

Physiolibrary a další užitečné knihovny

Studijní materiály

Fritson: Modelica

http://patf-biokyb.lf1.cuni.cz/wiki/cvut/mos_materialy

www.Physiolibrary.org

www.Physiomodel.org

<https://www.modelica.org/publications>

Physiolibrary
Modelica library for Physiology

Download

Physiolibrary

Physiolibrary is a free open-source Modelica library designed for modeling human physiology. This library contains basic physical laws governing human physiology, usable for cardiovascular circulation, metabolic processes, nutrient distribution, thermoregulation, gases transport, electrolyte regulation, water distribution, hormonal regulation and pharmacological regulation.

Library description

Our laboratory have a long tradition building physiological libraries, starting with PhysiLibrary in Matlab/Simulink environment. The origin of this Modelica PhysiLibrary was in the first version of our HumMod/Golem/Edison model implementation, where it was called HumMod Library. As the successors of Guyton's Medical Physiology School write: the original HumMod model is "The best, most complete, mathematical model of human physiology ever created". In cooperation with this group we are now developing together the new complex integrative model of physiology, called [IntegrativeModel](#) based on PhysiLibrary and HumMod.

We are also developing many types of smaller physiological models for use in medical education, so it was essential to separate this library from our Modelica model implementations. Our PhysiLibrary contains only carefully-chosen elementary physiological laws, which are the basis of more complex physiological processes. For example from only three type of blocks (ChemicalReaction, Substance and MolarConservationMass) it is possible to compose the allotropic transition or the Michaelis-Menten equation.

Library contains also the icons for higher level (HumMod) subsystems implementations:

Physiomodel
Model of physiology in Modelica based on PhysiLibrary and PhysiLibrary

IntegrativeModel

HumMod

Edison

Golem

Metabolism

Thermoregulation

Cardiovascular

Respiration

ChemicalReaction

MolarConservationMass

Presentations & Publications

- Matejka, M. (2013) Formalization of Integrative Physiology. Dissertation, Charles University in Prague.
- Matejka, M., Kulkarni, J. (2015), PhysiModel - An Integrative Physiology in Modelica, Proceedings of 17th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, IEEE, Milano, It, pp. 1494-1497, ISBN: 978-1-4799-1700-8.

Charles University in Prague
First Faculty of Medicine

Degree program: Human Physiology and Pathophysiology
Field of study: Biomedicine

Formalization of Integrative Physiology
by
Marek Matejka

(Dissertation Series)

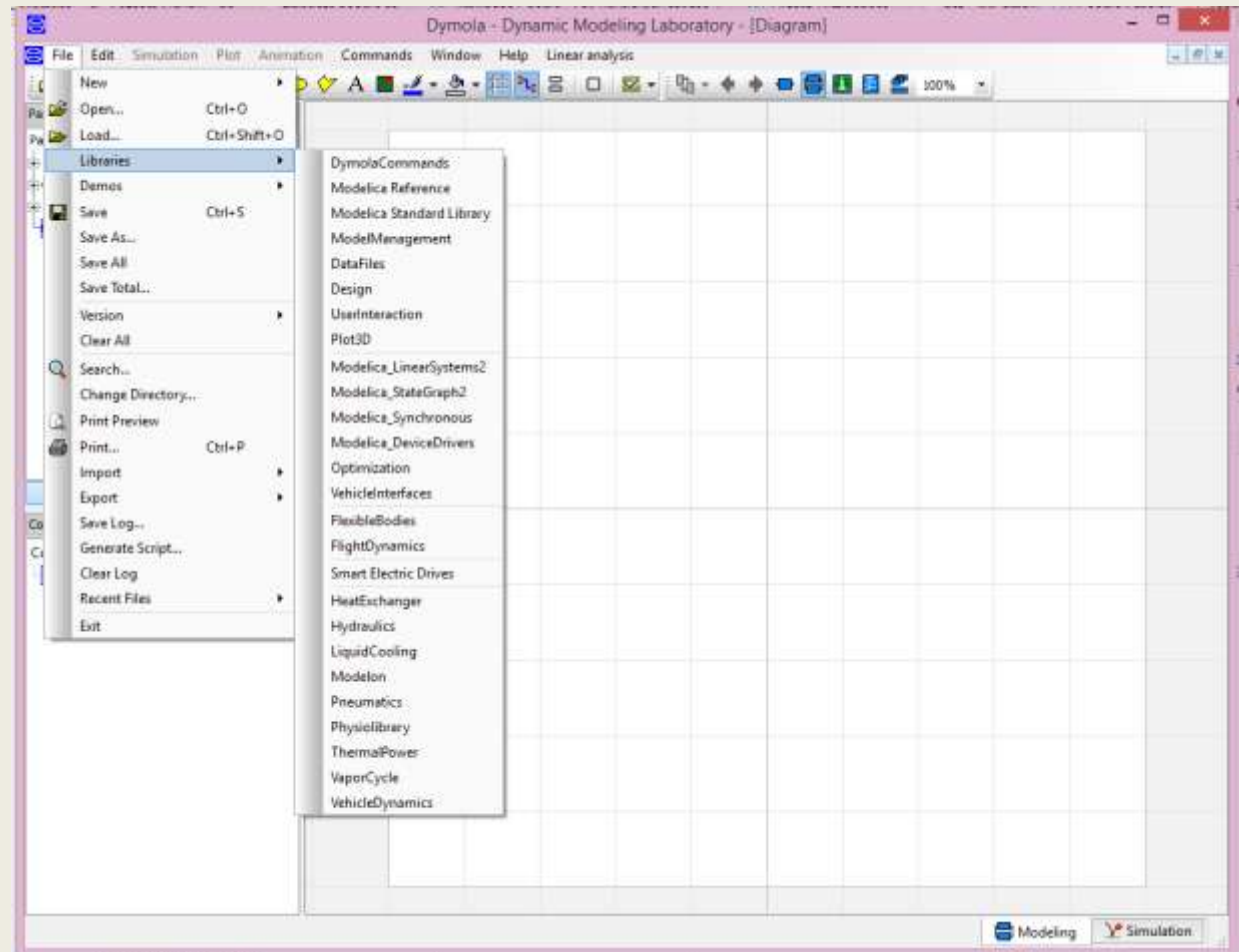
Supervisor: Doc. MUDr. Jan Koblížek, CSc.

Prague, 2013

Knihovny Modeliky

Základní knihovny

Aplikační knihovny



Package Browser

Packages

- Osmotic
- Pokus
- Optimization
 - User's Guide
 - Overview of library
 - Getting started
 - Examples of ibrary
 - FAQs of library
 - License conditions
 - Requirements

Každá knihovna má dokumentaci !



Component Browser

Components

- Optimization.UsersGuide.Overview
- Information - Modelica.Icons.Information

Overview of library

The optimization library mainly consists of six different optimization tasks. In a first step of an application you should decide which task is appropriate for your project.

Function Optimization	Model Optimization	Multi Case Model
<ul style="list-style-type: none"> FunctionOptimizationSetup <ul style="list-style-type: none"> Tuners <ul style="list-style-type: none"> Tuner parameters Discrete matrix Criteria Preferences 	<ul style="list-style-type: none"> ModelOptimizationSetup <ul style="list-style-type: none"> Tuners <ul style="list-style-type: none"> Tuner parameters Discrete matrix Criteria Preferences <ul style="list-style-type: none"> Optimization Simulation Jacobian 	<ul style="list-style-type: none"> MultiCaseModelOp <ul style="list-style-type: none"> Tuners <ul style="list-style-type: none"> Tuner par Discrete r Cases <ul style="list-style-type: none"> Name / A Paramete Paramete Criteria Demand Preferences <ul style="list-style-type: none"> Optimization Simulation Jacobian
Multi-criteria parameter optimization of a user defined Modelica function with optionally user defined Jacobian.	Multi-criteria parameter optimization of a Modelica model. The optimization algorithm starts one model simulation for each evaluation of the optimization objective functions.	Multi case parameter optimization of a Modelica model. The algorithm starts several simulations (from the class) for each evaluation of the optimization objective functions.

Knihovny Modeliky

Veškeré jednotky v knihovnách vnitřně v SI!

Problém v OM – zatím nefunguje DisplayUnit

Přepočty jednotek nutno dělat ručně (pro přepočty vhodné využít dědičnost)

Knihovna Physioblibrary

www.Physiolibrary.org

The screenshot displays the Physioblibrary UsersGuide application window. The title bar reads "UsersGuide - Physioblibrary.UsersGuide - [Documentation]". The menu bar includes File, Edit, Simulation, Plot, Animation, Commands, Window, Help, Linear analysis, and Optimization. The toolbar contains various icons for file operations, navigation, and simulation. The main interface is divided into three main sections:

- Package Browser:** A tree view showing the hierarchy of packages. The "Physiolibrary" package is expanded, showing sub-packages like "User's Guide", "Overview of Physioblibrary", "Connectors", "Release notes", "Contact", "BSD 3-Clause License", and "Publishing new release". Below these are "Hydraulic" and "Thermal" packages.
- Component Browser:** A list of components. The selected component is "Physiolibrary.UsersGuide", which is expanded to show "Information - Modelica.Icons.Information".
- User's Guide Information Panel:** A detailed view of the selected component. It includes a title "User's Guide", a section "Information", and a table of sub-libraries.

User's Guide Information

Package **Physiolibrary** is a modelica package for **Human Physiology** that is developed from **HumMod** modelica implementation, see <http://hummod.org>. It provides constants, types, connectors, partial models and model components fitted for physiological models of human body.

This is a short **User's Guide** for the overall library. Some of the main sublibraries have their own User's Guides that can be accessed by the following links:

Chemical	Library of chemical domain.
Hydraulic	Library of hydraulic domain. For modeling of cardiovascular system.
Thermal	Library of termoregulation support. As extension of Modelica.Thermal.HeatTransfer.
Osmotic	Library to model water fluxes through semipermeable membrane caused by osmotic pressure.
Population	Library for population models such as predator-prey or cells population.
Icons	Icons
Types	Physiological types. Physiological unit vs. SI units, nominals, inputs/outputs, typed constants.
Blocks	Useful blocks, that are missing in package Modelica.Blocks (MSL 3.2), cubic interpolation curves, multiplication factors.

Extends from [Modelica.Icons.Information](#) (Icon for general information packages).

Package Content

Name	Description
Overview	Overview of Physioblibrary
Connectors	Connectors
ReleaseNotes	Release notes
Contact	Contact
License	BSD 3-Clause License
NewRelease	Publishing new release

Name: UsersGuide
Path: Physioblibrary.UsersGuide

At the bottom right, there are buttons for "Modeling" and "Simulation".

Zobecněné úsilí
(effort)

$e(t)$

napětí
síla
moment
tlak
koncentrace
teplota
teplota

Zobecněná
hybnost

$p(t)$

indukční tok
impuls síly
impuls momentu síly
průtočná hybnost

Zobecněný tok
(flow)

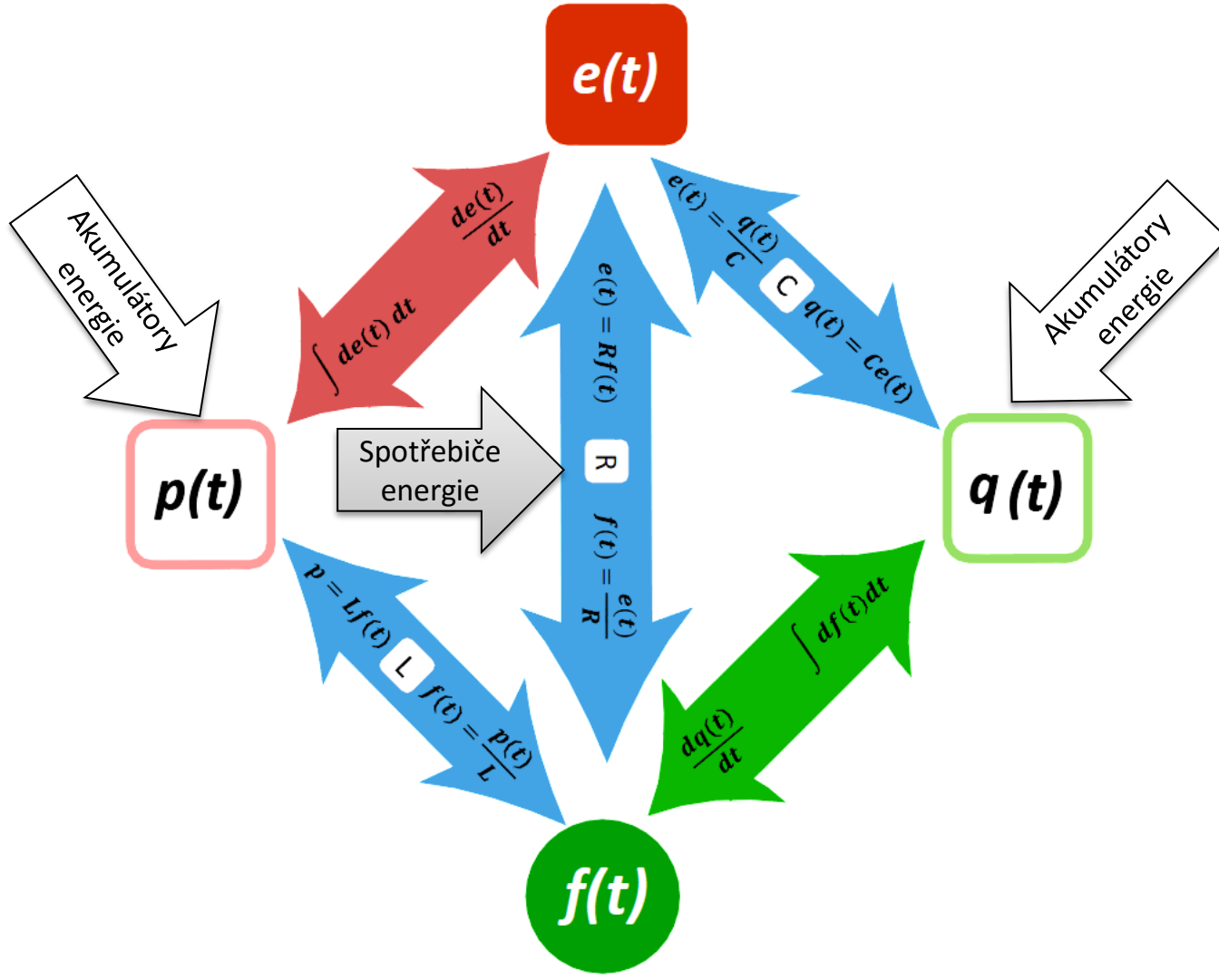
$f(t)$








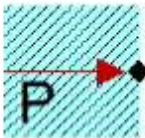
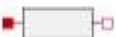


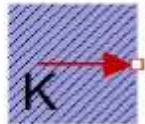






proud
rychlost
úhlová rychlost
objemový průtok
molární průtok
tepelný tok
entropický průtok

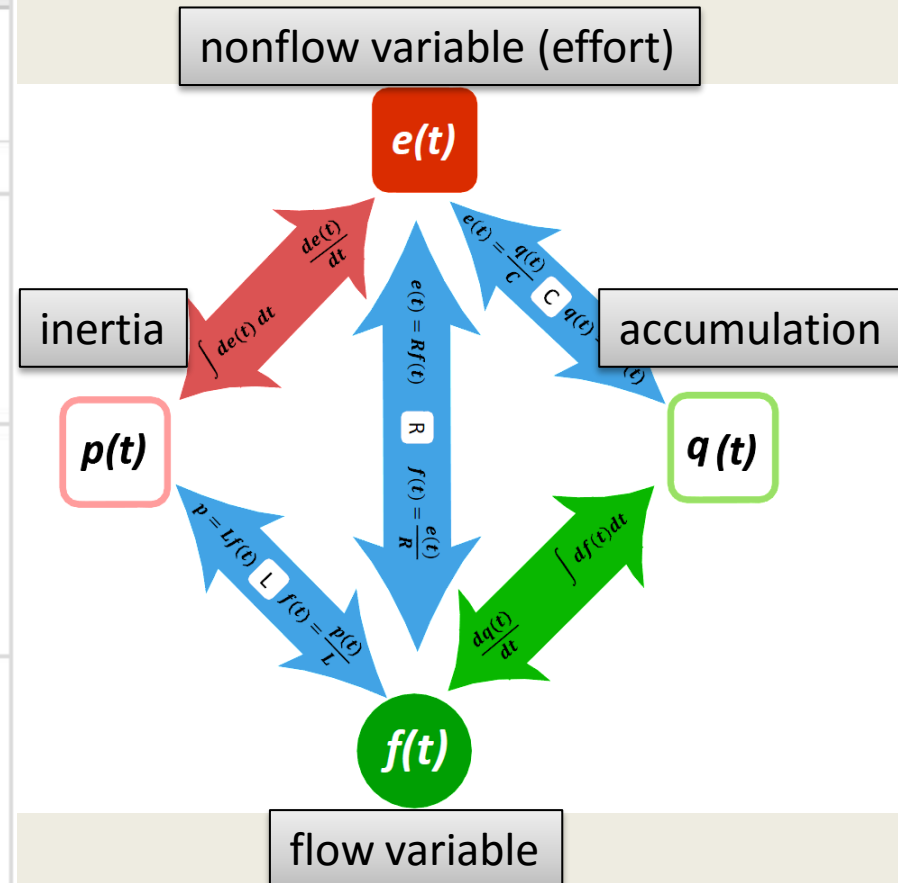
Zobecněná
akumulace

$q(t)$

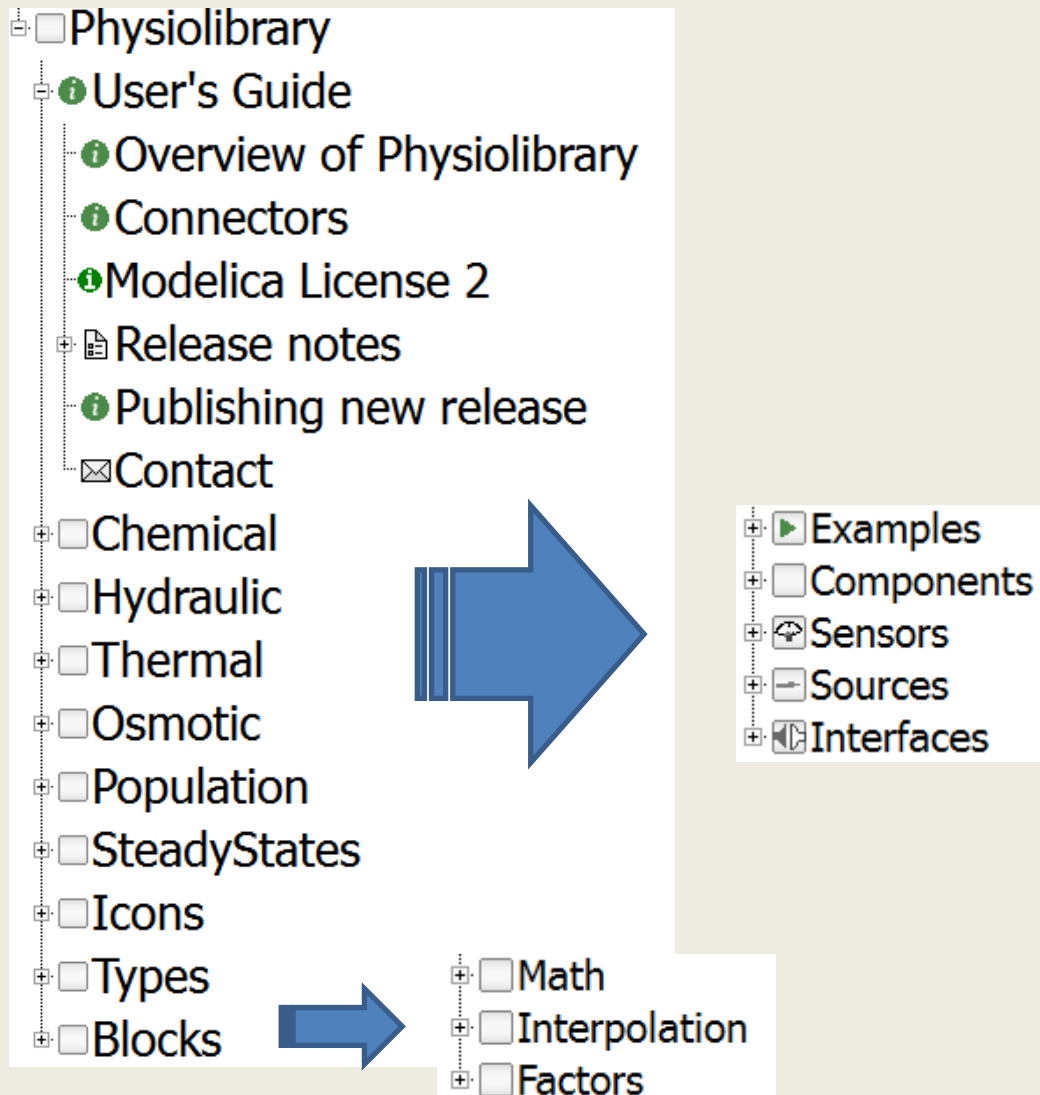
náboj
poloha
úhel
objem
množství
teplo
entropie



