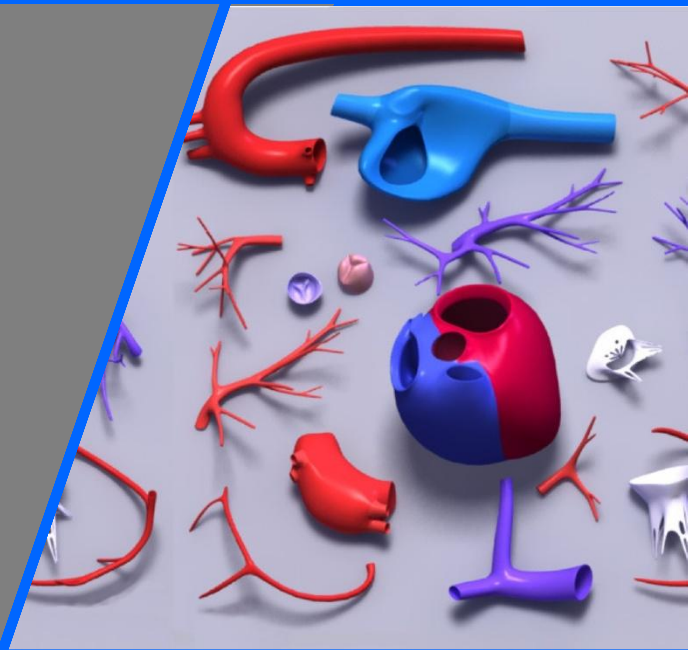
CircAdapt Simulator

interactive simulation tool for teaching cardiovascular (patho)physiology



Joost Lumens, PhD
on behalf of the CircAdapt Team

Department of Biomedical Engineering
CARIM School for Cardiovascular Diseases
Maastricht University Medical Center

Maastricht University

CircAdapt Simulator: online freeware

EUROPEAN SOCIETY OF CARDIOLOGY®

European Heart Journal (2014) **35**, 331–337
doi:10.1093/eurheartj/eht564

CARDIOPULSE

Creating your own virtual patient with CircAdapt Simulator

Dutch researchers have produced software for simulating cardiovascular dynamics for teaching and improving patient care

free stand-alone software compatible with both Windows and Mac OS X

development of the CircAdapt Simulator is funded by Stichting IT Projecten (www.stitpro.nl)

www.circadapt.org

Primary goals of the CircAdapt Model

Besides being a research tool, it should also be an educational tool on whole circulation dynamics for students in Biomedical Engineering and Medicine

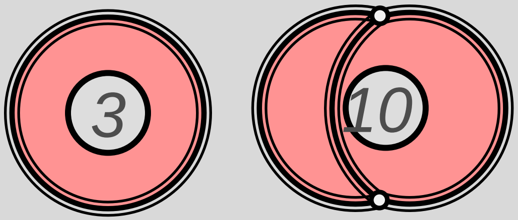
Requirements:

- Primarily based on physical principles (conservation of energy, force equilibrium, etc.)
- Physiologically accurate
- Modular structure, allowing modification by teacher or student
- Maximum validity range with minimum number of parameters

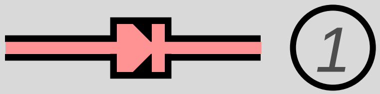
Arts T, et al. (2005) Am J Physiol 288: H1943-H1954
Lumens J, et al. (2009) Ann Biomed Eng 37: 2234-2255

Modules and their physical principles

N = number of state-variables

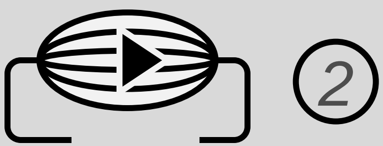


Myofibre-Patch-Wall forming cardiac cavities (atria & ventricles)

