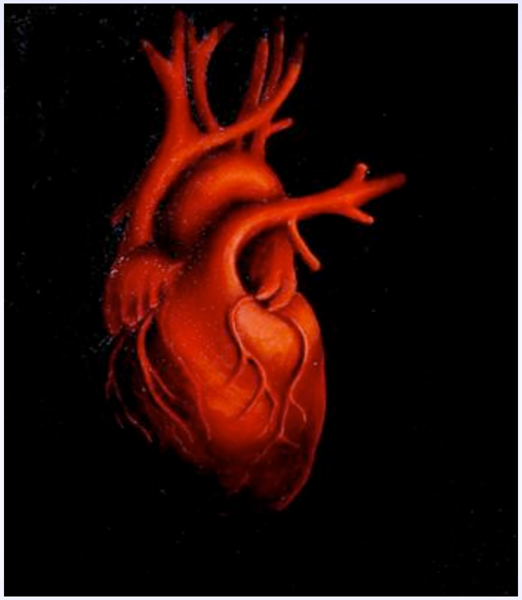
The Varying-Elastance Heart Model



Maxwell Neal

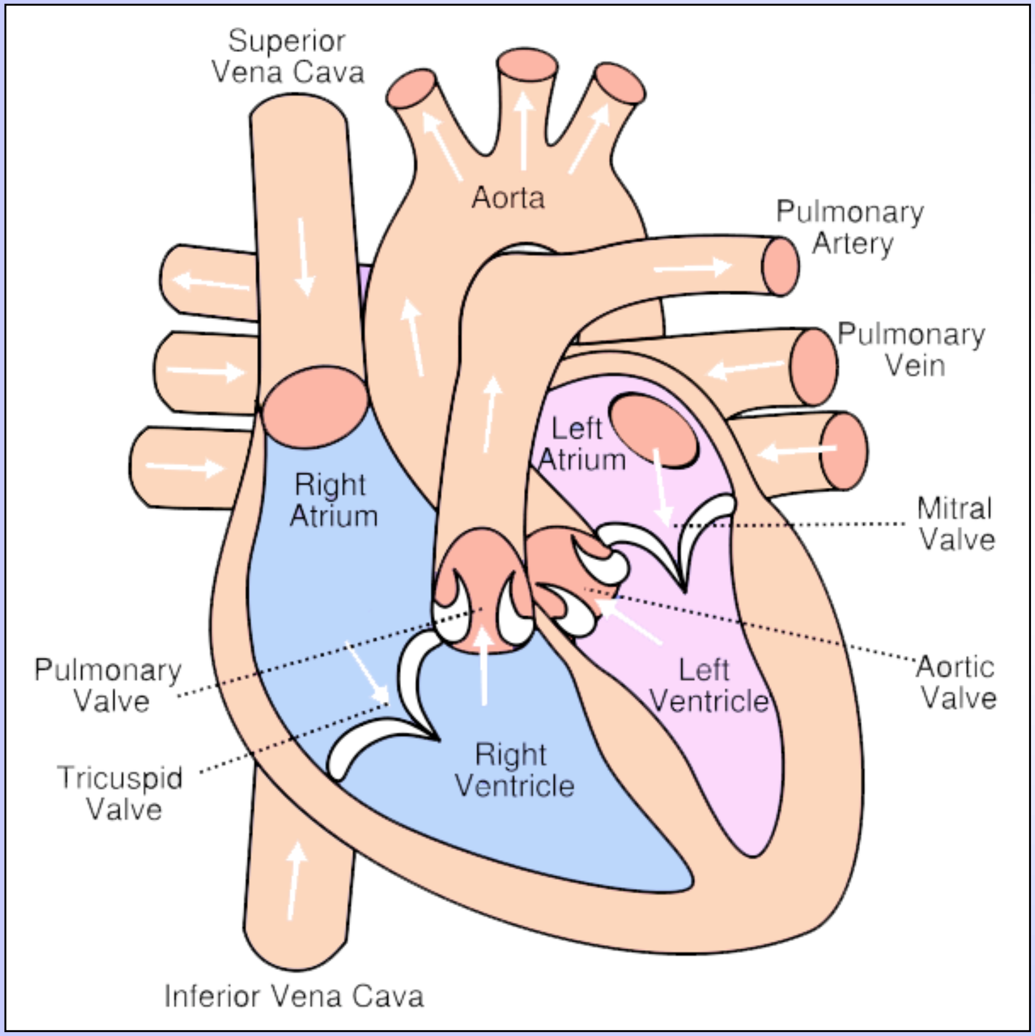
NSR Modeling Course

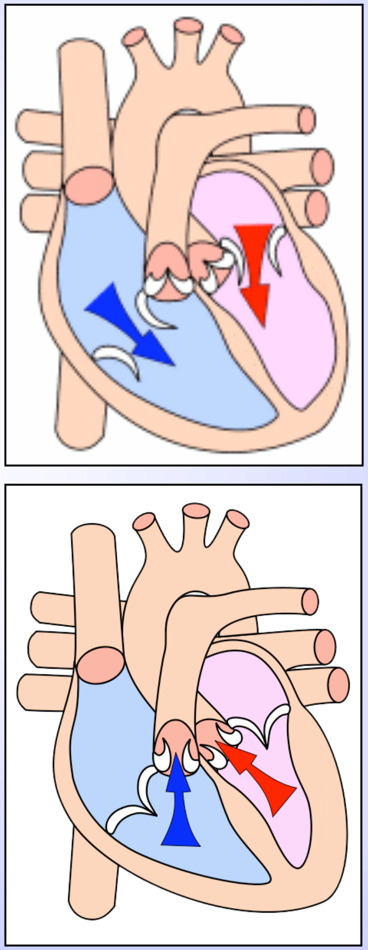
Aug 26th, 2008

Why simulate heart dynamics?