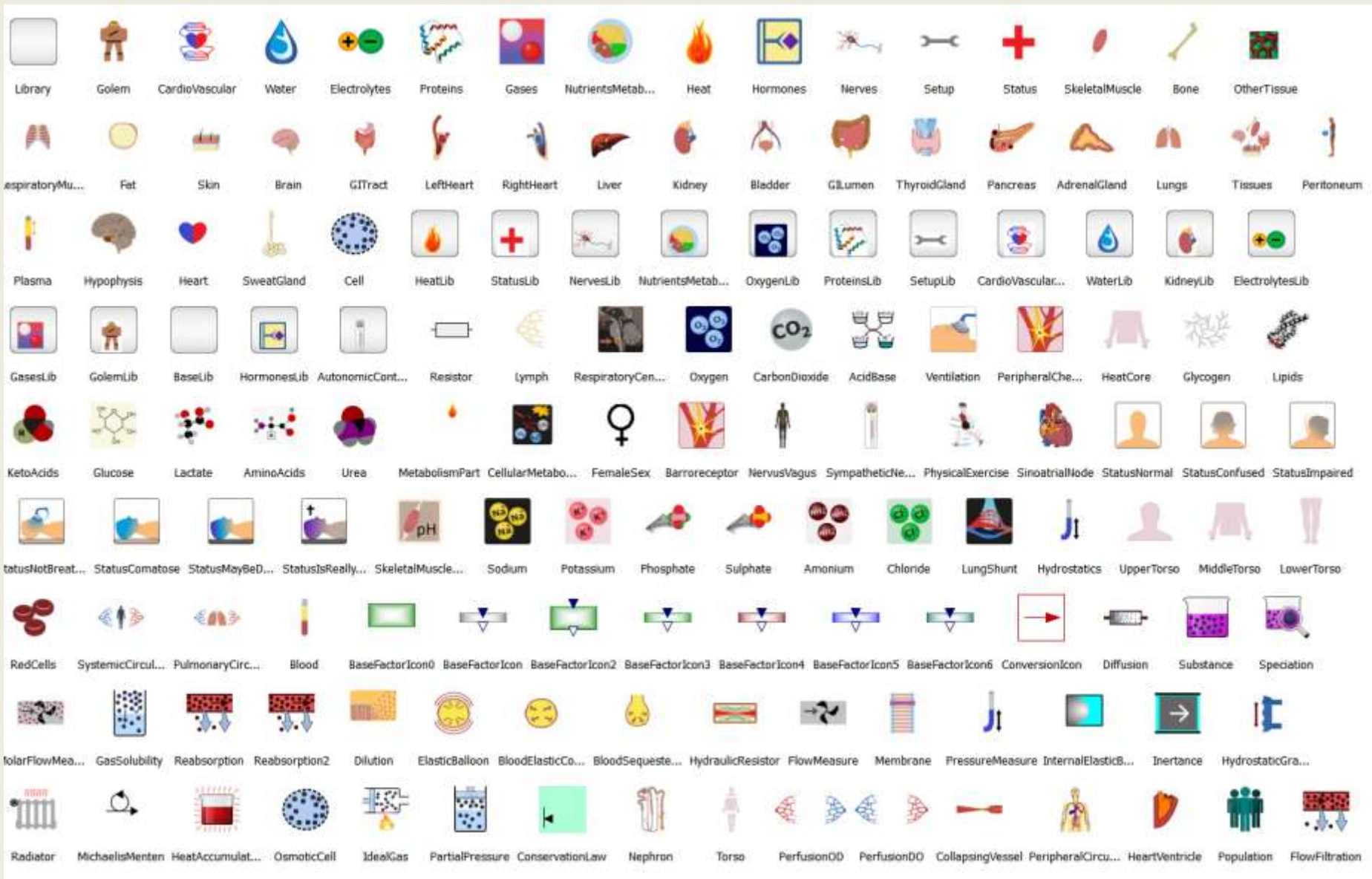
Resistance	Accumulation	Stream	Inertia	Effort source
$f_1 = G^*(e_1 - e_2)$ $f_1 + f_2 = 0$	$\int f = a$ $a = C * e$	$f_1 = \begin{cases} F e_1, F \geq 0 \\ F e_2, F < 0 \end{cases}$ $f_1 + f_2 = 0$	$f_1 = \int \frac{e_1 - e_2}{L}$ $f_1 + f_2 = 0$	$e = E$
G... conductance	C... capacitance	F... stream flow	L... inertia	E... effort
 Chemical diffusion	 Chemical substance	 Solution stream	not applicable	 Mole Fraction
 Hydraulic resistance	 Elastic vessel	not applicable	 Inertia	 Pressure
 Heat convection	 Heat accumulation	 Heated mass flow	not applicable	 Temperature
not applicable	 Population	 Growth, Differentiation	not applicable	not applicable
 Electrical resistor	 Electrical capacitor	not applicable	 Inductor	 Voltage



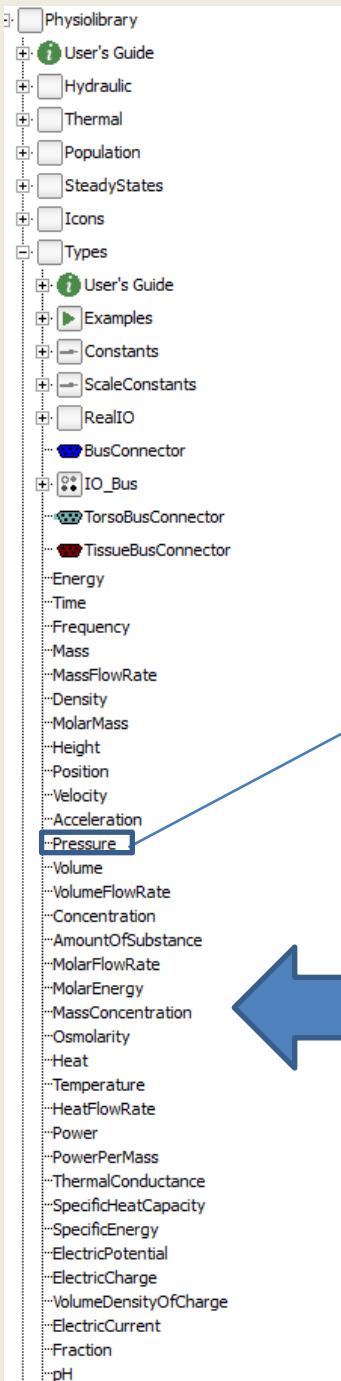
Physiolibrary Structure



Icons



Types - SI



```
type Pressure = Modelica.SIunits.Pressure(displayUnit="mmHg", nominal=133.322387415);
```

Veškeré jednotky jsou v SI
Automatický přepoččet - DisplayValues

Problém v OM – zatím nefunguje DisplayUnit

Přepočty jednotek nutno dělat ručně (pro přepočty vhodné využít dědičnost)

Blocks.Interpolation

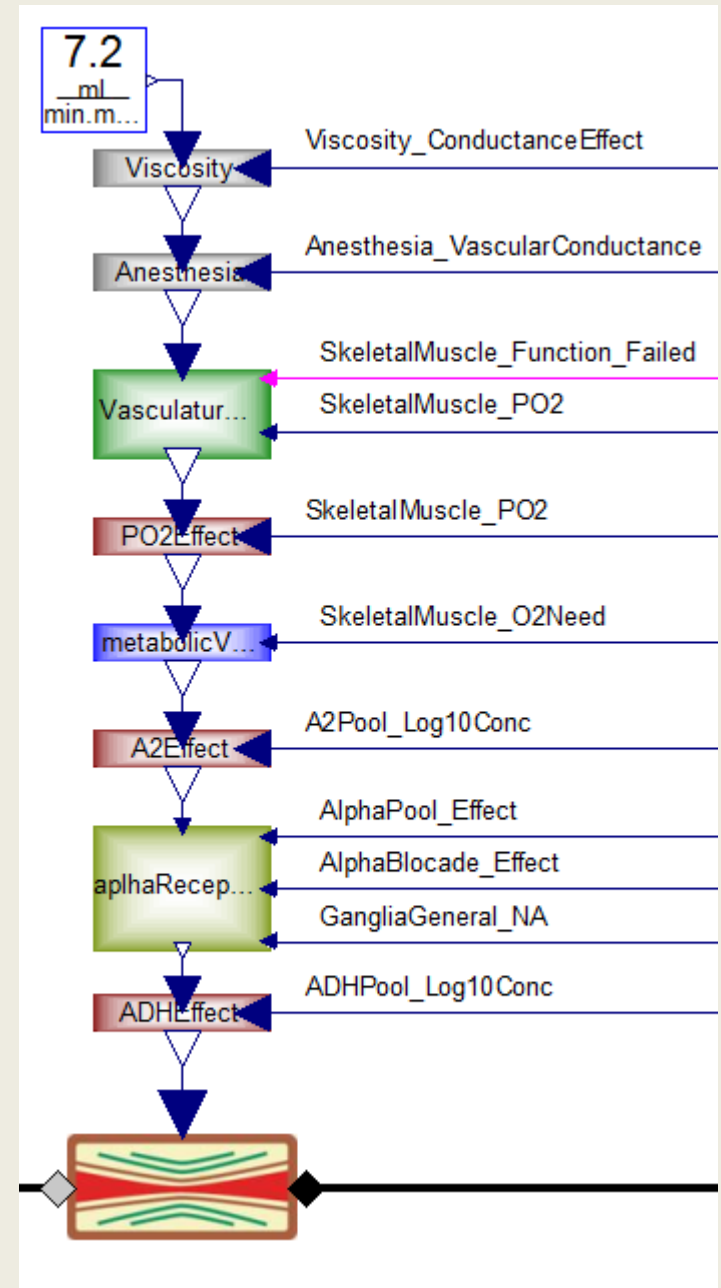
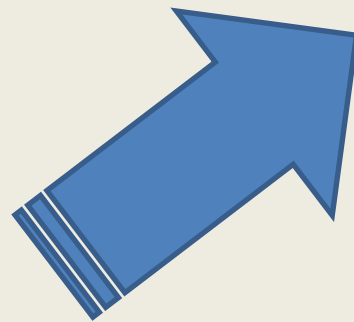
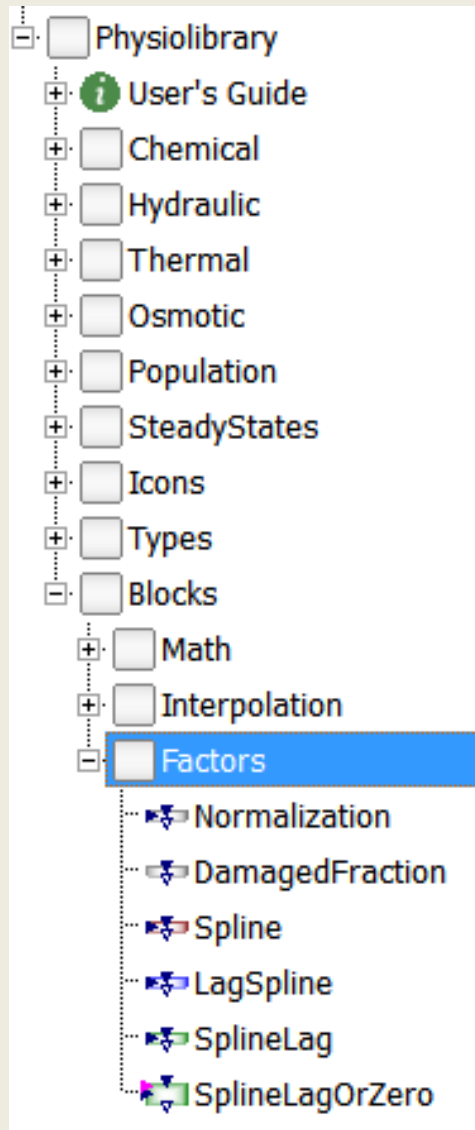
The image shows a software interface with a menu bar (File, Edit, Simulation, Plot, Animation, Commands, Window, Help, Linear analysis, Optimization) and a toolbar. On the left is a 'Package Browser' window listing various packages. The 'Interpolation' package is expanded, and the 'Curve' block is selected. On the right is a plot area showing a blue curve on a coordinate system. A large blue arrow points from the 'Curve' block to the plot, and a white arrow points from the plot to the right.

Package Browser

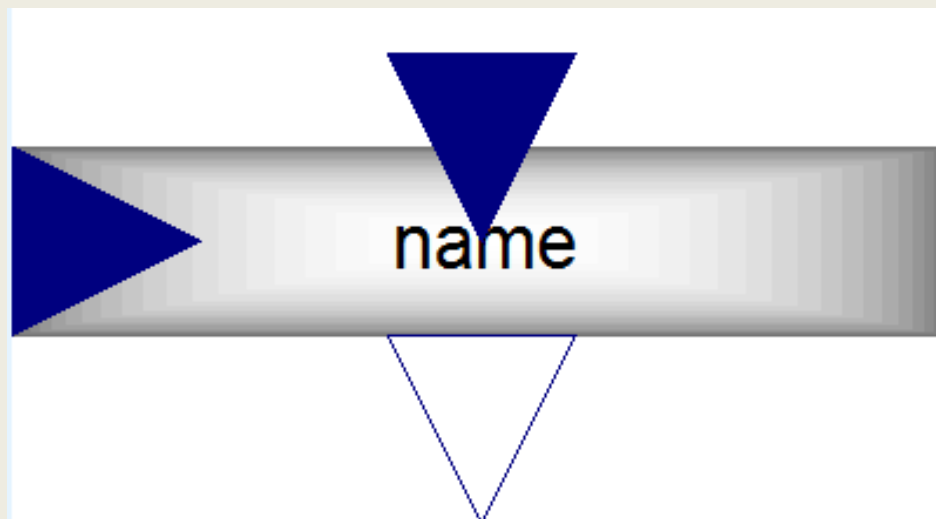
- Modelica
- Unnamed
 - Physiodel
 - Physiolibrary
 - User's Guide
 - Hydraulic
 - Thermal
 - Population
 - SteadyStates
 - Icons
 - Types
 - Blocks
 - Math
 - Interpolation
 - Spline
 - SplineCoefficients
 - Curve**
 - Factors
 - Chemical
 - Examples
 - Components
 - Sensors
 - Sources
 - Interfaces
 - Osmotic

Plot area showing a curve on a coordinate system.

Blocks.Factors



Normalisation



$effect = u/NormalValue$

Information

$y = yBase * u$

Extends from [Icons.BaseFactorIcon](#).

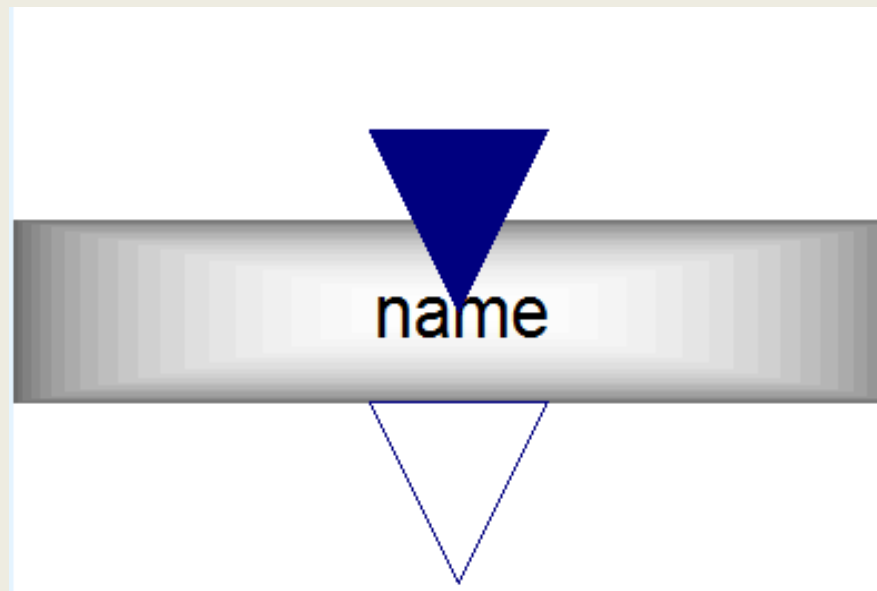
Parameters

Type	Name	Default	Description
Real	NormalValue	1	Normal value of u, because $y=(u/NormalValue)*yBase$.
Boolean	enabled	true	disabled => $y=yBase$

Connectors

Type	Name	Description
input RealInput	yBase	
output RealOutput	y	
input RealInput	u	

DamagedFraction



effect = 1 - DamagedAreaFraction

Information

Extends from [Icons.BaseFactorIcon](#).

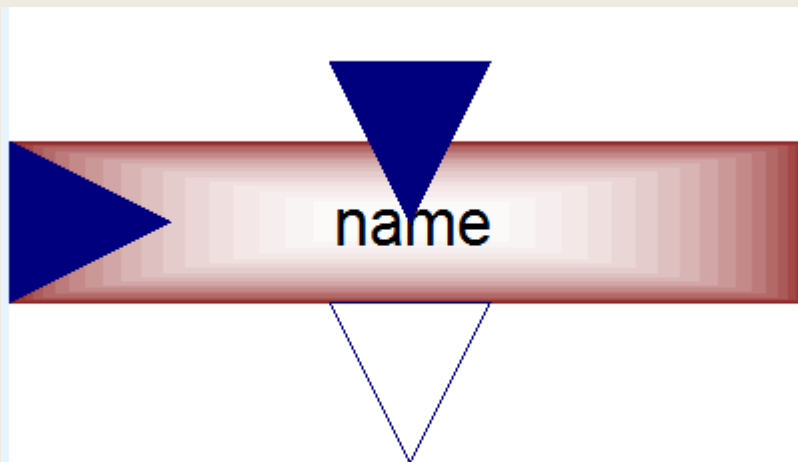
Parameters

Type	Name	Default	Description
Fraction	DamagedAreaFraction	0	[1]

Connectors

Type	Name	Description
input RealInput	yBase	
output RealOutput	y	

Spline



```
effect = spline(data,u)
```

Information

Extends from [Icons.BaseFactorIcon4](#).

