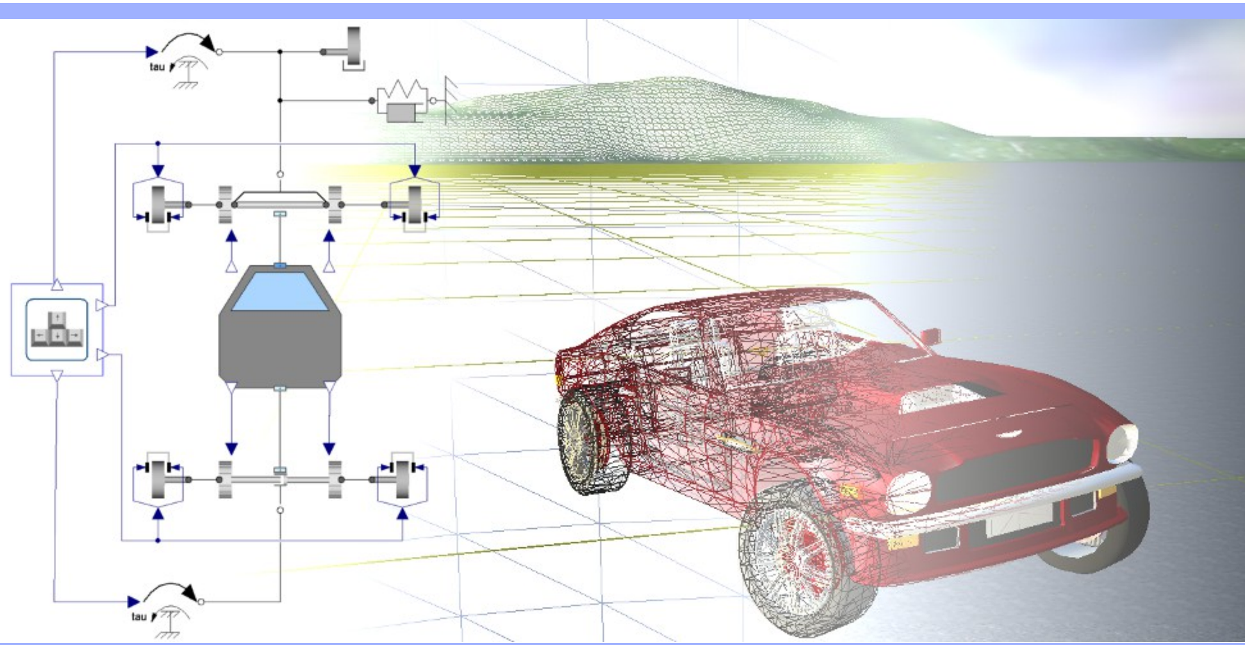
Virtual Physics
Equation-Based Modeling

TUM, December 09, 2014

Real-Time Simulation with Dymola

```
equation
  sx0 = cos(frame_a.phi)*sx_norm + …
  sy0 = -sin(frame_a.phi)*sx_norm + …
  vy = der(frame_a.y);
  w_roll = der(flange_a.phi);
  v_long = vx*sx0 + vy*sy0;
  v_lat = -vx*sy0 + vy*sx0;
  v_slip_lat = v_lat - 0;
  v_slip_long = v_long - R*w_roll;

  v_slip = sqrt(v_slip_long^2 + …
  -f_long*R = flange_a.tau;
  frame_a.t = 0;
  f = N*. S_Func(vAdhesion,vSlide,…
  f_long =f*v_slip_long/v_slip;
  f_lat  =f*v_slip_lat/v_slip;
  f_long = frame_a.fx*sx0 + …
  f_lat = -frame_a.fx*sy0 + …
```



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Real-Time Simulation

In this lecture, we give an example of modeling a fully functional real-time simulation. This concerns essentially three topics:

- Time-Integration for Real-Time and synchronization.
- Handling of User Input.
- Real-Time 3D Visualization.

Time Integration

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If we want to simulate something in real-time. The numerical ODE-solver is subject to a few severe constraints.

- The solver must compute fast enough
  → larger stepsizes or simple algorithms
- If the system is interactive, there is a maximum step-size
  → favors simple algorithm.
  → fixed step-size methods
- Each single integration step must be fast enough
  → no solvers with indefinite number of iterations (avoid any non-linearities)
  → no events.
  → no implicite solvers (will be explained after Christmas)

Time Integration

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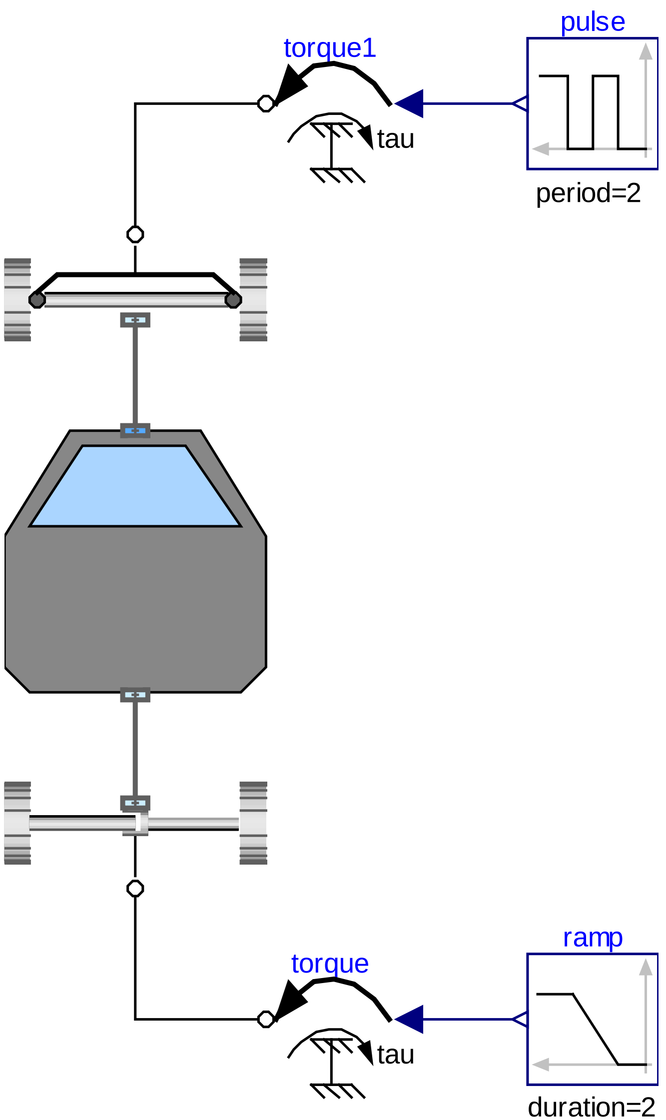
The two-track car model seems to be suited to be simulated in real time.