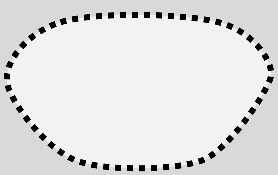


Valve: inertia + Bernoulli effect

Vessel: compliant cavity



Arterio-Venous network: resistances, compliances

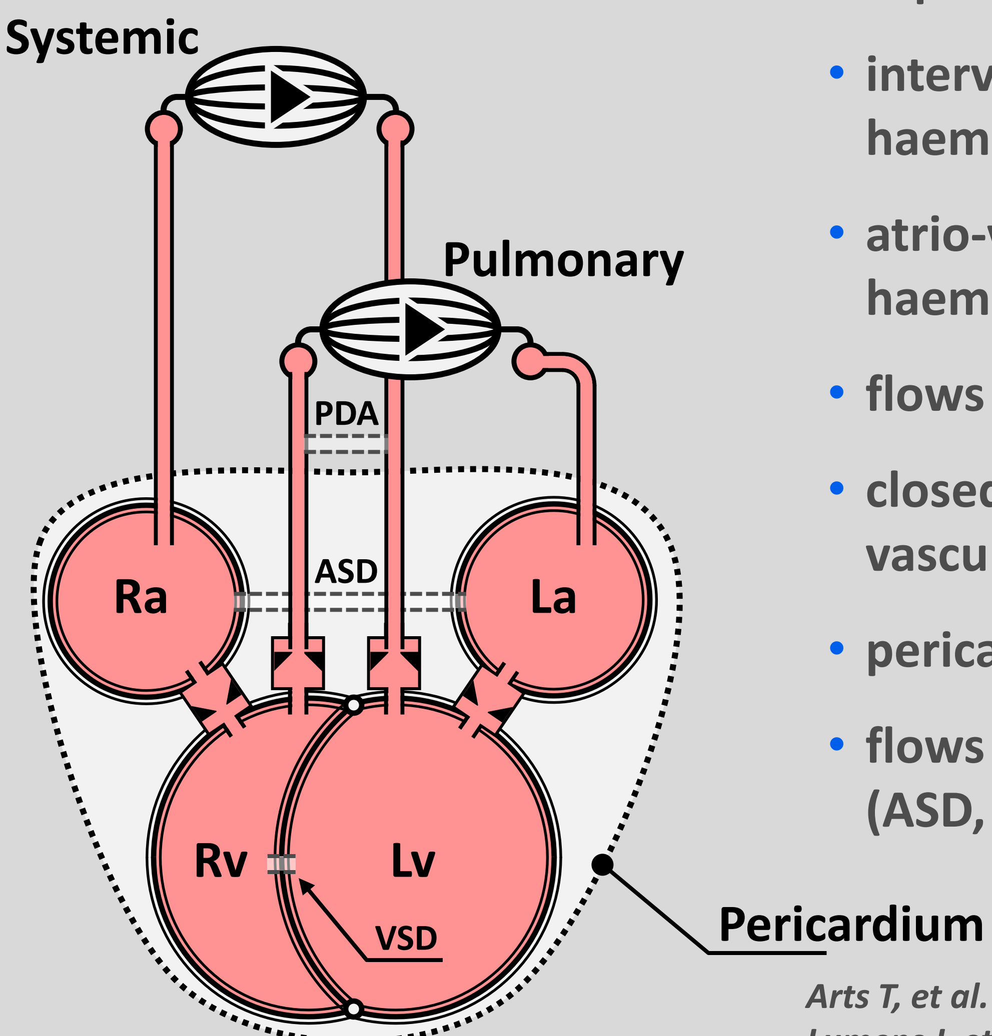


Bag: pressure around group of modules, compliant

Node for connections

Arts T, et al. (2005) Am J Physiol 288: H1943-H1954
Lumens J, et al. (2009) Ann Biomed Eng 37: 2234-2255

Plumbing a cardiovascular system



- 4-chamber heart with interventricular septum
- interventricular mechanical and haemodynamic interaction
- atrio-ventricular and ventriculo-arterial haemodynamic interaction
- flows through valves and vessels
- closed-loop system with 2 peripheral vascular beds (pulmonary and systemic)
- pericardium around heart
- flows through 3 potential shunts (ASD, VSD and PDA)

Arts T, et al. (2005) Am J Physiol 288: H1943-H1954
Lumens J, et al. (2009) Ann Biomed Eng 37: 2234-2255