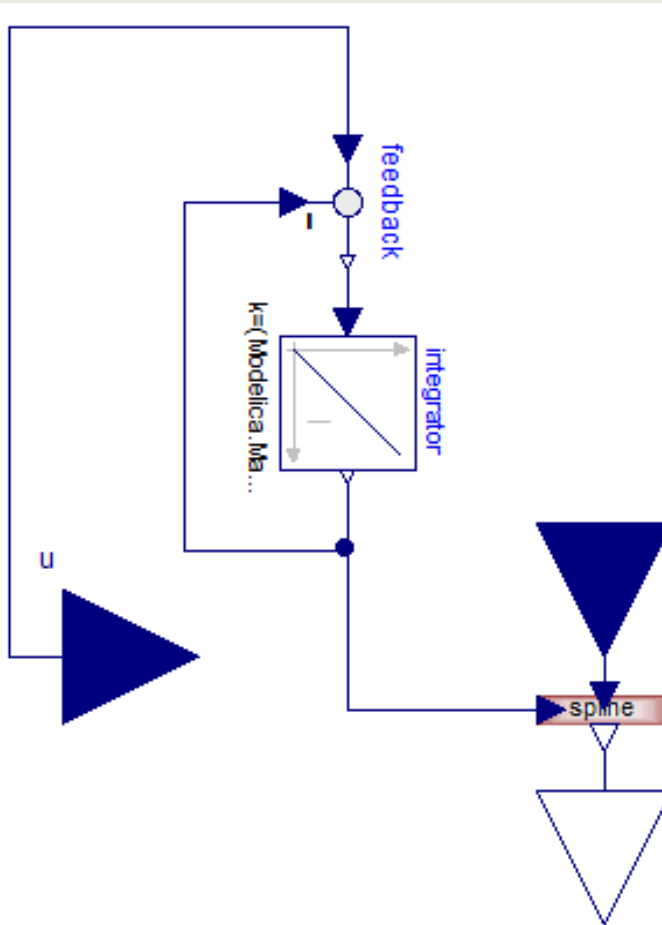
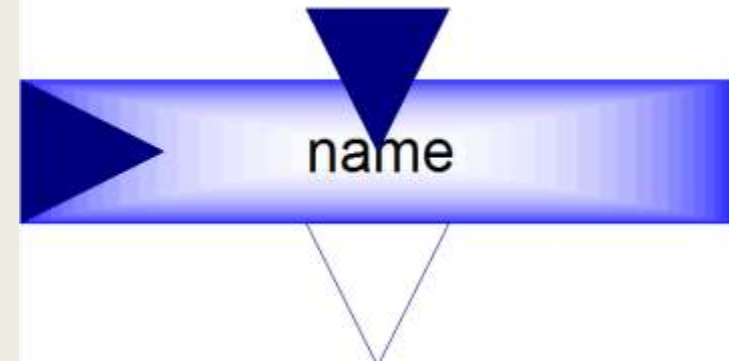
Parameters

Type	Name	Default	Description
Boolean	enabled	true	disabled => $y=y_{Base}$
Real	data[:, 3]		Array of interpolating points as $\{x,y,slope\}$
Real	Xscale	1	conversion scale to SI unit of x values
Real	Yscale	1	conversion scale to SI unit of y values
Boolean	UsePositiveLog10	false	$x = \text{if } u/\text{scaleX} \leq 1 \text{ then } 0 \text{ else } \log_{10}(u/\text{scaleX})$

Connectors

Type	Name	Description
input RealInput	yBase	
output RealOutput	y	
input RealInput	u	

LagSpline



Adapt the input signal before interpolation

Information

If the input signal u is constant and it is different from starting delayed input d , the middle value between u and d will be reached after HalfTime .

The mathematical background:

$d'(t) = k*(u(t) - d(t)) \Rightarrow$ The solution of $d(t)$ in special case, if $u(t)$ is constant at each time t : $d(t) = u + (d(0) - u) * e^{-(k*t)}$, where the definition of HalfTime is $d(\text{HalfTime}) = d(0) + (d(0) - u) / 2$.

Extends from [Icons.BaseFactorIcon5](#).

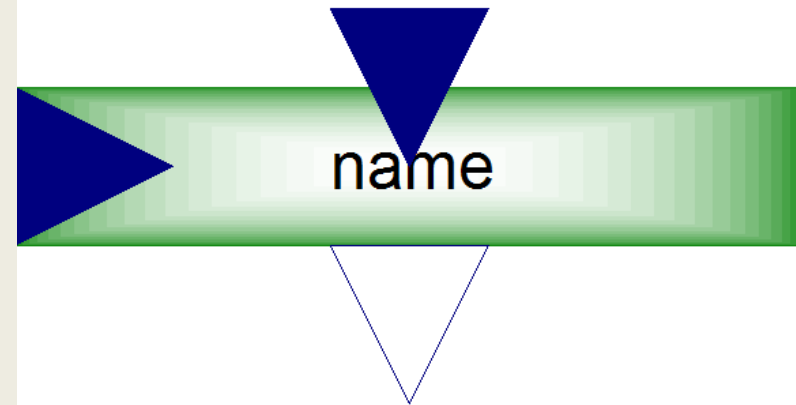
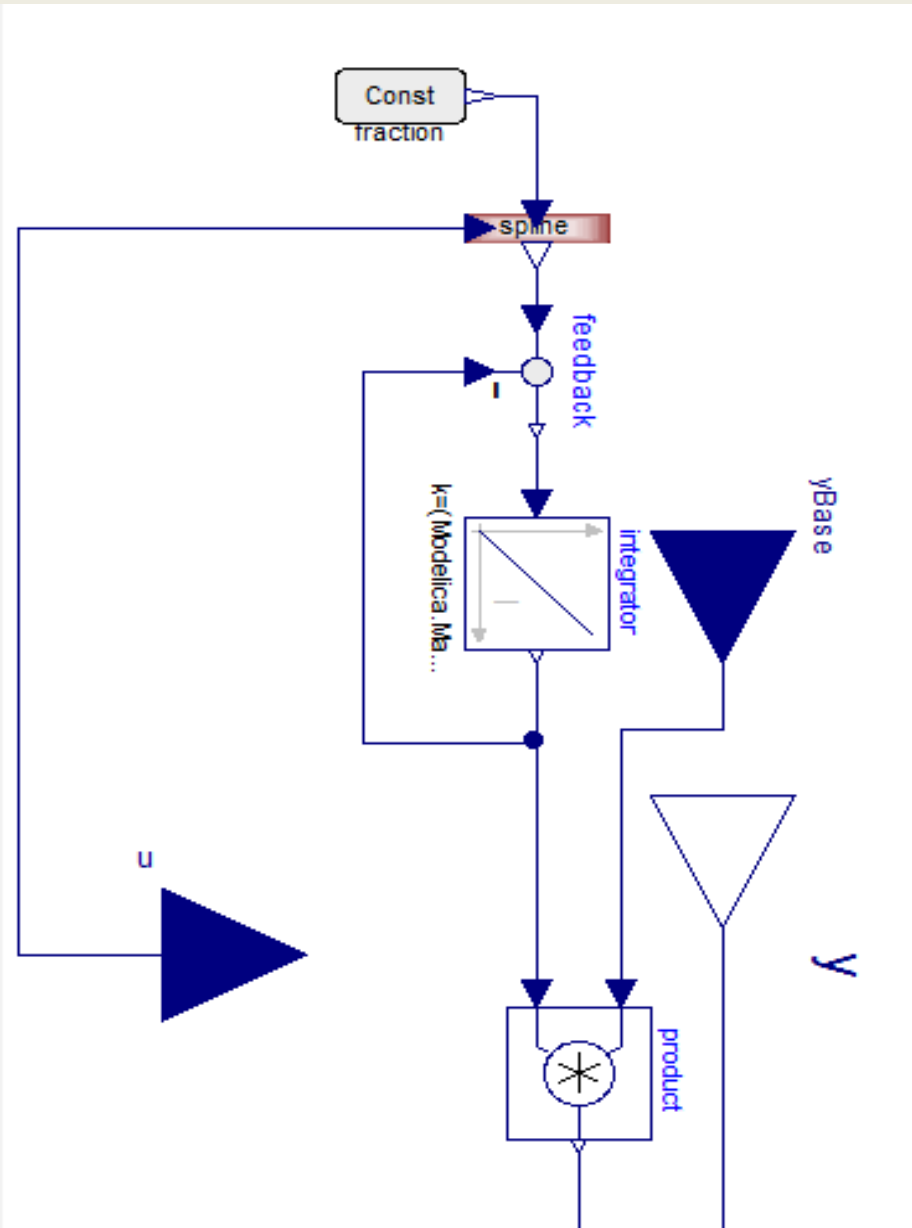
Parameters

Type	Name	Default	Description
Boolean	enabled	true	disabled => $y = y_{\text{Base}}$
Time	HalfTime		[s]
Real	initialValue	1	as u/X_{scale}
Real	Xscale	1	conversion scale to SI unit of x values
Real	Yscale	1	conversion scale to SI unit of y values
Boolean	UsePositiveLog10	false	$x = \text{if } u_{\text{delayed}}/\text{scaleX} \leq 1 \text{ then } 0 \text{ else } \log_{10}(u_{\text{delayed}}/\text{scaleX})$
Real	data[:, 3]		

Connectors

Type	Name	Description
input RealInput	yBase	
output RealOutput	y	
input RealInput	u	

SplineLag



Adapt the effect after interpolation

Information

Extends from [Icons.BaseFactorIcon3](#).

Parameters

Type	Name	Default	Description
Boolean	enabled	true	disabled => y=yBase
Time	HalfTime		[s]
Real	Xscale	1	conversion scale to SI unit of x values
Boolean	UsePositiveLog10	false	x = if u/scaleX <= 1 then 0 else log10(u/scaleX)
Real	data[:, 3]		

IO

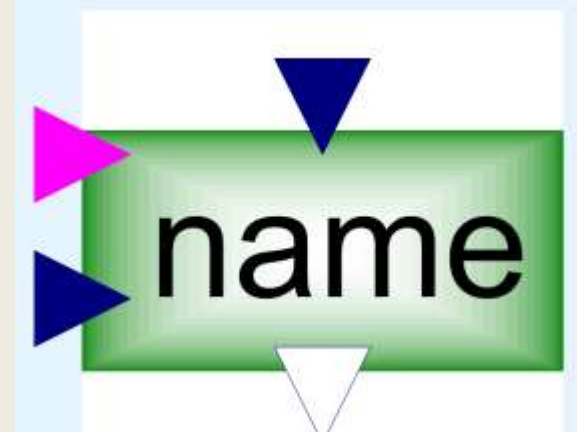
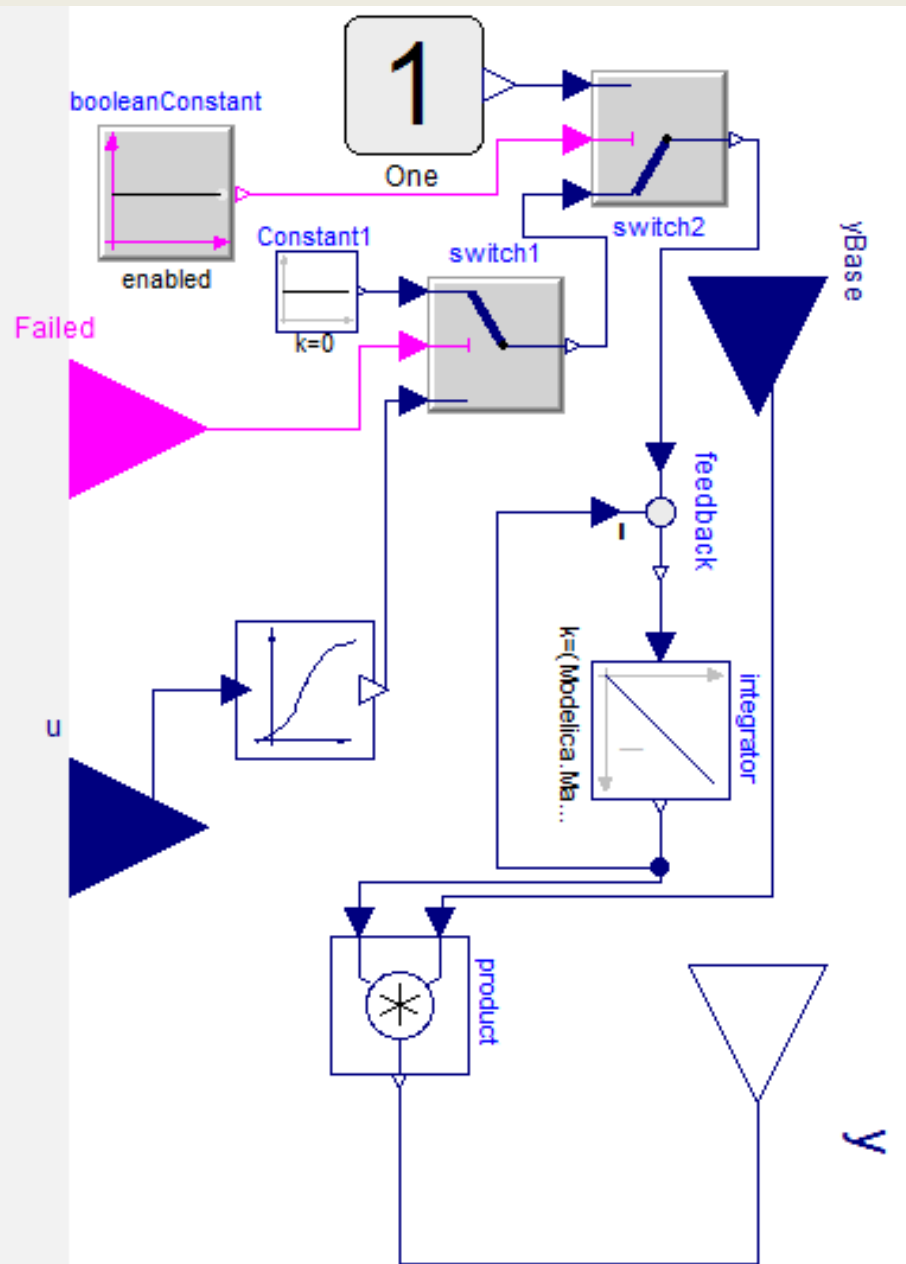
Value I/O

Type	Name	Default	Description
String	stateName	getInstanceName()	Name in Utilities input/output function

Connectors

Type	Name	Description
input RealInput	yBase	
output RealOutput	y	
input RealInput	u	

SplineLagOrZero



LagSpline if not Failed

Information

Extends from [Icons.BaseFactorIcon2](#).

Parameters

Type	Name	Default	Description
Boolean	enabled	true	disabled => $y=yBase$
Time	HalfTime		[s]
Real	data[:, 3]		
Real	Xscale	1	conversion scale to SI unit of x values

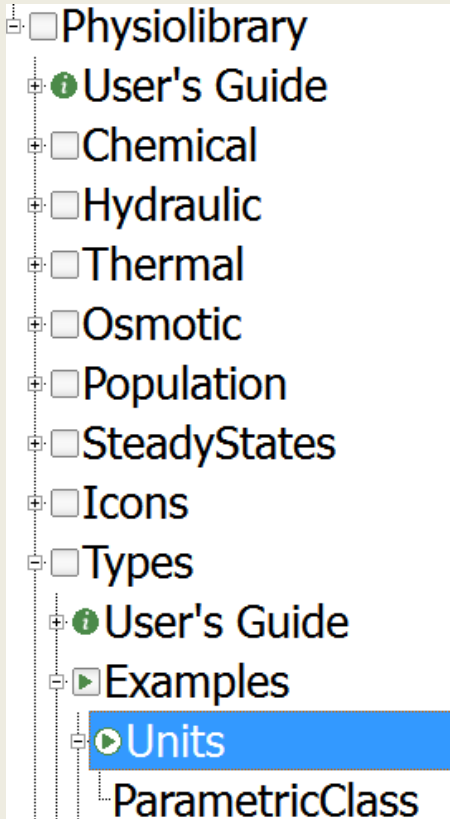
IO

Value I/O			
String	stateName	getInstanceName()	Name in Utilities input/output function

Connectors

Type	Name	Description
input RealInput	yBase	
output RealOutput	y	
input RealInput	u	
input BooleanInput	Failed	

Types



Parameters

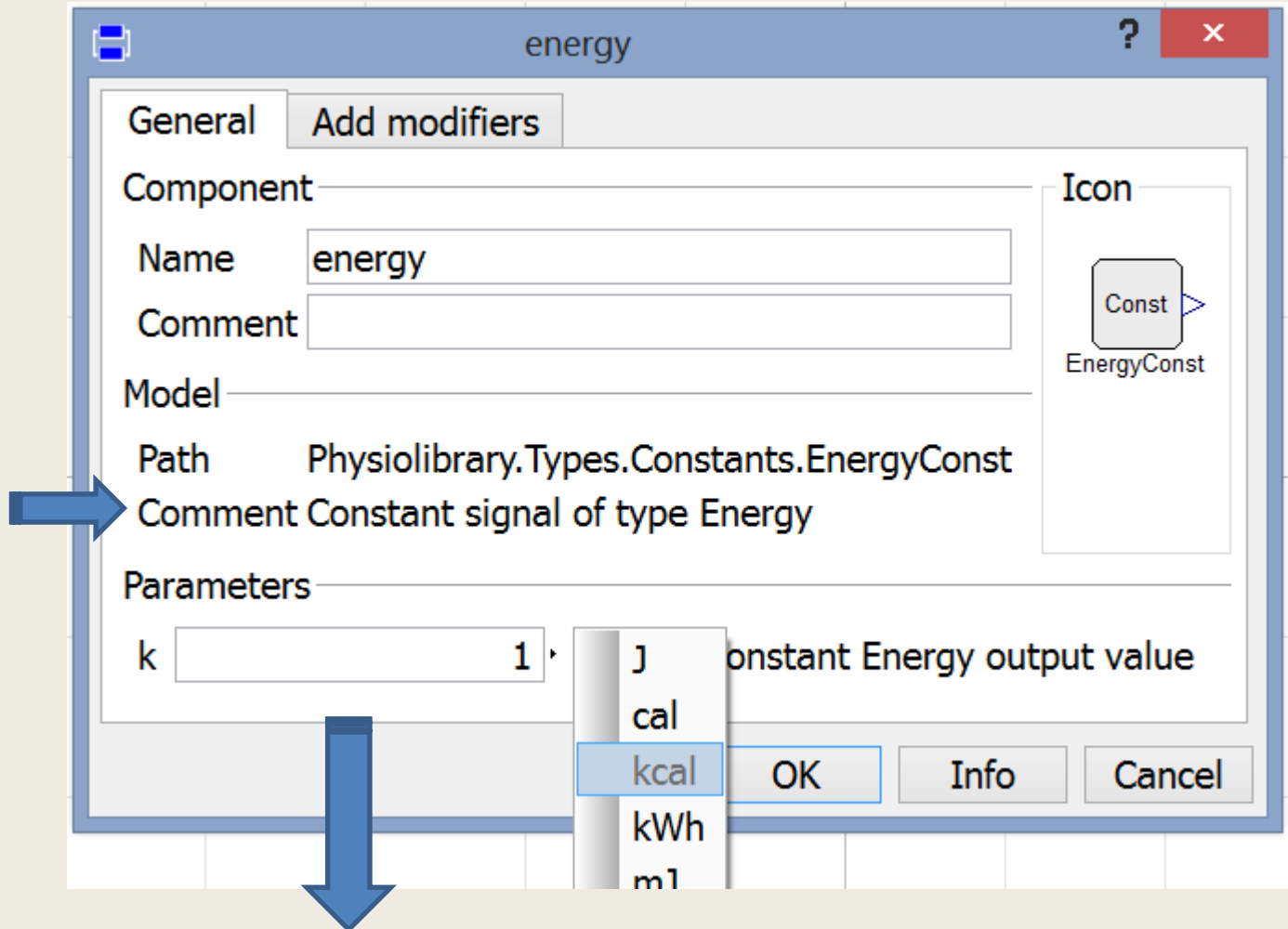
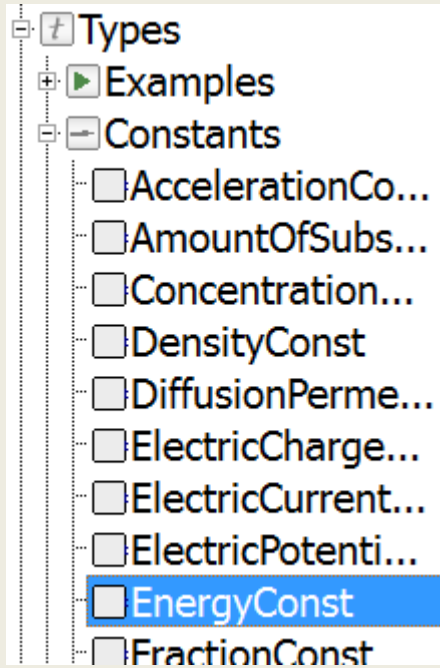
temperature	1	degC
heat	1	kcal
pressure	1	mmHg
volume	1	ml
amountOfSubstance	1	mmol
electricCharge	1	meq
electricCurrent	1	meq/min