- Educational purposes (especially in medicine)
- Integration of physiological theory
- Patient-specific modeling

Human heart anatomy & the cardiac cycle





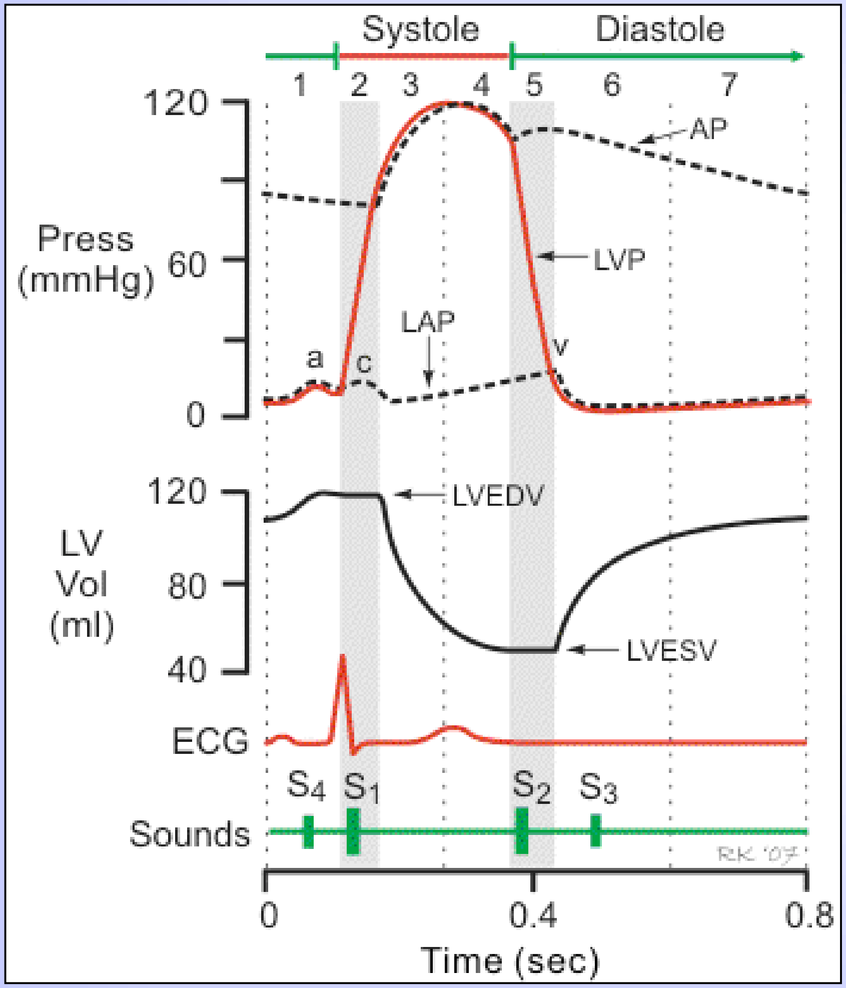
Diastole (relaxation)

Atrial systole (contraction)

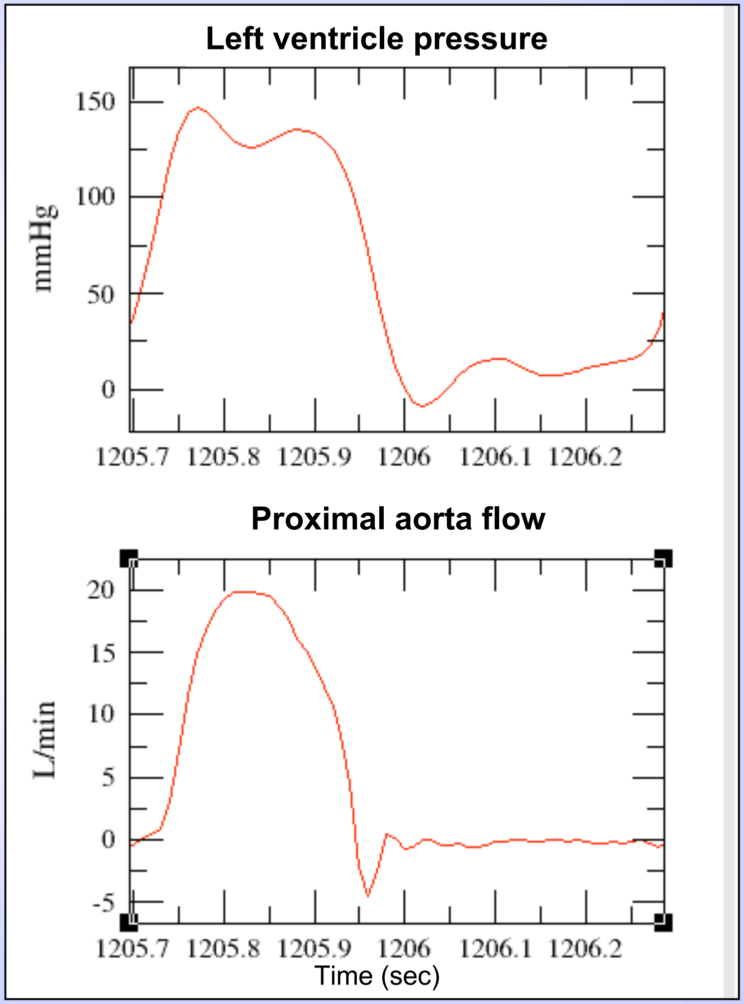
Ventricular systole

(contraction)

