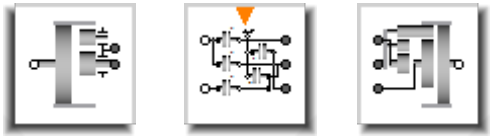


- CR-CR 4-Speed

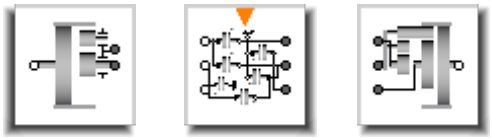
- Simpson 3-Speed



- Lepelletier 6-Speed



- Lepelletier 7-Speed



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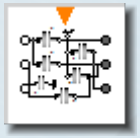
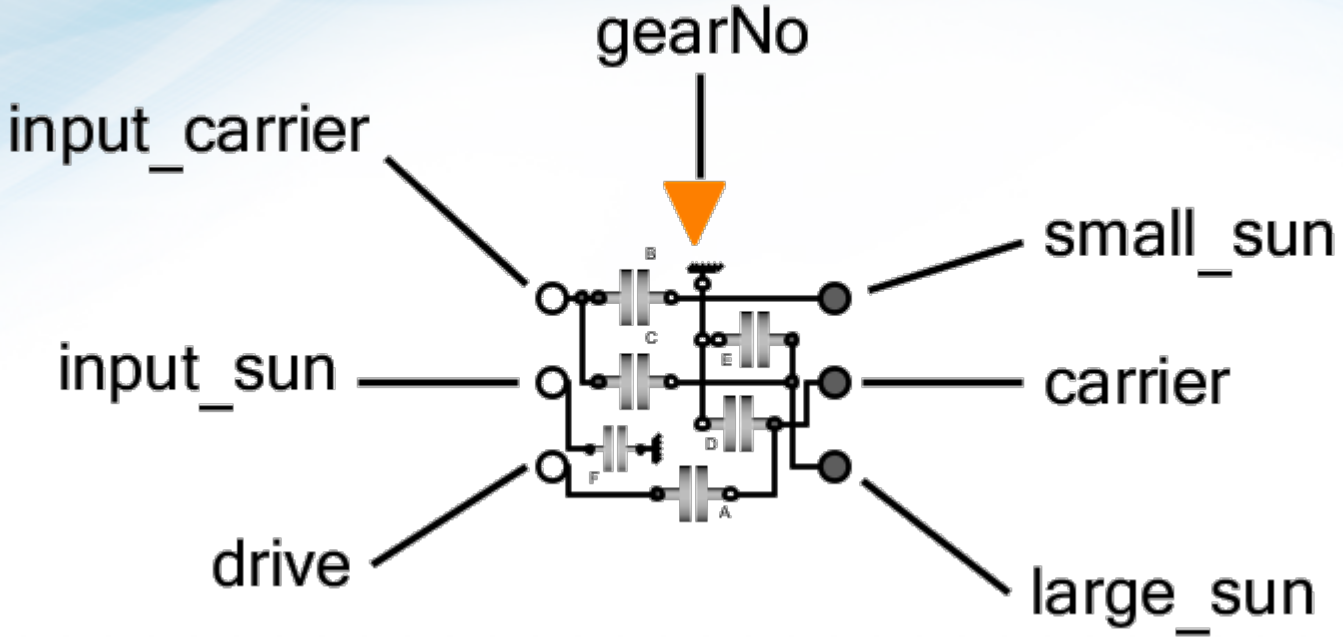
Modeling Transmissions

Actuation Components

Lepelletier 7-Speed





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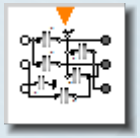
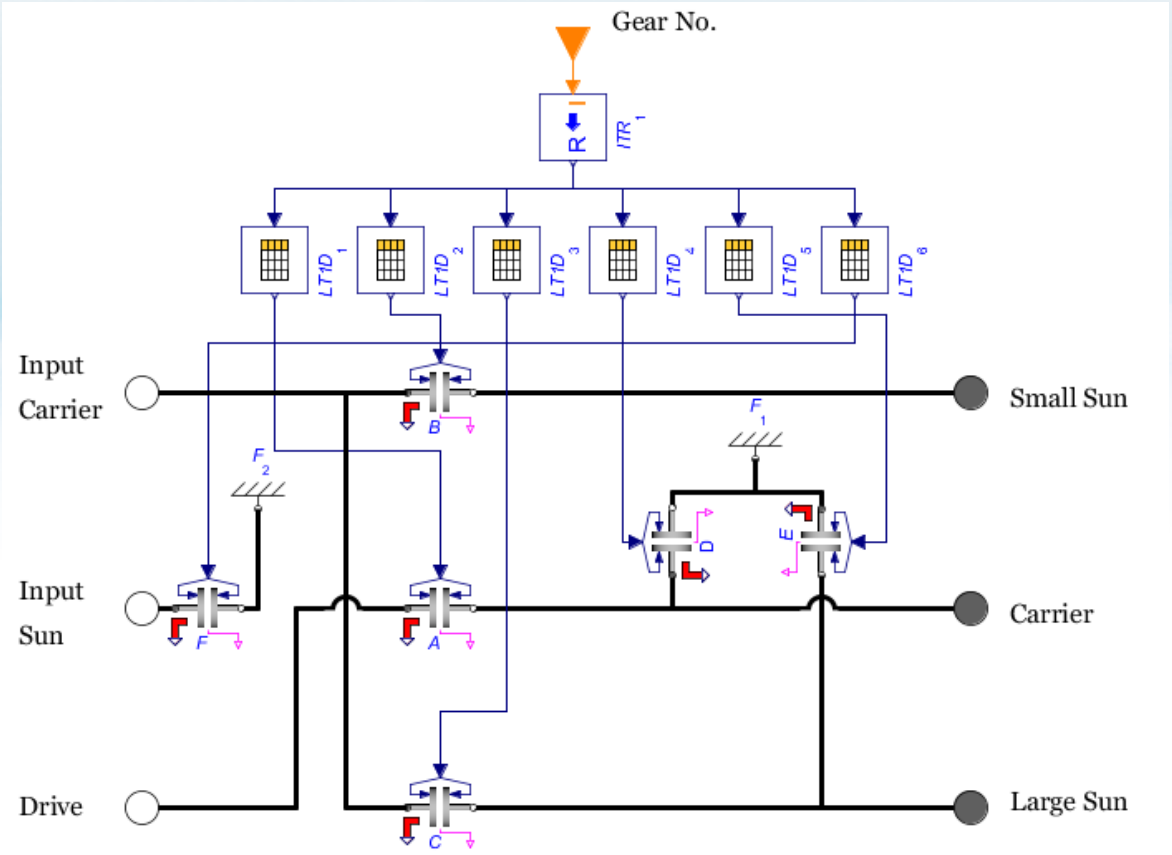
Modeling Transmissions

