Experiences in Teaching of Modeling and Simulation with Emphasize on Equation-based and Acausal Modeling Techniques.

Tomáš Kulhánek [*,1,2], Filip Ježek [2,3], Marek Mateják [2], Jan Šilar[2] and Jiří Kofránek [2]

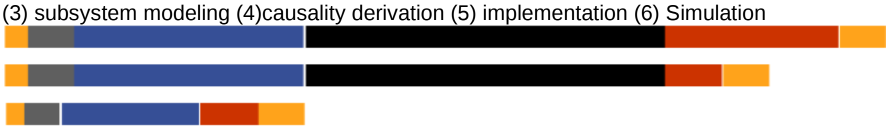
[*] corresponding author: tomas.kulhanek@matfyz.cz
[1] Musical Acoustic Research Center, Music and Dance Faculty, Academy of Performing Arts in Prague, Czech Republic
[2] Institute of Pathological Physiology, First Faculty of Medicine, Charles University in Prague, Czech Republic
[3] Department of Cybernetics, Faculty of Electrical Engineering, Czech Technical University in Prague

Models in biology and medicine = mathematical formalization of knowledge

Time need to design & implement model:

(1) system definition (2) decomposition (3) subsystem modeling (4)causality derivation (5) implementation (6) Simulation

Direct programming (C,Fortran, ...)
Block oriented (Simulink,...)
Acausal (Modelica, Simscape, ...)



Veins and arteries in dead body

Concept:

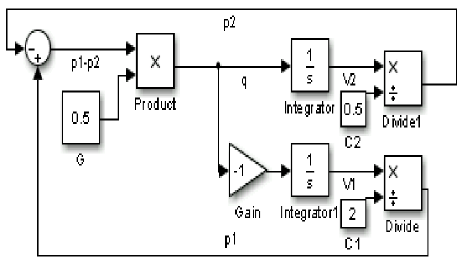
$$q_{in}.q = -q_{out}.q \quad (3)$$

$$q_{in}.q = G \times (q_{in}.p - q_{out}.p) \quad (4)$$

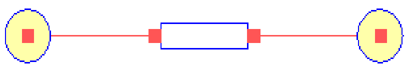
$$p - p_0 = \begin{cases} 0 & \text{if } V < V_0 \\ \frac{V - V_0}{C} & \text{otherwise} \end{cases} \quad (5)$$

$$\frac{\mathrm{d}V}{\mathrm{d}t} = q \quad (6)$$

Matlab:



Modelica:



Modelica components:

Icon	Modelica source

	connector HydraulicPort
	  flow Real q;
	  Real p;
	end HydraulicPort;

	model HydraulicConductor
	  parameter Real G;
	  HydraulicPort qin;
	  HydraulicPort qout;
	equation
	  qin.q= -qout.q; // eq.(3)
	  qin.q = G*(qin.p-qout.p); // eq.(4)
	end HydraulicConductor;

	model HydraulicElastance
	    Real V;
	    parameter Real V0;
	    parameter Real p0;
	    parameter Real C;
	    HydraulicPort qin;
	equation
	   // eq.(5)
	  qin.p-p0 = if (V<V0) then 0 else (V-V0)/C;
	  der(V) = qin.q; // eq.(6)
	end HydraulicElastance;

Spring/Mass System

Concept:

$$F = m \times a \quad (7)$$

$$a = \frac{\mathrm{d}^2 y}{\mathrm{d}t^2} \quad (8)$$

$$F_1 = F_2 \quad (9)$$

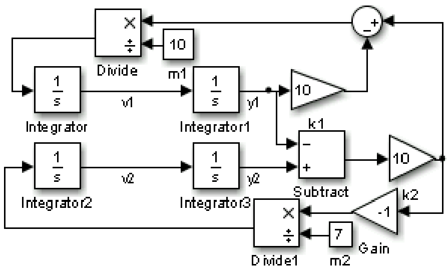
$$F = -k \times dy \quad (10)$$

$$dy = y_2 - y_1 \quad (11)$$

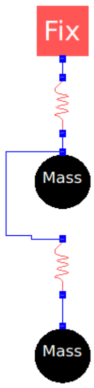
$$m_1 \frac{\mathrm{d}^2 y_1}{\mathrm{d}t^2} - k_2(y_2 - y_1) + k_1 y_1 = 0 \quad (14)$$

$$m_2 \frac{\mathrm{d}^2 y_2}{\mathrm{d}t^2} + k_2(y_2 - y_1) = 0 \quad (15)$$

Matlab:



Modelica:



Modelica components:

```
connector MechanicalJoint
  Real y "position";
  flow Real F "force";
end MechanicalJoint;
```

```
model MechanicalFix
  MechanicalJoint mechanicalJoint;
equation
  mechanicalJoint.y=0;
end MechanicalFix;
```

```
model MechanicalSpring
  Real dy "displacement";
  parameter Real k= 10;
  MechanicalJoint upperJoint;
  MechanicalJoint lowerJoint;
equation
   lowerJoint.F = -k * dy;
   upperJoint.F +lowerJoint.F = 0;
   dy = upperJoint.y - lowerJoint.y;
end MechanicalSpring;
```

```
model MechanicalMass
  MechanicalJoint mechanicalJoint;
  Real y "position of the mass";
  parameter Real initPos=0 "initial position";
  parameter Real m "mass";
  Real a "acceleration";
  Real v "velocity";
initial equation
  y=initPos;
equation
  mechanicalJoint.y = y;
  mechanicalJoint.F = m * a;
  v = der(y);
  a = der(v);
end MechanicalMass;
```

Conclusion:

- acausal modeling reduce mainly time of derivation of causality (4)
- acausal model follows concept, simplified visual verification
- students are able to comprehend and implement much more complex systems.

http://modelica.creativeconnections.cz/student-works/2014/