Pressure, volume and flow in the left ventricle

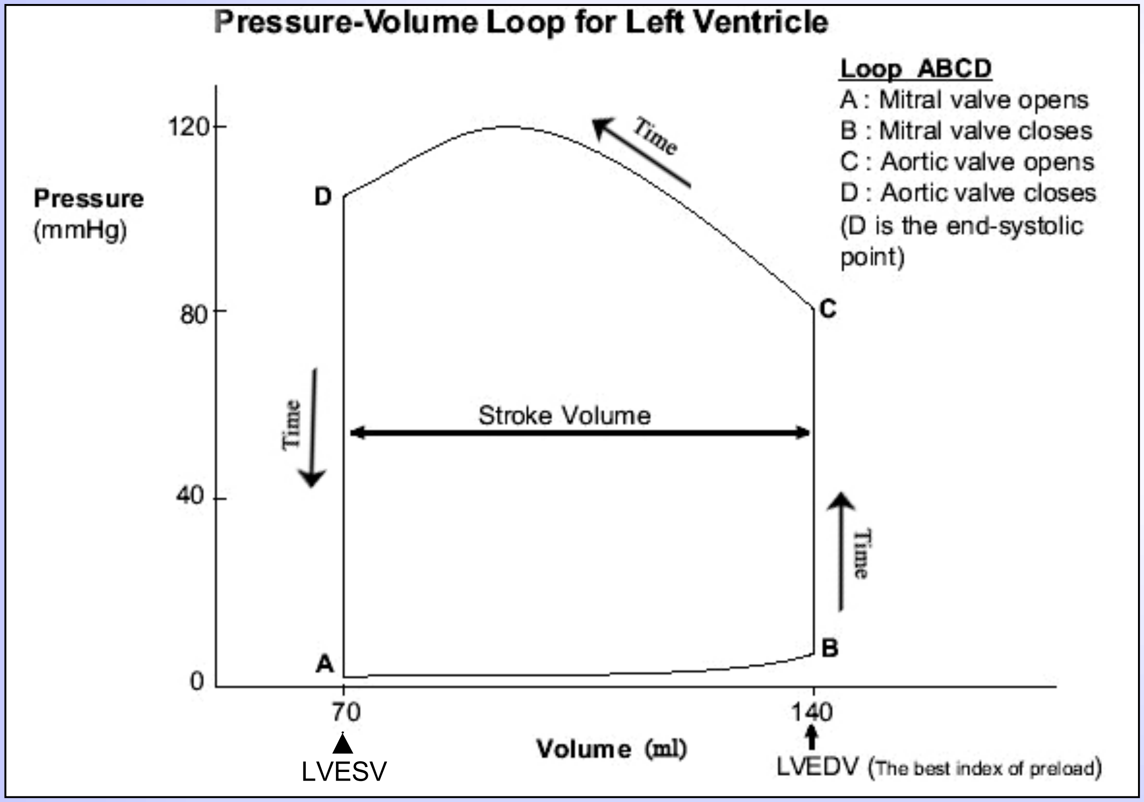


Textbook human

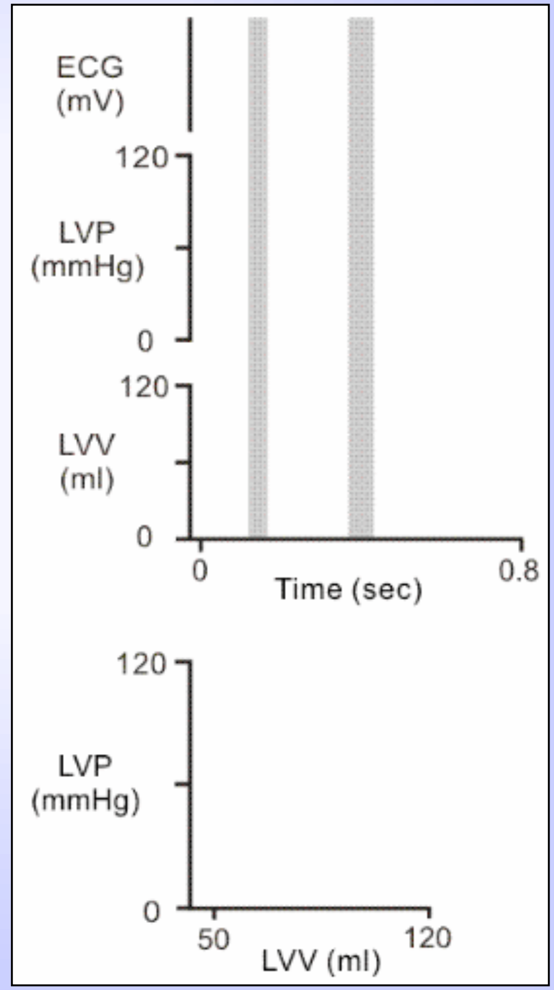


Actual pig

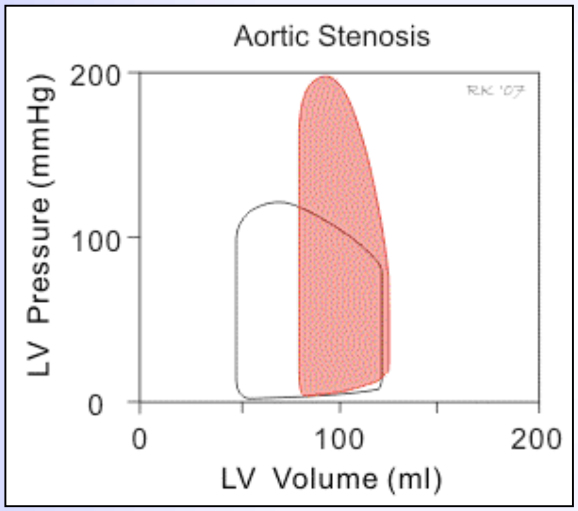
The left ventricular pressure-volume loop is used to evaluate cardiac function