- Only linear-systems of equations (non-linear solvers are not required)
- No events
- Limited stiffness.



Time Integration

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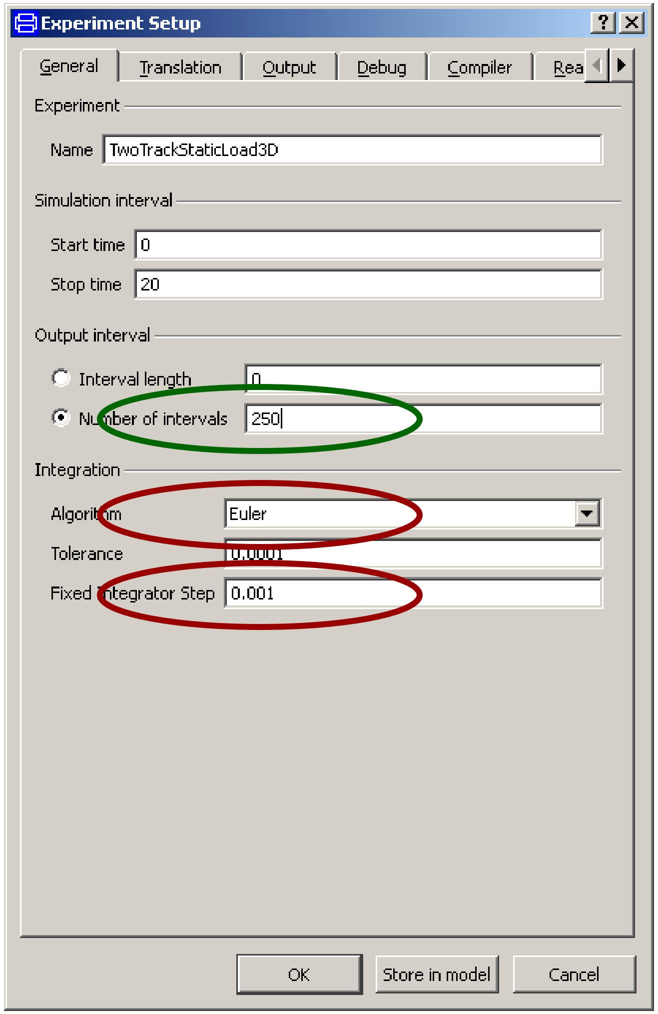
In Dymola, it is very easy to simulate the two-track model in real-time.



Time Integration

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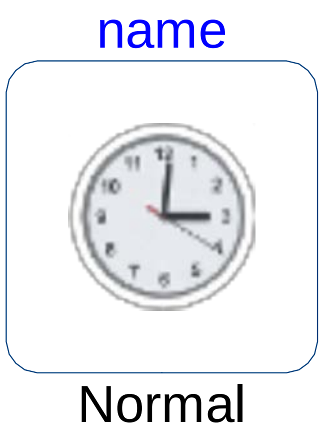
In Dymola it is very easy to simulate the two-track model in real-time.

- We simply use the most simple solver that is available: Forward Euler
- We use a fixed step-size of 1ms
- We may reduce the number of output values (since writing to the disc can easily be more time-consuming that the actual simulation…)
- In fact, we are much faster than real-time. We need to artificially slow-down the simulation in order to synchronize with real-time.

Real-Time Synchronization



- For time synchronization, we need a special model.
- This model is contained in the Modelica Device Drivers Library (developed by DLR)
- It slows down the simulation by calling a function that stays in an idle loop.

Synchronize Realtime Block

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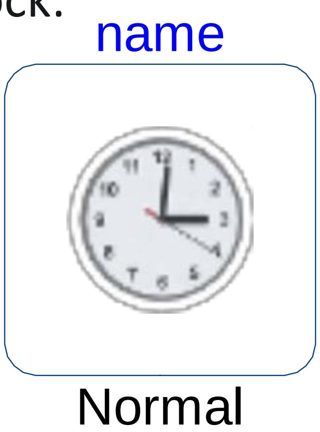
The Synchronize Realtime Block:



- The block simply calls an Modelica function of the DeviceDrivers Library.

```
block SynchronizeRealtime

  parameter Integer resolution(min = 1);
  parameter ProcessPriority p;
  output Real calculationTime;
  output Real availableTime;

equation

  when (initial()) then
    setProcessPriority(
      if (p == "Idle") then -2
      else if (p == "Below") then -1
      else if (p == "Normal") then 0
      else if (p == "High") then 1
      else if (p == "Realtime") then 2
      else 0);
  end when;

   (calculationTime,availableTime)
                   =
   realtimeSynchronize(time,resolution);

end SynchronizeRealtime;
```

Synchronize Realtime Function

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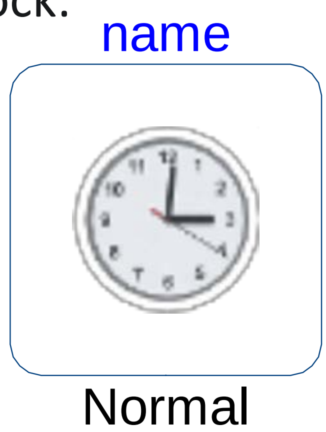
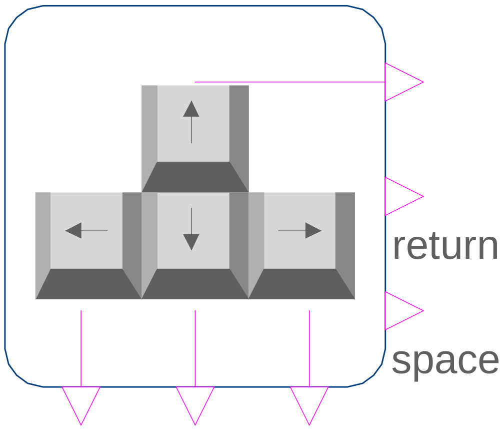
The Synchronize Realtime Block:



- The block simply calls an Modelica function of the DeviceDrivers Library.

```
function realtimeSynchronize
  input Real simTime;
  input Integer resolution = 1;
  output Real calculationTime;
  output Real availableTime;
  external "C" calculationTime =
OS_realtimeSynchronize(simTime,resolution,
availableTime);

annotation(Include = "
#ifndef MDDSYNC
#define MDDSYNC
#include <windows.h>
[…]

double OS_realtimeSynchronize(double simTime,
       int resolution, double * availableTime) {
  […]

  while((getTime(resolution)- startTime)/1000 <= simTime)
  {
      Sleep(0);
  }
  […]

}
 #endif
");
end realtimeSynchronize;
```

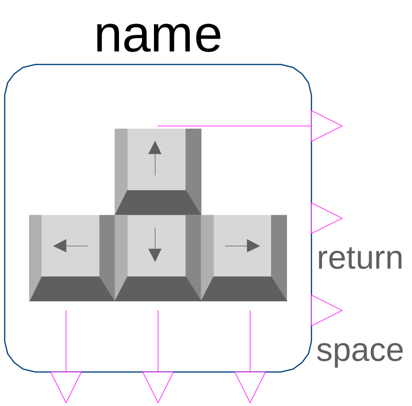
User Interaction



- Also for the user interaction, we need a special input block.
- This block is contained in the Modelica Device Drivers Library (developed by DLR)
- The Boolean output signals indicate when a certain key is pressed down.