Select display unit

model Units

```
ParametricClass parametricClass(  
  temperature(displayUnit="degC") = 274.15,  
  heat(displayUnit="kcal") = 4186.8,  
  pressure(displayUnit="mmHg") = 133.322387415,  
  volume(displayUnit="ml") = 1e-06,  
  amountOfSubstance(displayUnit="mmol") = 0.001,  
  electricCharge(displayUnit="meq") = 96.4853399,  
  electricCurrent(displayUnit="meq/min") = 1.6080889983333,
```

Types.Constants



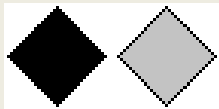
```
Physiolibrary.Types.Constants.EnergyConst energy (k=4186.8)  
;
```

Connectors



ChemicalPort

- molar concentration, molar flow



HydraulicPort

- pressure, volumetric flow



ThermalPort

- temperature, heat flow



OsmoticPort

- osmolarity, osmotic volumetric flow

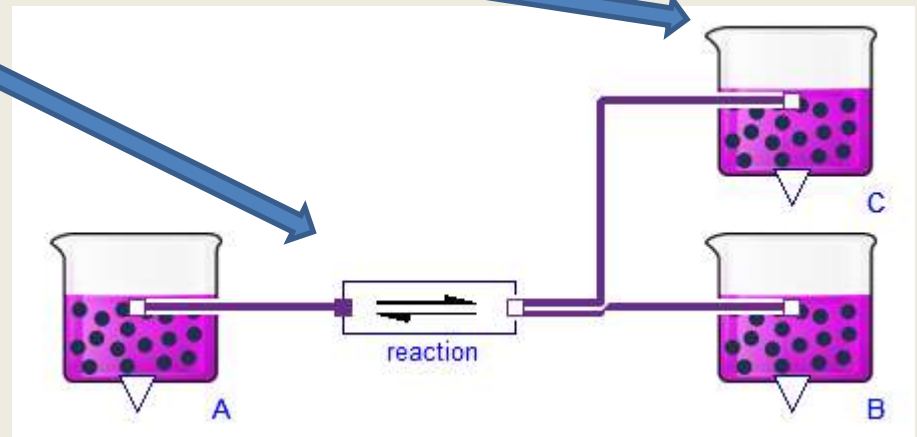


PopulationPort

- size of population, change of population

Chemical

- [-] Chemical
- [+] Examples
- [+] Components
 - [-] Substance
 - [-] ChemicalReaction
 - [-] Diffusion
 - [-] GasSolubility
 - [-] Degradation
 - [-] Clearance
 - [-] Stream
 - [-] SolutePump
 - [-] Speciation
 - [-] Dilution
 - [-] Reabsorption
 - [-] Membrane
- [+] Sensors
- [+] Sources
- [+] Interfaces
 - [-] ChemicalPort
 - [-] ChemicalPort_a
 - [-] ChemicalPort_b

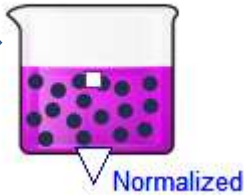


```
connector ChemicalPort
  Types.Concentration conc;
  flow Types.MolarFlowRate q;
  a
end ChemicalPort;
```


CONDITIONAL INPUTS

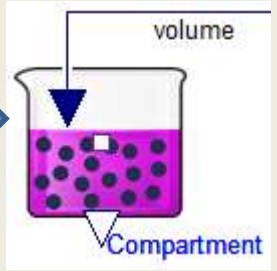
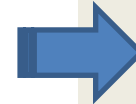
External inputs/outputs

useNormalizedVolume



External inputs/outputs

useNormalizedVolume



Parameters

Conductance ml/min

External inputs/outputs

useConductanceInput

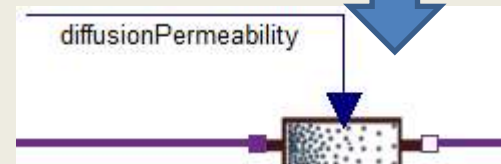


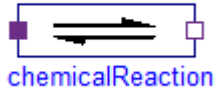
Parameters

Conductance ml/min

External inputs/outputs

useConductanceInput





Chemical Reaction


reaction in Physiolibary.Chemical.Examples.SimpleReaction

General Reaction type Temperature dependence Add modifiers

Component

Name

Comment

Icon 

Model

Path Physiolibary.Chemical.Components.ChemicalReaction

Comment Chemical Reaction

Parameters

K Fixed dissociation constant [SI-unit] if useDissociationConstantInput=false

kf Forward reaction rate coefficient [SI unit]

solventFraction % Free solvent fraction in liquid (i.e. water fraction in plasma=0.94, in RBC=0.65, in blood=0.81)

External inputs/outputs

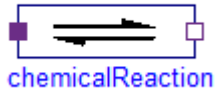
useNormalizedVolume =true, if solvent volume is 1 liter

useDissociationConstantInput =true, if external dissociation ratio is used

useForwardRateInput =true, if external forward rate is used

useHeatPort =true, if HeatPort is enabled

OK Info Cancel



Chemical Reaction

reaction in Physiolibary.Chemical.Examples.SimpleReaction

General Reaction type Temperature dependence Add modifiers

Substrates

nS Number of substrates types

s 1 Stoichiometric reaction coefficient for substrates

as 1 Activity coefficients of substrates

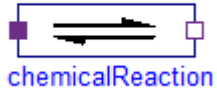
Products

nP Number of products types

p 1 Stoichiometric reaction coefficients for products

ap 1 Activity coefficients of products

OK Info Cancel



Chemical Reaction

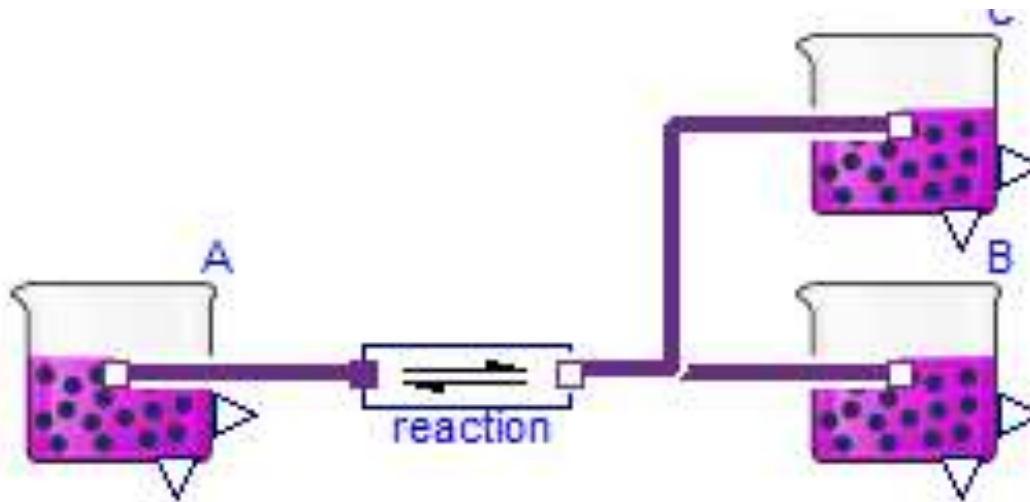
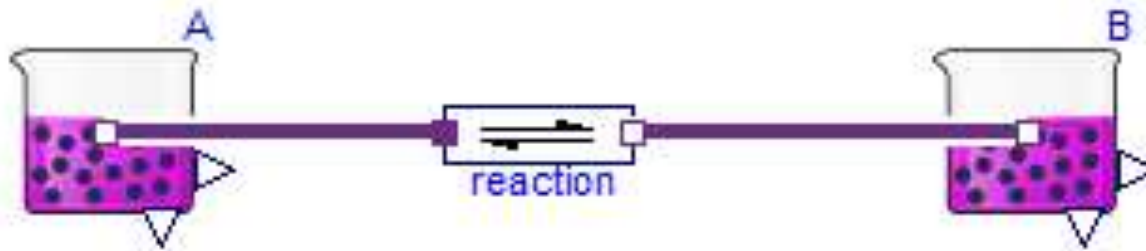
reaction in Physiobrary.Chemical.Examples.SimpleReaction

General Reaction type Temperature dependence Add modifiers

T	<input type="text" value="37"/>	degC	Fixed device temperature if useHeatPort = false
TK	<input type="text" value="25"/>	degC	Base temperature
dH	<input type="text" value="0"/>	kcal/mol	Standard Enthalpy Change (negative=exothermic)

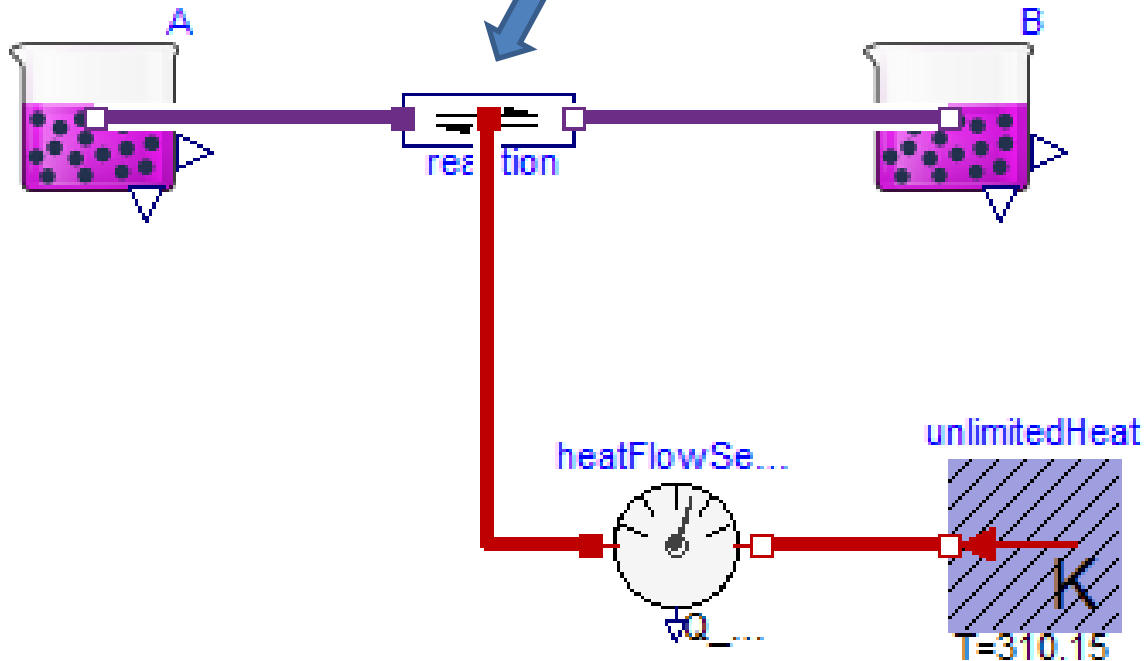
OK Info Cancel

Simple Reaction

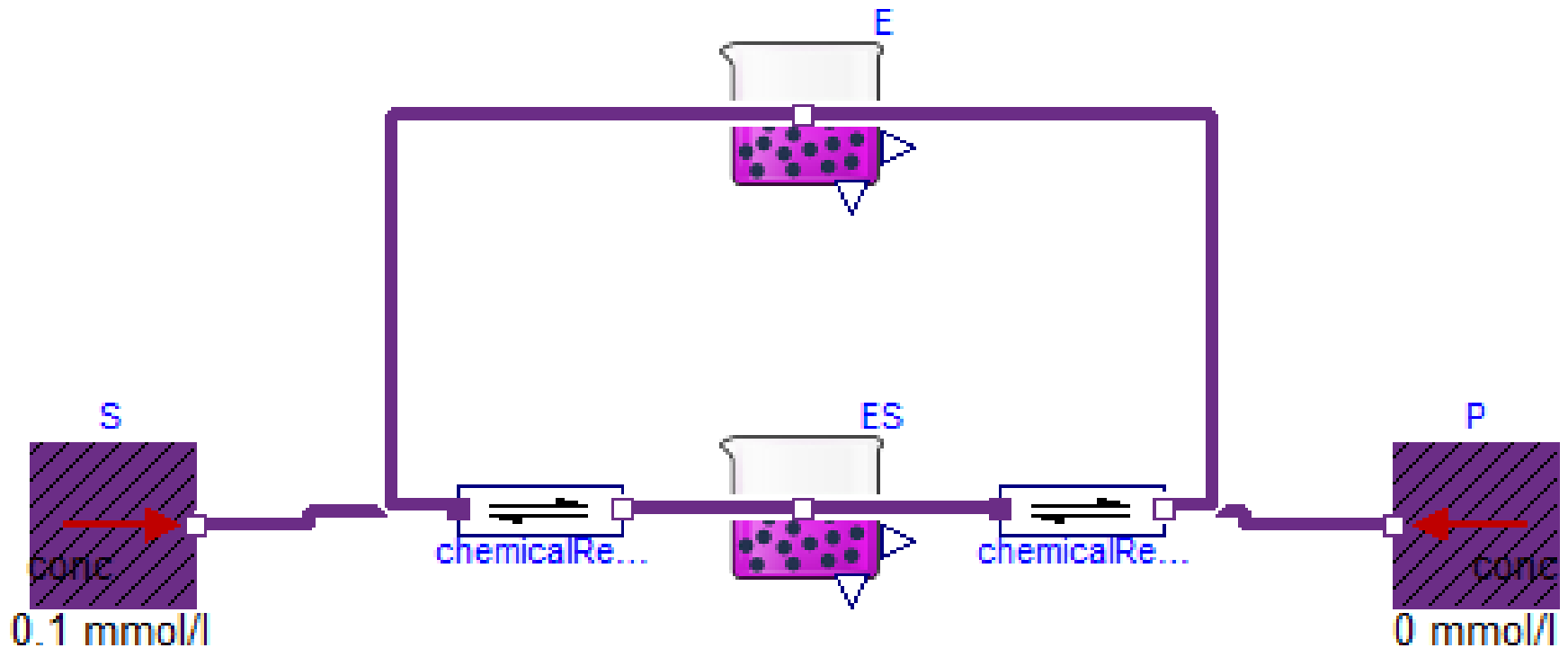
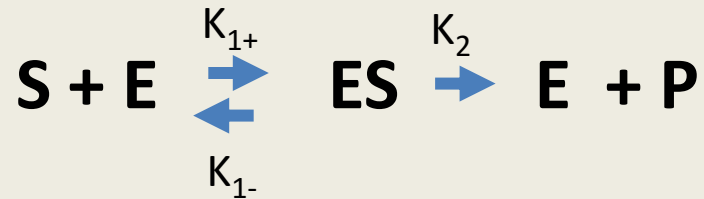


Exothermic Reaction

General	Reaction type	Temperature dependence	Add modifiers
T		37	degC Fixed device temperature if useHeatPort = fa
TK		25	degC Base temperature
dH		-0.2388458966275	kcal/mol Standard Enthalpy Change (negative=exothe