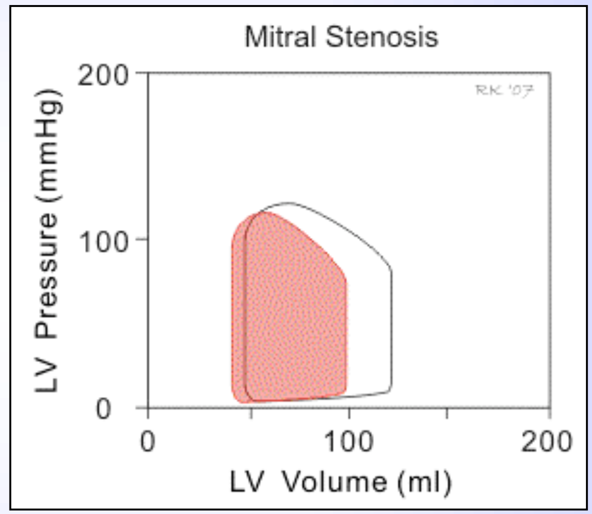


Textbook human

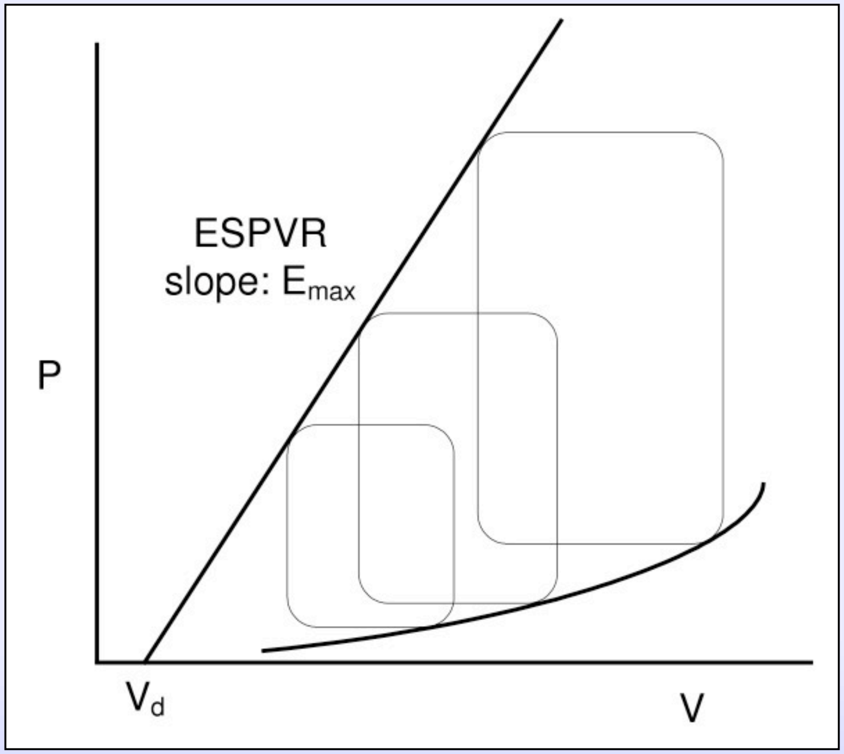


The left ventricular pressure-volume loop is used to evaluate cardiac function

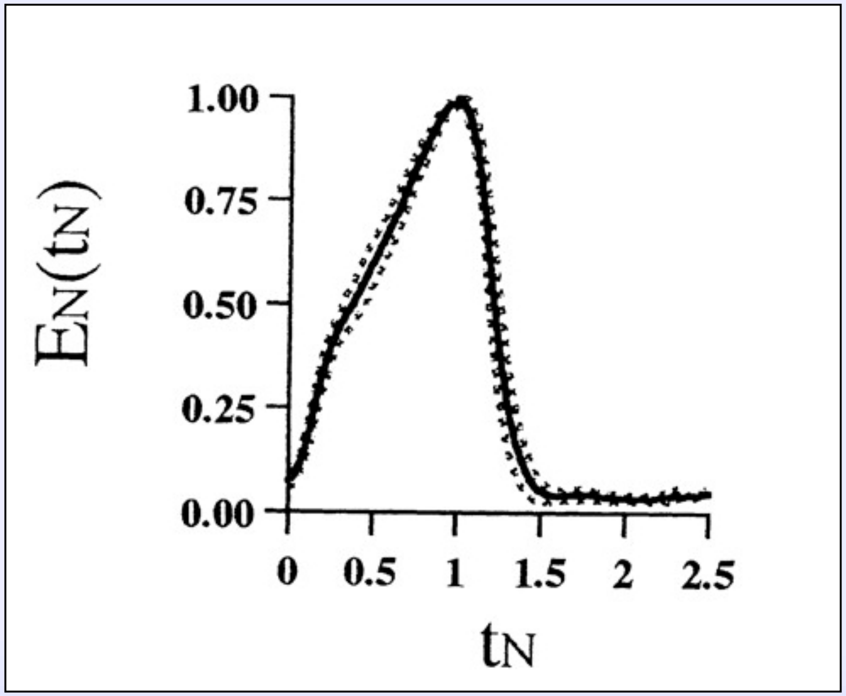




Elastance is the slope of a line between the unstressed volume and a point on the PV curve