Actuation Components

Lepelletier 7-Speed





Clutch Table

Gear \ Clutch	A	B	C	D	E	F
−1	0	0	1	1	0	1
0	0	0	0	0	0	0
1	0	1	0	1	0	1
2	0	1	0	0	1	1
3	0	1	1	0	0	1
4	1	1	0	0	0	1
5	1	1	1	0	0	0
6	1	0	1	0	0	1
7	1	0	0	0	1	1

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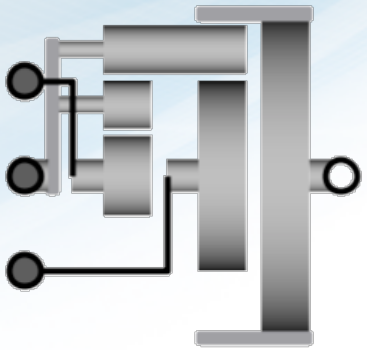
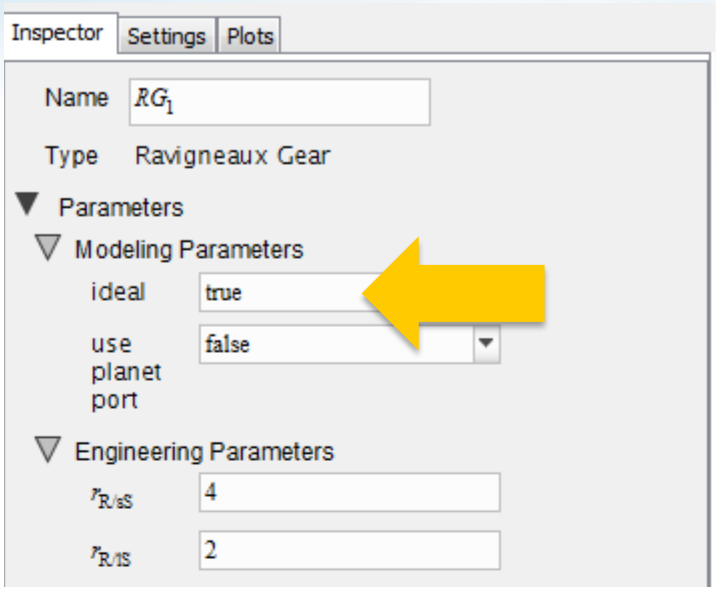
Adding Losses to Gears and Gear Sets

Option: Ideal Gear



Ravigneaux Gear



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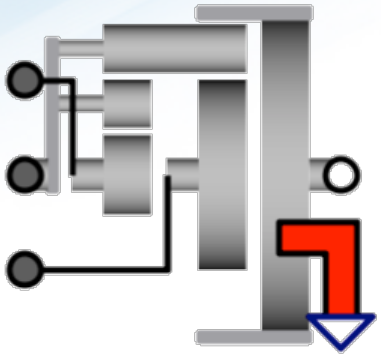
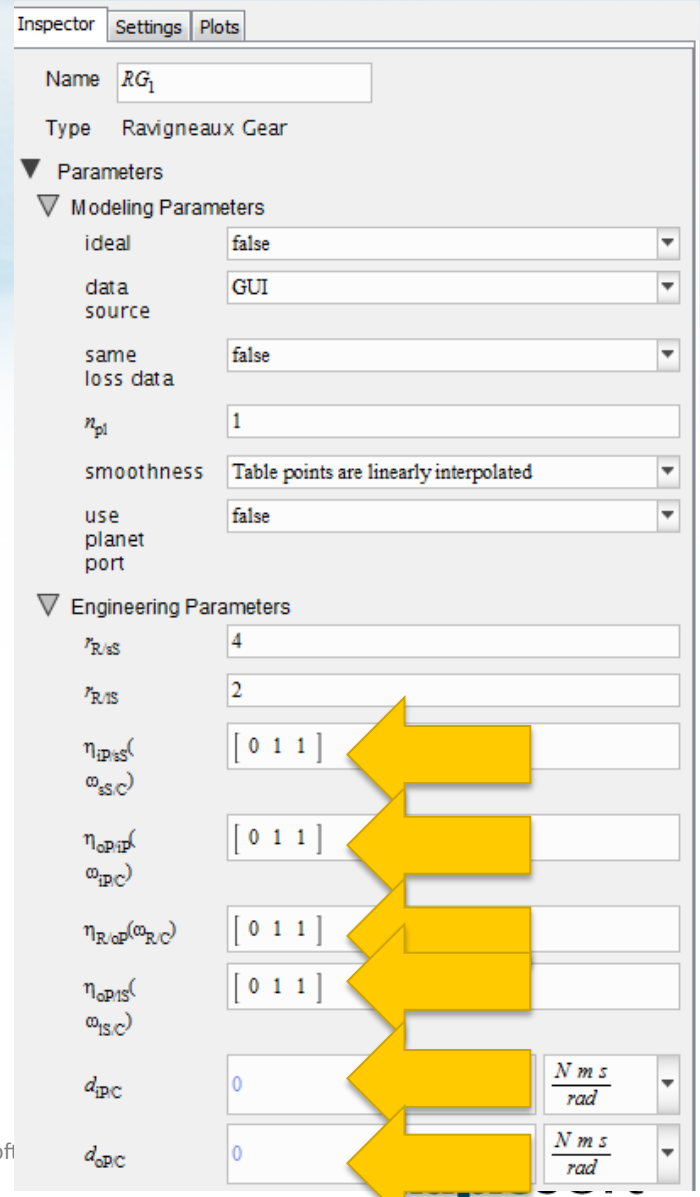
Adding Losses to Gears and Gear Sets

Option: Lossy Gear

- Adding Meshing Friction
- Loss data is entered via:
  - GUI
  - Data File
  - External Input
- Adding Bearing Damping



