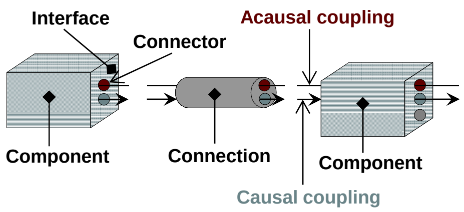
Components, Connectors and Connections

Software Component Model



A component class should be defined *independently of the environment,* very essential for *reusability*

A component may internally consist of other components, i.e. *hierarchical* modeling

Complex systems usually consist of large numbers of *connected* components

Connectors and Connector Classes

Connectors are instances of *connector classes*

electrical connector

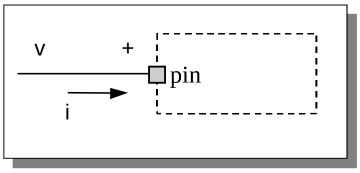
connector class

keyword `flow` indicates that currents of connected pins sum to zero.

an instance `pin` of class `Pin`

```
connector Pin
  Voltage      v;
  flow Current i;
end Pin;

Pin pin;
```



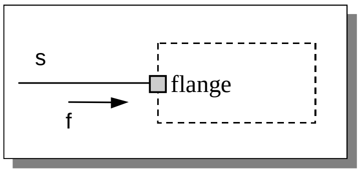
mechanical connector

connector class

an instance `flange` of class `Flange`

```
connector Flange
  Position    s;
  flow Force  f;
end Flange;

Flange flange;
```



The `flow` prefix

Two kinds of variables in connectors:

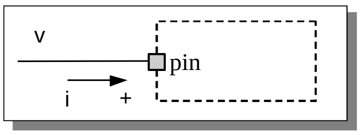
- *Non-flow variables* effort, *potential* or energy level
- *Flow variables* represent some kind of flow

Coupling

- *Equality coupling*, for `effort (non-flow)` variables
- *Sum-to-zero coupling*, for `flow` variables

The value of a `flow` variable is *positive* when the current or the flow is *into* the component

positive flow direction:



Physical Connector Classes Based on Energy Flow

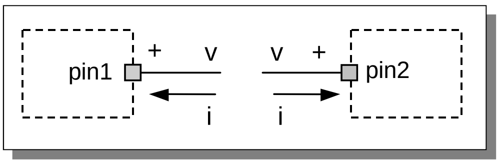
Domain Type	Potential	Flow	Carrier	Modelica Library
Electrical	Voltage	Current	Charge	`Electrical.Analog`
Translational	Position	Force	Linear momentum	`Mechanical.Translational`
Rotational	Angle	Torque	Angular momentum	`Mechanical.Rotational`
Magnetic	Magnetic potential	Magnetic flux rate	Magnetic flux	
Hydraulic	Pressure	Volume flow	Volume	`HyLibLight`
Heat	Temperature	Heat flow	Heat	`HeatFlow1D`
Chemical	Chemical potential	Particle flow	Particles	Under construction
Pneumatic	Pressure	Mass flow	Air	`PneuLibLight`

`connect`-equations

Connections between connectors are realized as *equations* in Modelica

```
connect(connector1,connector2)
```

The two arguments of a `connect`-equation must be references to *connectors*, either to be declared directly *within* the *same class* or be *members* of one of the declared variables in that class




```
Pin pin1,pin2;
//A connect equation
//in Modelica:
connect(pin1,pin2);
```

Corresponds to

```
pin1.v = pin2.v;
pin1.i + pin2.i =0;
```


Connection Equations

```
Pin pin1,pin2;
//A connect equation
//in Modelica
connect(pin1,pin2);
```

Corresponds to

```
pin1.v = pin2.v;
pin1.i + pin2.i =0;
```

Multiple connections are possible:

```
connect(pin1,pin2); connect(pin1,pin3); ... connect(pin1,pinN);
```

Each primitive connection set of effort (nonflow) variables is used to generate equations of the form:

Across variable

$$v_1 = v_2 = v_3 = \dots v_n$$

Each primitive connection set of flow variables is used to generate *sum-to-zero* equations of the form:

Through variable

$$i_1 + i_2 + \dots (-i_k) + \dots i_n = 0$$

Acausal, Causal, and Composite Connections

Two *basic* and one *composite* kind of connection in Modelica

- *Acausal connections*
- *Causal connections*, also called *signal* connections
- *Composite connections*, also called structured connections, composed of basic or composite connections

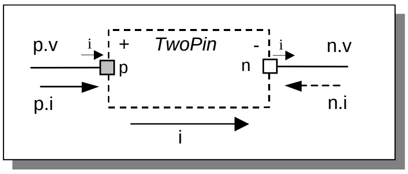
connector class ← `connector`

fixed causality ← `output`

```
connector OutPort
  output Real signal;
end OutPort
```

Common Component Structure

The base class `TwoPin` has two connectors `p` and `n` for positive and negative pins respectively



partial class (cannot be instantiated)

positive pin

negative pin

```
partial model TwoPin
  Voltage    v
  Current    i
  Pin p;
  Pin n;
equation
  v = p.v - n.v;
  0 = p.i + n.i;
  i = p.i;
end TwoPin;
// TwoPin is same as OnePort in
// Modelica.Electrical.Analog.Interfaces
```

```
connector Pin
  Voltage        v;
  flow Current   i;
end Pin;
```

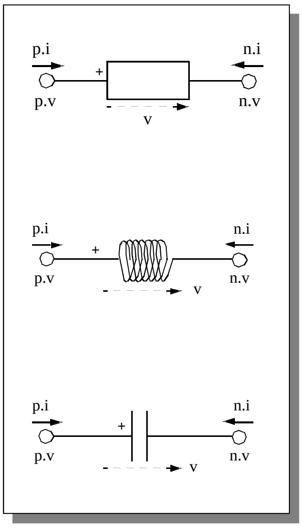
electrical connector class

Electrical Components

```
model Resistor "Ideal electrical resistor"
  extends TwoPin;
  parameter Real R;
equation
  R*i = v;
end Resistor;
```

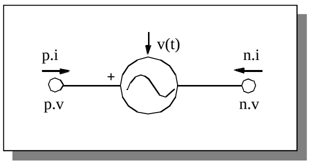
```
model Inductor "Ideal electrical inductor"
  extends TwoPin;
  parameter Real L "Inductance";
equation
  L*der(i) = v;
end Inductor;
```

```
model Capacitor "Ideal electrical capacitor"
  extends TwoPin;
  parameter Real C ;
equation
  i=C*der(v);
end Capacitor;
```

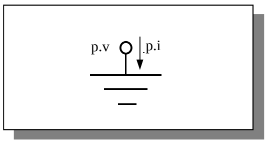


Electrical Components cont'

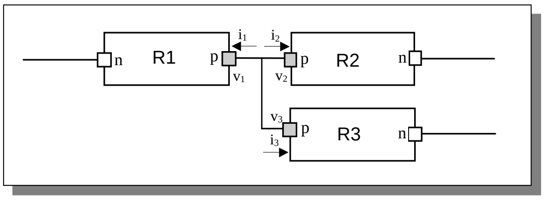
```
model Source
   extends TwoPin;
   parameter Real A,w;
equation
   v = A*sin(w*time);
end Resistor;
```




```
model Ground
   Pin p;
equation
   p.v = 0;
end Ground;
```



Resistor Circuit

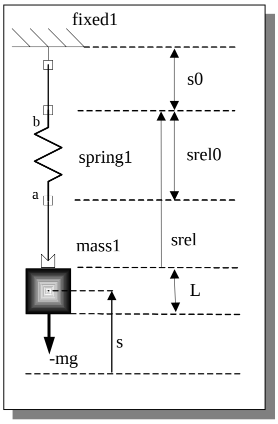



```
model ResistorCircuit
  Resistor R1(R=100);
  Resistor R2(R=200);
  Resistor R3(R=300);
equation
  connect(R1.p, R2.p);
  connect(R1.p, R3.p);
end ResistorCircuit;
```