Download and installation

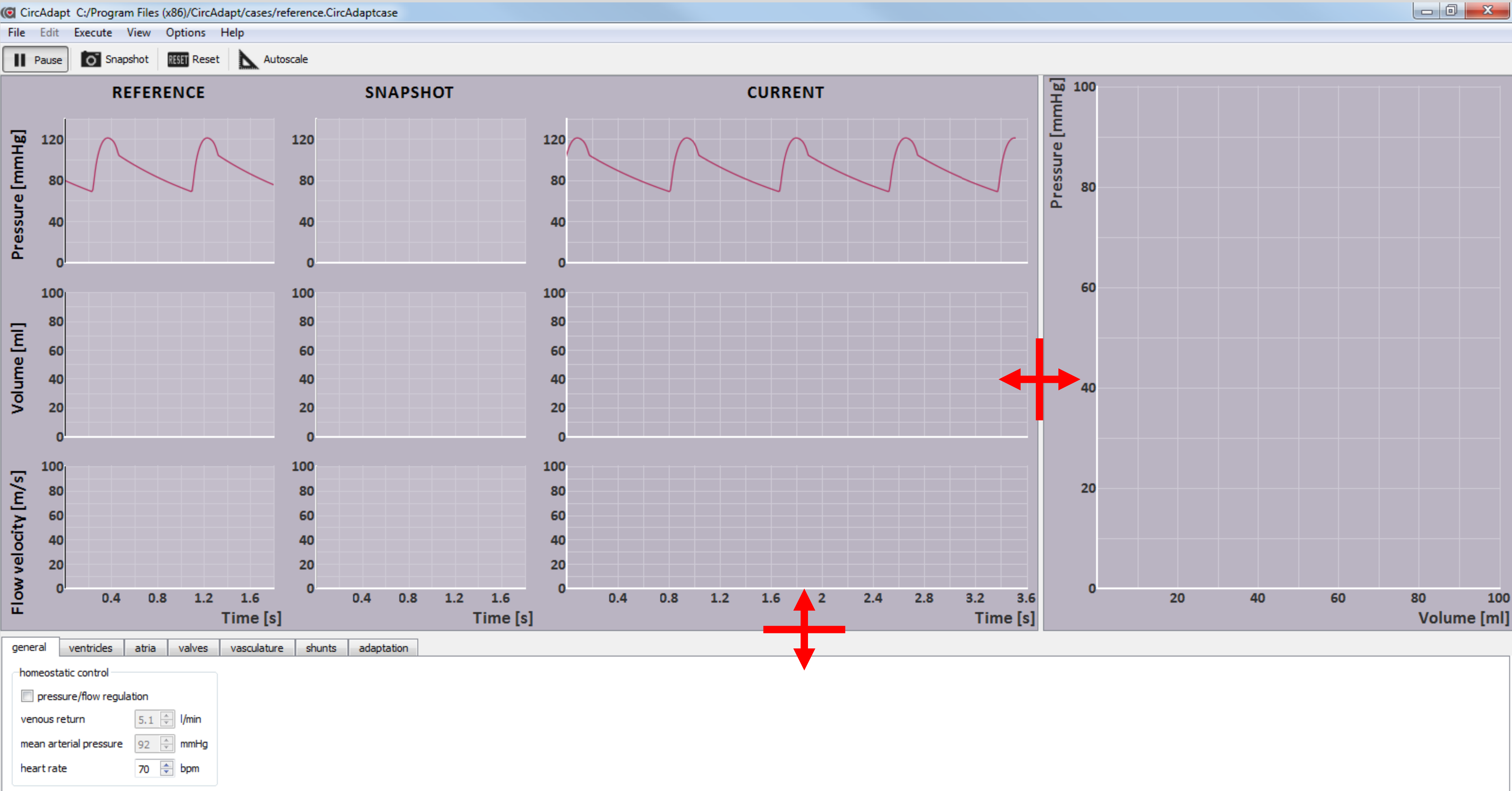
Download the software from our website
www.circadapt.org
and install it on your computer.

Visit www.circadapt.org for more information.

