An introduction to the VehicleInterfaces package

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Agenda

- Motivation
- How is VehicleInterfaces different?
- Influences
- Working with VehicleInterfaces
- Example 1 – Simple 1D driveline
- Commercial model libraries
- Example 2 – Creating a vehicle model
- Example 3 – Combining automotive libraries

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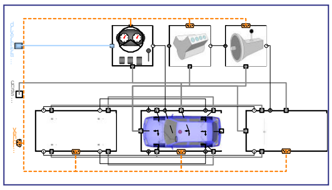
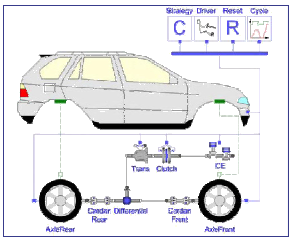
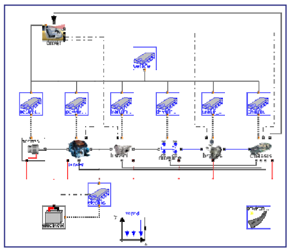
Why a standard model architecture?

- Different organisations are developing models and libraries
- Each group is likely to define a model architecture
  - These are unlikely to be immediately compatible
- Efficiency can be improved by increasing model reuse







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The industrial perspective

- OEM’s want models from suppliers
- OEM’s want standard tools internally
- Suppliers deal with multiple OEM’s who probably use different tools
- Suppliers don’t have the resources to support multiple versions of the same model
- Ideal solution is to use a tool neutral model format
  - Modelica

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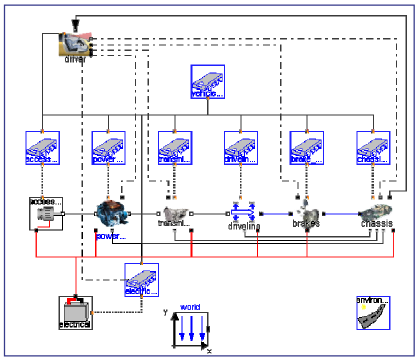
Modelica VMA ("VehicleSystems")

- Based on the "Vehicle Model Architecture" developed at Ford Motor Company
  - Developed by vehicle modelling groups across the organisation (e.g. Ford, Jaguar, Volvo, etc.)
  - The architecture was developed with Simulink in mind
- The Modelica implementation attempted to address many of the limitations of the original



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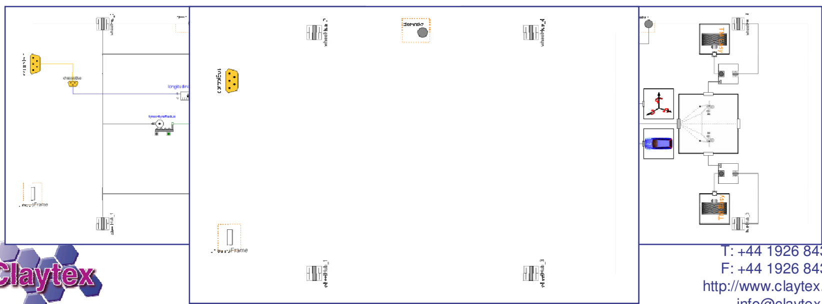
How is VehicleInterfaces different?

- The development has focused on standardising the subsystem interface definitions without enforcing a standard vehicle model architecture
  - For example, the chassis subsystem uses the same interface definition regardless of it being a basic 1D longitudinal model or a complex MultiBody vehicle dynamics model



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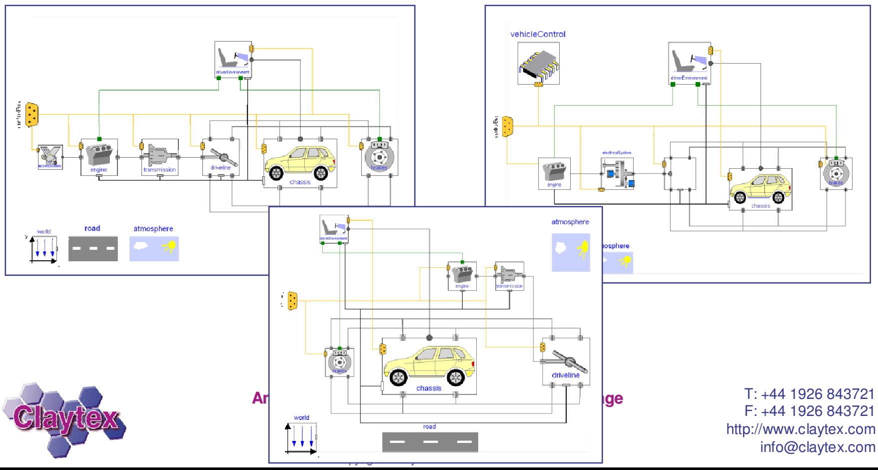
How is VehicleInterfaces different?

- The same subsystem models can be reused in different model architectures



What influenced the development?

- Reviewed existing model architectures
- Considered the range of simulation tasks that Modelica is and might be used for
- For example
  - Performance and fuel economy simulation
    - 1D Powertrain and Vehicle models
  - Vehicle Dynamics simulation
    - Multibody Vehicle models
  - Control system calibration and strategy development
    - Detail varies depending on the system being developed
    - Powertrain controller development would typically need 1D Powertrain and Vehicle models
    - Chassis controller development would typically need Multibody Vehicle models

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Scenario: Driveline dynamics

Problem

Understand how the driveline components behave during various driving manoeuvres, for example during a shift, launch or tip-in.

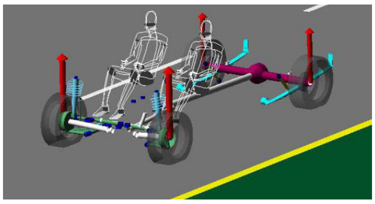
Model detail

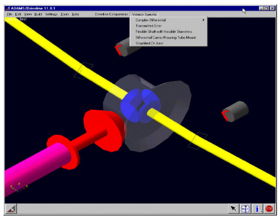
MultiBody model of the entire driveline and suspension system with the appropriate control systems

Why

To develop the driveline components including the mounting systems to understand the motion of these components and the effect on the driver

To understand the joint angles achieved to ensure they don't lock or over extend





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Scenario: Hybrid vehicle simulation

Problem

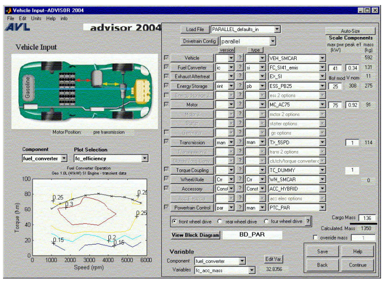
Hybrid vehicles offer the potential to improve performance and fuel economy but due to the variety of technologies and possible configurations simulation must be used for up-front analysis

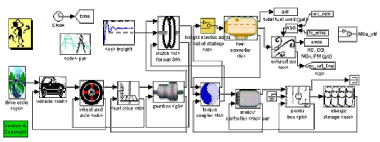
Model detail

Initial studies would require 1D rotational powertrain models with electrical system models (motors and batteries) plus all the associated control systems.