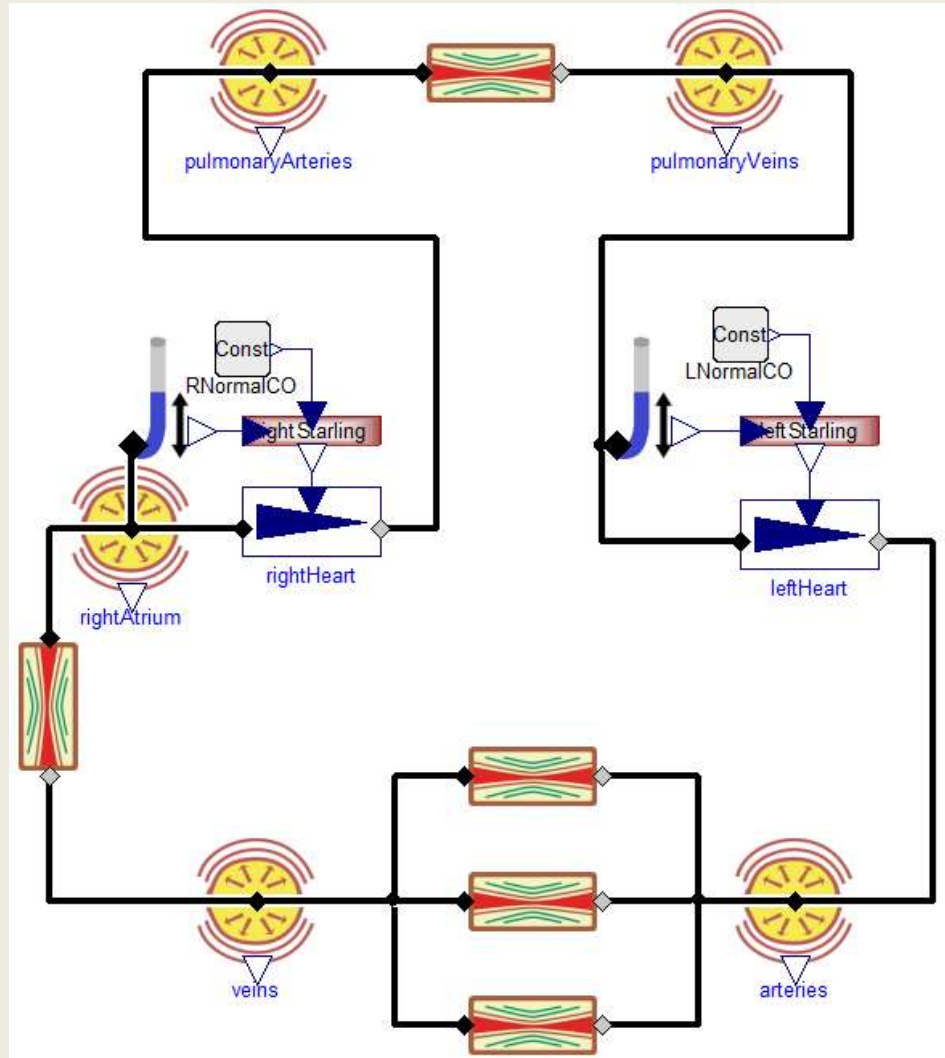


Michaelis-Menten

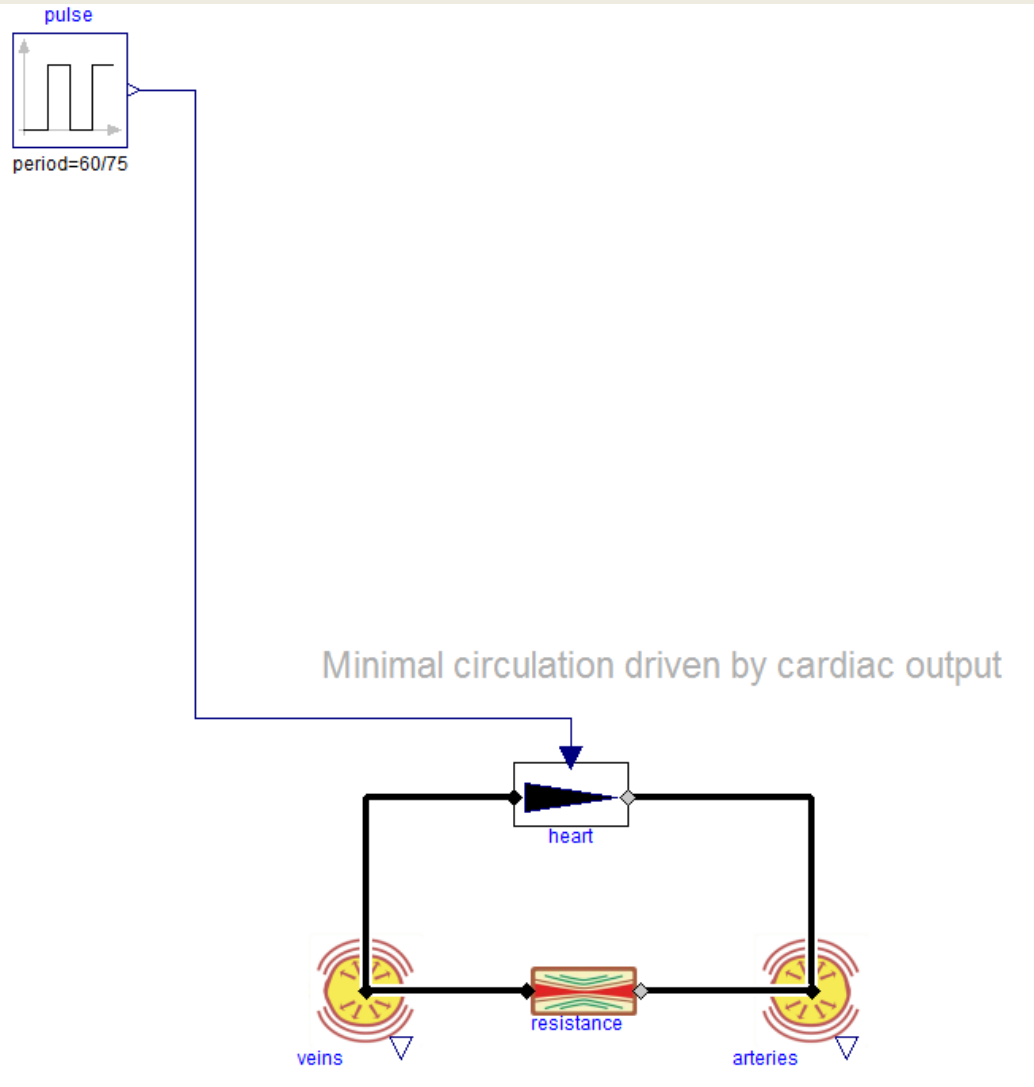


- [-] Physiolibrary
- + [i] User's Guide
- + [] Chemical
- [] Hydraulic
- + [▶] Examples
- [] Components
 - [▶] ElasticVessel
 - [▶] Conductor
 - [▶] HydrostaticColumn
 - [▶] Pump
 - [▶] IdealValve
 - [▶] Inertia
 - [▶] ElasticMembrane
 - [▶] Reabsorption
- [] Sensors
 - [▶] FlowMeasure
 - [▶] PressureMeasure
- [] Sources
 - [▶] UnlimitedPump
 - [▶] UnlimitedVolume
 - [▶] UnlimitedOutflowPump
- [] Interfaces
 - [▶] HydraulicPort
 - [▶] HydraulicPort_a
 - [▶] HydraulicPort_b
 - [▶] OnePort

Hydraulic

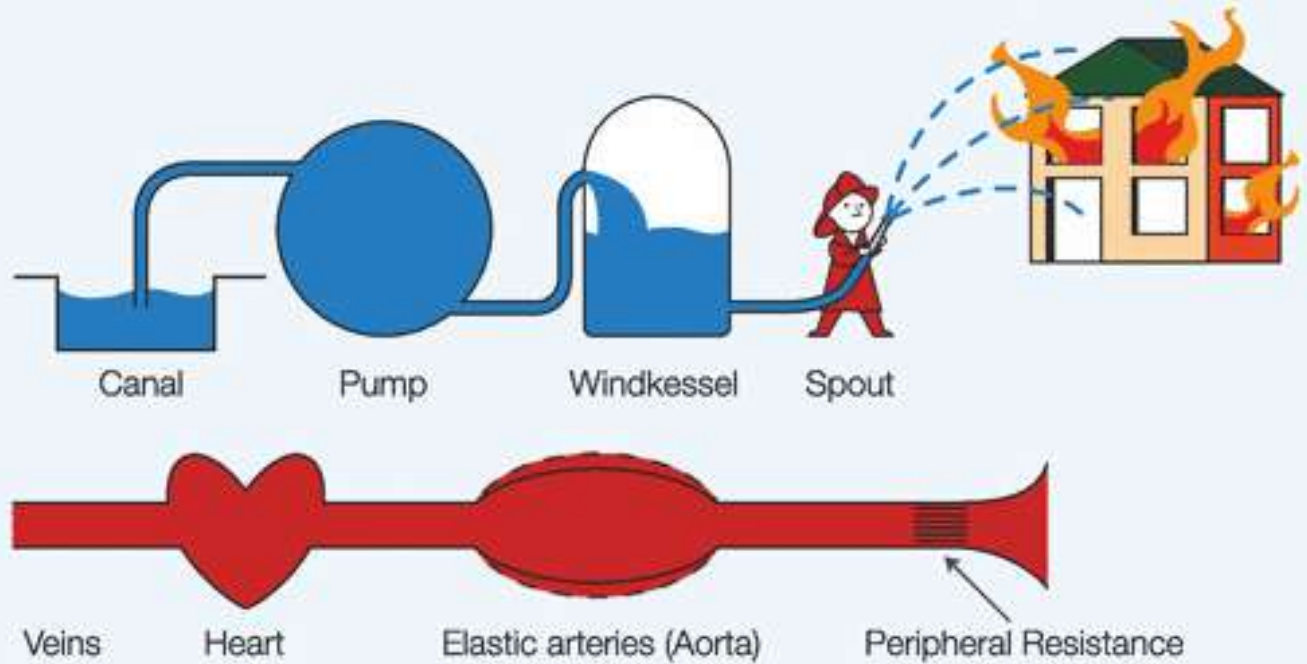


Minimal circulation



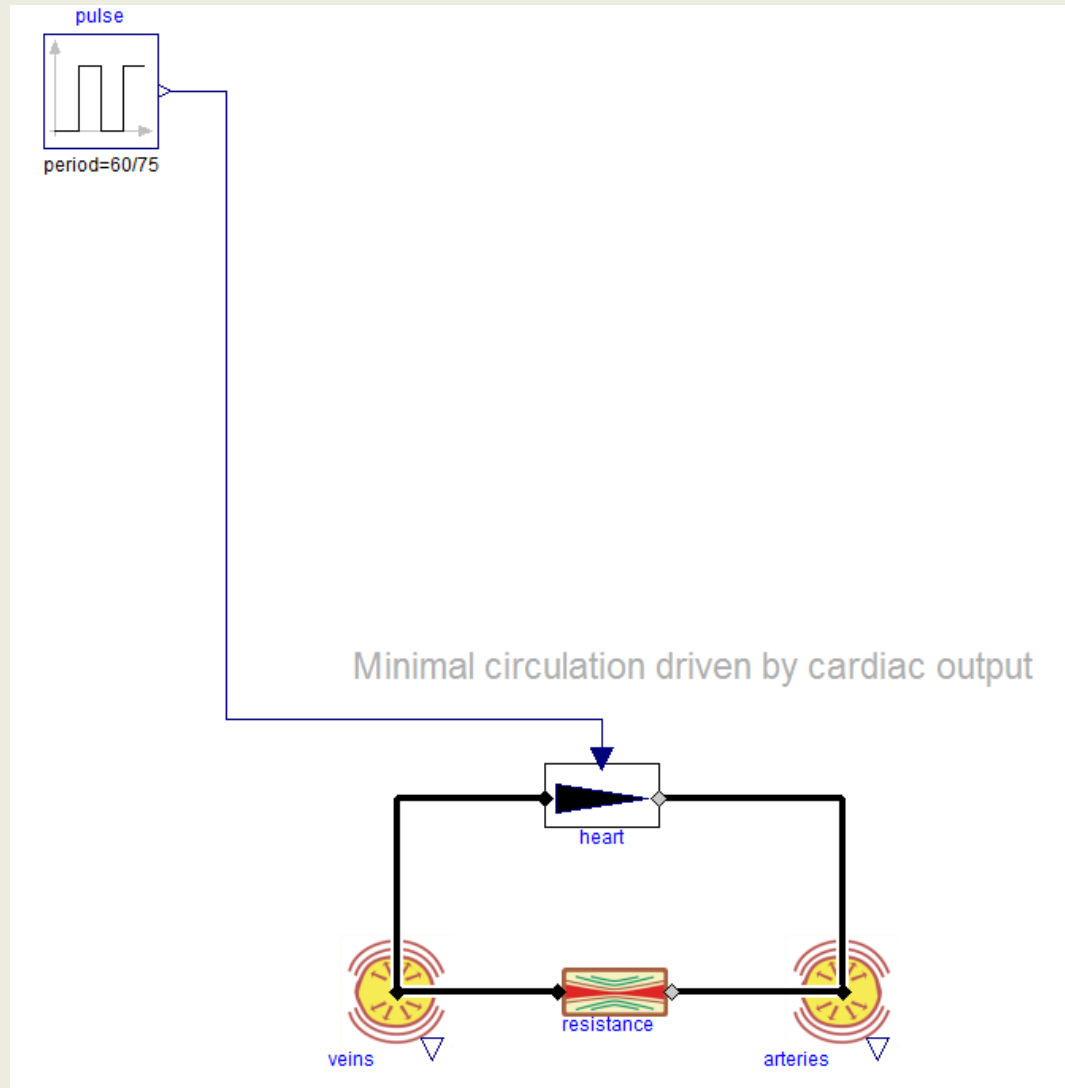
Windkessel model

- Hydraulic
- Examples
- Components
 - Conductor
 - Resistor
 - ElasticVessel
 - ElasticVesselElastance
 - HydrostaticColumn
 - Inertia
 - IdealValve
 - IdealValveResistance
 - Pump
 - Reabsorption
 - ElasticMembrane
- Sensors
 - FlowMeasure
 - PressureMeasure
- Sources
 - UnlimitedPump
 - UnlimitedVolume
 - UnlimitedOutflowPump
- Interfaces
 - HydraulicPort
 - HydraulicPort_a
 - HydraulicPort_b
 - OnePort
 - ConditionalSolutionFlow

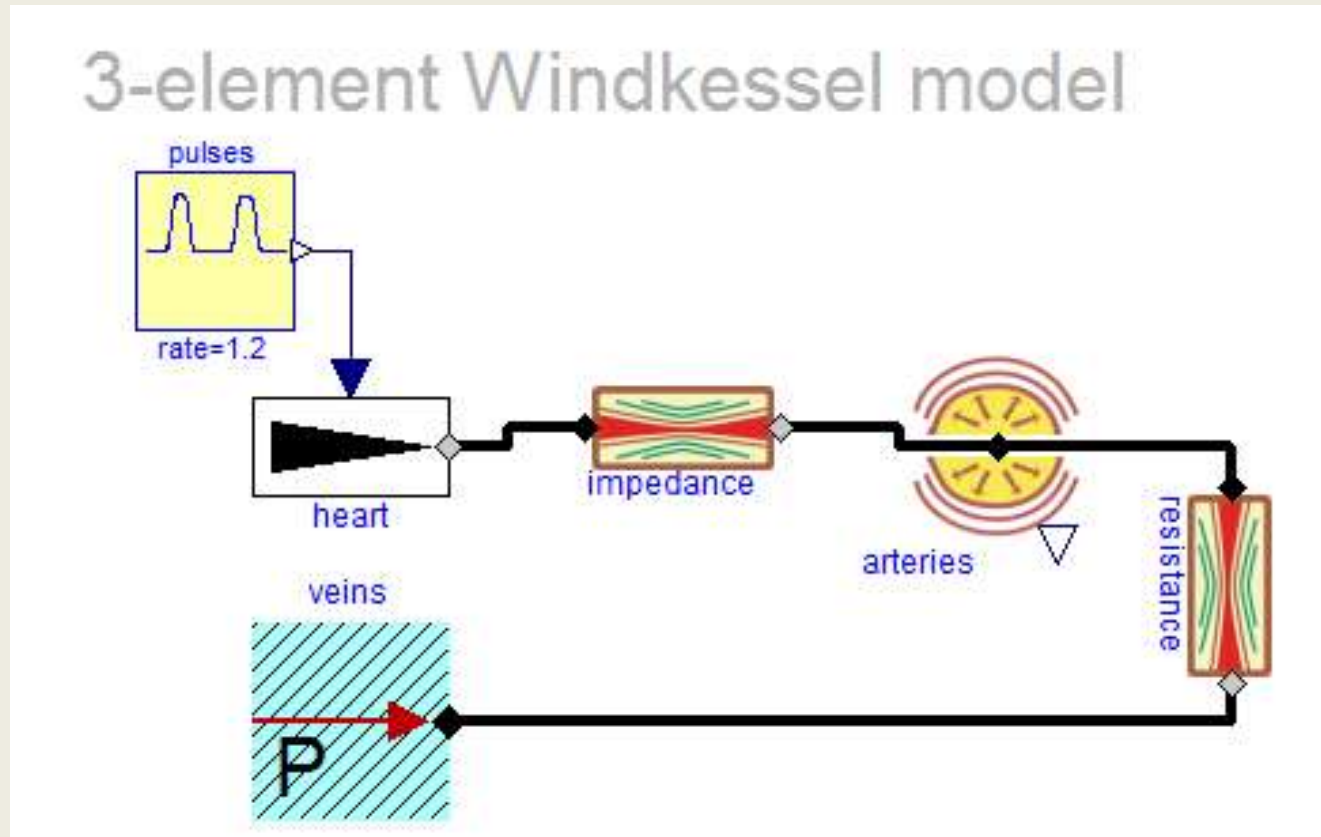


The analogy between the fire engine with the Windkessel and the arterial system. The peripheral resistance is the summed resistance of all small arteries, arterioles and capillaries. Total arterial compliance is the sum of the compliances of all arteries, mainly the conduit arteries. The Windkessel model can help us to understand how the arterial system functions, can be used as a realistic load in isolated heart studies, can be used in modeling, and can form the basis for estimating arterial system parameters. Adapted from [1], used by permission.