Ravigneaux Gear



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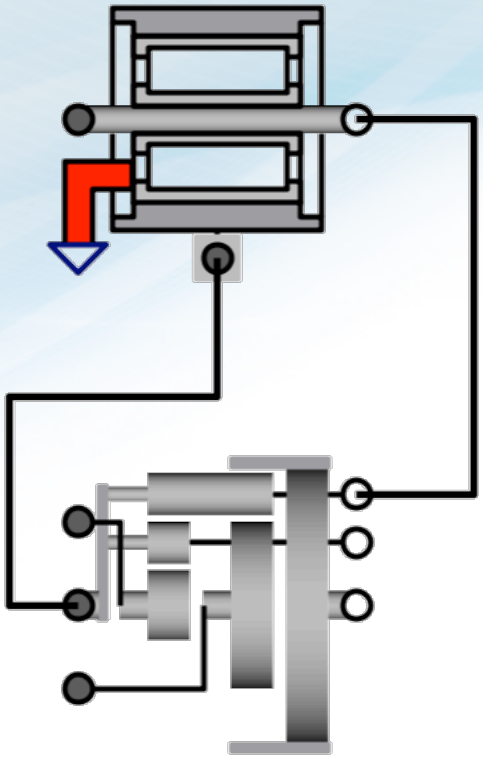
Adding Losses to Gears and Gear Sets

More Options for Modeling Losses Gears

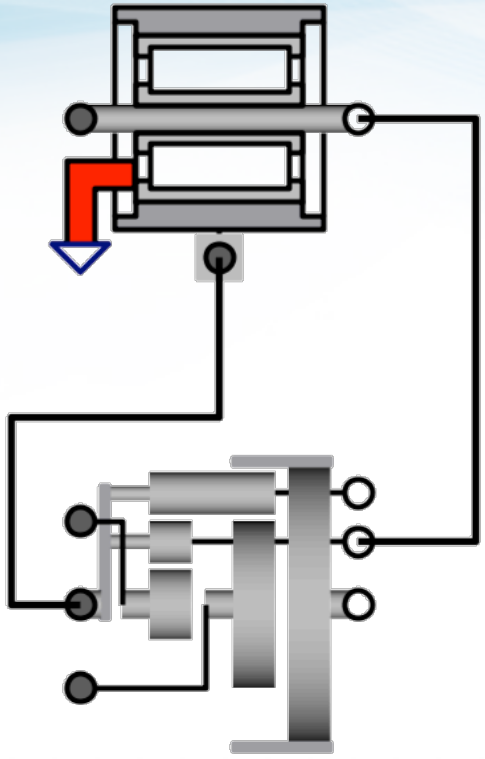
- Adding “friction” to internal bearings

Bearing Friction

Ravigneaux Gear



Outer Planet/Carrier Bearing friction



Inner Planet/Carrier Bearing friction

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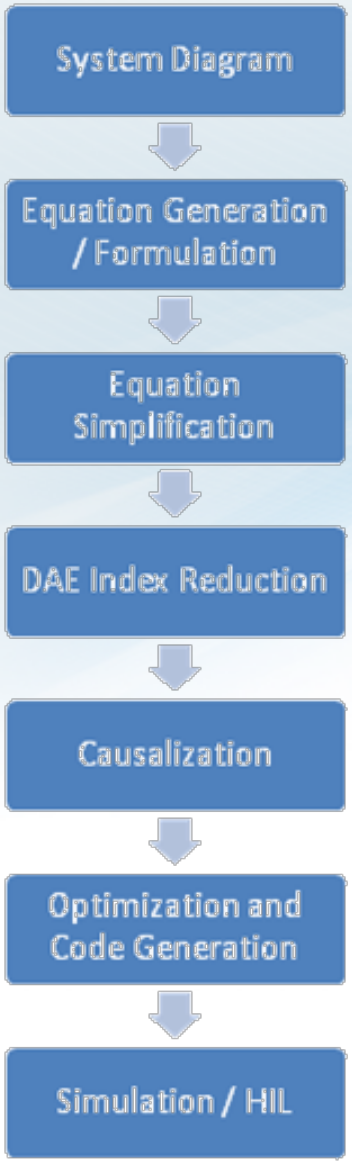
Advantage of the Symbolic Technology



Generation of the complete set of equations in symbolic parametric form

Symbolic techniques are used to simplify this set of equations as much as possible

Symbolic techniques are essential in allowing the differentiation of equations and efficient index reduction

Performed efficiently using symbolic computing based on tools from graph theory

These optimizations involve detecting common computation sequences that can be factored out...

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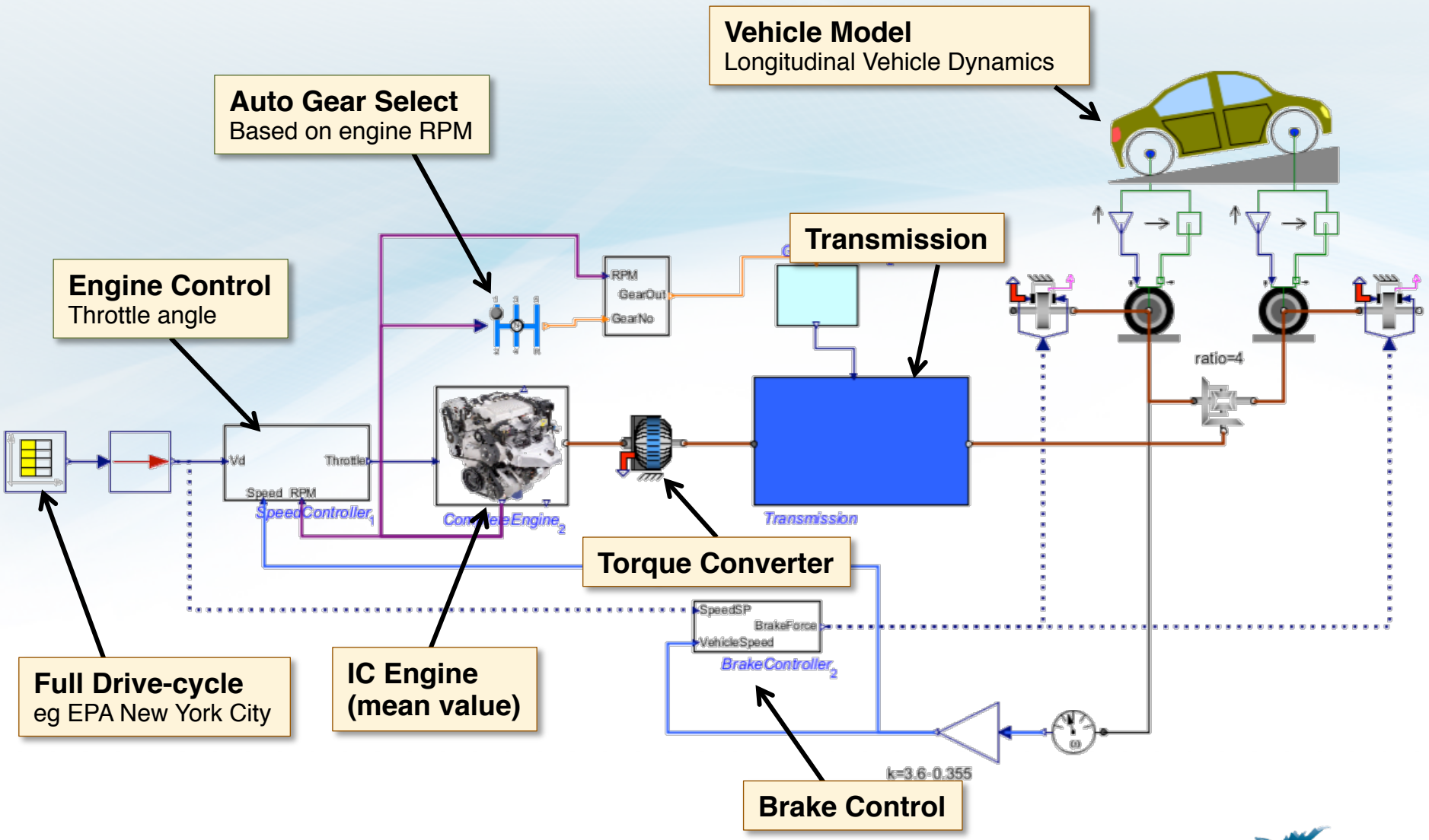
Full Powertrain Model