Why

It's prohibitively expensive to build and test all the possible configurations to assess their performance so simulation is used





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Scenario: Integrated vehicle control

Problem

Vehicles are gaining more active systems that are largely independent. OEM's are moving towards integrated control of chassis and powertrain systems

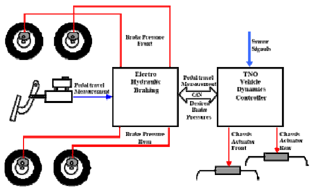
Model detail

1D Powertrain models coupled to simple Vehicle Dynamics models. Transient engine model and control systems.

Why

To enable whole vehicle controllers to be developed that oversee the control of the engine, transmission, and any active driveline, steering and suspension systems

To enable the interaction of the different vehicle systems to be understood



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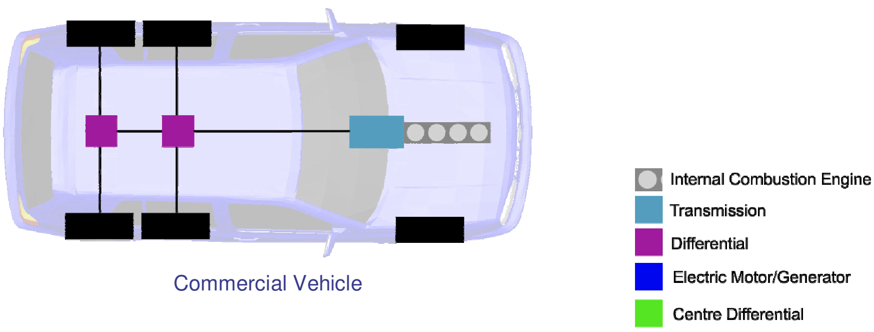
Vehicle architectures

- Current production vehicles and concepts come in many different forms, these are just some



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The VehicleInterfaces package

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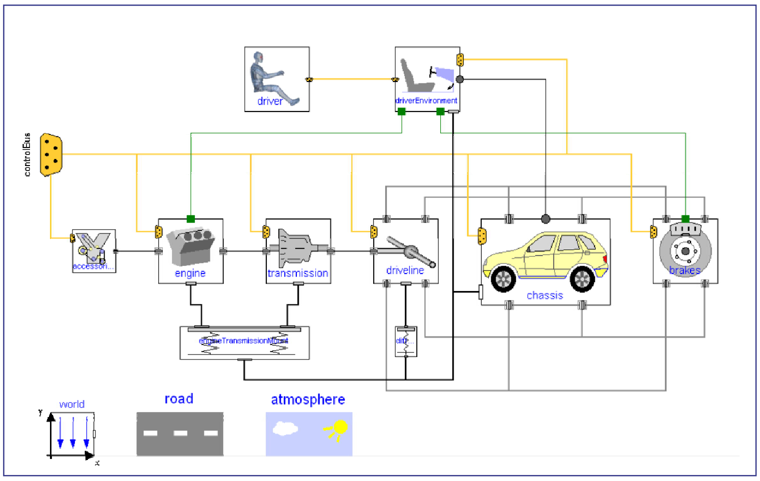
Example architecture: Passenger car - automatic transmission



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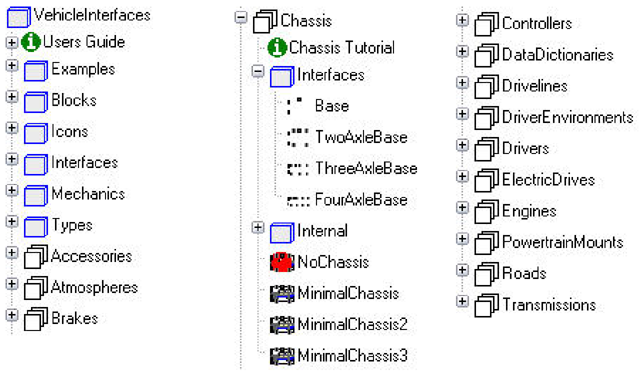
Package structure



- Package contains interface definitions, examples and some new components

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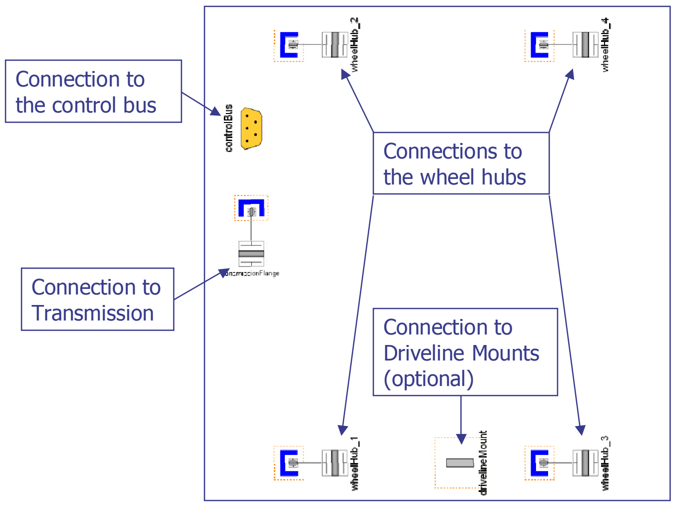
The driveline subsystem



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Modelling rotating components

- Different simulation tasks require different levels of detail
  - Fuel consumption prediction only needs a 1D powertrain and vehicle model
  - Studying detailed driveline dynamics requires a MultiBody powertrain and vehicle model
- VehicleInterfaces can support modelling rotating systems as both 1D and MultiBody systems

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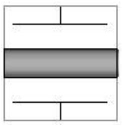
FlangeWithBearing connector

- Uses a new Modelica standard connector called FlangeWithBearing
  - Available in the Modelica.Mechanics.MultiBody package
- Heirarchical connector
  - 1D Rotational connection called flange
  - Conditional MultiBody connection called bearingFrame
    - Represents the bearing supporting the rotating component



```
connector FlangeWithBearing
  parameter Boolean
    includeBearingConnector=false;
  Rotational.Interfaces.Flange_a flange;
  MultiBody.Interfaces.Frame bearingFrame
    if IncludeBearingConnector;
end FlangeWithBearing;
```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The control bus