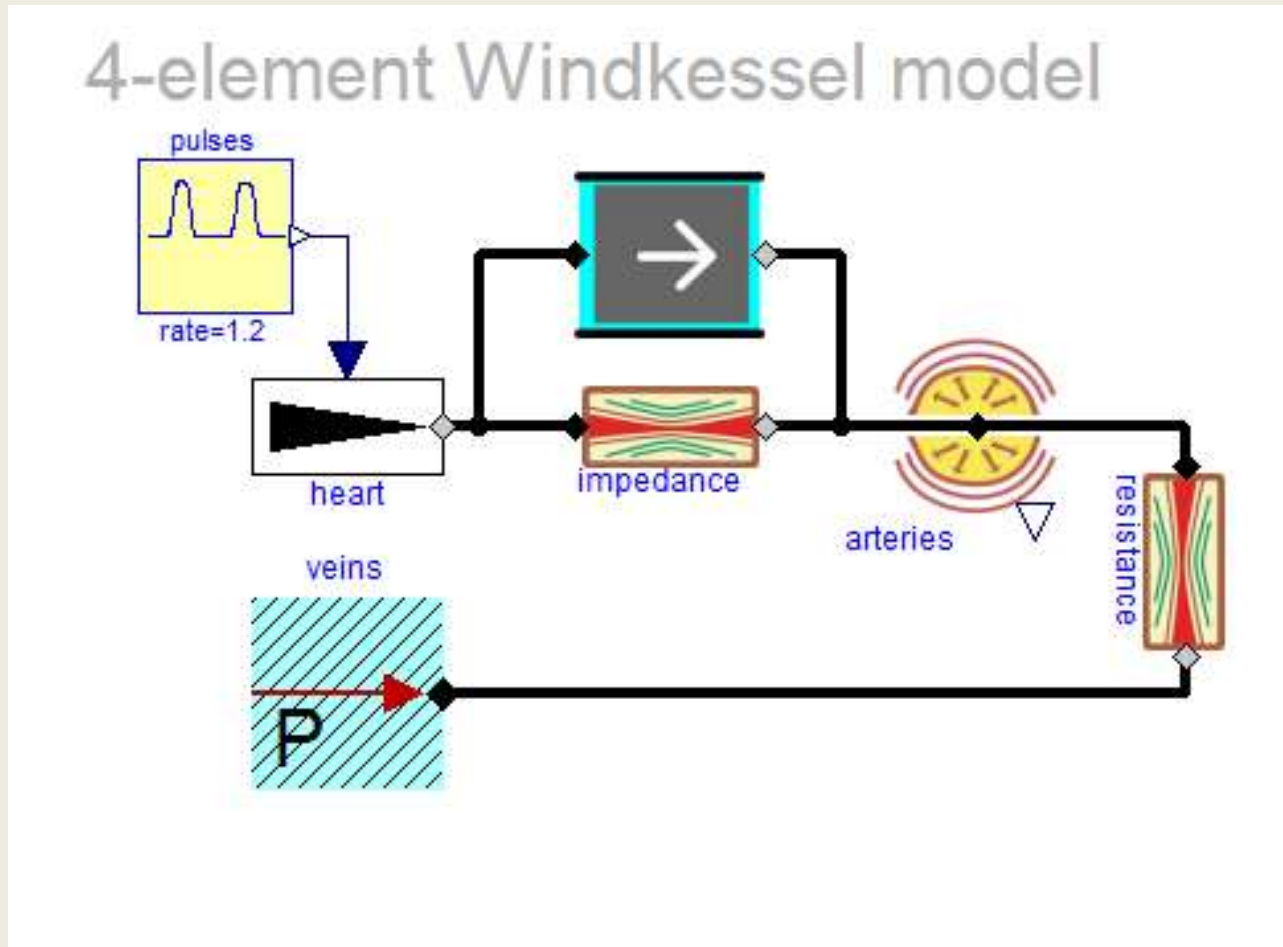
2-element Windkessel model



3-element Windkessel model

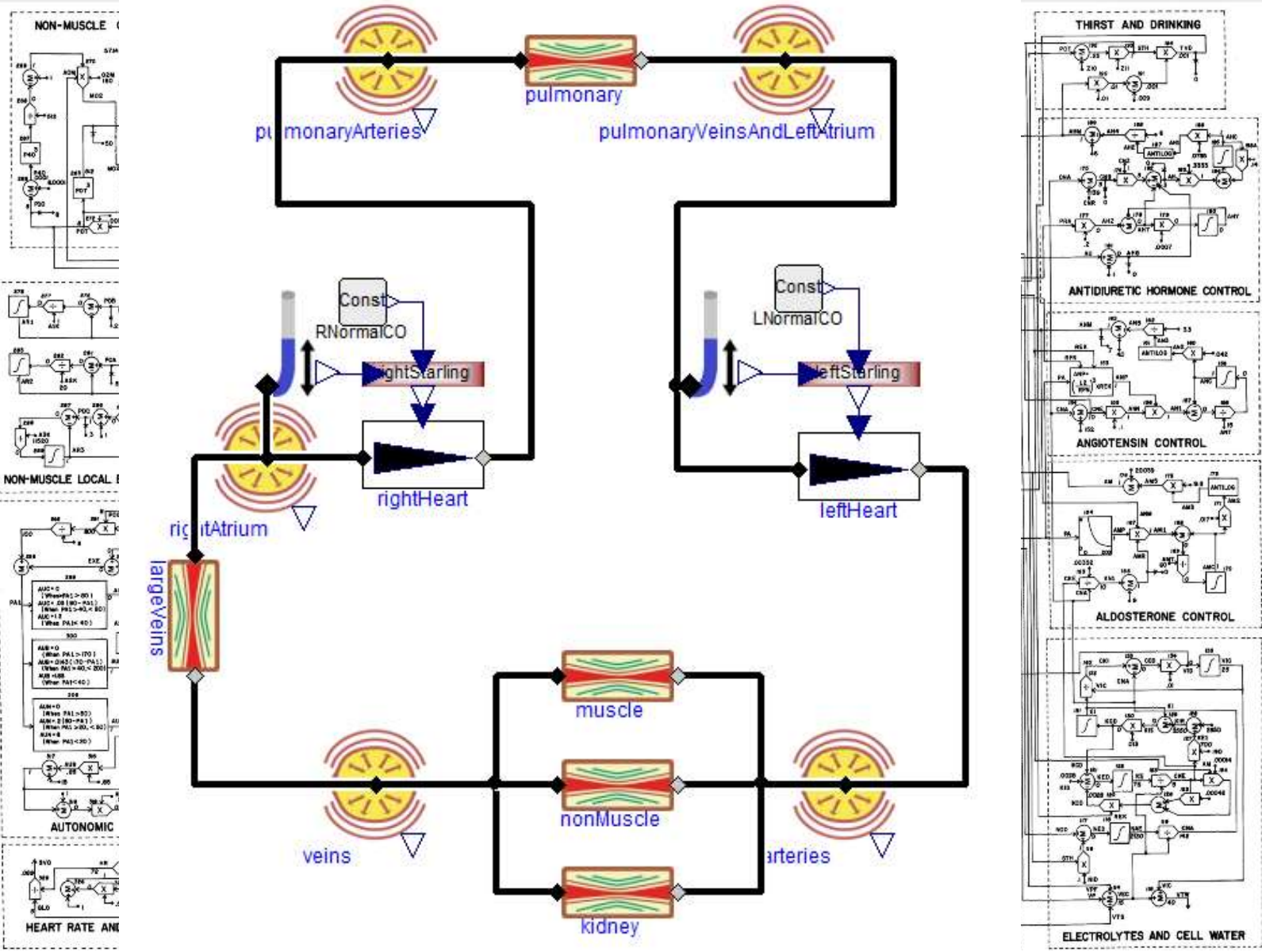


4-element Windkessel model

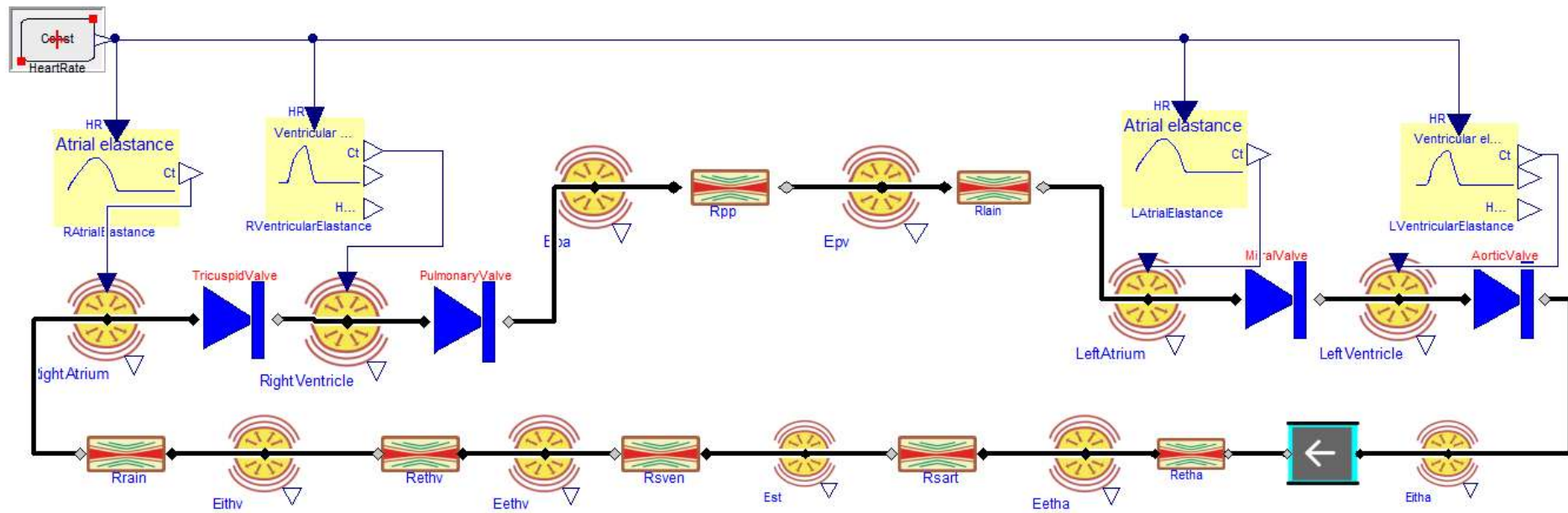


Circulation dynamics of Guyton-Coleman-Granger's model 1972

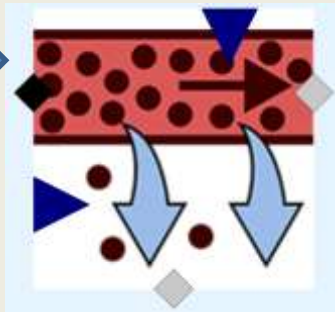
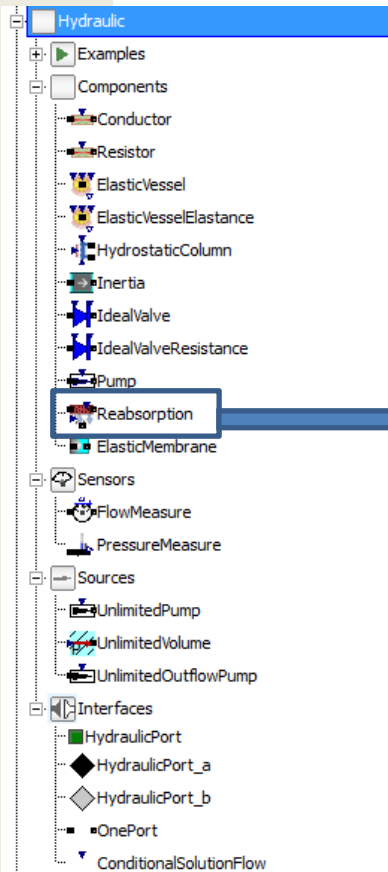
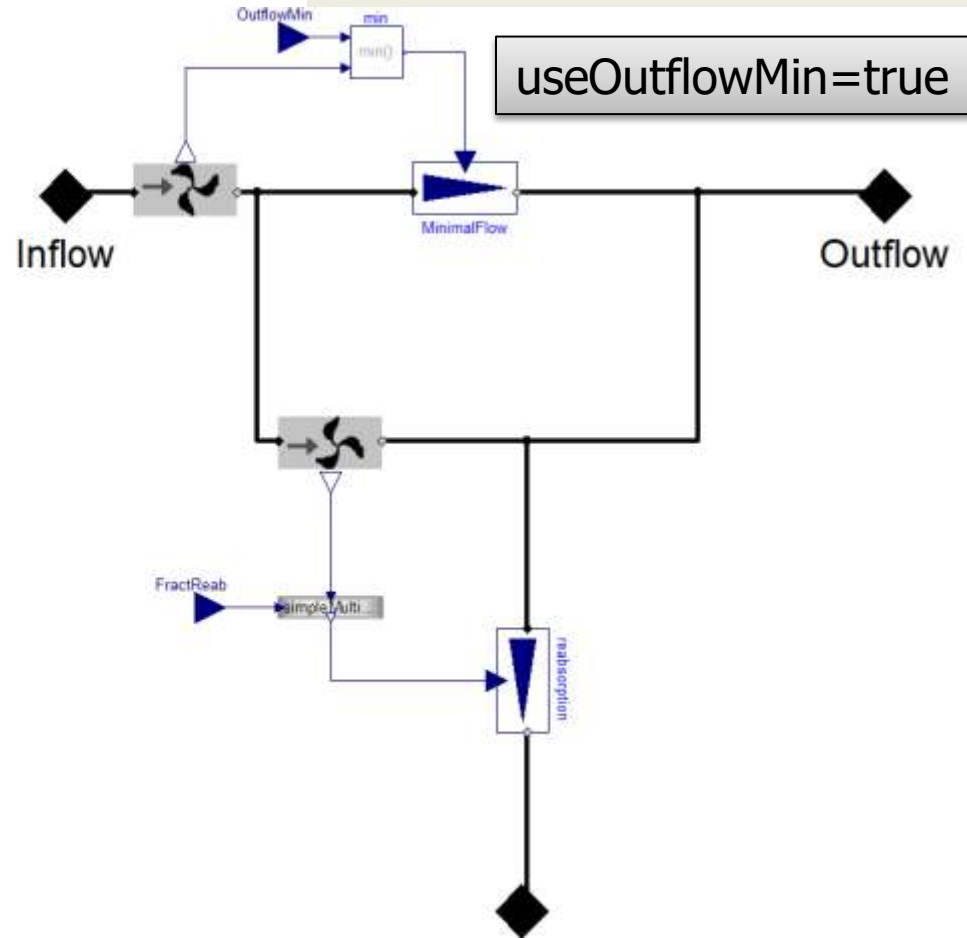
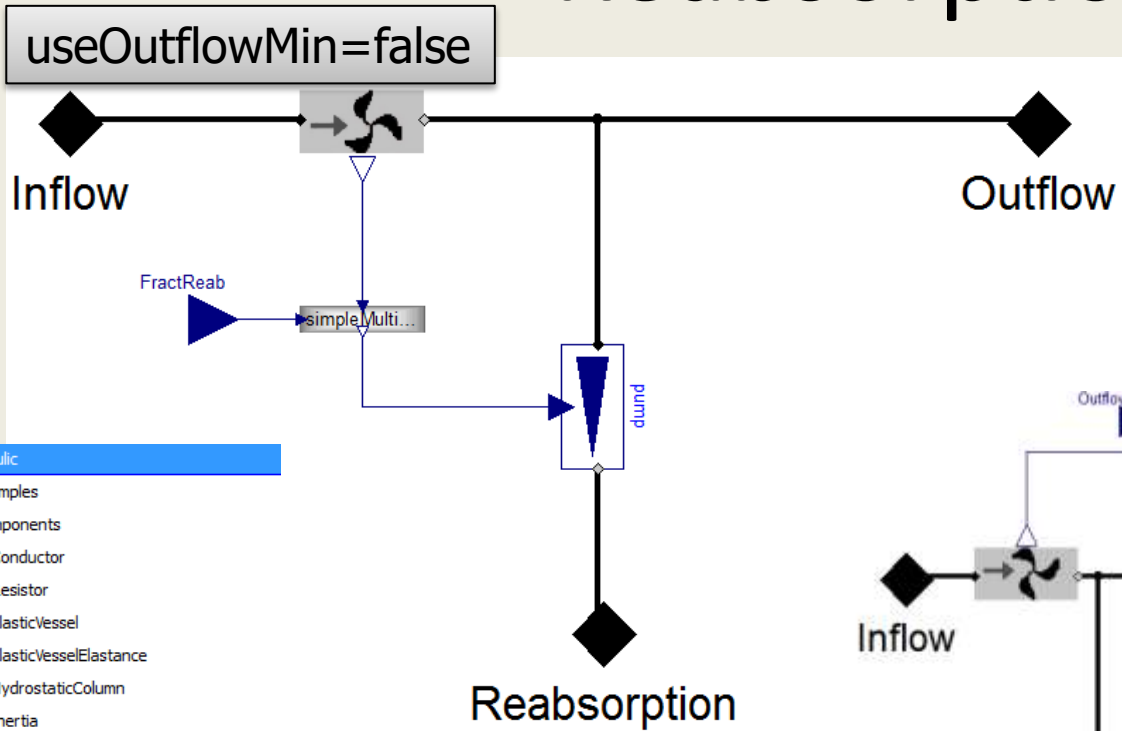
Soubor Zobra:



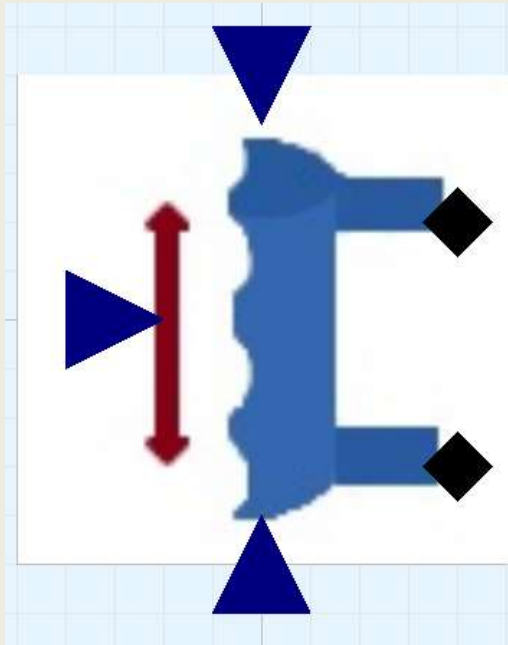
Hemodynamics Meurs model (flat model)



Reabsorption



Hydrostatic



Hydrostatic column pressure between two connectors (with specific muscle pump effect)

Information

The hydrostatic pressure is proportional to height of the column.

Extends from [Icons.HydrostaticGradient](#).

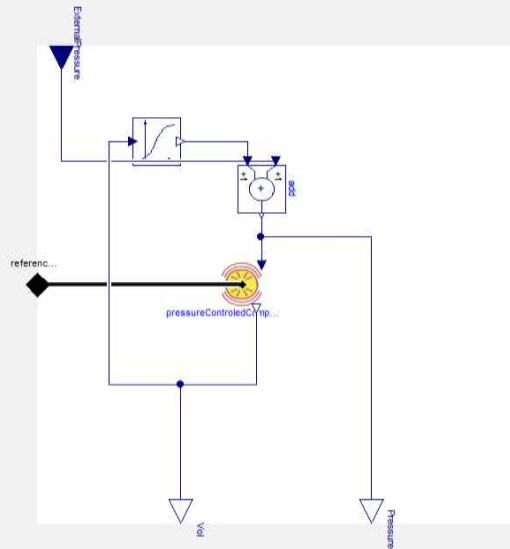
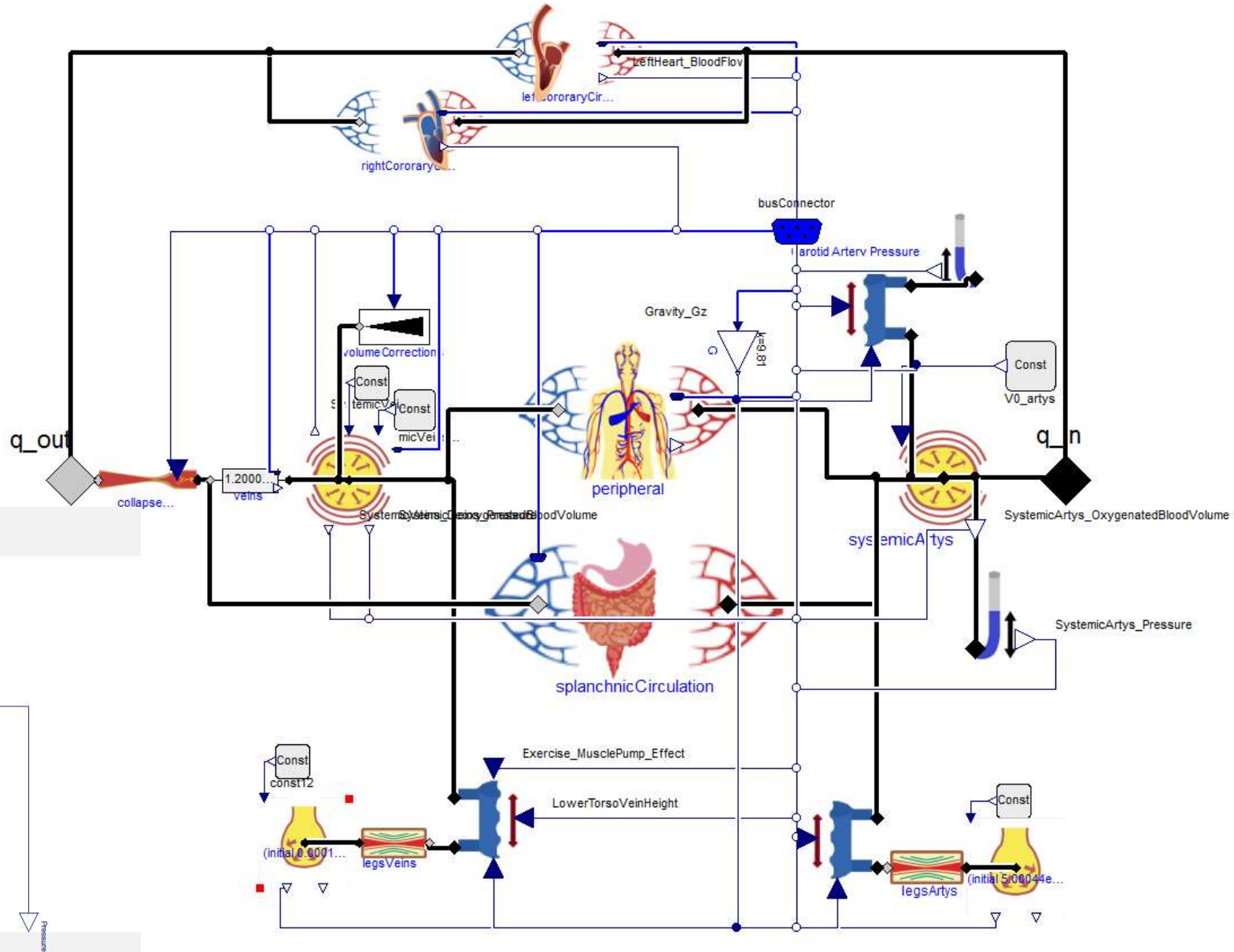
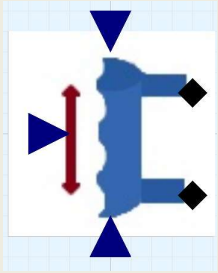
Parameters

Type	Name	Default	Description
Height	H	0	Height of hydrostatic column if useHeightInput=false [m]
Density	ro	1060	[kg/m ³]
Acceleration	GravityAcceleration	9.81	Gravity acceleration if useExternalG=false [m/s ²]
External inputs/outputs			
Boolean	useHeightInput	false	=true, if height input is used
Boolean	useExternalG	false	=true, if external gravity acceleration is used
Boolean	usePumpEffect	false	=true, if musce pump effect is used