Keyboard Input Block

The Keyboard Input Block:

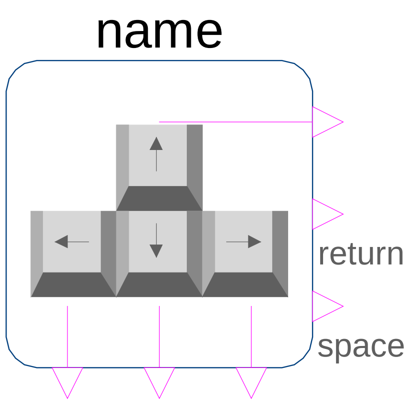


- The block simply calls an Modelica function of the DeviceDrivers Library.
- It simply polls the current state of the keyboard with a given sample rate.

```
block KeyboardInput
  parameter Real sampleT = 0.01

  BooleanOutput keyUp;
  BooleanOutput keyDown;
  BooleanOutput keRight;
  […]

  Integer KeyCode[10];
  InputDevices.Keyboard keyboard;

equation
  when (sample(0,sampleT))then
    KeyCode = keyboard.getData();
  end when;

  keyUp = (KeyCode[1]==1);
  keyDown = (KeyCode[2]==1);
  keyRight = (KeyCode[3]==1);
  […]

end Frame;
```

Keyboard Input Block

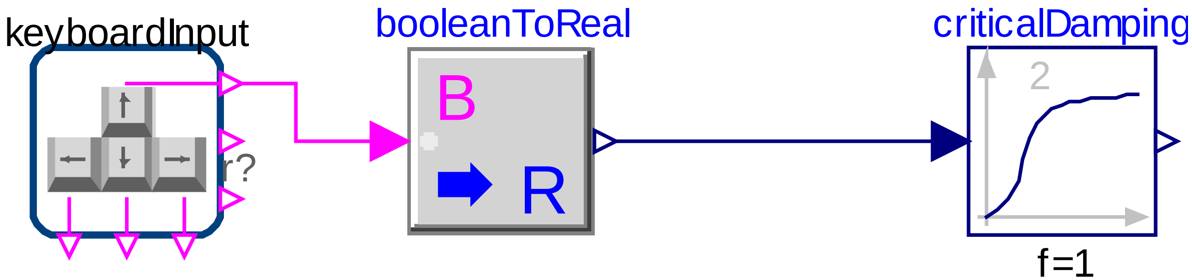
The Keyboard Input Block:



- On the right you see the getData function that is called to poll the keyboard state.
- It calls an external C function.
- The code is contained in the annotation.

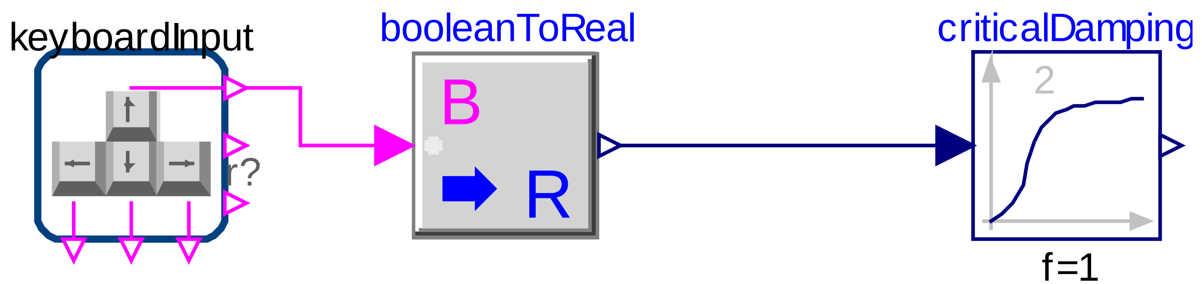
```
function getData

  output Integer KeyCode[10];

  external "C" KEY_getData(KeyCode);

  annotation (Include="
#define VOID void
typedef char CHAR;
typedef short SHORT;
typedef long LONG;
#include <windows.h>
[…]
void KEY_getData(int * piKeyState)
{
  if(GetAsyncKeyState(VK_UP))
    piKeyState[0] = 1;
  else piKeyState[0] = 0;");
[…]
"


end getData;
```