- Every subsystem has a connection to the control bus
- The control bus is used to pass information between the subsystems that would normally be passed along the CAN bus (or similar vehicle communication network)
- Modelled using a series of hierarchical expandable connectors
  - Enables the user to easily add any signal they need to the bus
  - Provides a logical structure to the bus to organise the data
- Note: We are not modelling how the vehicle communication network behaves

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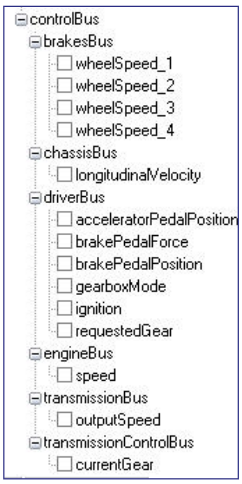
Signal names and structure

- A naming convention and structure for the control bus forms part of the VehicleInterfaces architecture
- A minimum set of signals has been defined
- Following these conventions promotes compatibility between subsystem models developed by different groups
  - Full documentation for the naming convention and meanings of the different signals are included in the Users Guide



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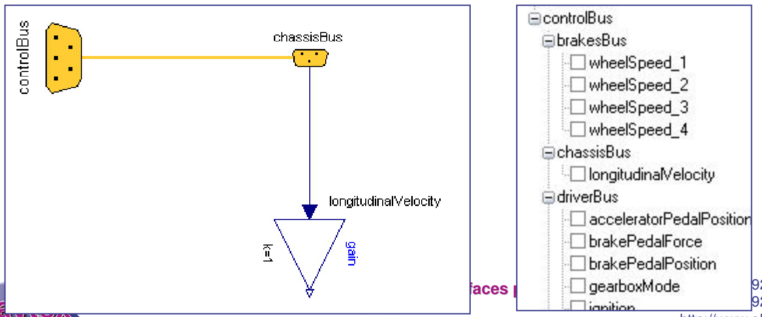
Working with the control bus

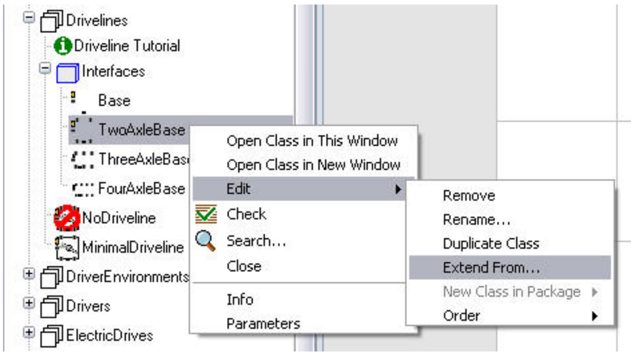
- To access a signal within the control bus first need to add the appropriate sub-bus connector
  - These can be found in VehicleInterfaces.Interfaces
  - Need to turn on a hidden setting in Dymola
    - `Hidden.AddAllBusReferenced=true;`



Example 1 – Simple 1D driveline

- Create a simple 1D rear-wheel drive driveline model
- Add a sensor to measure the propshaft speed and add this to the control bus
- Include the following components:
  - Propshaft
  - Final drive ratio
  - Rear differential
  - Left and right halfshafts
- Open the VehicleInterfaces package
- Run the script setup.mos in VITutorial directory
  - Sets the Dymola flag `Hidden.AddAllBusReferenced=true;`

Step 1 – Extend the template



- Select the appropriate interface definition and create a new model that extends from it

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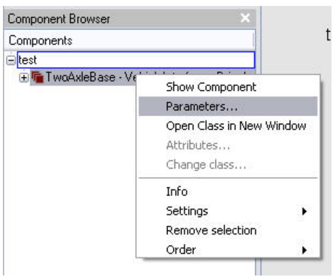
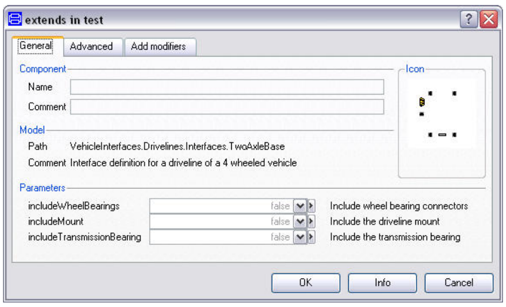
Step 2 – Set the internal parameters





- Each subsystem has a set of protected parameters that control which of the optional connections are enabled

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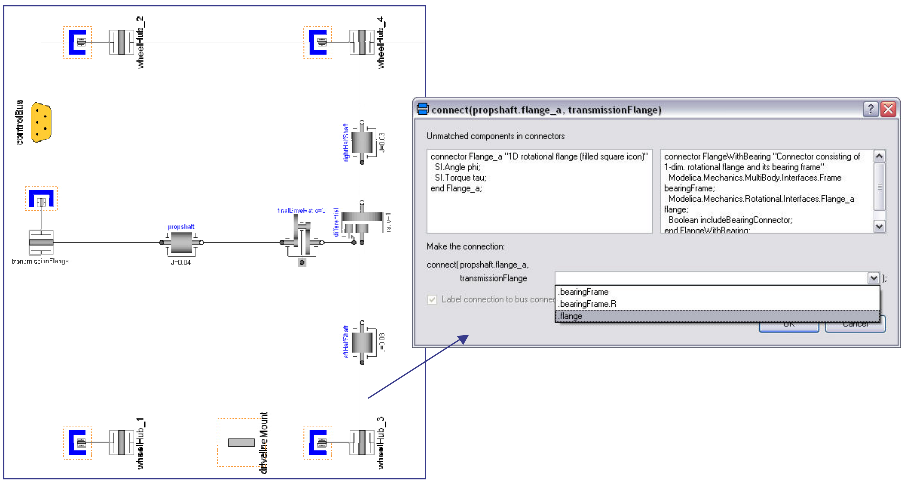
Step 3 – Create the model



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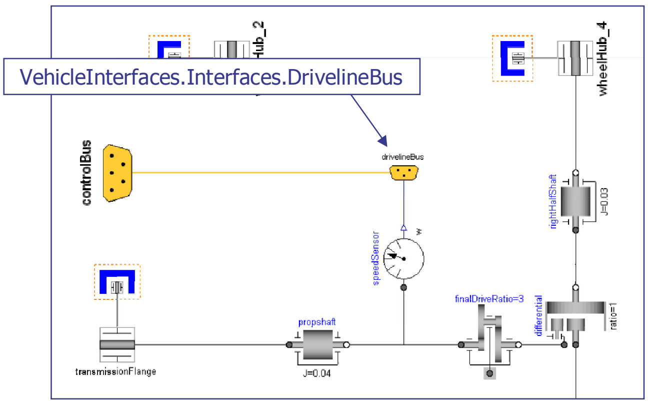
Step 4 – Measuring the propshaft speed