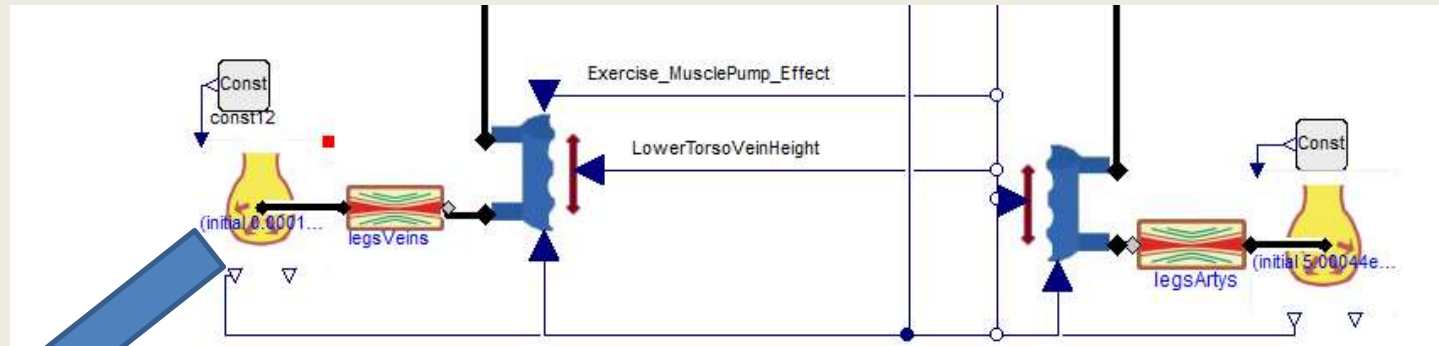
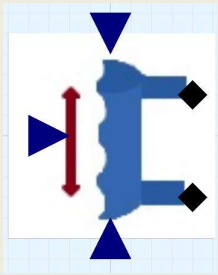
Connectors

Type	Name	Description
HydraulicPort_a	q_up	Top site
HydraulicPort_a	q_down	Bottom site
input HeightInput	height	Vertical distance between top and bottom connector [m]
input AccelerationInput	G	Gravity acceleration [m/s ²]
input FractionInput	pumpEffect	[1]

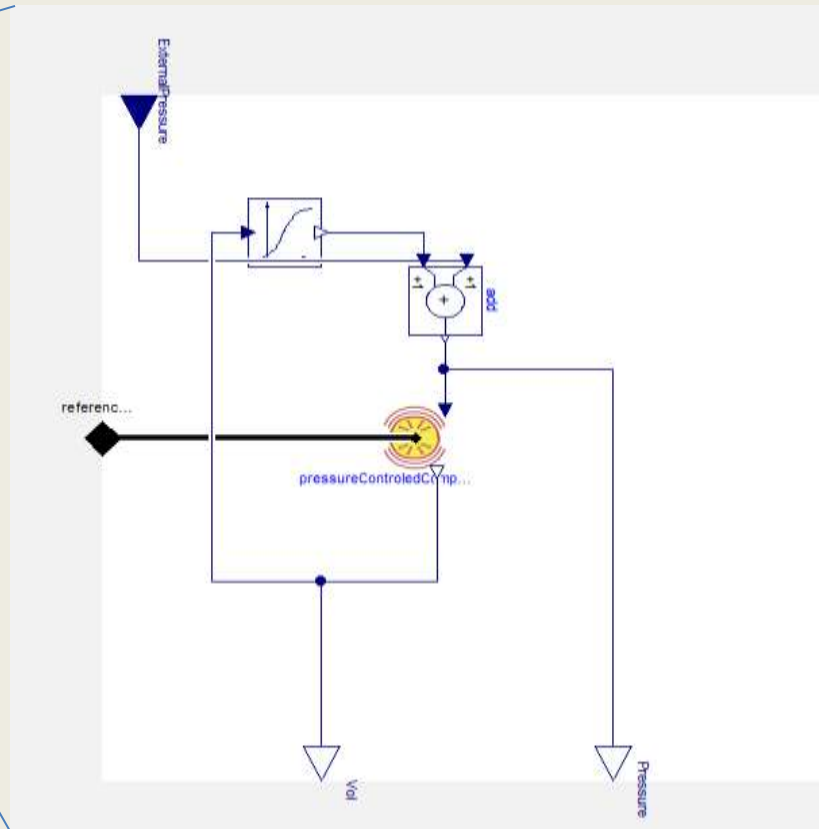
Hydrostatic



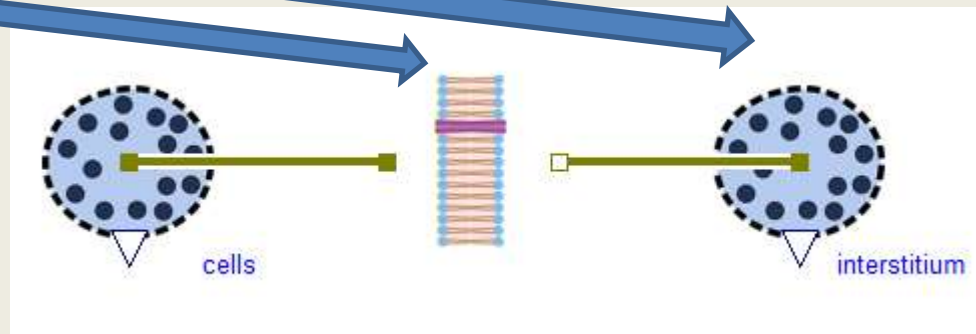
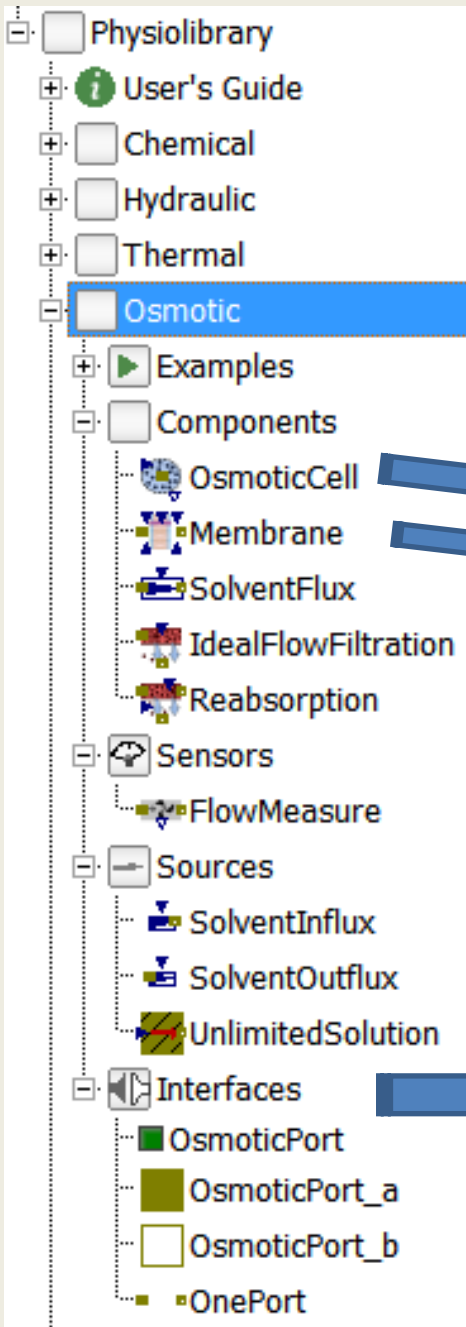
Hydrostatic



SequesteredBlood

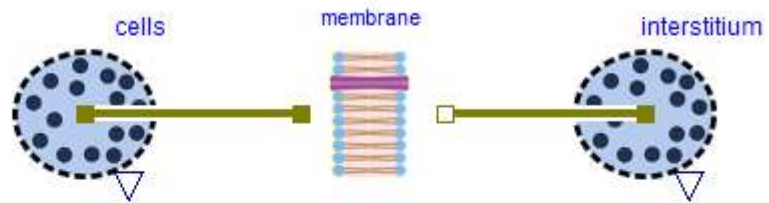


Osmotic

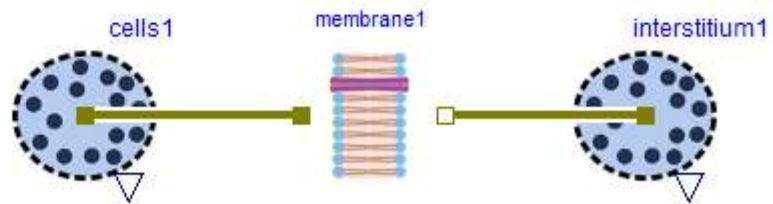


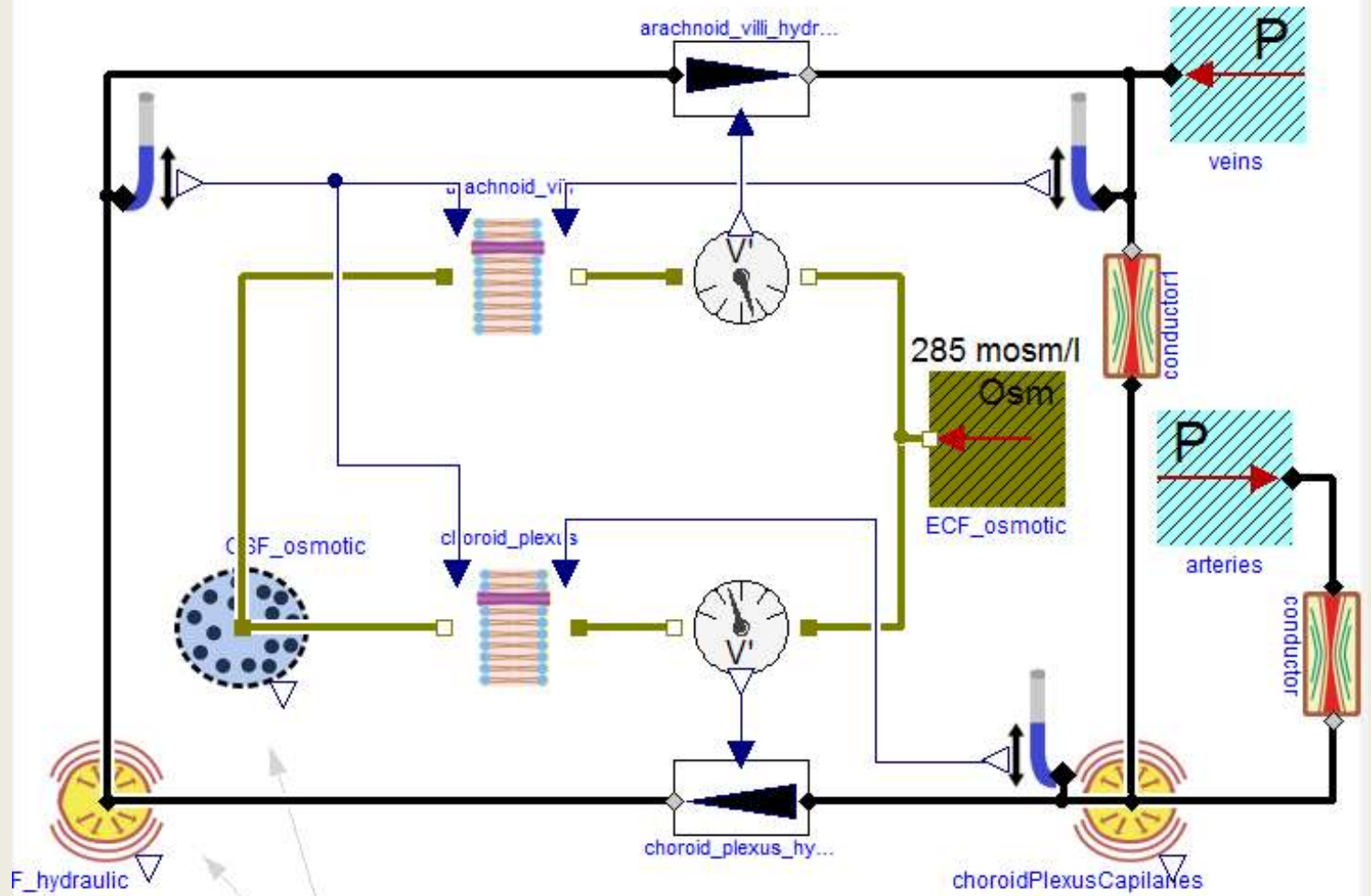
```
connector OsmoticPort
  "Osmolarity and osmotic flux"
  Types.Concentration o "Osmolarity";
  flow Types.VolumeFlowRate q "Osmotic flux";
  a
end OsmoticPort;
```

Cells in hypotonic environment



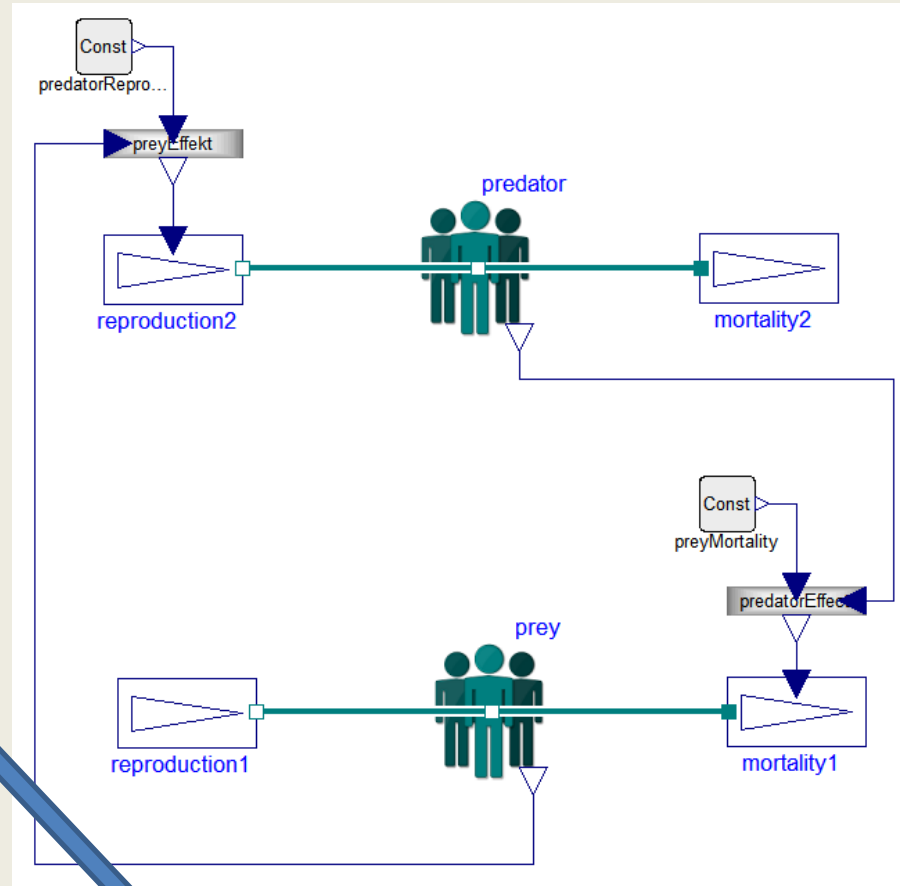
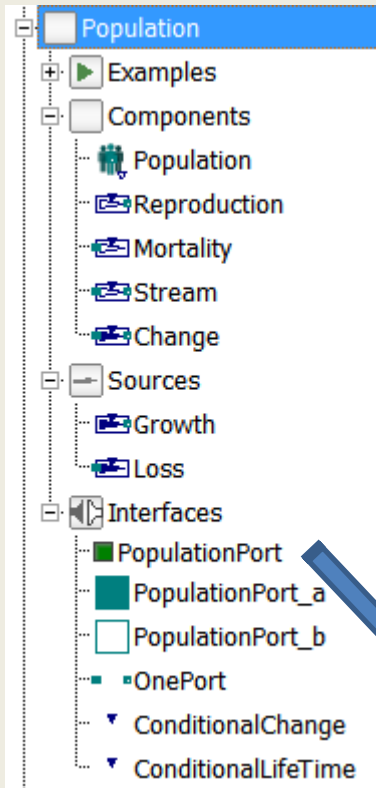
Cells in hypertonic environment