Manual & example tutorial:
http://www.circadapt.org/documentation

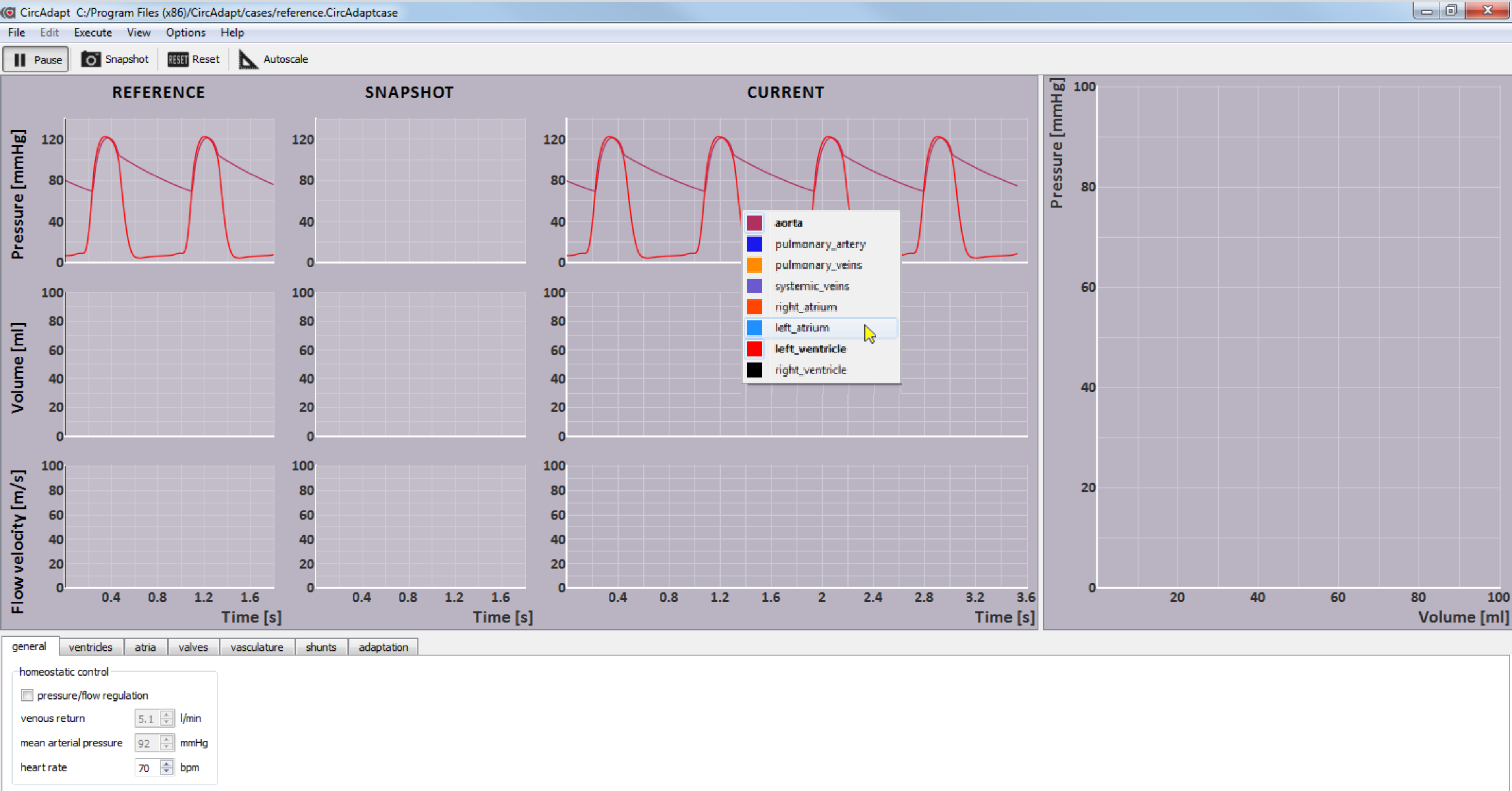
Getting started I

- Launch the program.
- Default screen: user can optimise the sizes of the panels (red arrows).



