```
global Q K M g DV L;
%
dydt     = zeros(2,1);
%
G        = g - Q/M*DV/L;
dydt(1) = y(2) ;
dydt(2) = -K/M*y(1) + G;
%
return
```

29.2 MATLAB FUNCTIONS FOR PART 4

This section contains the Matlab codes that are used in Chapter 15.

29.2.1 FUNCTIONS USED IN CHAPTER 15

This section contains the codes used in Chapter 15.

29.2.1.1 Comparison Between Compliant and Collapsible Tubes

Matlab coding 29.13. The following Matlab function implements the electric model described in Fig. 15.5 and constituted by a hydraulic system made by three different fluid compartments, denoted *comp*1, *comp*2, and *comp*3. In this case the hydraulic resistance of each compartment (assumed compliant) is modeled by the Laplace law (15.38). All the values of the model parameters are taken from [137].

```
function Y = el_fluid1(x,Pext)
global Pin Pout
% fluid parameters
mu_f   = 3 ;                          % fluid viscosity
rho_f = 1060 ;                        % mass density of the fluid
kr     = 8*pi*mu_f/rho_f ;
% Comp1 and Comp3
l_cra = 0.2;                          % Length of SA vessel [cm]
d_cra = 175*1e-4;                     % Comp1, Comp3 diameter [mum], converted in [cm] by the
   factor 1e-4
A_cra = pi*d_cra^2/4   ;
wall_to_lumen_ratio_cra = 0.15 ;
h_cra = wall_to_lumen_ratio_cra*d_cra/2;  % Comp1,Comp3 thickness [cm]
E_cra = 0.3e6;                        % Young modulus [Pa]
nu_cra = 0.49;                        % Poisson ratio
kp_cra = E_cra/(12*(1-nu_cra^2))*(2*h_cra/d_cra)^3 ;
kl_cra = 12*(0.5*d_cra/h_cra)^2 ;
alpha_cra = kr*rho_f*l_cra/A_cra^2 ;
% Comp2
l_crv= 0.1;                           % Length of Comp2 vessel [cm]
d_crv = 238*1e-4;                     % Comp2 diameter [mum], converted in [cm] by the factor 1e-4
A_crv = pi*d_crv^2/4   ;
```

```
wall_to_lumen_ratio_crv = 0.022 ;
h_crv = wall_to_lumen_ratio_crv*d_crv/2;  % Comp2 thickness [cm]
E_crv = 0.6e6;                            % Young modulus [Pa]
nu_crv = 0.49;                            % Poisson ratio
kp_crv = E_crv/(12*(1-nu_crv^2))*(2*h_crv/d_crv)^3 ;
kl_crv = 12*(0.5*d_crv/h_crv)^2 ;
alpha_crv = kr*rho_f*l_crv/A_crv^2 ;
%
Y(1) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
       alpha_crv*((x(3)-Pext)/(kp_crv*kl_crv)+1)^(-4)+...
       alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                         (Pin-x(1))/(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4));
Y(2) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
       alpha_crv*((x(3)-Pext)/(kp_crv*kl_crv)+1)^(-4)+...
       alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                         (x(1)-x(2))/(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4));
Y(3) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
       alpha_crv*((x(3)-Pext)/(kp_crv*kl_crv)+1)^(-4)+...
       alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                         (x(2)-x(3))/(alpha_crv*((x(3)-Pext)/(kp_crv*kl_crv)+1)^(-4));
Y(4) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
       alpha_crv*((x(3)-Pext)/(kp_crv*kl_crv)+1)^(-4)+...
       alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                         (x(3)-x(4))/(alpha_crv*((x(3)-Pext)/(kp_crv*kl_crv)+1)^(-4));
Y(5) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
       alpha_crv*((x(3)-Pext)/(kp_crv*kl_crv)+1)^(-4)+...
       alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                         (x(4)-x(5))/(alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4));
%
return
```