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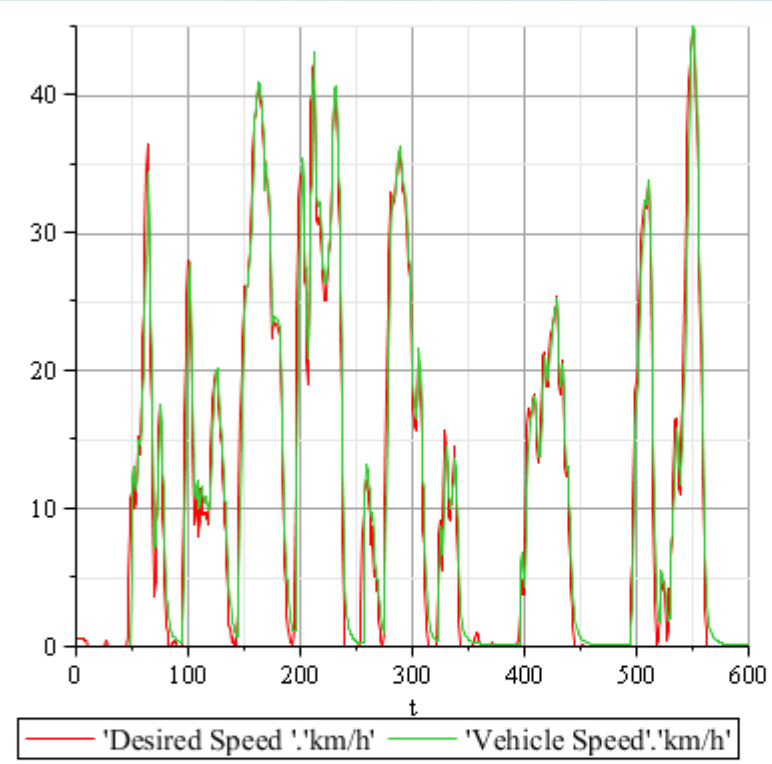
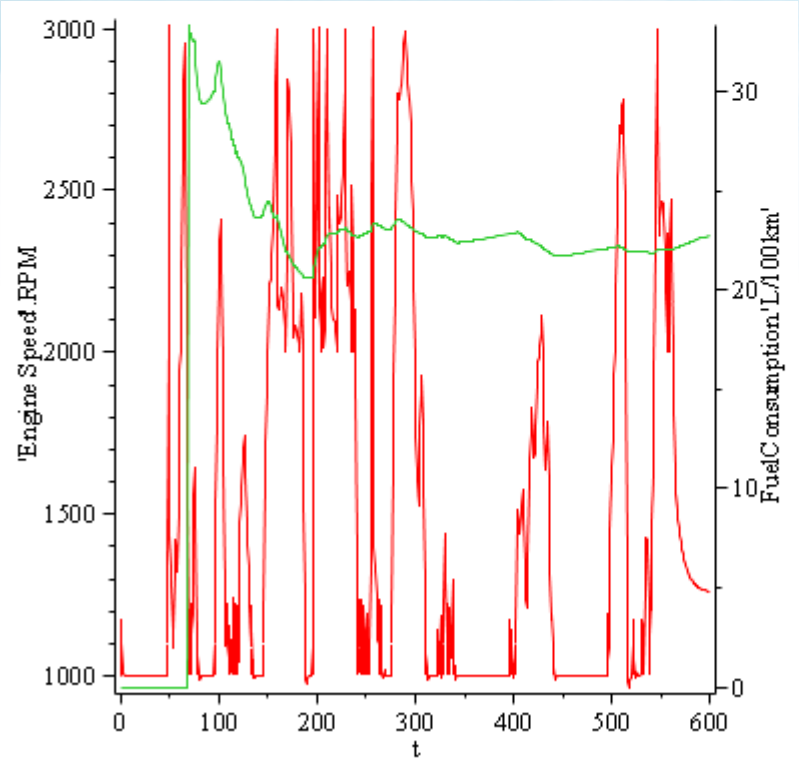
Full Powertrain Model