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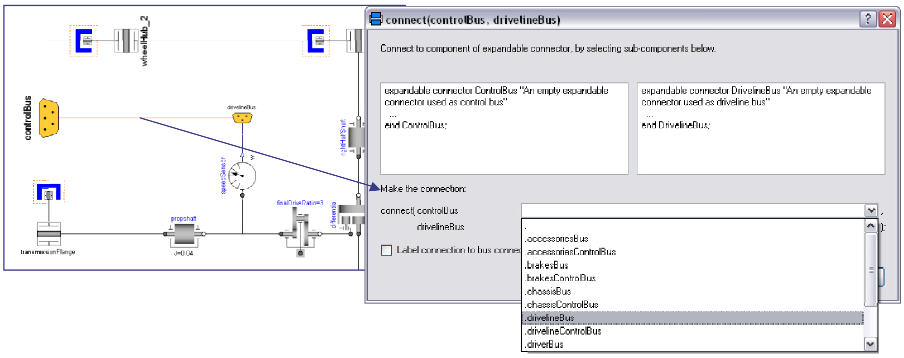
Step 4 – Measuring the propshaft speed



- When connecting the speed sensor to the drivelineBus node the dialog contains an empty list of signal choices, simply type in the signal name required "propshaftSpeed"

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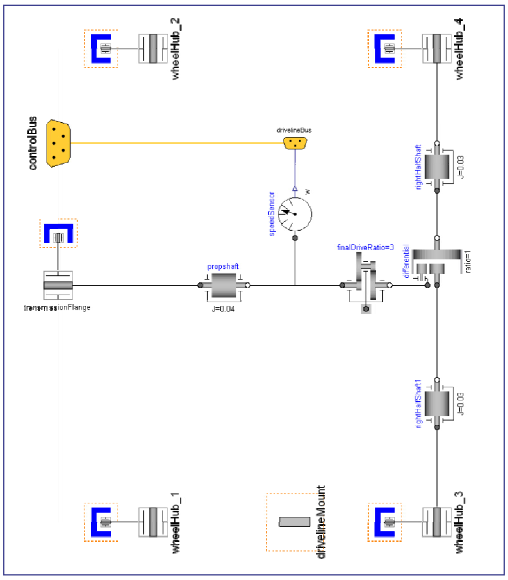
Completed driveline model



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Commercial model libraries

An introduction to the commercial
automotive libraries

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PowerTrain

- New release of the existing PowerTrain library
  - Adopts the Vehicle Interfaces model architecture
- New analysis types include:
  - Driveability
  - Performance
- Wide range of new components
  - A number of new differential types including MultiBody variants
  - Drivelines can now be modelled as 1D rotational or MultiBody systems
  - Tyre slip models introduced
  - Plus many other improvements

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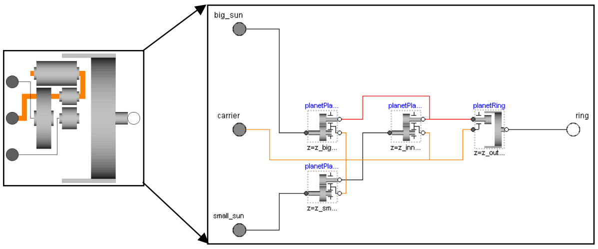
Modelling of any planetary gear

- Every planetary gearbox can be modeled with the two base components PlanetRing, PlanetPlanet
- Example: Ravigneaux wheelset



- Compute overall efficiency based on efficiencies of gearwheel pairings

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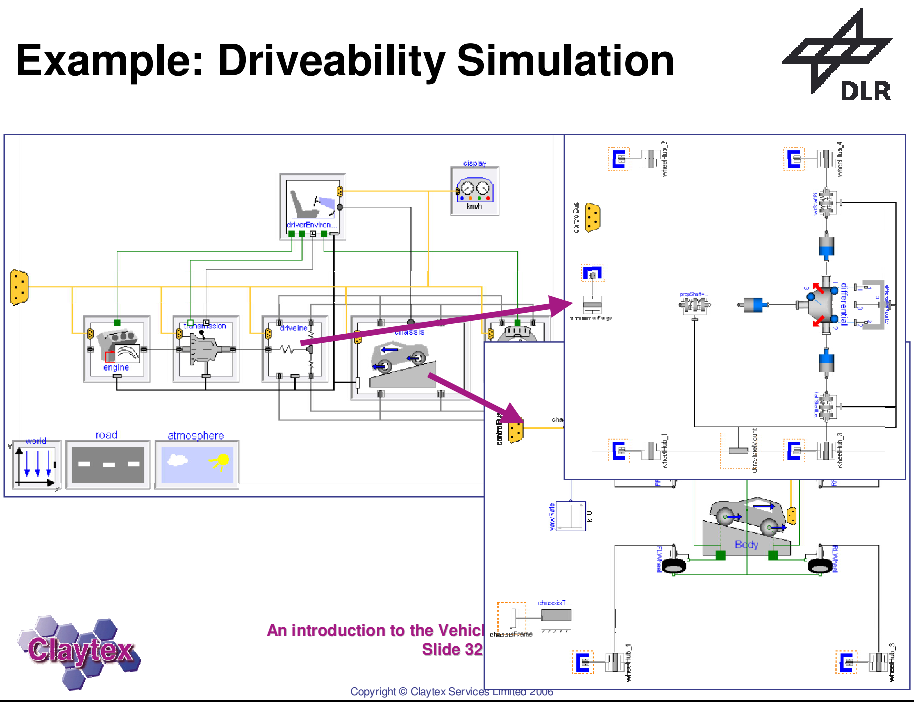
Example: Driveability Simulation



SmartElectricDrives

arsenal research
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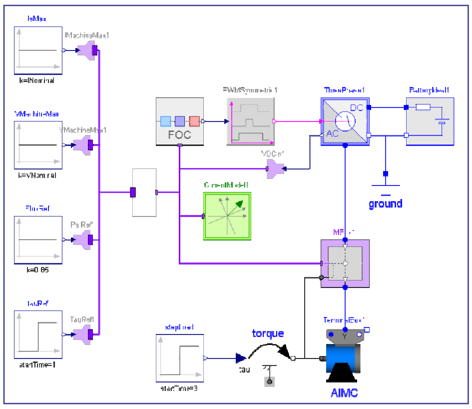
- New library of electric motors, storage devices, power electronics and control strategies
  – Provides models for the simulation of electric and hybrid vehicles



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SmartElectricDrives

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- Asynchronous induction machines, permanent magnet induction machines, dc machines
  – Varying levels of detail including quasi-stationary and transient machines
- Various machine controllers provided
  – Field oriented control, direct torque control, speed control, etc.
- Energy storage systems
  – Batteries, supercaps, fuel cells
- Power electronics
  – DC-AC, DC-DC converters of varying levels of detail (ideal, switching)