Matlab coding 29.14. The following Matlab function implements the electric model described in Fig. 15.5 and constituted by a hydraulic system made up of three different fluid compartments, denoted *comp*1, *comp*2, and *comp*3. In this case the hydraulic resistance of compartments *comp*1 and *comp*3 (assumed compliant) is modeled by the Laplace law (15.38), whereas the hydraulic resistance of compartment *comp*2 (assumed collapsible) is described by the Starling law (15.47). All the values of the model parameters are taken from [137].

```
function Y = el_fluid2(x,Pext)
global Pin Pout
% fluid parameters
mu_f  = 3 ;                               % fluid viscosity
rho_f = 1060 ;                            % mass density of the fluid
kr    = 8*pi*mu_f/rho_f ;
% Comp1 and Comp3
l_cra = 0.2;                              % Length of Comp1 and Comp3 vessels [cm]
d_cra = 175*1e-4;                         % Comp1, Comp3 diameter [mum], converted in [cm] by the
   factor 1e-4
A_cra = pi*d_cra^2/4  ;
wall_to_lumen_ratio_cra = 0.15 ;
```

```
h_cra = wall_to_lumen_ratio_cra*d_cra/2;    % Comp1, Comp3 vessel thickness [cm]
E_cra = 0.3e6;                              % Young modulus [Pa]
nu_cra = 0.49;                              % Poisson ratio
kp_cra = E_cra/(12*(1-nu_cra^2))*(2*h_cra/d_cra)^3 ;
kl_cra = 12*(0.5*d_cra/h_cra)^2 ;
alpha_cra = kr*rho_f*l_cra/A_cra^2 ;
% Comp2
l_crv= 0.1;                               % Length of Comp2 vessel [cm]
d_crv = 238*1e-4;                         % Comp2 diameter [mum], converted in [cm] by the factor 1e-4
A_crv = pi*d_crv^2/4  ;
wall_to_lumen_ratio_crv = 0.028 ;
h_crv = wall_to_lumen_ratio_crv*d_crv/2;  % Comp2 vessel thickness [cm]
E_crv = 0.6e6;                            % Young modulus [Pa]
nu_crv = 0.49;                            % Poisson ratio
kp_crv = E_crv/(12*(1-nu_crv^2))*(2*h_crv/d_crv)^3 ;
kl_crv = 12*(0.5*d_crv/h_crv)^2 ;
alpha_crv = kr*rho_f*l_crv/A_crv^2 ;
%
Y(1) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
       alpha_crv*(1-(x(3)-Pext)/(kp_crv))^(4/3)+...
       alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                         (Pin-x(1))/(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4));
Y(2) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
       alpha_crv*(1-(x(3)-Pext)/(kp_crv))^(4/3)+...
       alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                         (x(1)-x(2))/(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)) ;
Y(3) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
        alpha_crv*(1-(x(3)-Pext)/(kp_crv))^(4/3)+...
        alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                                (x(2)-x(3))/(alpha_crv*(1-(x(3)-Pext)/(kp_crv))^(4/3)) ;
Y(4) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
        alpha_crv*(1-(x(3)-Pext)/(kp_crv))^(4/3)+...
        alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                                (x(3)-x(4))/(alpha_crv*(1-(x(3)-Pext)/(kp_crv))^(4/3)) ;
Y(5) = -(Pin-Pout) + 2*(alpha_cra*((x(1)-Pext)/(kp_cra*kl_cra)+1)^(-4)+...
         alpha_crv*(1-(x(3)-Pext)/(kp_crv))^(4/3)+...
         alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))*...
                                 (x(4)-x(5))/(alpha_cra*((x(5)-Pext)/(kp_cra*kl_cra)+1)^(-4))  ;  %
return
```

Matlab coding 29.15. The following `Matlab` function implements the hydraulic resistance of compartments *comp*1 and *comp*3 (assumed compliant) using the Laplace constitutive model (15.38). All the values of the model parameters are taken from [137].

```
function [ Y ] = cra( P , Pext )
% fluid parameter
mu_f = 3 ;                                  % fluid viscosity
rho_f = 1060 ;                              % mass density of the fluid
kr = 8*pi*mu_f/rho_f ;
% resistance model parameter
l_cra = 0.1;                                % Length of Comp1 and Comp3 vessels [cm]
```

```
d_cra = 175*1e-4;                         % Comp1 and Comp3 diameter [mum] will be converted in [cm] by the factor 1e-4
A_cra = pi*d_cra^2/4
wall_to_lumen_ratio_cra = 0.15 ;
h_cra = wall_to_lumen_ratio_cra*d_cra/2;    % Comp1 and Comp3 thickness [cm]
E_cra = 0.3e6;                            % Young modulus [Pa]
nu_cra = 0.49;                            % Poisson ratio
kp_cra = E_cra/(12*(1-nu_cra^2))*(2*h_cra/d_cra)^3
kl_cra = 12*(0.5*d_cra/h_cra)^2
alpha_cra = kr*rho_f*l_cra/A_cra^2 ;
Y         = alpha_cra*((P-Pext)/(kp_cra*kl_cra)+1).^(-4) ;
end
```