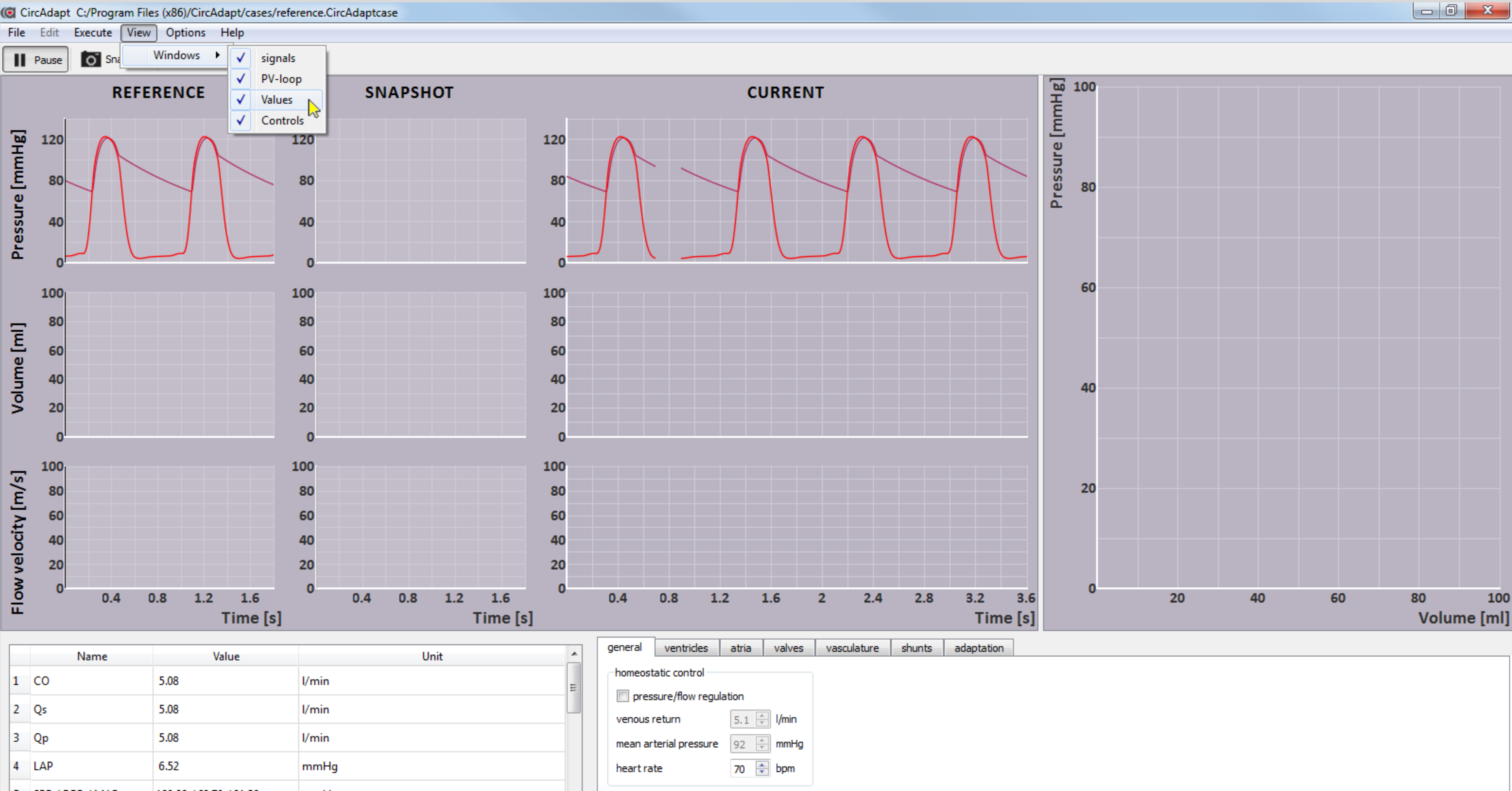
Getting started II

- Display any desired signal by clicking right mouse button in any of the panels.
- Available signals are vascular and cardiac pressures, cardiac volumes, valvular blood flow velocities and cardiac pressure-volume relations.



Getting started III

- Display the Values-pane by clicking View >> Windows >> Values in the menu-bar.
- This pane shows values of hemodynamic variables on a beat-to-beat basis from current simulation.
- Mouse over the different symbols/abbreviations to see their definitions.