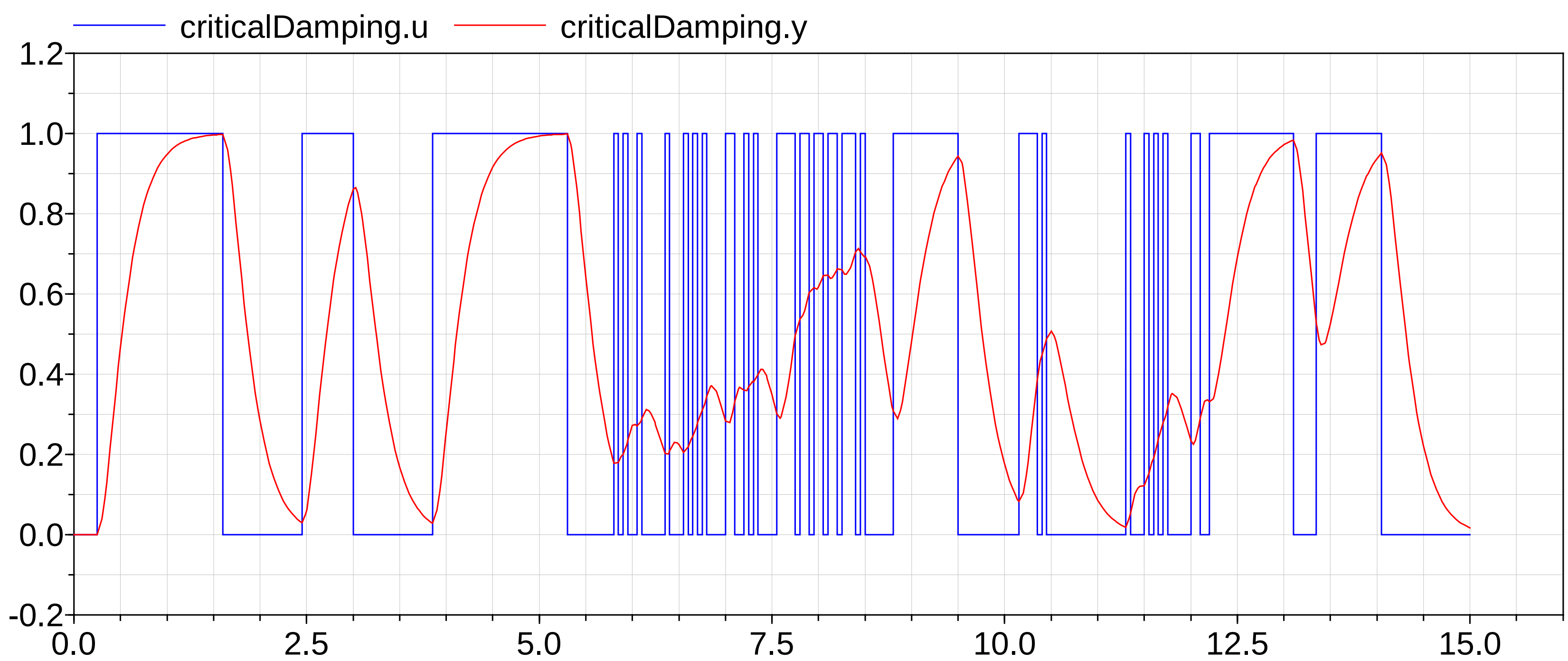
Filtering User Input



- Using this input block, the user can only control in a Boolean way: ON or OFF.
- To enable a more continuous control, we can filter the input signal.
- To this end, we apply the critical-Damping Filter from the Modelica Standard Library.

Filtering User Input





Filtering User Input

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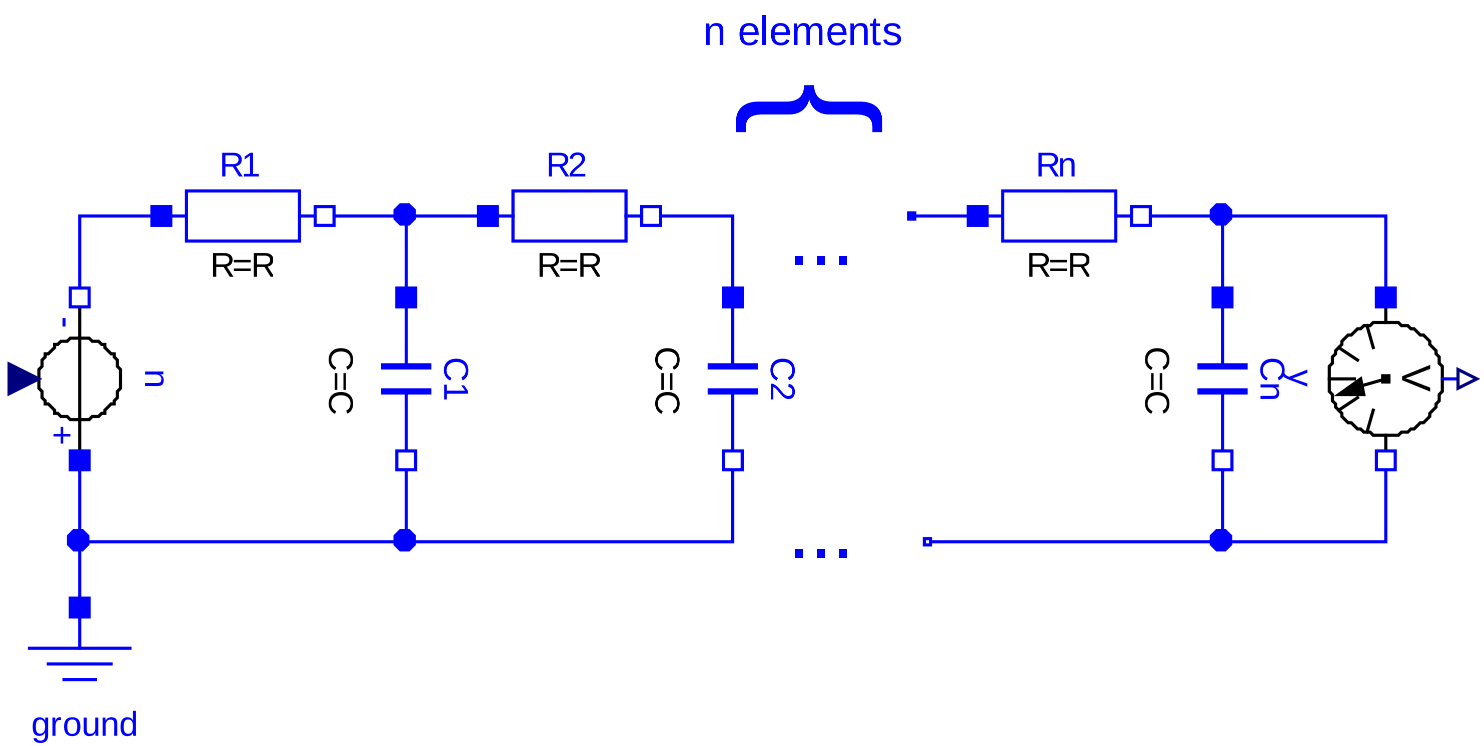
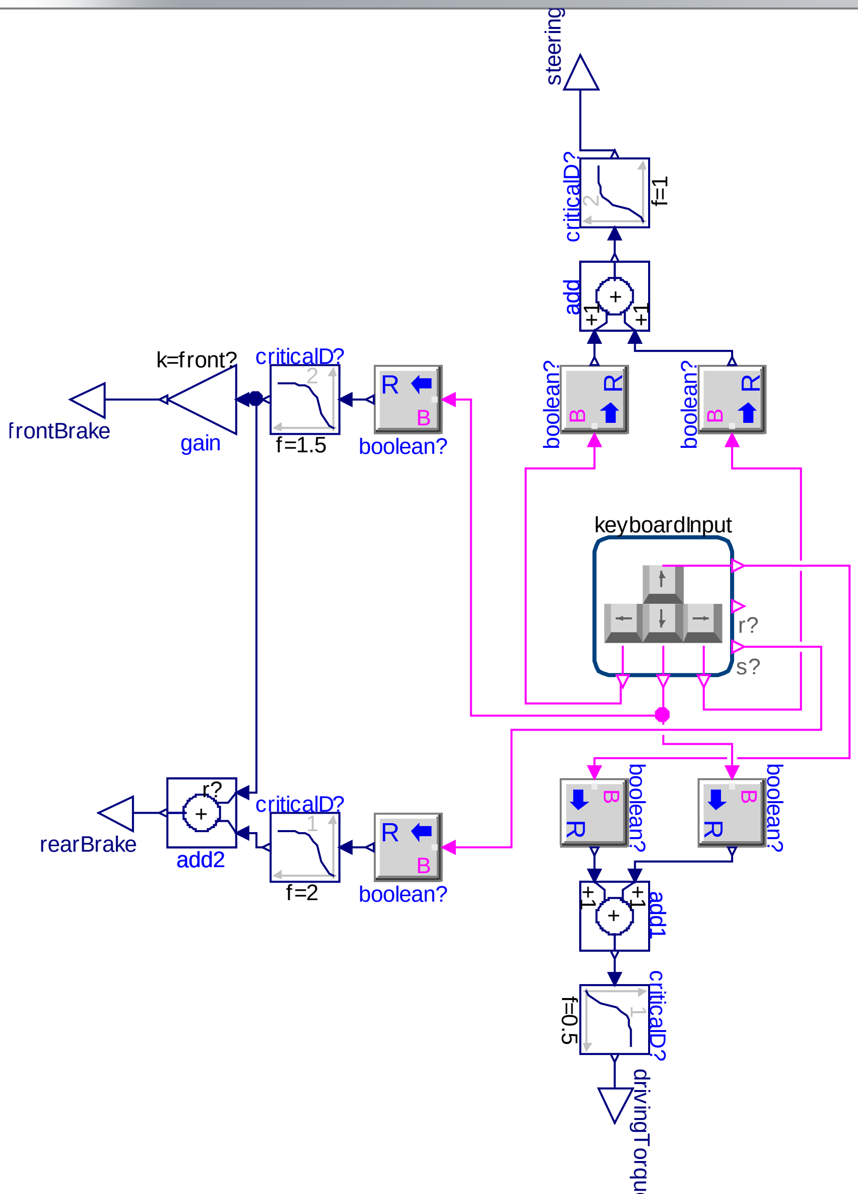