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Detailed AC machine model

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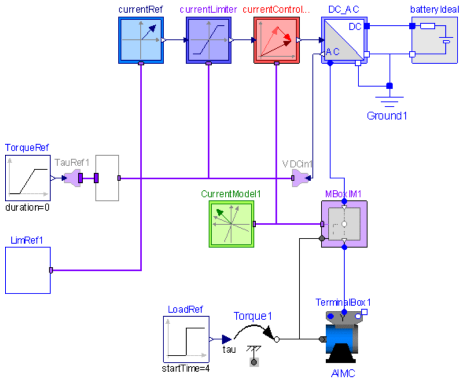

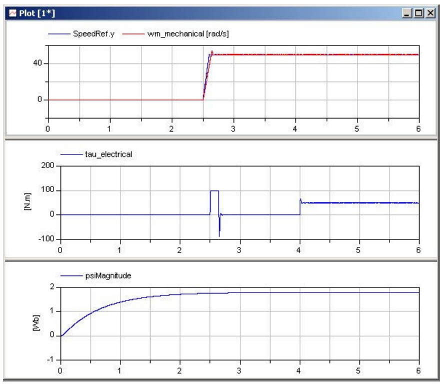

Field Oriented Control of an asynchronous induction machine drive – analysis of transient behavior

(a) Desired speed and real speed of the drive; (b) electrical torque generated by the machine; (c) flux of the machine

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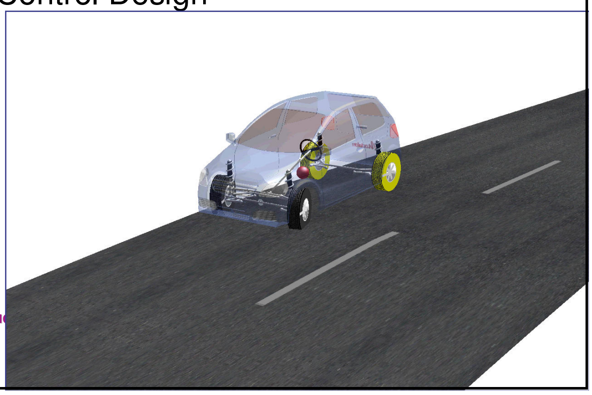
VehicleDynamics

Modelon

- A commercial library for Vehicle Dynamics simulation
- Chassis Design including Suspensions and Steerings
- Handling Behaviour Analysis
- Active Systems and Control Design



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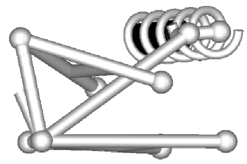
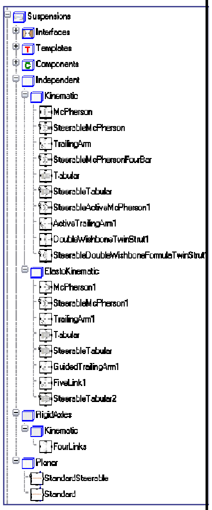
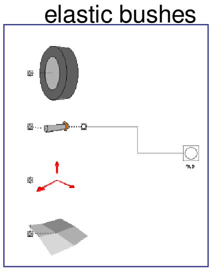
VehicleDynamics

- Wide range of suspension models available
  - Detail ranges from planar models through table based models to high fidelity MultiBody models including elastic bushes







- Three tyre models included:
  - MFTyre (Pacejka), TMEasy (Rill), GST (Bakker)
  - Modular wheel description can be easily extended to add user-defined tyre force models

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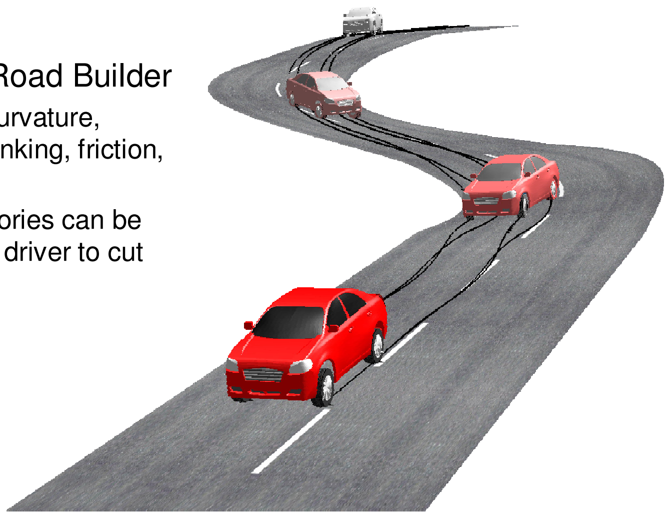
VehicleDynamics

- Powerful 3D Road Builder
  - Can define curvature, gradients, banking, friction, etc.
  - Driver trajectories can be used to tell a driver to cut corners, etc.



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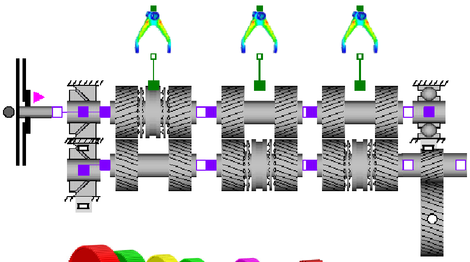
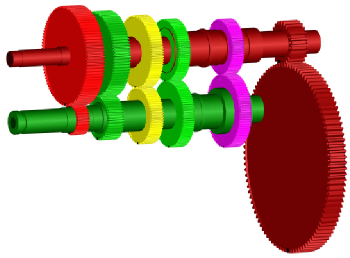
Transmission Library

- New library for the detailed design and modelling of Transmissions
- Models the axial and rotational motion of the gearbox
- Suitable for all types of transmission





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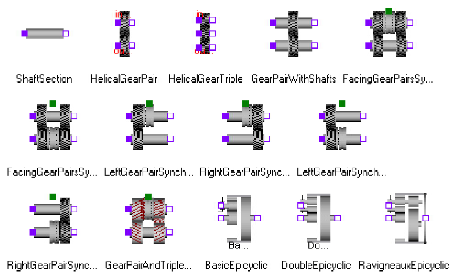
Wide range of components

- Gears
  - Parallel gears
  - Gear mesh models
    - Ideal, impulse, stiffness, lash
- Shafts
  - Geometry and material properties used to determine stiffness and inertias
- Engagement Devices
  - Synchroniser models
  - Dog clutches
  - Wet clutches
  - Variators