We need to create a time-varying elastance (stiffness) to simulate periodic contraction and relaxation of the ventricle



Grouped human data: average (solid), +/- 1 SD (dashed)

From Senzaki et al. Circulation. 1996

Fluid analogs of electrical circuit laws relate blood pressures, volumes and flows

Analogs
Charge : Volume (V)
Voltage : Pressure drop (Pd)
Current : Flow (F)
Elastance : Elastance (E)
(1/Capacitance = Elastance)

Ohm's Law for fluids

$$F = P_d/R$$

Law of elastance

$$E = P_t/(V-V_{rest})$$

Kirchoff's Conservation Law

$$dV/dt = F_{in} - F_{out}$$

Time to open the simpleRC3.proj file

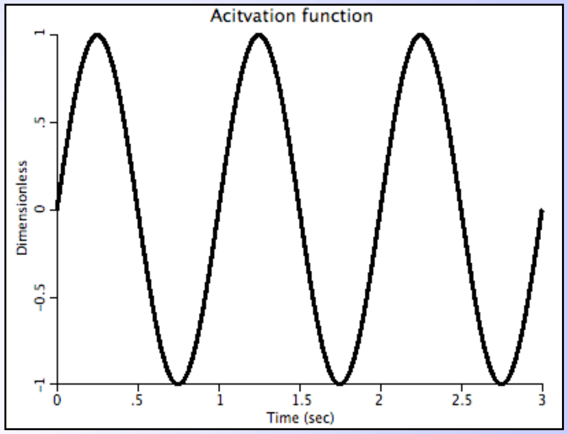
On Course Materials page?

http://nsr.bioeng.washington.edu/ > Model > ModelWiki > Cardiovascular_System > Hemodynamics > ventricle_driven_two_vessel > download

The time-varying elastance in simpleRC3.proj uses a sinusoidal activation function

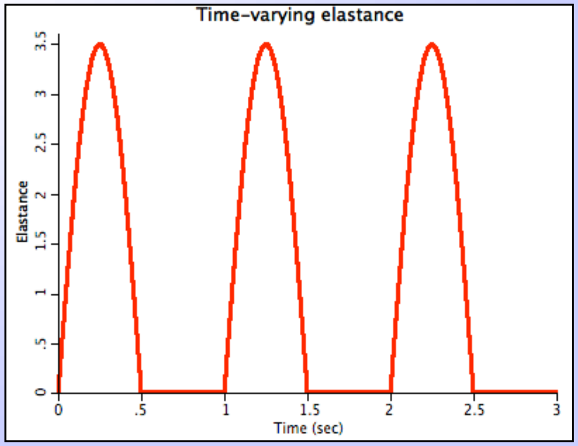
Activation function

y = sin(2*PI*HR*t);



Time-varying elastance

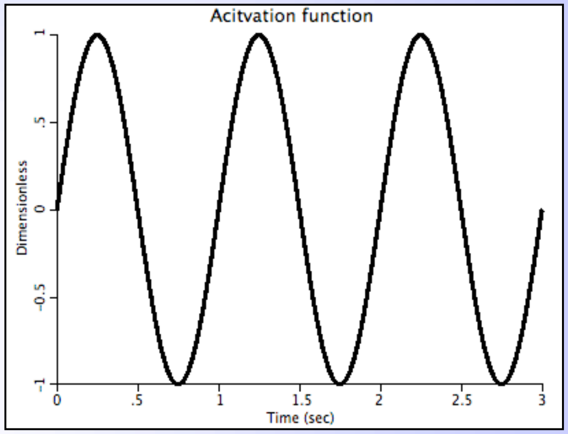
$Ev = \textit{if } (y>y0)\ ((y-y0)/(1-y0))*(E_{maxv}-E_{minv}) + E_{minv}$
$\quad \textit{else } E_{minv};$



simpleRC3.proj ***uses a sinusoidal activation function to set the time-varying unstressed volume***

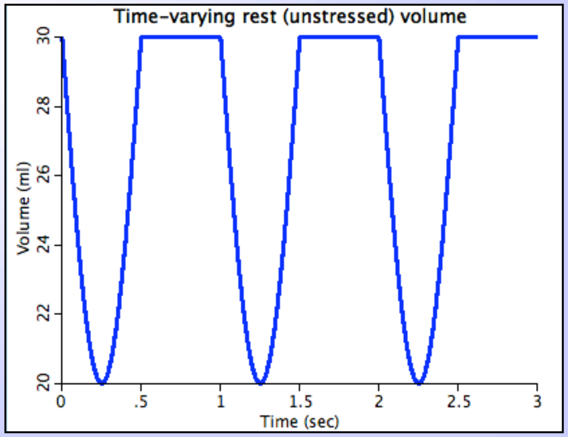
Activation function

y = sin(2*PI*HR*t);