- This electrical circuit illustrates the functionality of the critical-damping filter
- It can be regarded as RC lowpass filter with multiple stages (in our case: 2)

Applying User Interaction



- Using critical damping filters, I created a control block for the car model.
- Its outputs are the breaking forces and the driving and steering torque.

Applying User Interaction

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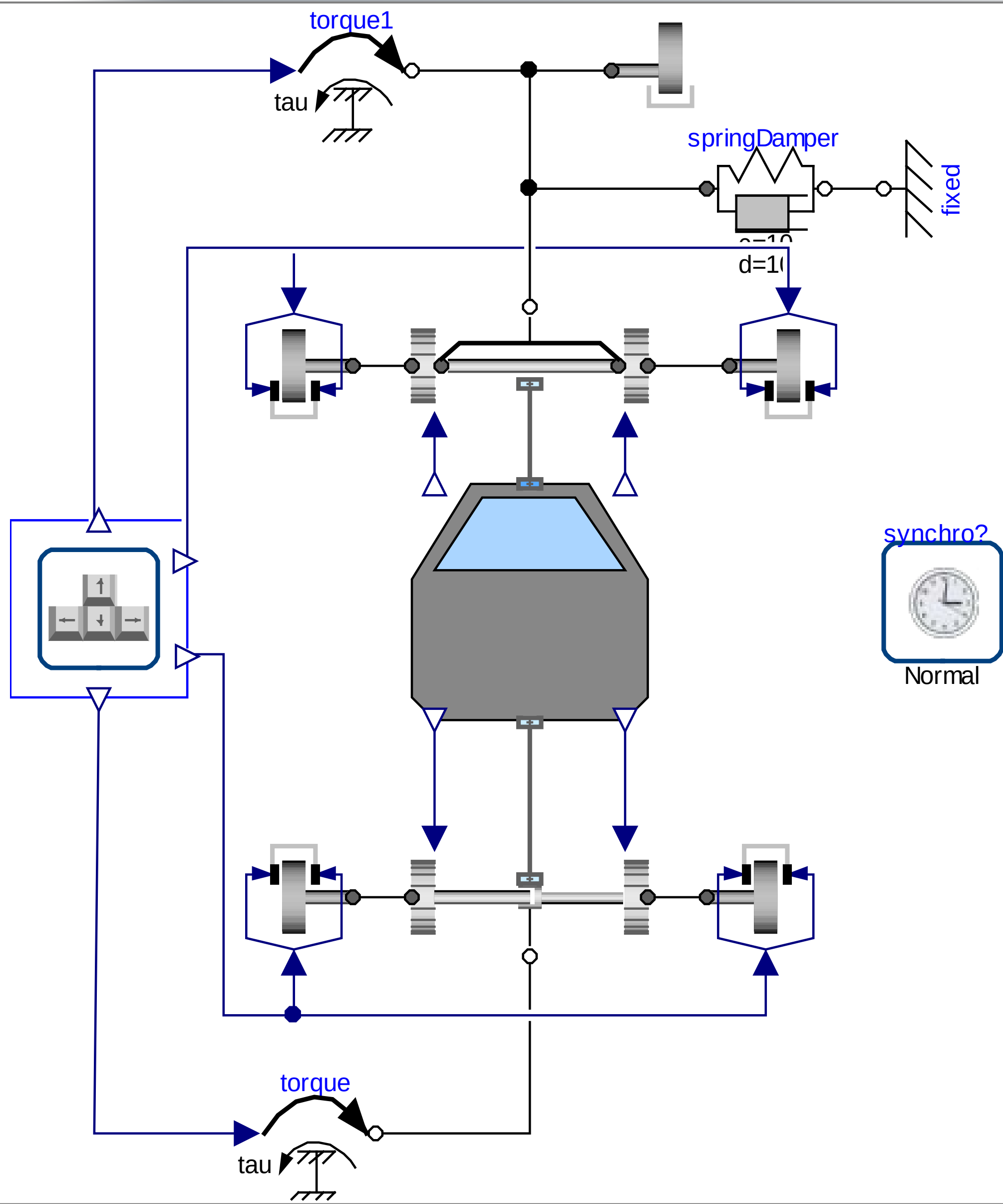

- The forces and torques are then applied on the car model.