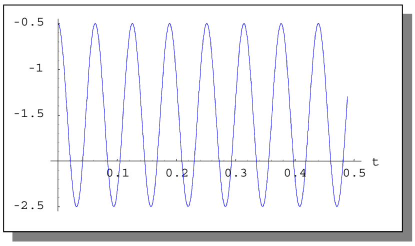
Corresponds to

```
R1.p.v = R2.p.v;
R1.p.v = R3.p.v;
R1.p.i + R2.p.i + R3.p.i = 0;
```


An Oscillating Mass Connected to a Spring




```
model Oscillator
  Mass     mass1(L=1, s(start=-0.5));
  Spring   spring1(srel0=2, c=10000);
  Fixed    fixed1(s0=1.0);
equation
  connect(spring1.flange_b, fixed1.flange_b);
  connect(mass1.flange_b, spring1.flange_a);
end Oscillator;
```

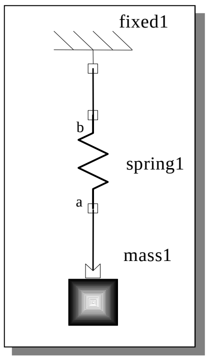


Extra Exercise

- Locate the Oscillator model in DrModelica using OMNotebook!
- Simulate and plot the example. Do a slight change in the model e.g. different elasticity c, re-simulate and re-plot.

- Draw the `Oscillator` model using the graphic connection editor e.g. using the library `Modelica.Mechanical.Translational`
- Including components `SlidingMass`, `Force`, `Blocks.Sources.Constant`

- Simulate and plot!



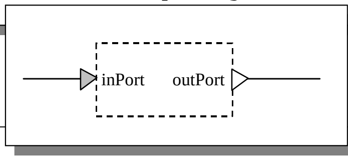
Signal Based Connector Classes

fixed causality

```
connector InPort "Connector with input signals of type Real"
  parameter Integer n=1 "Dimension of signal vector";
  input Real signal[n]  "Real input signals";
end InPort;
```

fixed causality

```
connector OutPort "Connector with output signals of type Real"
  parameter Integer n=1  "Dimension of signal vector";
  output Real signal[n]  "Real output signals";
end OutPort;
```

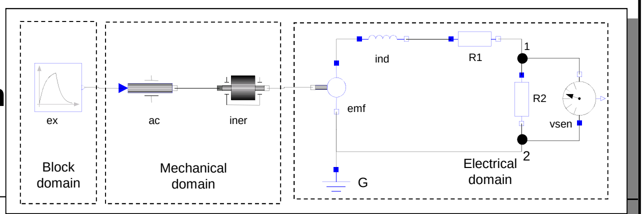


multiple input single output block

```
partial block MISO
  "Multiple Input Single Output continuous control block"
  parameter Integer nin=1 "Number of inputs";
  InPort    inPort(n=nin) "Connector of Real input signals";
  OutPort   outPort(n=1)  "Connector of Real output signal";
protected
  Real u[:] = inPort.signal     "Input signals";
  Real y    = outPort.signal[1] "Output signal";
end MISO; // From Modelica.Blocks.Interfaces
```