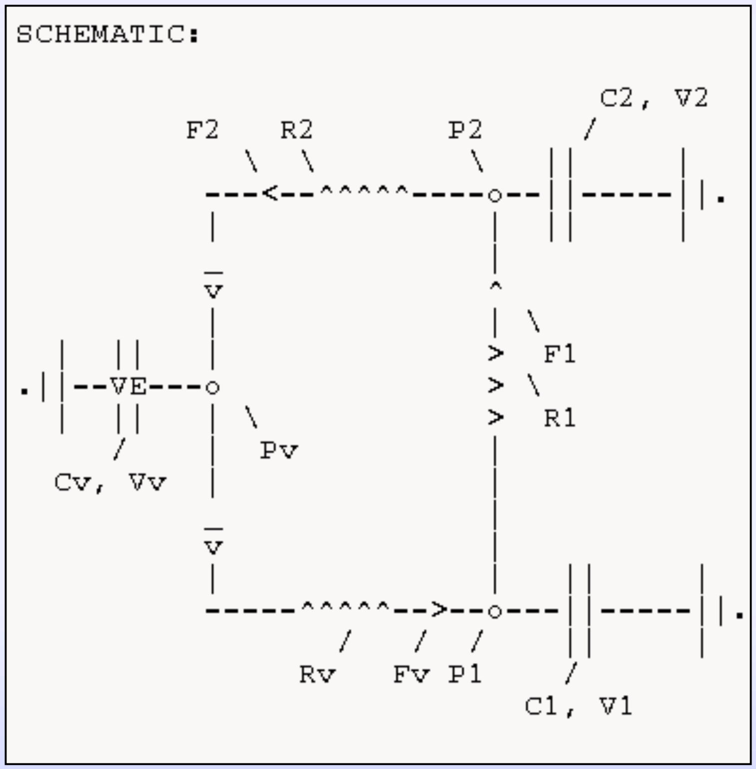


Time-varying unstressed volume

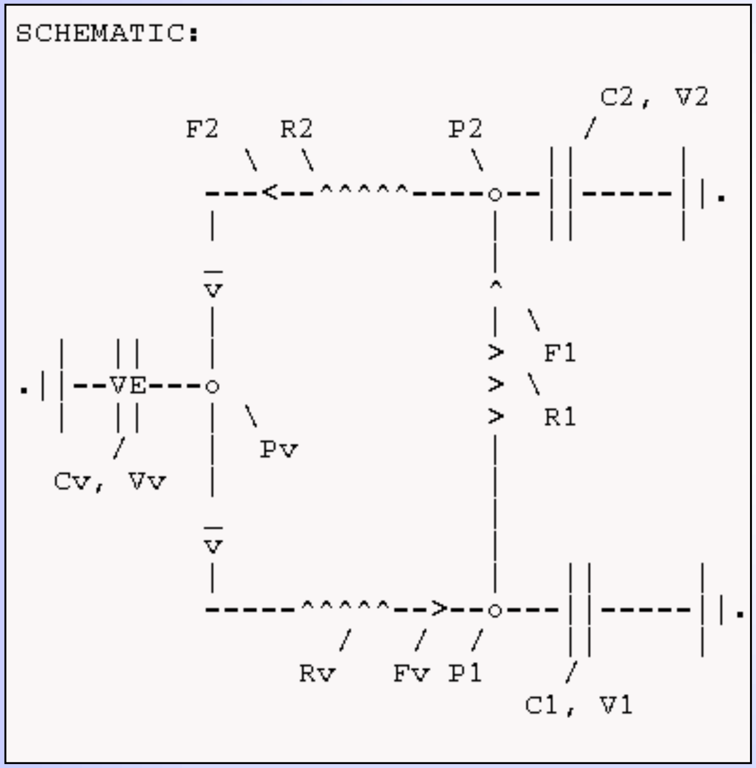
restVv = if (y>y0) ((1-y)/(1-y0))*(restVvd-restVvs) + restVvs
else restVvd;

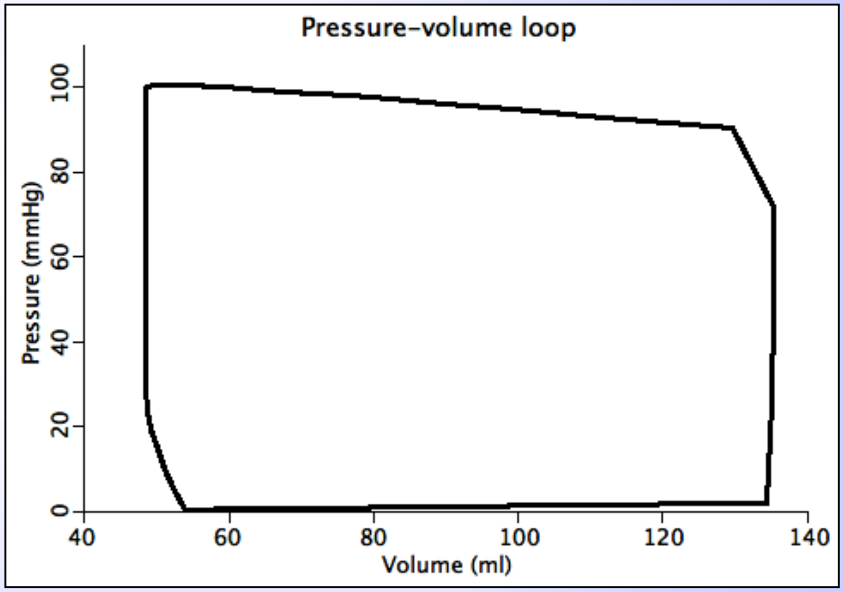


simpleRC3.proj simulates the systemic circulation as two compliant vessels: arteries and veins