the same volume of CSF

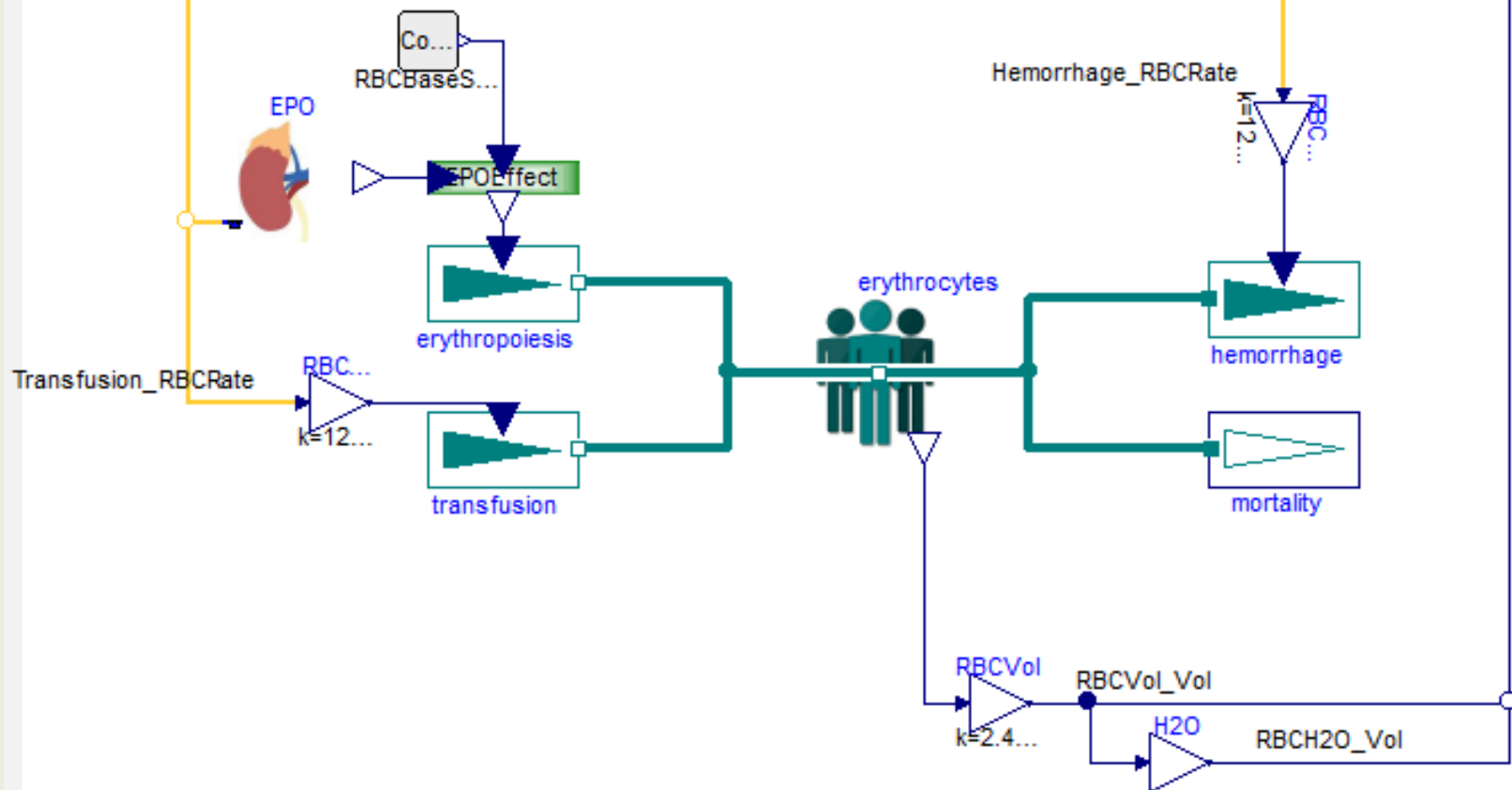
Population



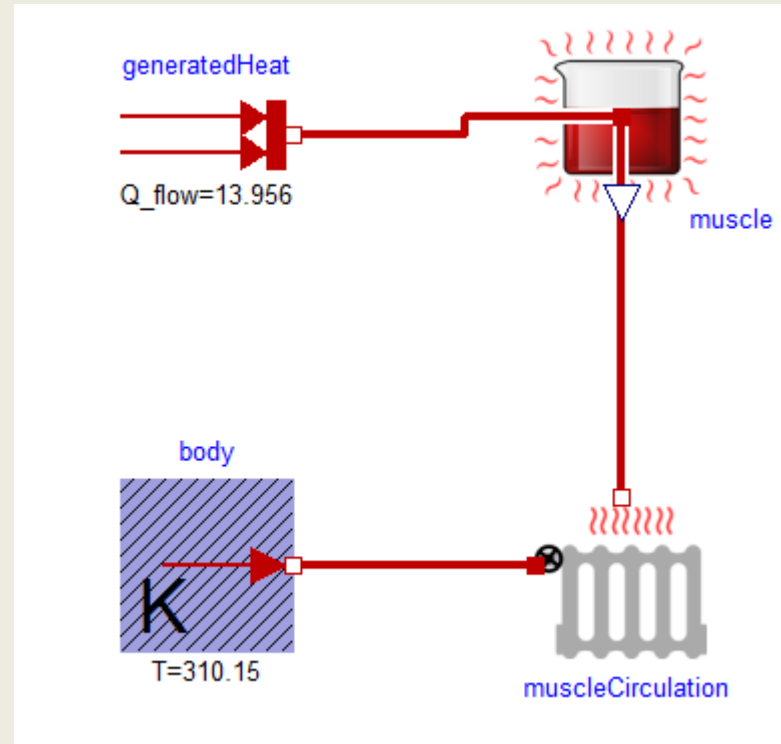
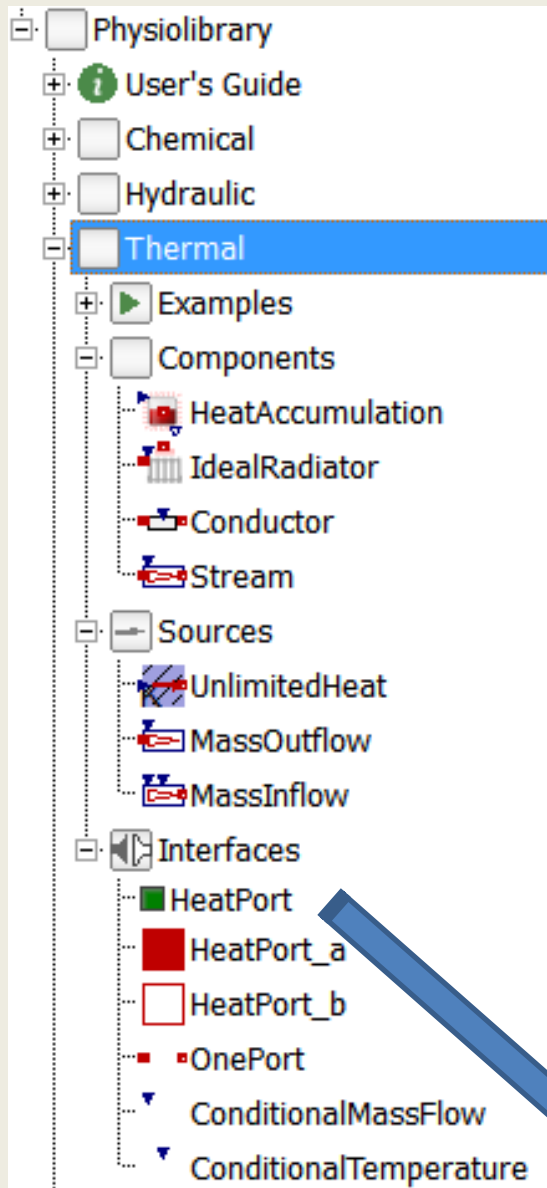
```
connector PopulationPort "Average number of population members and their change"  
Types.Population population "Average number of population individuals";  
flow Types.PopulationChange change "Average population change = change of population individuals";  
a  
end PopulationPort;
```

busConnector

Hemopoiesis

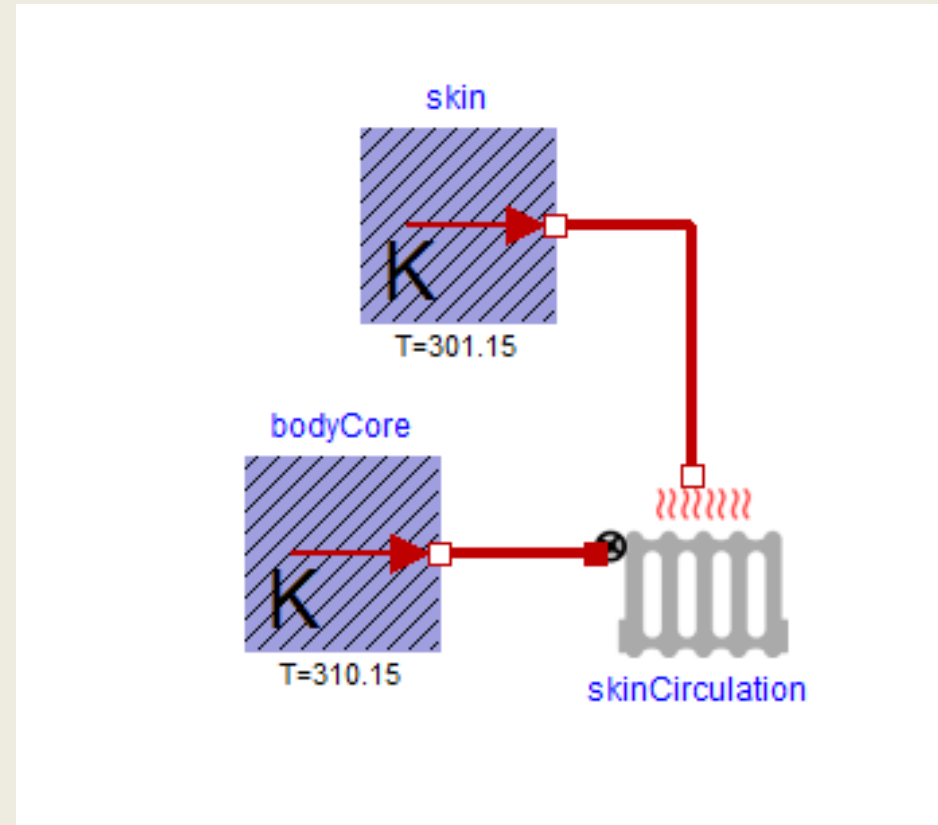
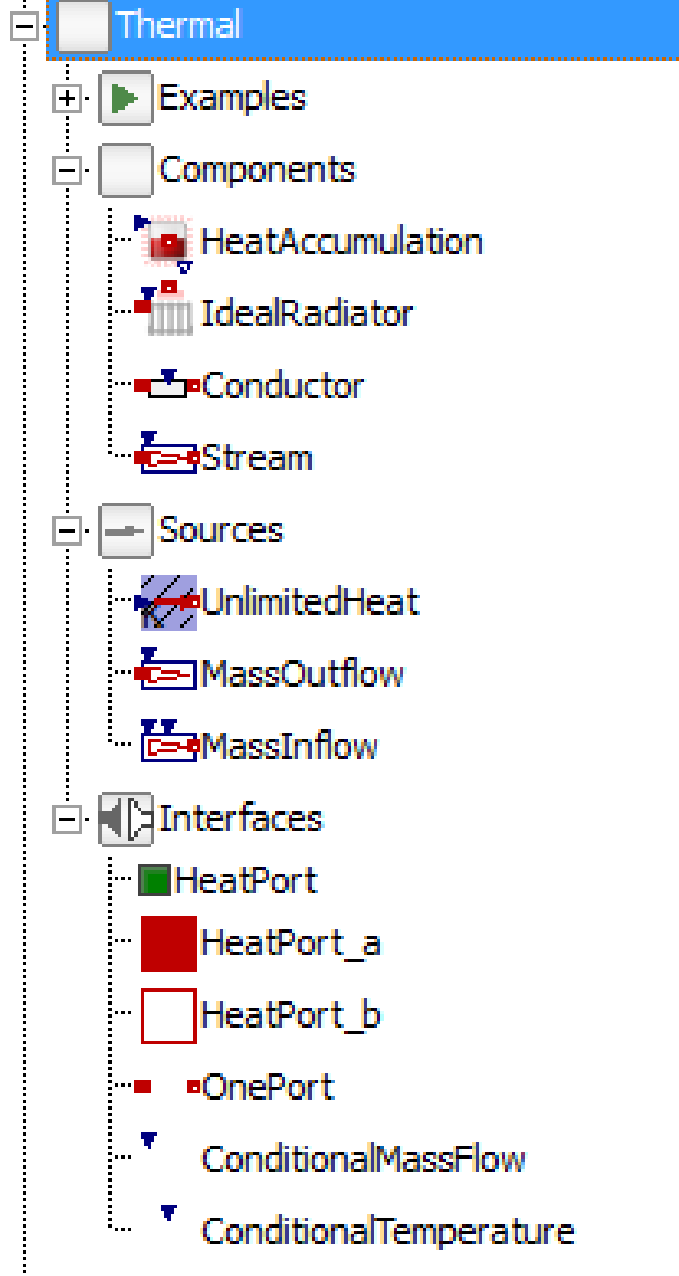


Thermal



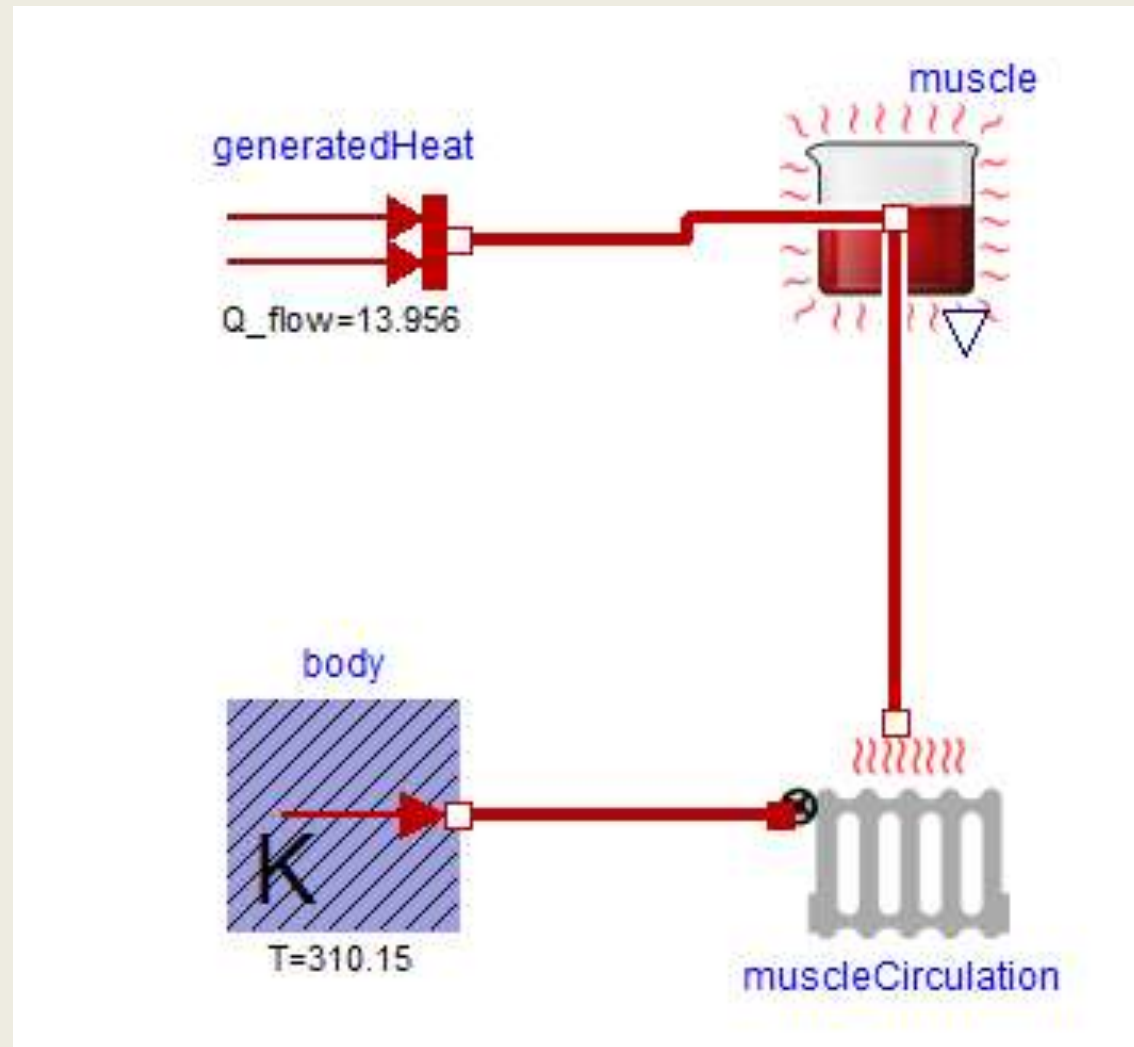
```
connector HeatPort = Modelica.Thermal.HeatTransfer.Interfaces.HeatPort
```

Skin Heat Flow



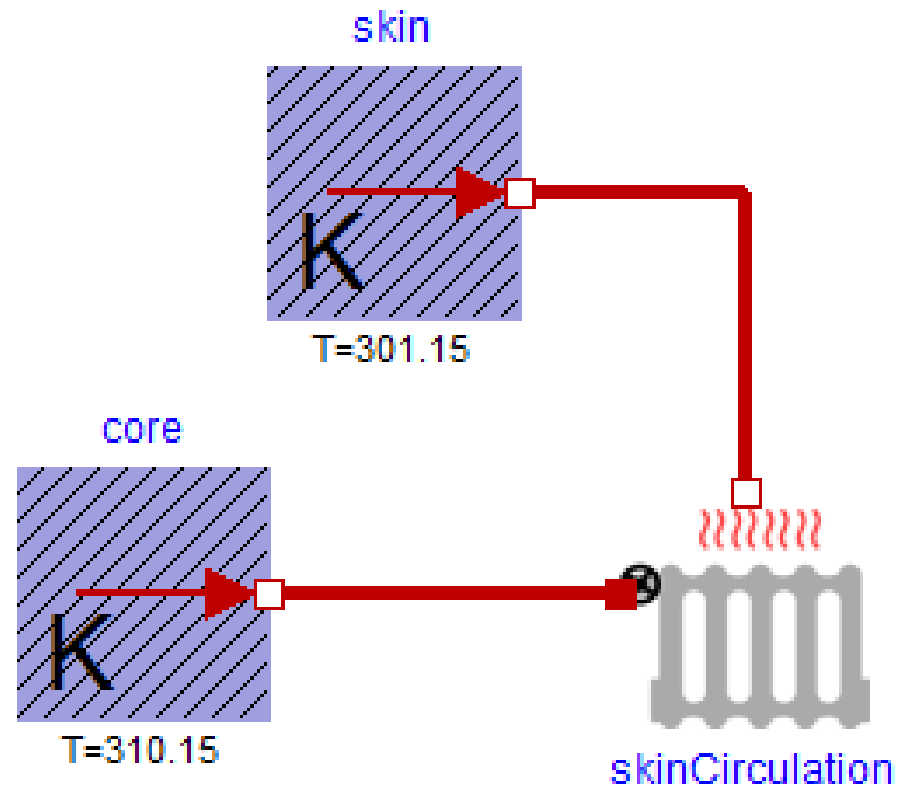
Muscle Heat

- Thermal
- Examples
- Components
 - HeatAccumulation
 - IdealRadiator
 - Conductor
 - Stream
- Sources
 - UnlimitedHeat
 - MassOutflow
 - MassInflow
- Interfaces
 - HeatPort
 - HeatPort_a
 - HeatPort_b
 - OnePort
 - ConditionalMassFlow
 - ConditionalTemperature

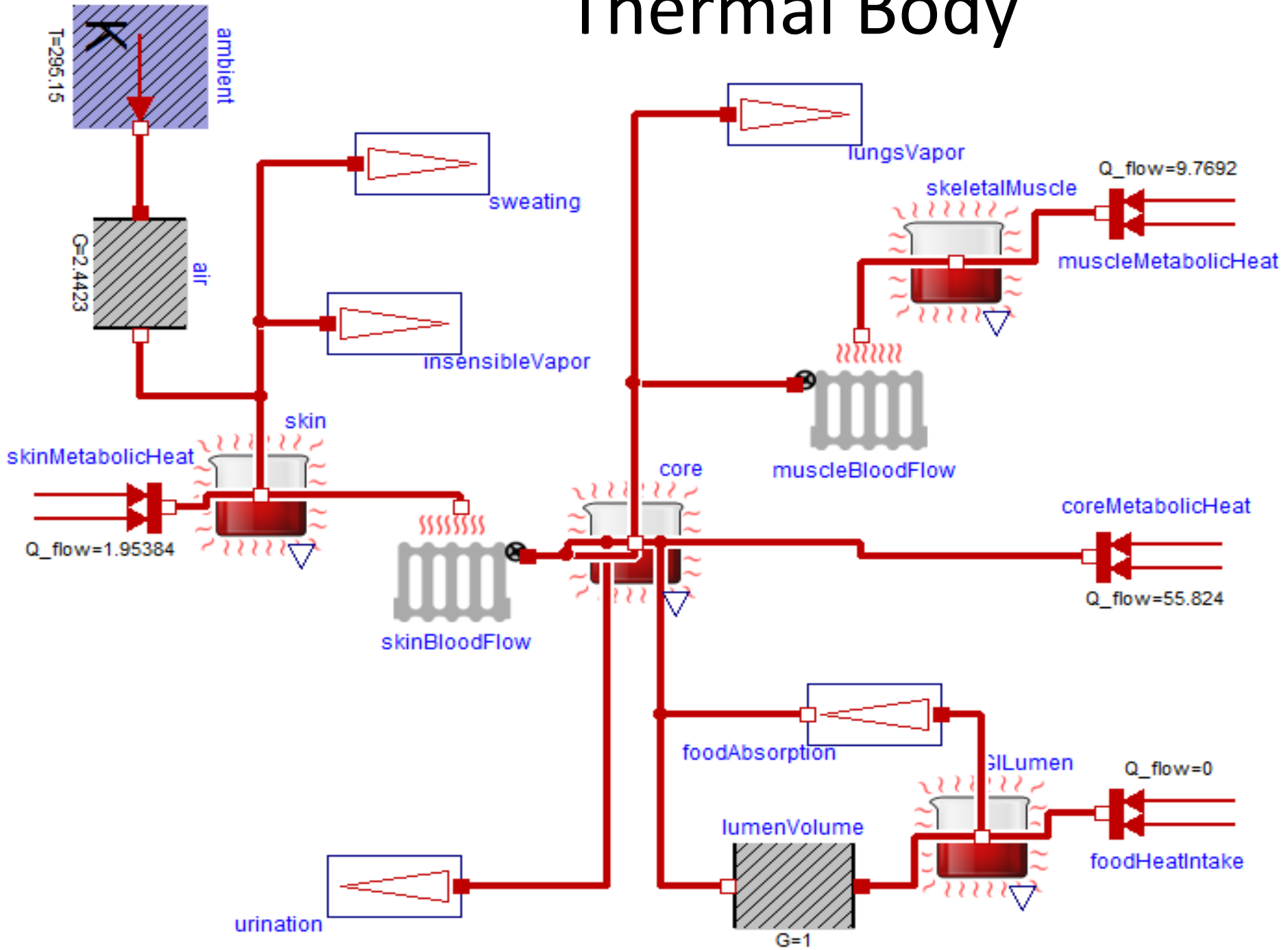


Skin Heat Transfer on Blood Flow

- Thermal
- Examples
- Components
 - HeatAccumulation
 - IdealRadiator
 - Conductor
 - Stream
- Sources
 - UnlimitedHeat
 - MassOutflow
 - MassInflow
- Interfaces
 - HeatPort
 - HeatPort_a
 - HeatPort_b
 - OnePort
 - ConditionalMassFlow
 - ConditionalTemperature



Thermal Body



Komplexní příklad využití knihovny PHYSIOLIBRAY:

Physiomodel 1.1

viz: www.physiomodel.org