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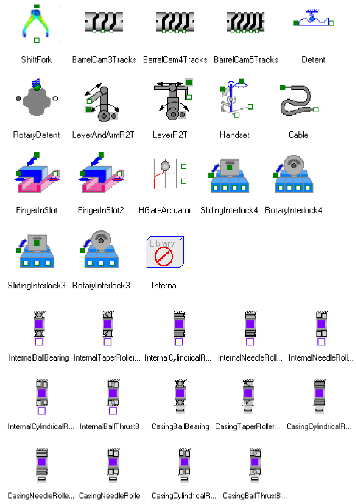
Wide range of components

- Selector Mechanisms
  - Selector forks, cables, interlocks, levers and detents for manual transmissions
  - Barrel cams are included for motorsport and motorcycle applications
- Bearings
  - Provide shaft constraints and include drag, preload, translation of loads into casing models
  - Casing models provide location for bearings, stiffness and connection to multibody components



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Example 2 – Creating a vehicle model

- A new vehicle model can be created in two ways:
  - Either extend an existing model architecture and redeclare subsystems
  - Or drag-and-drop subsystems in to a new model
- In this example we will extend an existing model and redeclare the subsystems
- Open the PowerTrain library
- Create a new vehicle model that extends VehicleInterfaces.Examples.ConventionalAutomaticVehicle

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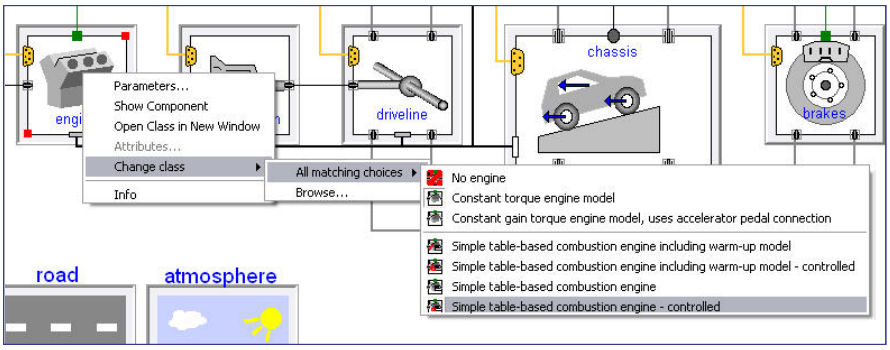
Redeclaring subsystems using Dymola



At the bottom left of the Dymola window the full Modelica name of the class that is highlighted in the choices menu is shown

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Make the following redeclarations

- Engine
  - Class name: PowerTrain.Engines.SimpleEngineControl
  - Description: Simple table-based combustion engine – controlled
- Transmission
  - Class name: PowerTrain.Transmissions.AutomaticNGear
  - Description: N-speed automatic gearbox model
- Driveline
  - The class you created in Example 1
- Chassis
  - Class name: PowerTrain.Chassis.DragByCurvewithLinearTireSlip
  - Description: Lumped chassis with linear tyre slip, fixed rolling radius
- DriverEnvironment
  - Class name: PowerTrain.DriverEnvironments.PerfDriver_AutoTrans
  - Description: Performance test driver for vehicles with Automatic Transmissions,
  - fixed steering
- Brakes
  - Class name: PowerTrain.Brakes.SimpleBrakes
  - Description: Individual wheel brakes, simple actuation

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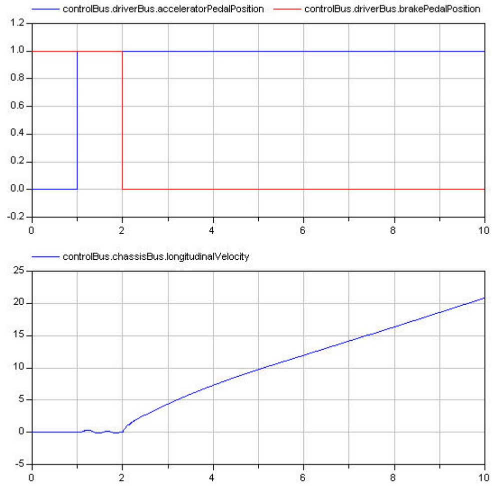
Sample simulation results

- Simulate the model for 10s using Lsodar



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Example 3 – Combining automotive libraries

- Duplicate Example 2 to create another new model
- Open the library VITutorial which contains a suitable chassis model
  - VITutorial.Chassis.Car
  - The VehicleDynamics and VDLAdapters libraries will open automatically
- Change the chassis subsystem to be a VehicleDynamics chassis model
  - You'll also need to redeclare the world, road and atmosphere components
    - World component should be redeclared as VehicleDynamics.World
    - The road and atmosphere models should be redeclared as variants from the VDLAdapters package

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Using the VehicleDynamics library within VehicleInterfaces

- Currently the VehicleDynamics library uses it's own model architecture
- The VDLAdapters package allows VehicleDynamics models to be used within the VehicleInterfaces architecture
- It provides classes that interface the two different model architectures in an intuitive way

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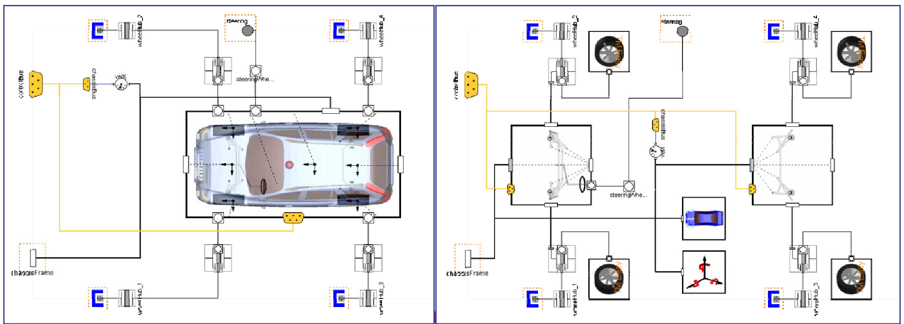
The chassis model

- VDLAdapters provides 2 chassis templates
  - One enables you to use models based on VehicleDynamics.Vehicles.Chassis.Templates.StandardCar
  - One is an equivalent template to VehicleDynamics.Vehicles.Chassis.Templates.StandardCar



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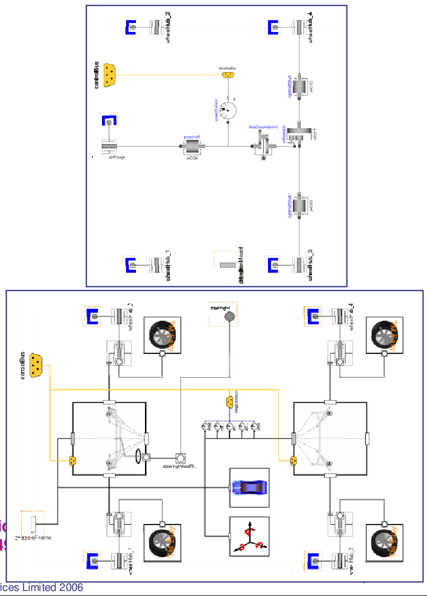
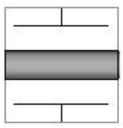
Connecting 1D and MultiBody subsystems