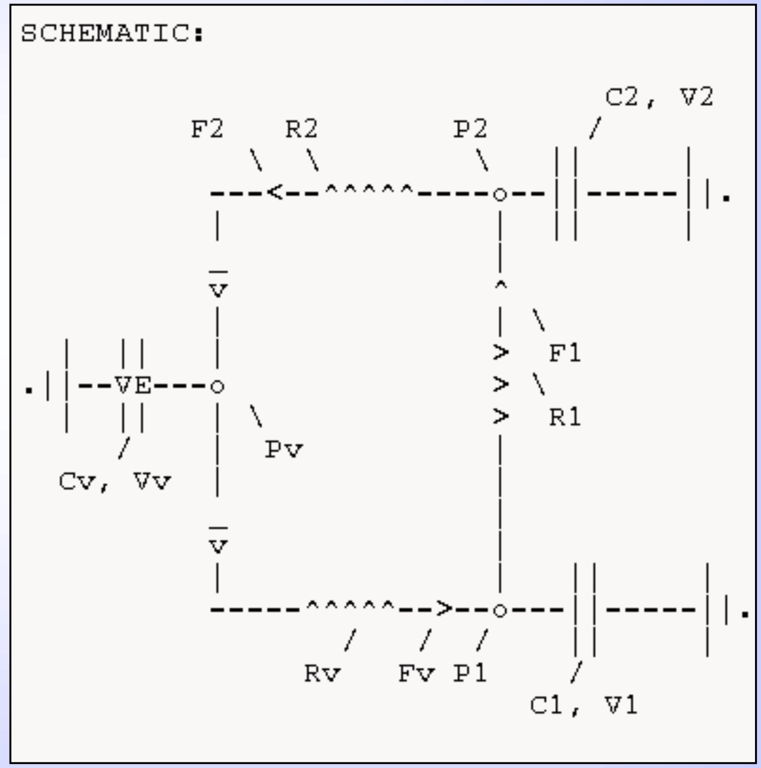
A single varying-elastance ventricle pumps blood through the circulation





We compute ventricle pressure from the elastance, volume, unstressed volume of the ventricle and external pressure

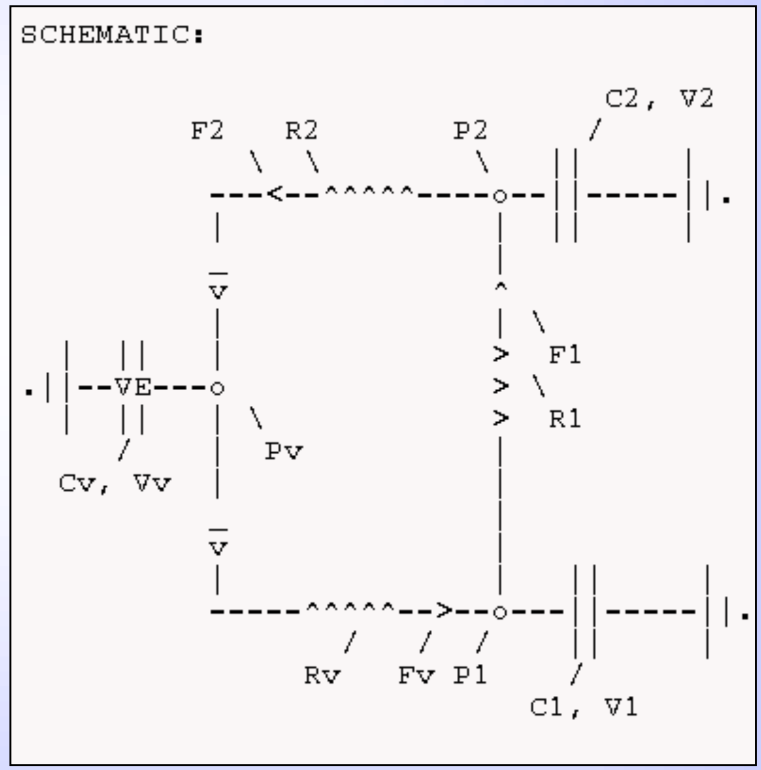
Pv = Ev*(Vv-restVv) + Pext;



Outflow through the ventricle is set using a conditional Ohm's Law for Fluids, simulating the aortic valve