Sample simulation results





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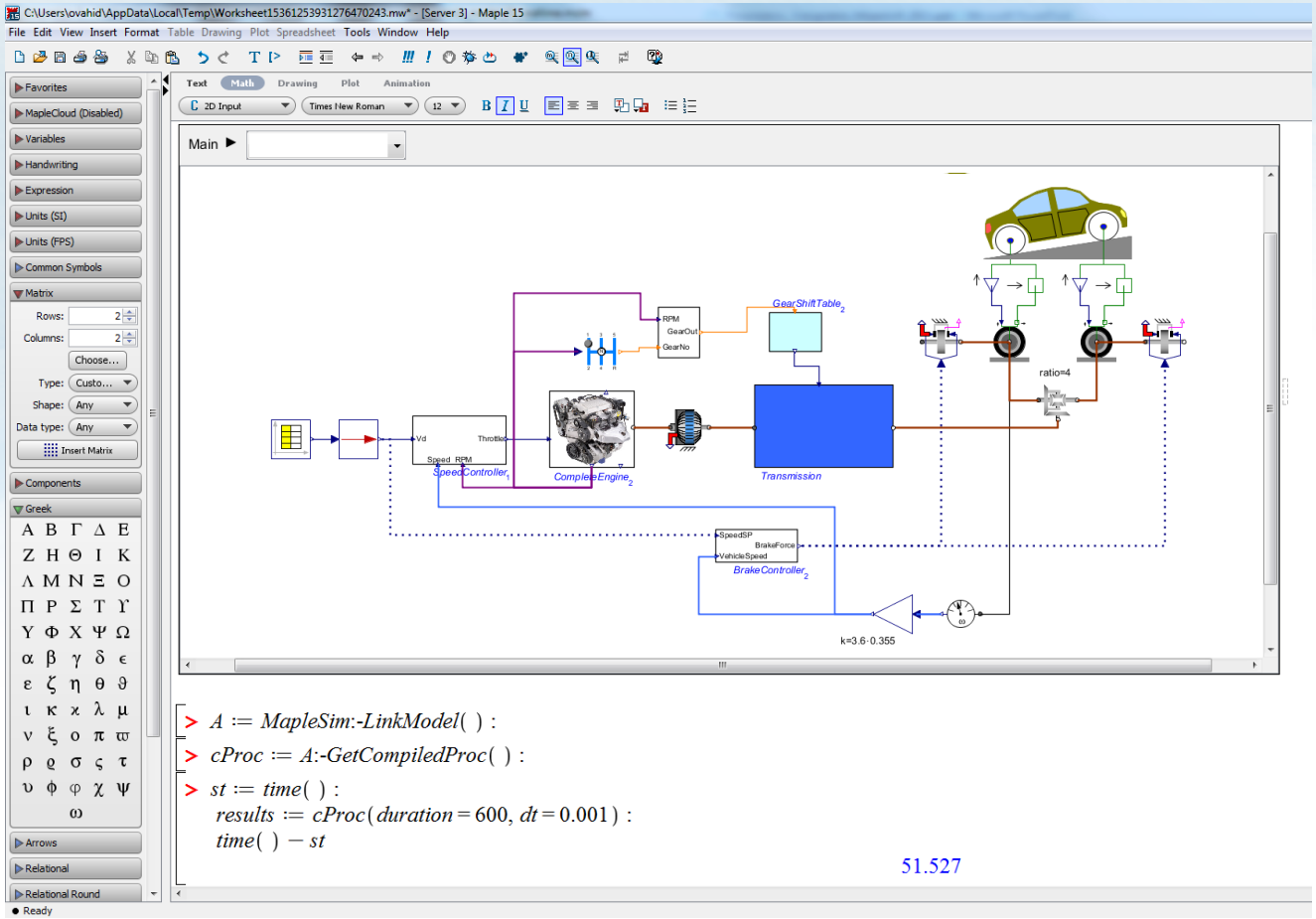
Real-time Performance

MapleSim's API



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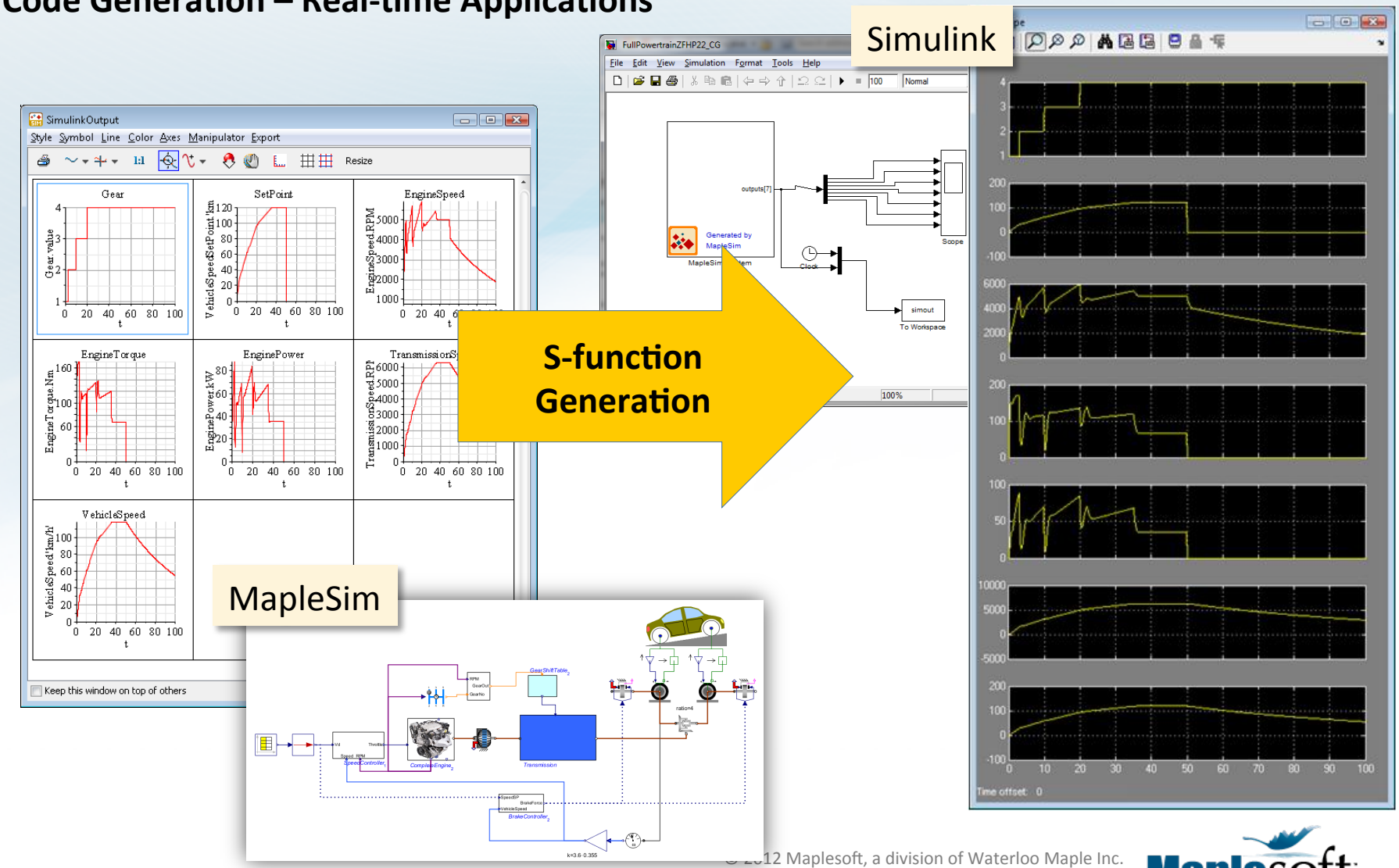
Code Generation and Export