- Subsystems support both 1D and MultiBody rotating systems
- It is conceivable that a user wants to use a mixture of both in their vehicle model
- Example: Coupling a MultiBody chassis model to a simple 1D powertrain



The problem

- When defining a 1D subsystem the bearingFrame connector is not included
- But, when defining a MultiBody subsystem the bearingFrame connector is included
- When we connect these together we have unmatched connectors



```
connector FlangeWithBearing
  parameter Boolean
    includeBearingConnector=false;
  Rotational.Interfaces.Flange_a flange;
  MultiBody.Interfaces.Frame bearingFrame
    if IncludeBearingConnector;
end FlangeWithBearing;
```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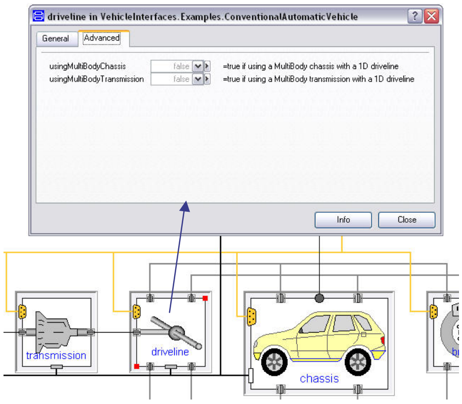
The solution

- We have to include the bearingFrame connectors in the 1D subsystem to make the connectors compatible
- An “Advanced” parameter is available that will cause the bearingFrame connectors to be included automatically



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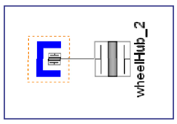
How does this work?



- Every FlangeWithBearing connector is connected to a MultiBodyEnd component within the interface definitions
- This component applies zero force and torque to both the flange and bearingFrame connectors within FlangeWithBearing (assuming bearingFrame is included)
- Activating the “Advanced” parameter enables the bearingFrame in both FlangeWithBearing and MultiBodyEnd

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Make the following redeclarations

- Chassis
  - Class name: VITutorial.Chassis. SedanTEKBakker
  - Description: SedanTEKBakker from VehicleDynamics Library
- Road
  - Class name: VDLAdapters.Roads.FlatRoad
  - Description: Flat road, compatible with VehicleDynamics Library
- Atmosphere
  - Class name: VDLAdapters.Atmospheres.ConstantAtmosphere
  - Description: Constant atmosphere, compatible with VehicleDynamics Library
- World
  - Class name: VehicleDynamics.World
  - Description: World object

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Sample simulation results

- Simulate the model for 10s using Radau
  - Takes about 3 minutes

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Subsystem interface definitions

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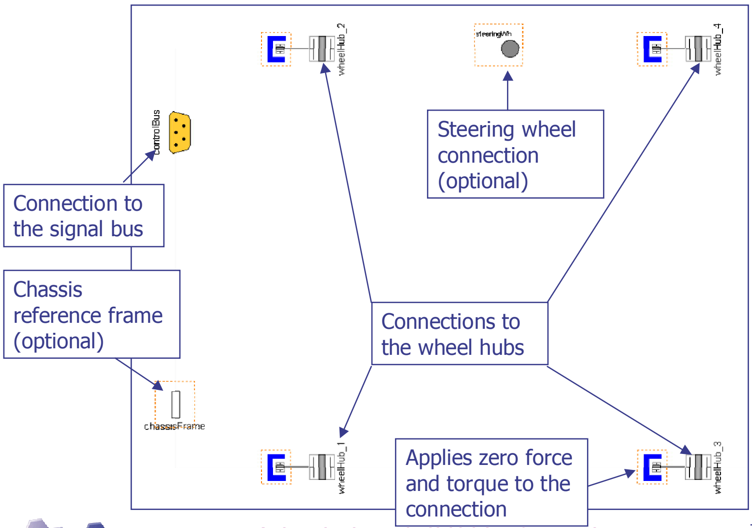
The Chassis subsystem



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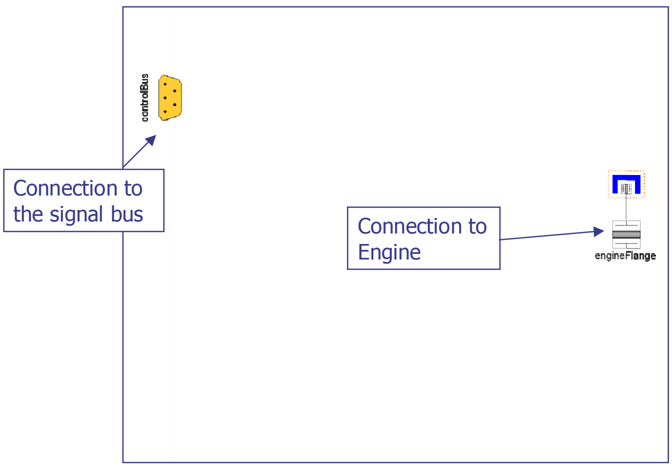
The Accessories subsystem



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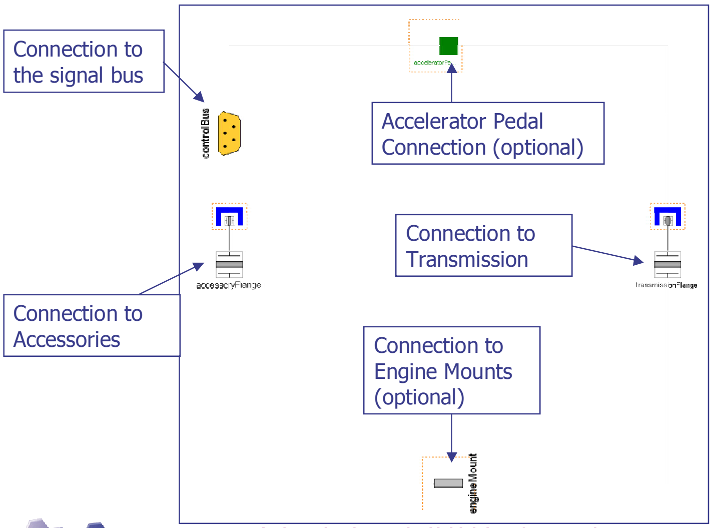
The Engine subsystem