Applying User Interaction

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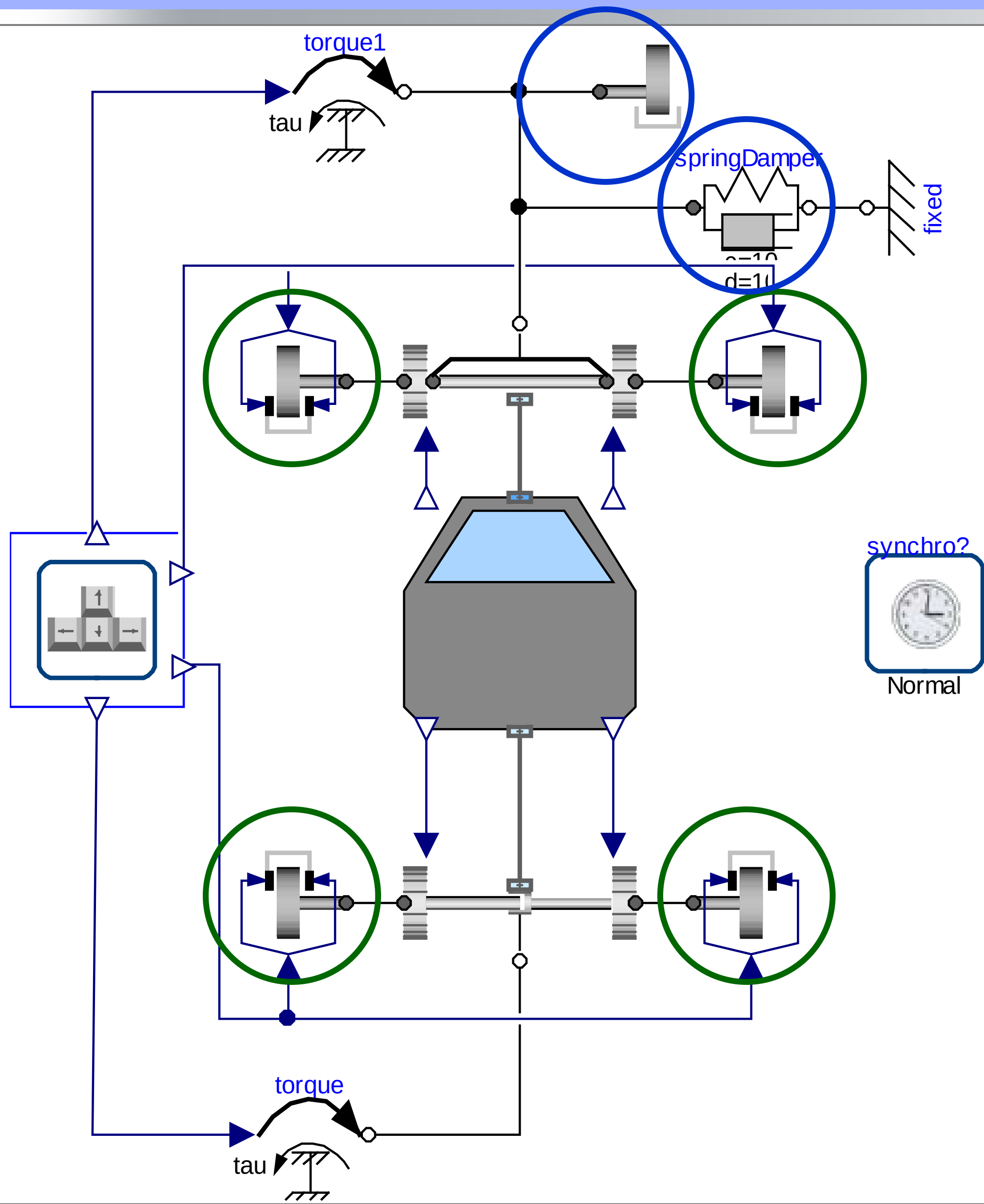

- The forces and torques are then applied on the car model.
- There is simple brake model
- The steering is limited and auto-centered by a spring-damper system.

Visualization

- Now we can steer and simulate our car model in real-time but this makes hardly any fun, if we do not have a 3D real-time visualization.
- The SimVis Library supports a real-time visualization in 3D. It has been developed by DLR.
- SimVis is based on the OpenSceneGraph Technology that itself uses the OpenGL standard.
- The SimVis library is conceptually similar to the DeviceDrivers library. It provides a set of Modelica models that then call external C-functions.

OpenSceneGraph

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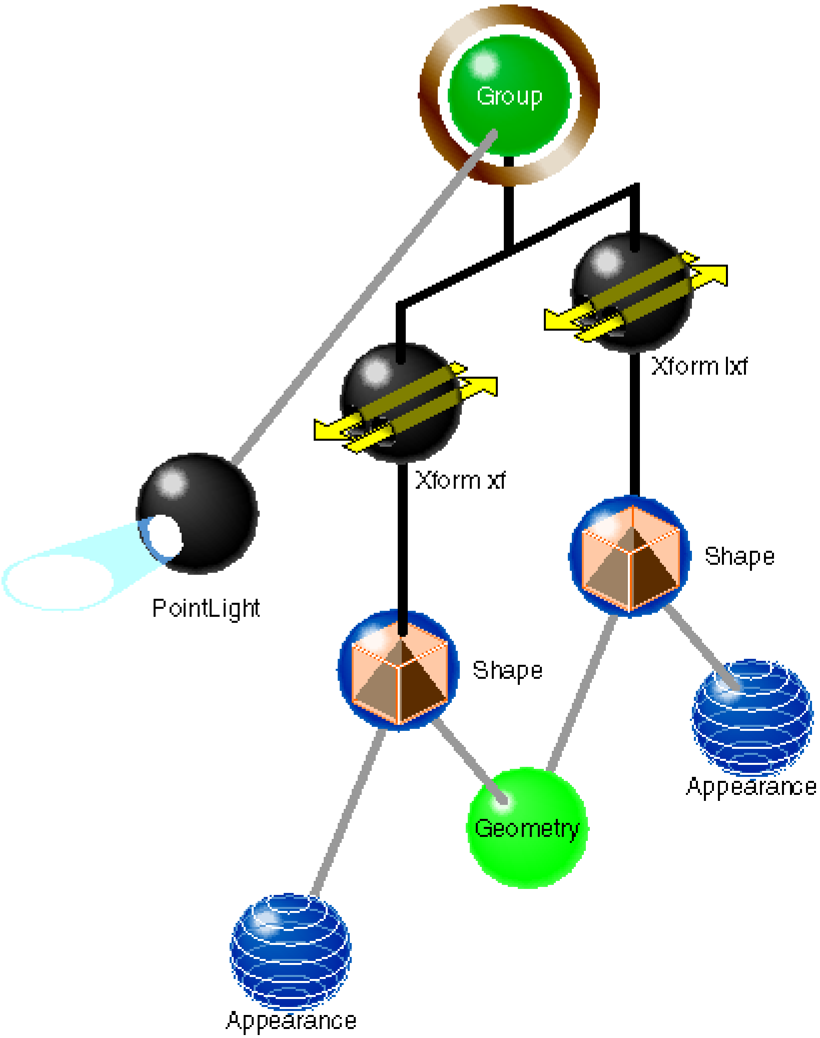
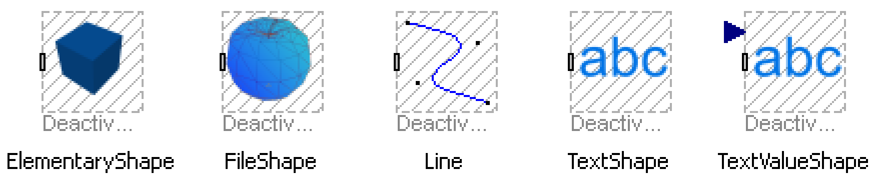
- OpenSceneGraph is an open source implementation of the scene graph technology.
- In the scene graph technology the scene is describes as a graph.
- The visualization of the graph is based on the OpenGL 2.1 standard.
- For the online-visualization, all we need to do is to update the graph.