Connecting Components from Multiple Domains

- Block domain
- Mechanical domain
- Electrical domain

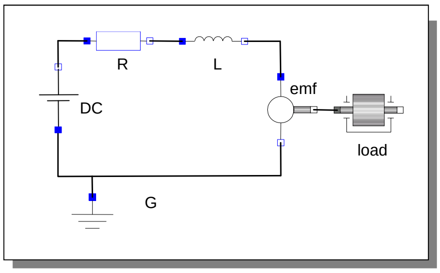



```
model Generator
  Modelica.Mechanics.Rotational.Accelerate ac;
  Modelica.Mechanics.Rotational.Inertia iner;
  Modelica.Electrical.Analog.Basic.EMF emf(k=-1);
  Modelica.Electrical.Analog.Basic.Inductor ind(L=0.1);
  Modelica.Electrical.Analog.Basic.Resistor R1,R2;
  Modelica.Electrical.Analog.Basic.Ground G;
  Modelica.Electrical.Analog.Sensors.VoltageSensor vsens;
  Modelica.Blocks.Sources.Exponentials ex(riseTime={2},riseTimeConst={1});
equation
  connect(ac.flange_b, iner.flange_a); connect(iner.flange_b, emf.flange_b);
  connect(emf.p, ind.p); connect(ind.n, R1.p); connect(emf.n, G.p);
  connect(emf.n, R2.n); connect(R1.n, R2.p); connect(R2.p, vsens.n);
  connect(R2.n, vsens.p); connect(ex.outPort, ac.inPort);
end Generator;
```


Simple Modelica DCMotor Model
Multi-Domain (Electro-Mechanical)

A DC motor can be thought of as an electrical circuit
which also contains an electromechanical component.

```
model DCMotor
   Resistor R(R=100);
   Inductor L(L=100);
   VsourceDC DC(f=10);
   Ground G;
   EMF emf(k=10,J=10, b=2);
   Inertia load;
equation
   connect(DC.p,R.n);
   connect(R.p,L.n);
   connect(L.p, emf.n);
   connect(emf.p, DC.n);
   connect(DC.n,G.p);
   connect(emf.flange,load.flange);
end DCMotor;
```



Corresponding DCMotor Model Equations

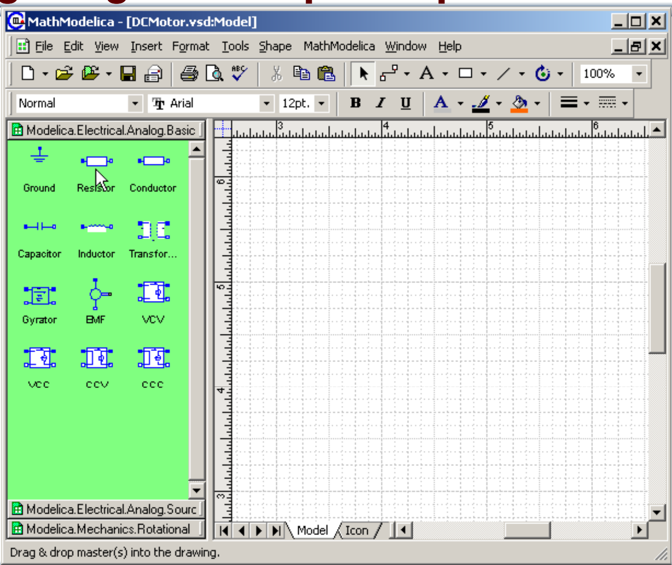
The following equations are automatically derived from the Modelica model:

0 == DC.p.i + R.n.i	EM.u == EM.p.v − EM.n.v	R.u == R.p.v − R.n.v
DC.p.v == R.n.v	0 == EM.p.i + EM.n.i	0 == R.p.i + R.n.i
	EM.i == EM.p.i	R.i == R.p.i
0 == R.p.i + L.n.i	EM.u == EM.k * EM.ω	R.u == R.R * R.i
R.p.v == L.n.v	EM.i == EM.M / EM.k	
	EM.J * EM.ω == EM.M − EM.b * EM.ω	L.u == L.p.v − L.n.v
0 == L.p.i + EM.n.i		0 == L.p.i + L.n.i
L.p.v == EM.n.v	DC.u == DC.p.v − DC.n.v	L.i == L.p.i
	0 == DC.p.i + DC.n.i	L.u == L.L * L.i'
0 == EM.p.i + DC.n.i	DC.i == DC.p.i	
EM.p.v == DC.n.v	DC.u == DC.Amp * Sin[2 π DC.f * t]	
0 == DC.n.i + G.p.i		
DC.n.v == G.p.v	(load component not included)	

Automatic transformation to ODE or DAE for simulation:

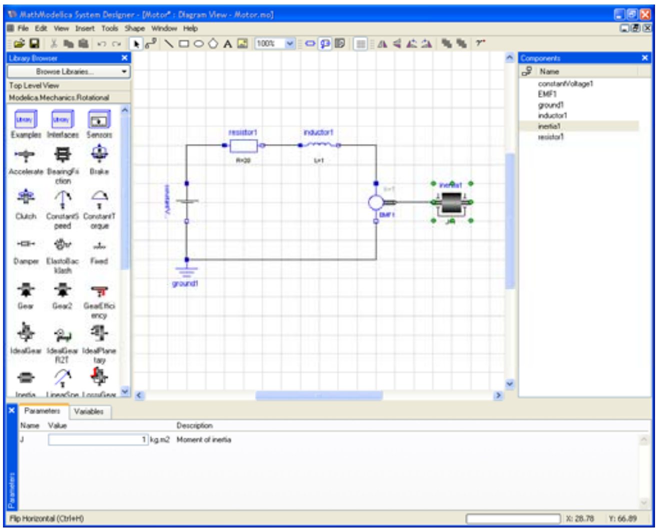
$$\frac{dx}{dt} == f[x, u, t] \qquad g\left[\frac{dx}{dt}, x, u, t\right] == 0$$

Graphical Modeling
Using Drag and Drop Composition



Courtesy
MathCore
Engineering AB

Completed DCMotor using Graphical Composition

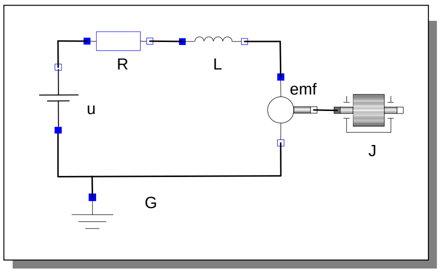


Courtesy MathCore
Engineering AB

Graphical Exercise 3.1

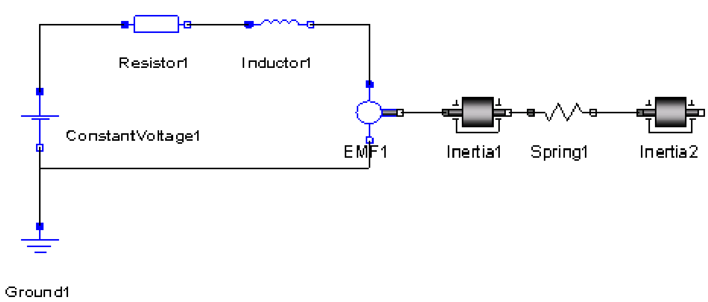
- Open `Exercise02-graphical-modeling.onb` and the corresponding .pdf
- Draw the `DCMotor` model using the graphic connection editor using models from the following Modelica libraries: `Mechanics.Rotational`, `Electrical.Analog.Basic`, `Electrical.Analog.Sources`

- Simulate it for 15s and plot the variables for the outgoing rotational speed on the inertia axis and the voltage on the voltage source (denoted u in the figure) in the same plot.



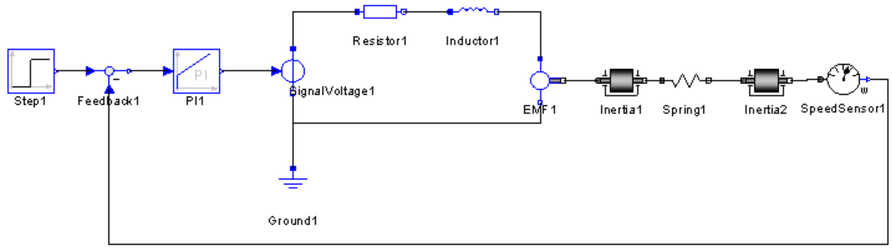
Exercise 3.2

- If there is enough time: Add a torsional spring to the outgoing shaft and another inertia element. Simulate again and see the results. Adjust some parameters to make a rather stiff spring.



Exercise 3.3

- If there is enough time: Add a PI controller to the system and try to control the rotational speed of the outgoing shaft. Verify the result using a step signal for input. Tune the PI controller by changing its parameters in simForge.