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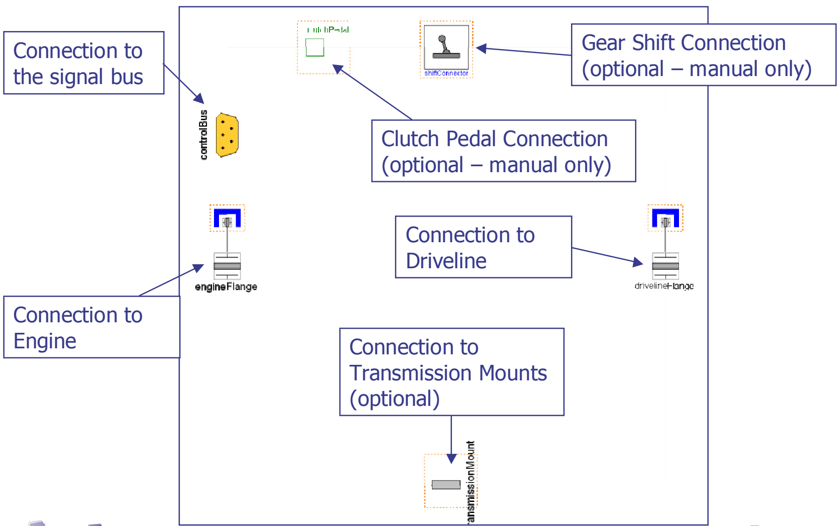
The Transmission subsystem



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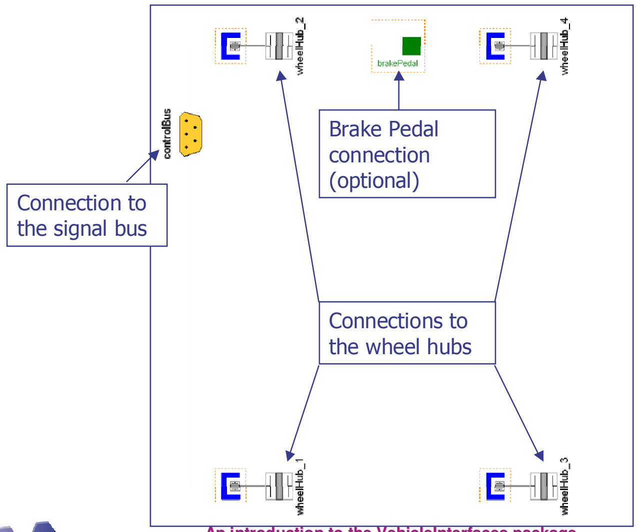
The Brakes subsystem



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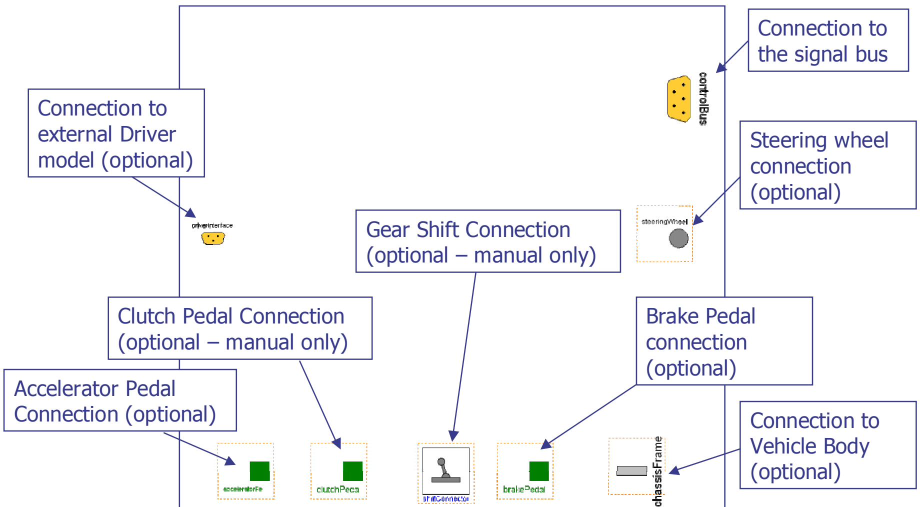
The DriverEnvironment subsystem



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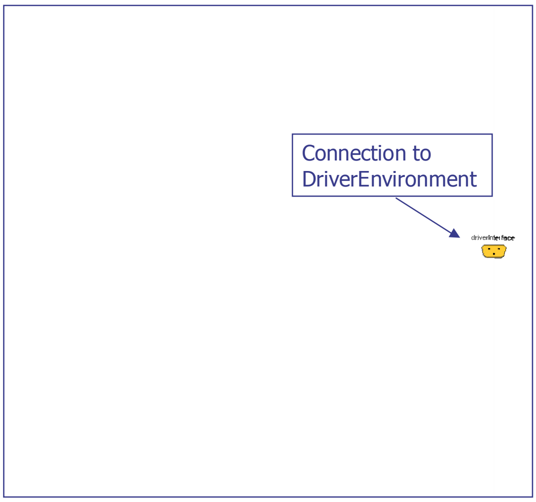
The Driver subsystem



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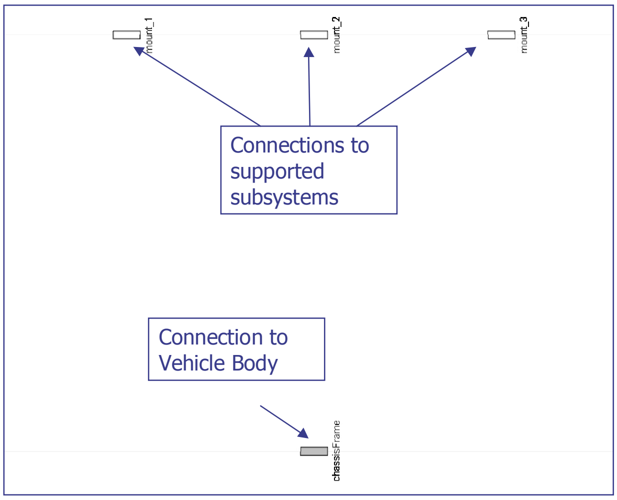
The PowerTrainMounts subsystem



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The Road subsystem

- Uses replaceable functions to define friction, gradient, curvature and banking
- By redeclaring the functions different road models can be created
  – VehicleInterfaces includes a straight road and a circular road
- When the road is included at the top level of a model it is declared inner so that it can be referenced from any subsystem or component within the model

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The Atmosphere subsystem

- Uses replaceable functions to define temperature, pressure, humidity and wind speed and direction
- By redeclaring the functions different atmospheric models can be created
  – VehicleInterfaces includes a constant atmosphere model
- When the atmosphere is included at the top level of a model it is declared inner so that it can be referenced from any subsystem or component within the model

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