Matlab coding 29.16. The following `Matlab` function implements the hydraulic resistance of compartment *comp*2 (assumed compliant) using the Laplace constitutive model (15.38). All the values of the model parameters are taken from [137].

```
function [ Y ] = crv( P,Pext )
index = numel(P);
% fluid parameter
mu_f = 3 ;                                % fluid viscosity
rho_f = 1060 ;                            % mass density of the fluid
kr = 8*pi*mu_f/rho_f ;
% resistance model parameter
l_crv= 0.2;                               % Length of Comp2 vessel [cm]
d_crv = 238*1e-4;                         % Comp2 diameter [mum] will be converted in [cm] by the factor 1e-4
A_crv = pi*d_crv^2/4  ;
wall_to_lumen_ratio_crv = 0.028 ;
h_crv = wall_to_lumen_ratio_crv*d_crv/2;    % Comp2 thickness [cm]
E_crv = 0.6e6;                            % Young modulus [Pa]
nu_crv = 0.49;                            % Poisson ratio
kp_crv = E_crv/(12*(1-nu_crv^2))*(2*h_crv/d_crv)^3 ;
kl_crv = 12*(0.5*d_crv/h_crv)^2 ;
alpha_crv = kr*rho_f*l_crv/A_crv^2 ;
for i=1:index
    Y(i) = alpha_crv*((P(i)-Pext(i))/(kp_crv*kl_crv)+1)^(-4) ;
end
end
```

Matlab coding 29.17. The following `Matlab` function implements the hydraulic resistance of compartments *comp*2 (assumed collapsible) using the Starling (collapsible) constitutive model (15.47). All the values of the model parameters are taken from [137].

```
function [ Y ] = crv_col( P,Pext )
index = numel(P);
% fluid parameter
mu_f = 3 ;                                % fluid viscosity
rho_f = 1060 ;                            % mass density of the fluid
```

```
kr = 8*pi*mu_f/rho_f ;
% resistance model parameter
l_crv= 0.2;                              % Length of Comp2 vessel [cm]
d_crv = 238*1e-4;                        % Comp2 diameter [mum] will be converted in [cm] by the
   factor 1e-4
A_crv = pi*d_crv^2/4  ;
wall_to_lumen_ratio_crv = 0.028 ;
h_crv = wall_to_lumen_ratio_crv*d_crv/2;    % Comp2 thickness [cm]
E_crv = 0.6e6;                           % Young modulus [Pa]
nu_crv = 0.49;                           % Poisson ratio
kp_crv = E_crv/(12*(1-nu_crv^2))*(2*h_crv/d_crv)^3 ;
kl_crv = 12*(0.5*d_crv/h_crv)^2 ;
alpha_crv = kr*rho_f*l_crv/A_crv^2 ;
for i=1:index
    Y(i) = alpha_crv*(1-(P(i)-Pext(i))/(kp_crv))^(4/3) ;
end
end
```

29.2.1.2 Representative Segment Model of the Retinal Microcirculation

Matlab coding 29.18. The following `Matlab` function computes the right-hand side of the ordinary differential equation system (15.72) representing the lumped parameter model of retinal microcirculation illustrated in Section 15.7.

```
function dydt = retina_fun(t, y)
% dydt = retina_fun(t, y)
global C Y I
%
dydt = zeros(4,1);
%
dydt  = inv(C)*(-Y*y + I);
%
return
```

29.3 MATLAB FUNCTIONS FOR PART 5

This section contains the `Matlab` codes that are used in Chapters 17, 18, and 19.

29.3.1 NUMERICAL STUDY OF THE HODGKIN–HUXLEY MODEL

In this section we illustrate the various functions that are used in the numerical simulation of the Hodgkin–Huxley model conducted in Example 17.3.

Matlab coding 29.19. The following `Matlab` function defines the class parameters of the ions used in the numerical simulation of the Hodgkin–Huxley model (17.37).