Code Generation – Real-time Applications



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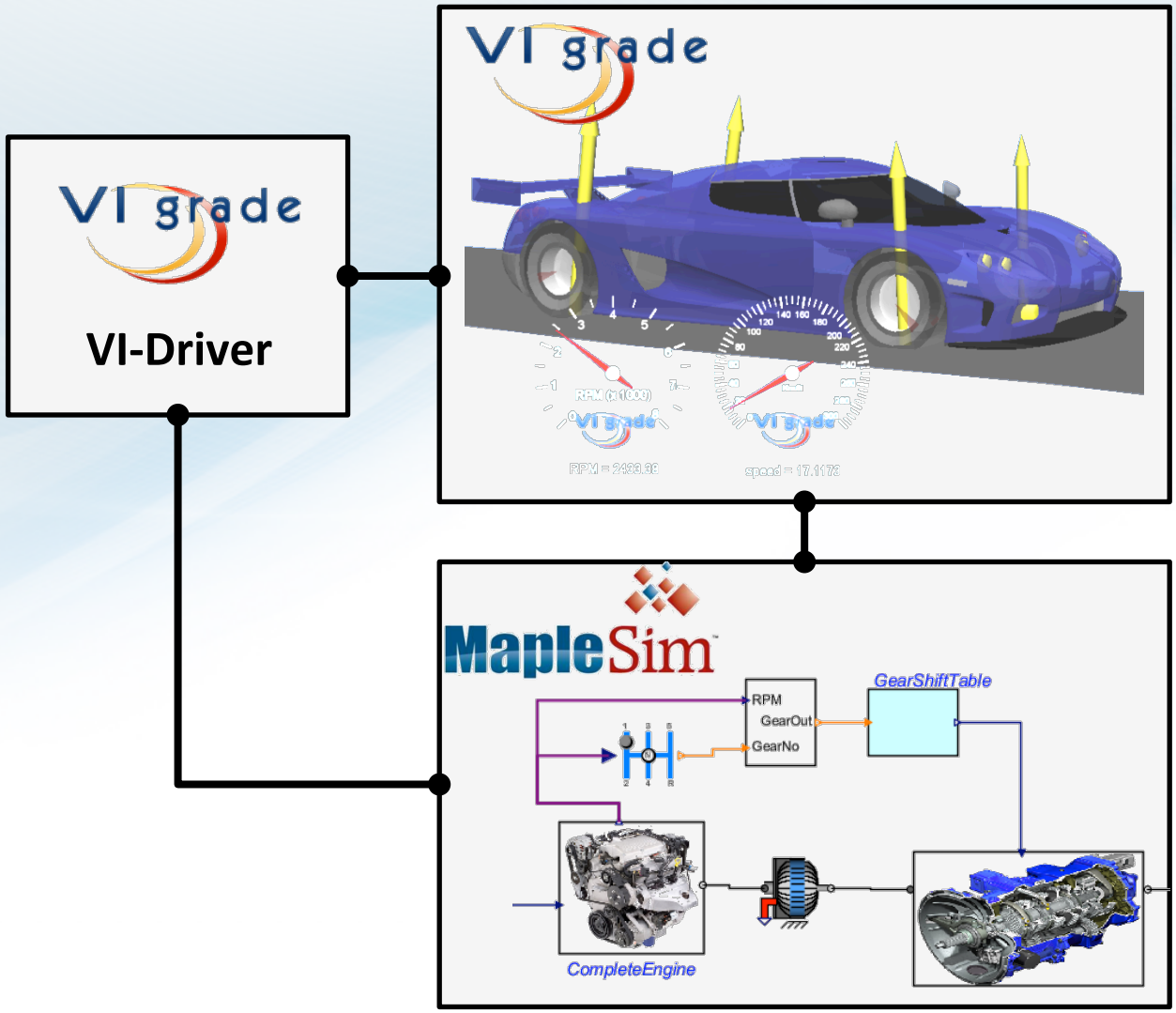
MapleSim and VI-CarRealTime



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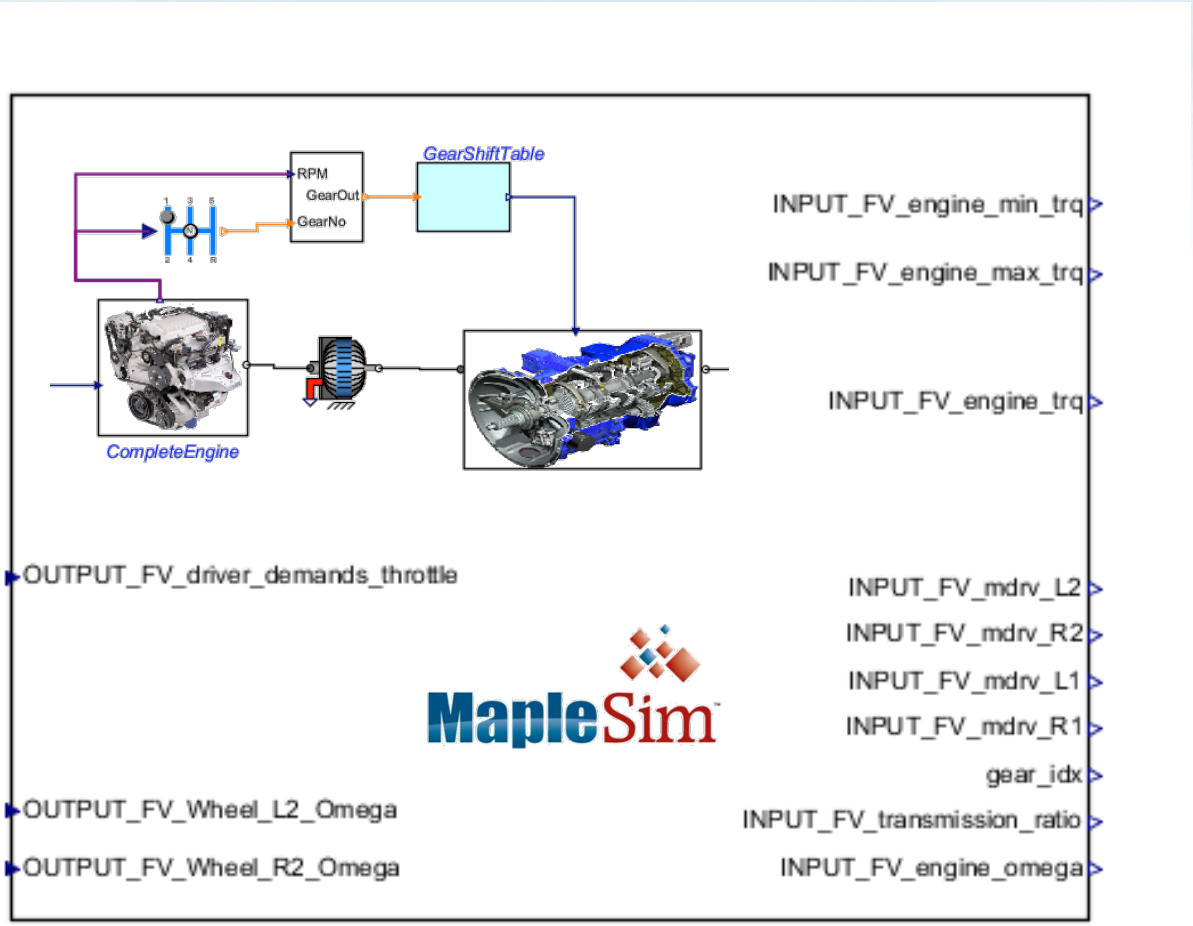
MapleSim and VI-CarRealTime