Fv = if (Pv>P1) (Pv-P1)/Rv

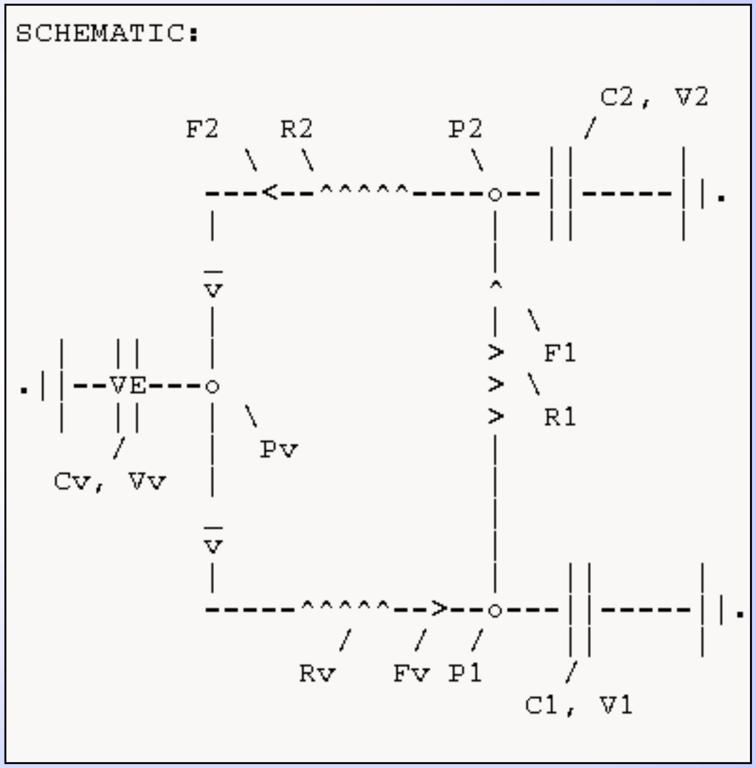
else 0



Inflow is also set using a conditional Ohm's Law for Fluids, simulating the mitral valve

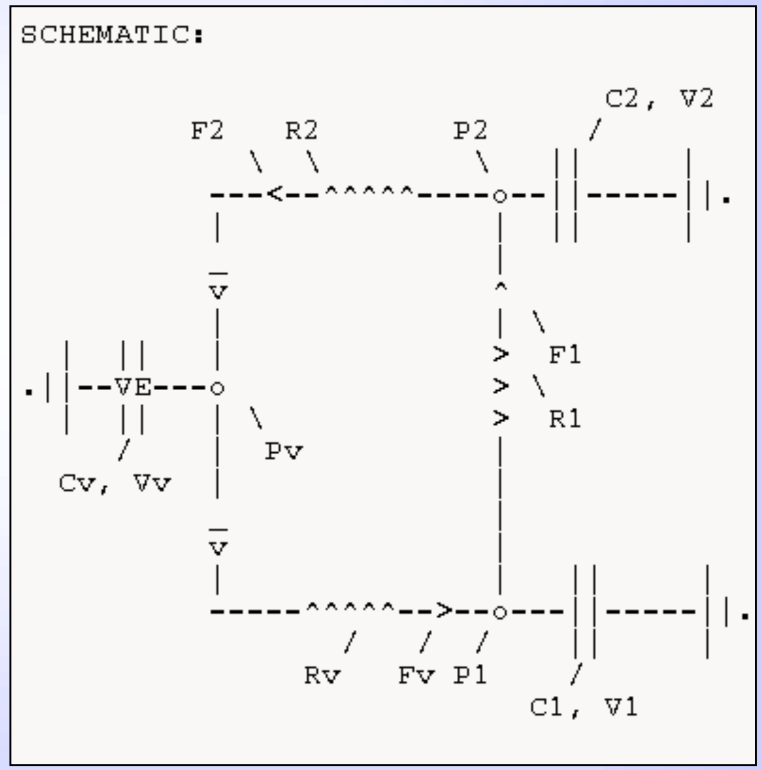
Fv = if (P2>Pv) (P2-Pv)/R2

else 0

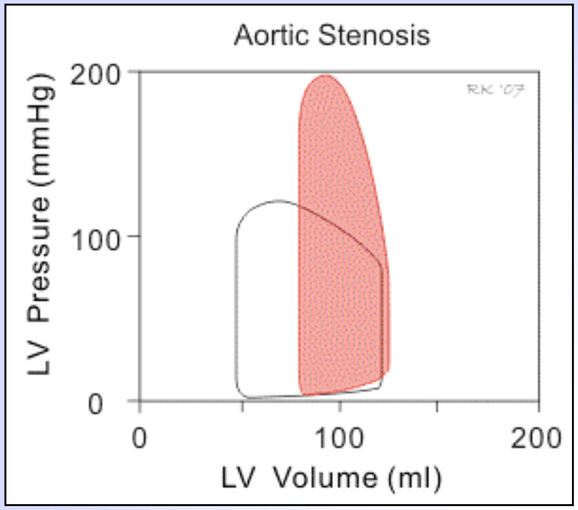


The change in ventricle volume is inflow minus outflow

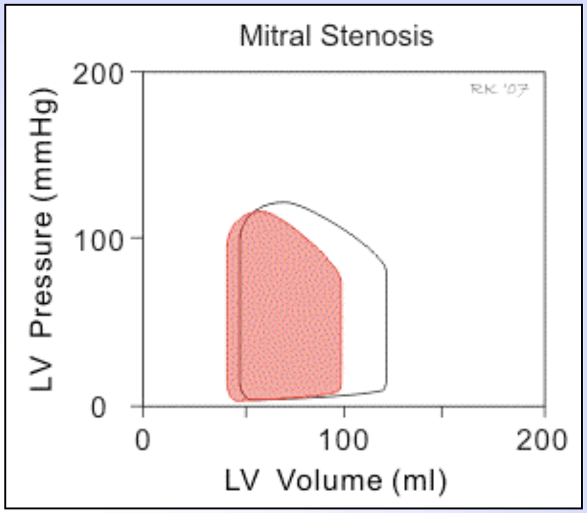
dVv/dt = F2-Fv;



Simulate cardiac abnormalities by adjusting parameters in JSim loops tab



Adjust parameter Rv



Adjust parameter R2

More questions:

- ***What parameter(s) would you adjust to simulate a heart attack?***
- ***How does the PV loop change after a heart attack?***
- ***What happens to Pv and Vv when HR is increased?***
- ***How do elastance and resistance parameters influence flow throughout the circulation?***