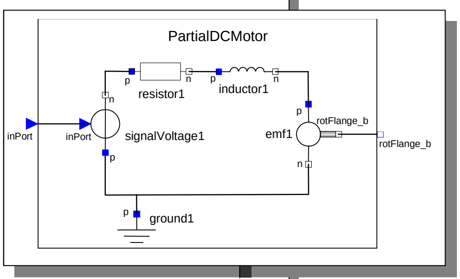


Hierarchically Structured Components

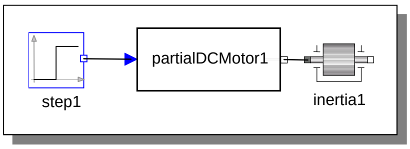
An *inside connector* is a connector belonging to an *internal component* of a structured component class.

An *outside connector* is a connector that is part of the *external interface* of a structured component class, is declared directly within that class

```
partial model PartialDCMotor
  InPort        inPort;      //  Outside signal connector
  RotFlange_b   rotFlange_b; // Outside rotational flange connector
  Inductor      inductor1;
  Resistor      resistor1;
  Ground        ground1;
  EMF           emf1;
  SignalVoltage signalVoltage1;
equation
  connect(inPort,signalVoltage1.inPort);
  connect(signalVoltage1.n, resistor1.p);
  connect(resistor1.n,      inductor1.p);
  connect(signalVoltage1.p, ground1.p);
  connect(ground1.p,        emf1.n);
  connect(inductor1.n,      emf1.p);
  connect(emf1.rotFlange_b, rotFlange_b);
end PartialDCMotor;
```



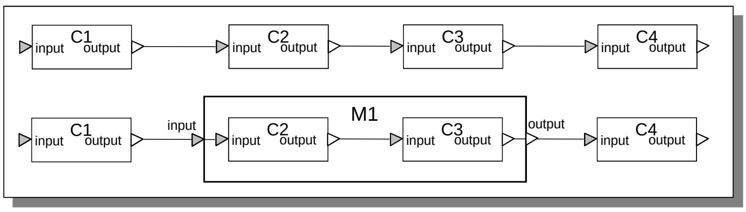
Hierarchically Structured Components cont'




```
model DCMotorCircuit2
  Step           step1;
  PartialDCMotor partialDCMotor1;
  Inertia        inertia1;
equation
  connect(step1.outPort, partialDCMotor1.inPort);
  connect(partialDCMotor1.rotFlange_b, inertia1.rotFlange_a);
end DCMotorCircuit2;
```


Connection Restrictions

- Two *acausal* connectors can be connected to each other
- An `input` connector can be connected to an `output` connector or vice versa
- An `input` or `output` connector can be connected to an *acausal* connector, i.e. a connector without `input`/`output` prefixes
- An *outside* `input` connector behaves approximately like an `output` connector internally
- An *outside* `output` connector behaves approximately like an `input` connector internally



Connector Restrictions cont'

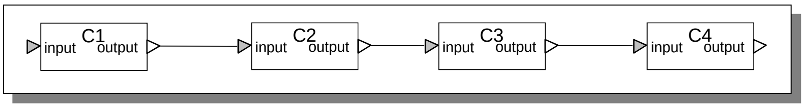
```
connector RealInput
  input Real signal;
end RealInput;
```

```
connector RealOutput
  output Real signal;
end RealOutput;
```

```
class C
  RealInput  u;  // input connector
  RealOutput y;  // output connector
end C;
```

```
class CInst
  C  C1, C2, C3, C4; // Instances of C
equation
  connect(C1.outPort, C2.inPort);
  connect(C2.outPort, C3.inPort);
  connect(C3.outPort, C4.inPort);
end CInst;
```

A circuit consisting of four connected components `C1`, `C2`, `C3`, and `C4` which are instances of the class `C`