SimVis Structure

The SimVis Library contains various elements:

- Shapes



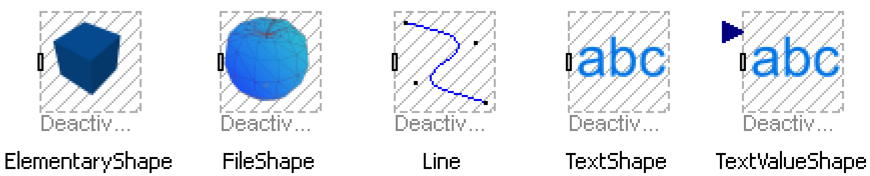
- Cameras

- Lights

SimVis Structure

The SimVis Library contains various elements:

- Shapes



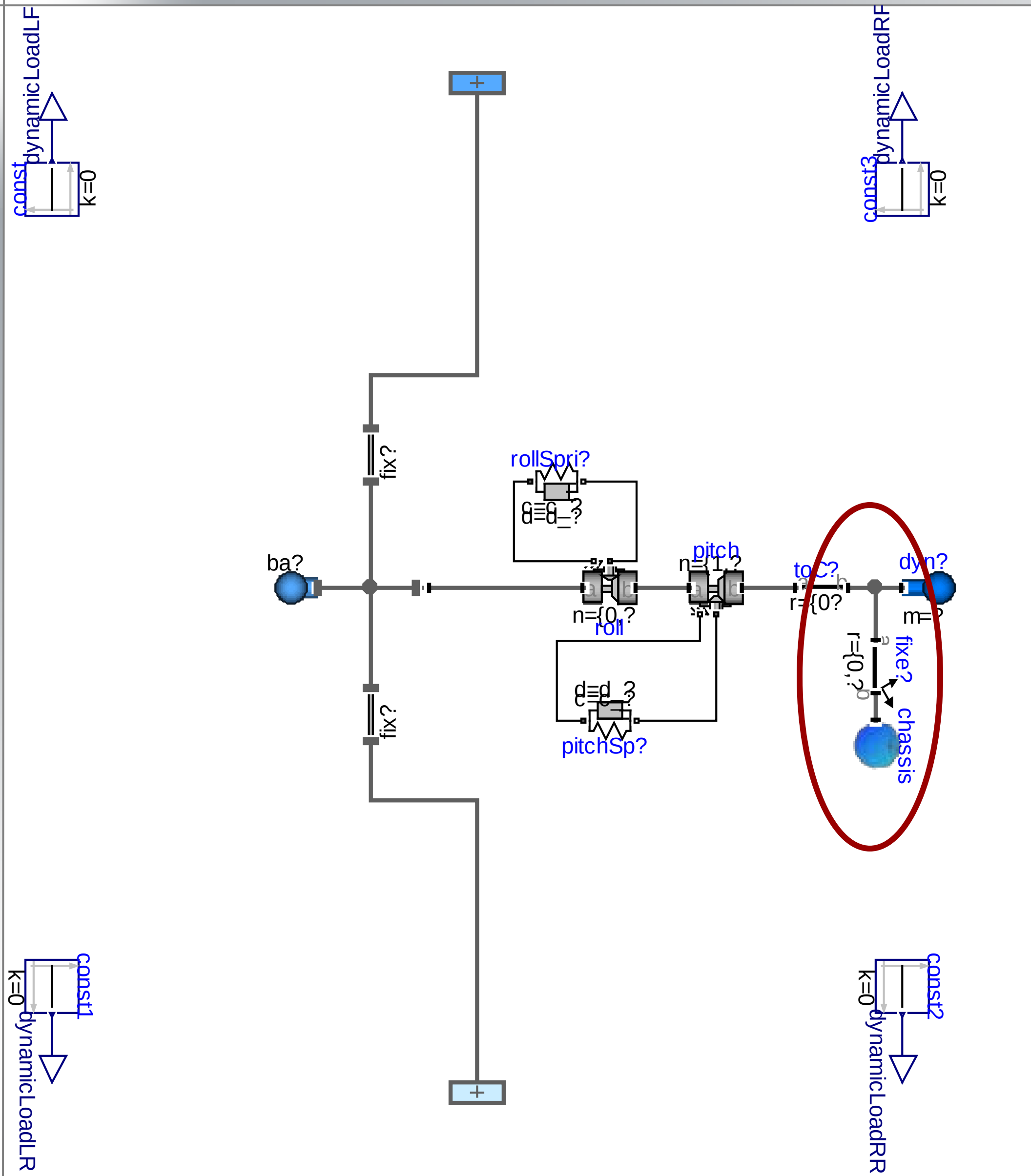
- Cameras

- Lights

All these elements use the Frame Connector form the MultiBody library.

Hence they can simply be used like MultiBody components.