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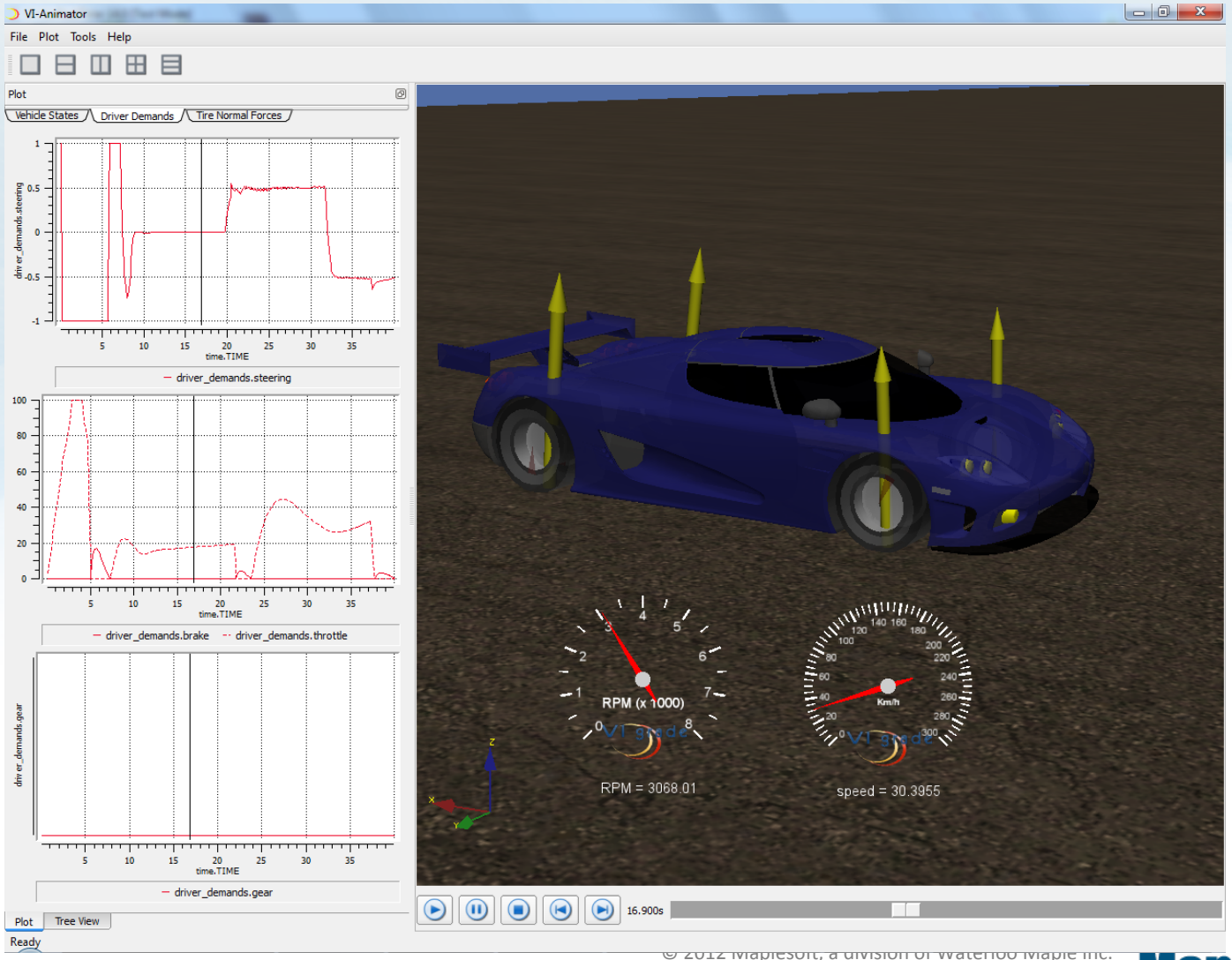
Sample Simulation Results in VI-Animator