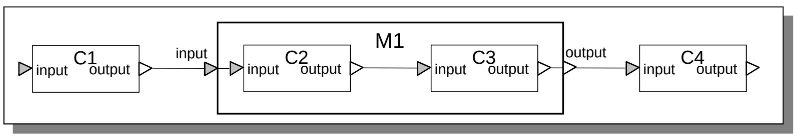


Connector Restrictions cont'

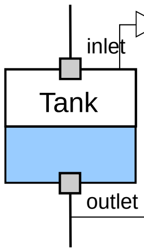
```
class M   "Structured class M"
  RealInput  u; // Outside input connector
  RealOutput y; // Outside output connector
  C  C2;
  C  C3;
end M;
```

A circuit in which the middle components `C2` and `C3` are placed inside a structured component `M1` to which two outside connectors `M1.u` and `M1.y` have been attached.

```
class MInst
  M  M1;   // Instance of M
equation
  connect(C1.y, M1.u); // Normal connection of outPort to inPort
  connect(M1.u, C2.u); // Outside inPort connected to inside inPort
  connect(C2.y, C3.u); // Inside outPort connected to inside inPort
  connect(C3.y, M1.y); // Inside outPort connected to outside outPort
  connect(M1.y, C4.u); // Normal connection of outPort to inPort
end MInst;
```



Parameterization and Extension of Interfaces




```
connector Stream
   Real pressure;
   flow Real volumeFlowRate;
end Stream;
```

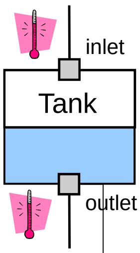
External interfaces to component classes are defined primarily through the use of connectors.

```
model Tank
  parameter Real Area=1;
  replaceable connector TankStream = Stream;
  TankStream inlet, outlet; // The connectors
  Real level;
equation
  // Mass balance
  Area*der(level) = inlet.volumeFlowRate +
     outlet.volumeFlowRate;
  outlet.pressure = inlet.pressure;
end Tank;
connector Stream    // Connector class
  Real pressure;
  flow Real volumeFlowRate;
end Stream
```

Parameterization of interfaces

The `Tank` model has an external interface in terms of the connectors `inlet` and `outlet`

Parameterization and Extension of Interfaces – cont'



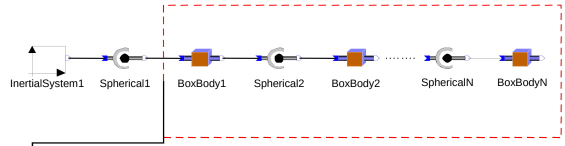
We would like to extend the Tank model to include temperature-dependent effects, analogous to how we extended a resistor to a temperature-dependent resistor

```
model HeatTank
  extends Tank(redeclare connector TankStream = HeatStream);
  Real temp;
equation
  // Energy balance for temperature effects
  Area*level*der(temp) = inlet.volumeFlowRate*inlet.temp +
                         outlet.volumeFlowRate*outlet.temp;
  outlet.temp = temp;   // Perfect mixing assumed.
end HeatTank;
```

```
connector HeatStream
  extends Stream;
  Real temp;
end HeatStream;
```


Arrays of Connectors

Part built up with a for-equation (see Lecture 4)



The model uses a for-equation to connect the different segments of the links

```
model ArrayOfLinks
   constant Integer n=10 "Number of segments (>0)";
   parameter Real[3,n] r={fill(1,n),zeros(n),zeros(n)};
   ModelicaAdditions.MultiBody.Parts.InertialSystem InertialSystem1;
   ModelicaAdditions.MultiBody.Parts.BoxBody[n]
              boxBody(r = r, Width=fill(0.4,n));
   ModelicaAdditions.MultiBody.Joints.Spherical spherical[n];
equation
   connect(InertialSystem1.frame_b, spherical[1].frame_a);
   connect(spherical[1].frame_b, boxBody[1].frame_a);
   for i in 1:n-1 loop
      connect(boxBody[i].frame_b, spherical[i+1].frame_a);
      connect(spherical[i+1].frame_b, boxBody[i+1].frame_a);
   end for;
end ArrayOfLinks;
```