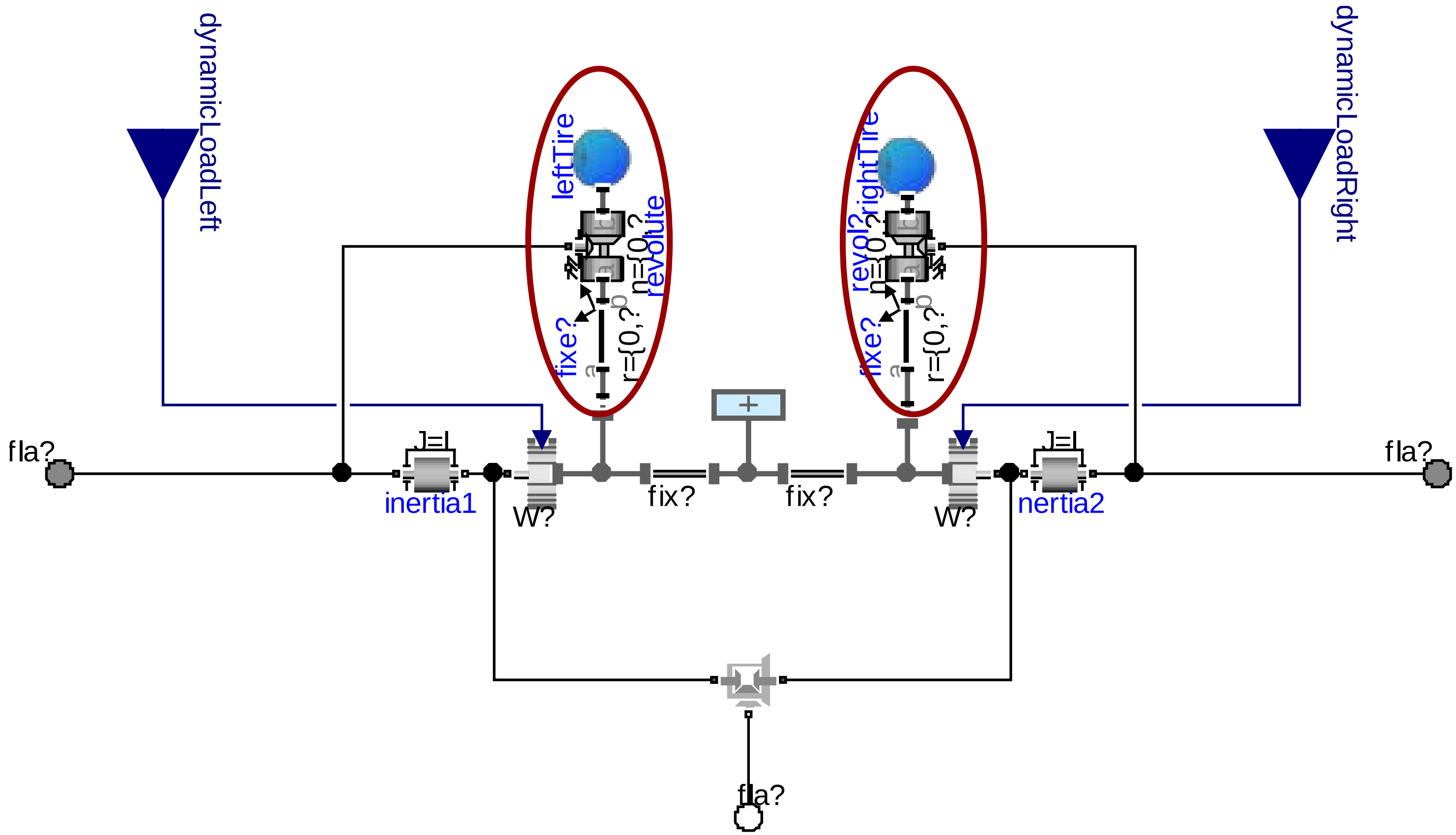
Applying SimVis



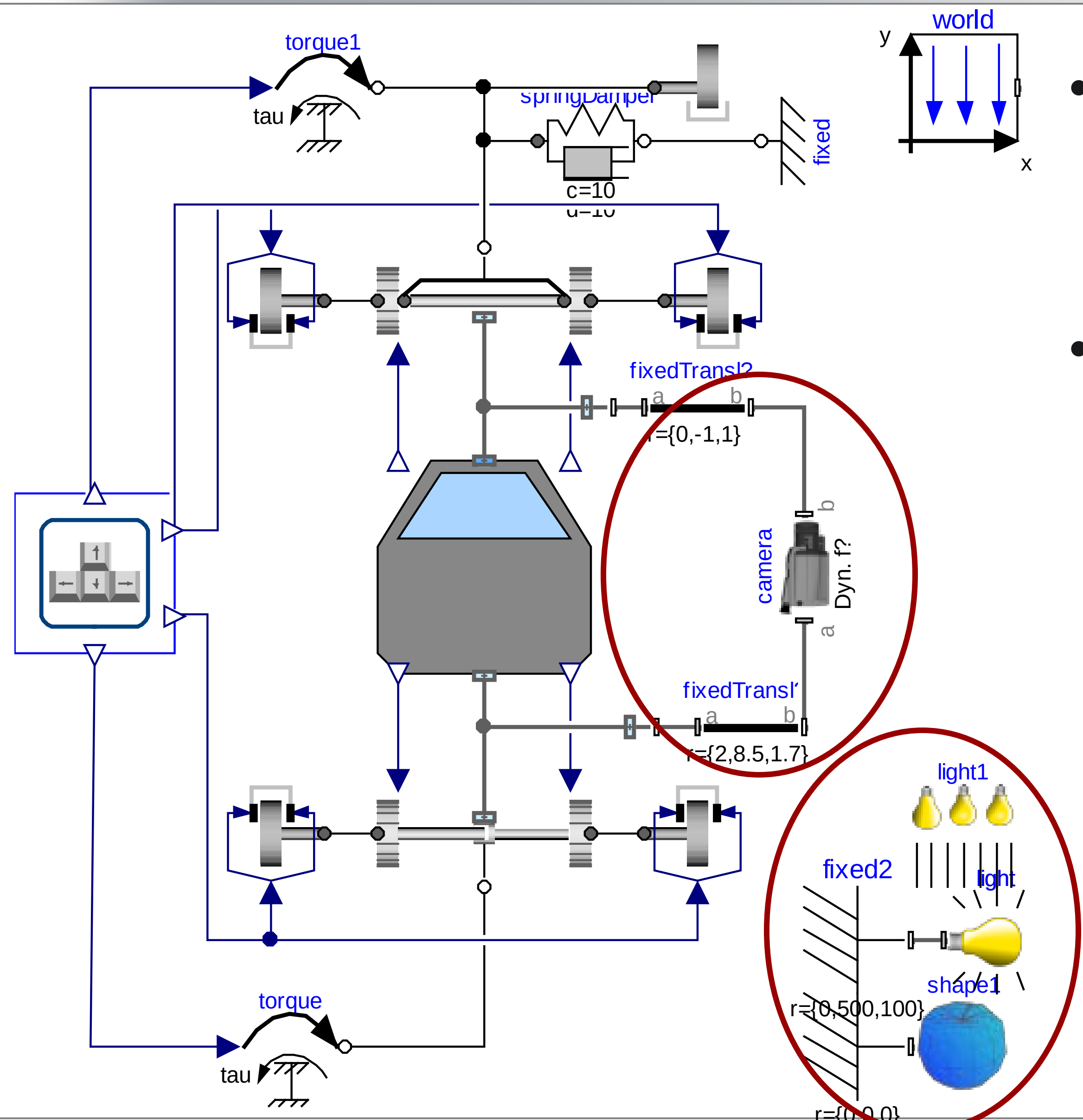
- The visualization of the wheels is integrated into the chassis model

Applying SimVis

- The visualization of the wheels is integrated into the axis model



Applying SimVis



- Lights and Landscape are added to form the complete scene.
- A dynamic follow camera is attached to the rear end of the car pointing to the nose.

Finally….

- And voila!

- We're done! Almost… the rest is your task in Exercise 9.

Questions ?