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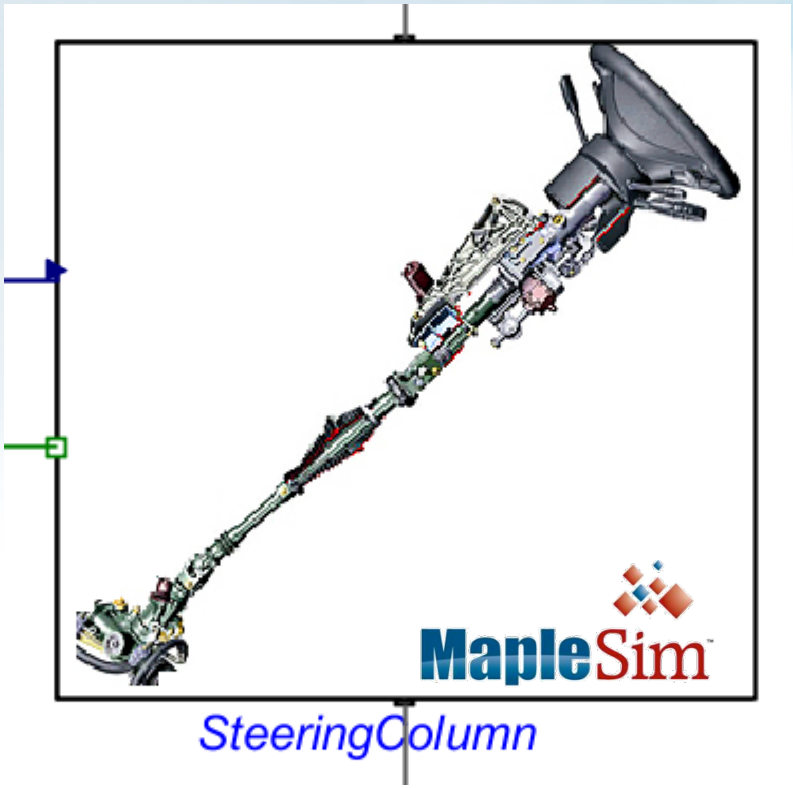
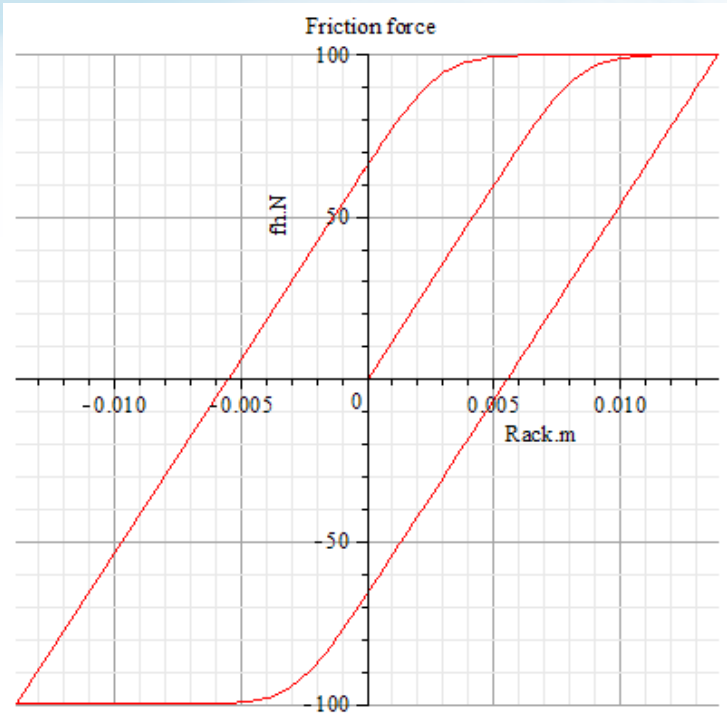
Examples of other subsystems that can be integrated

Detailed Powered Steering Subsystem





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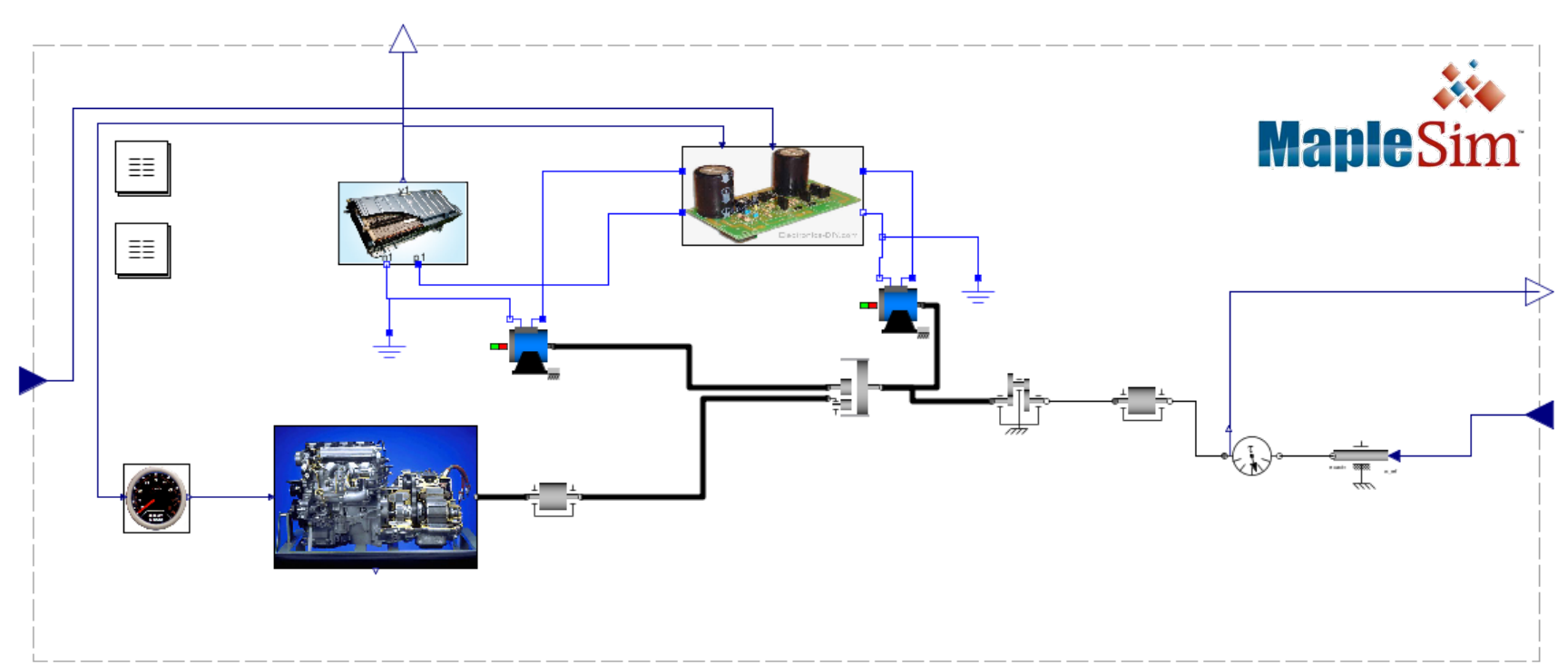
Examples of other subsystems that can be integrated

Hybrid Electric Powertrain



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Summary

- **Physical modeling:** increasingly important – and increasingly complex – in automotive systems design, testing and integration.

- **Driveline Component Library**: a collection of components for modeling all stages in powertrain system – from the engine and transmission through to the differential, wheels and vehicle dynamics.

- **The Symbolic technology:** proven engineering technology that significantly improves model fidelity without sacrificing real-time performance.

- **VI-Grade** and **Maplesoft** established a partnership to make real-time modeling applications more cost and time-effective.

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Thank You!

Questions?

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