Some examples of simulations

1) **Physiology 1:**

   basal knowledge about haemodynamics

2) **Physiology 2:**

   left ventricular filling and the role of the atrioventricular delay

3) **Pathophysiology:**

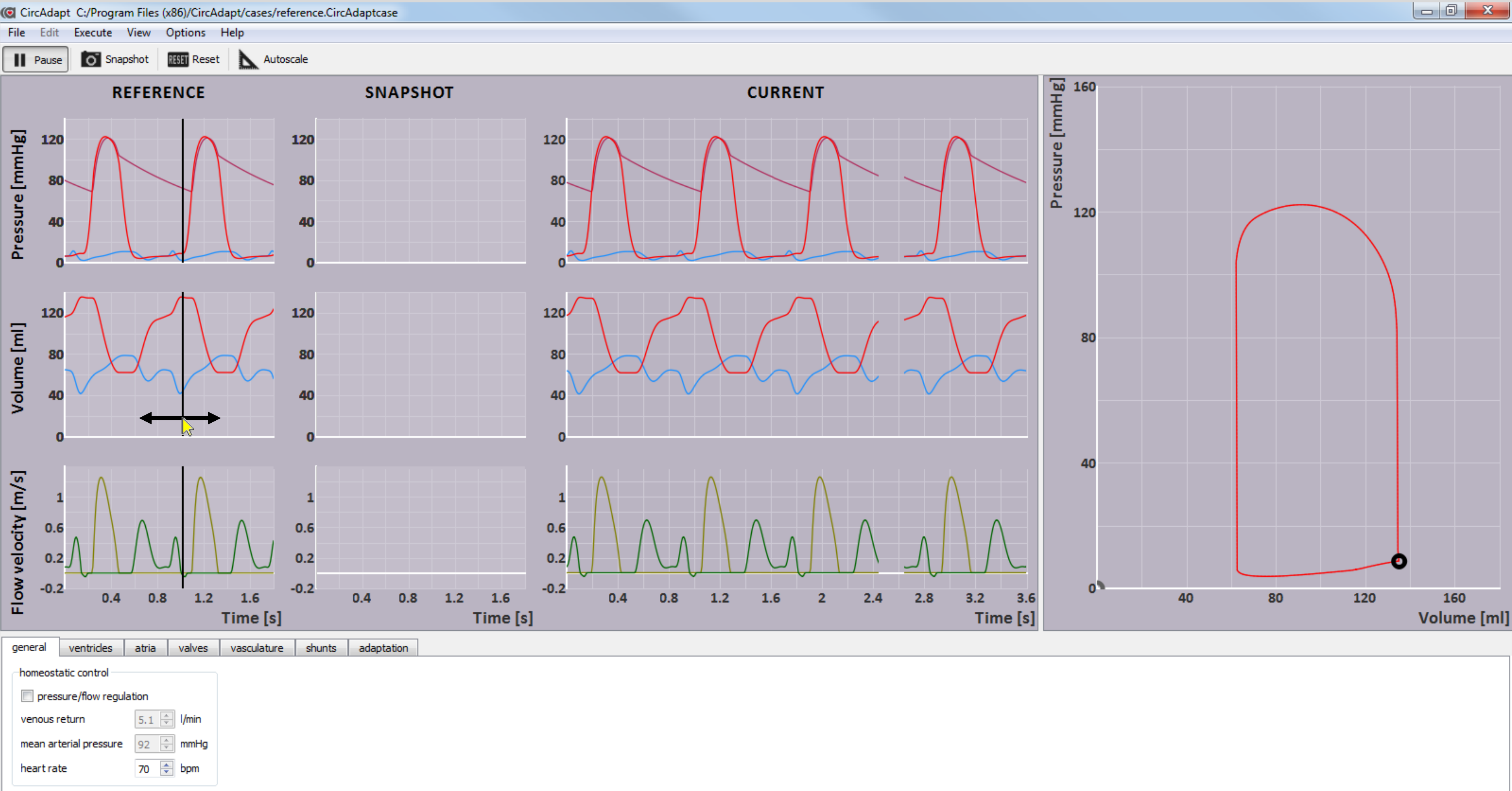
   mitral insufficiency / aortic stenosis

Visit www.circadapt.org for more information.

Manual & example tutorial:
http://www.circadapt.org/documentation

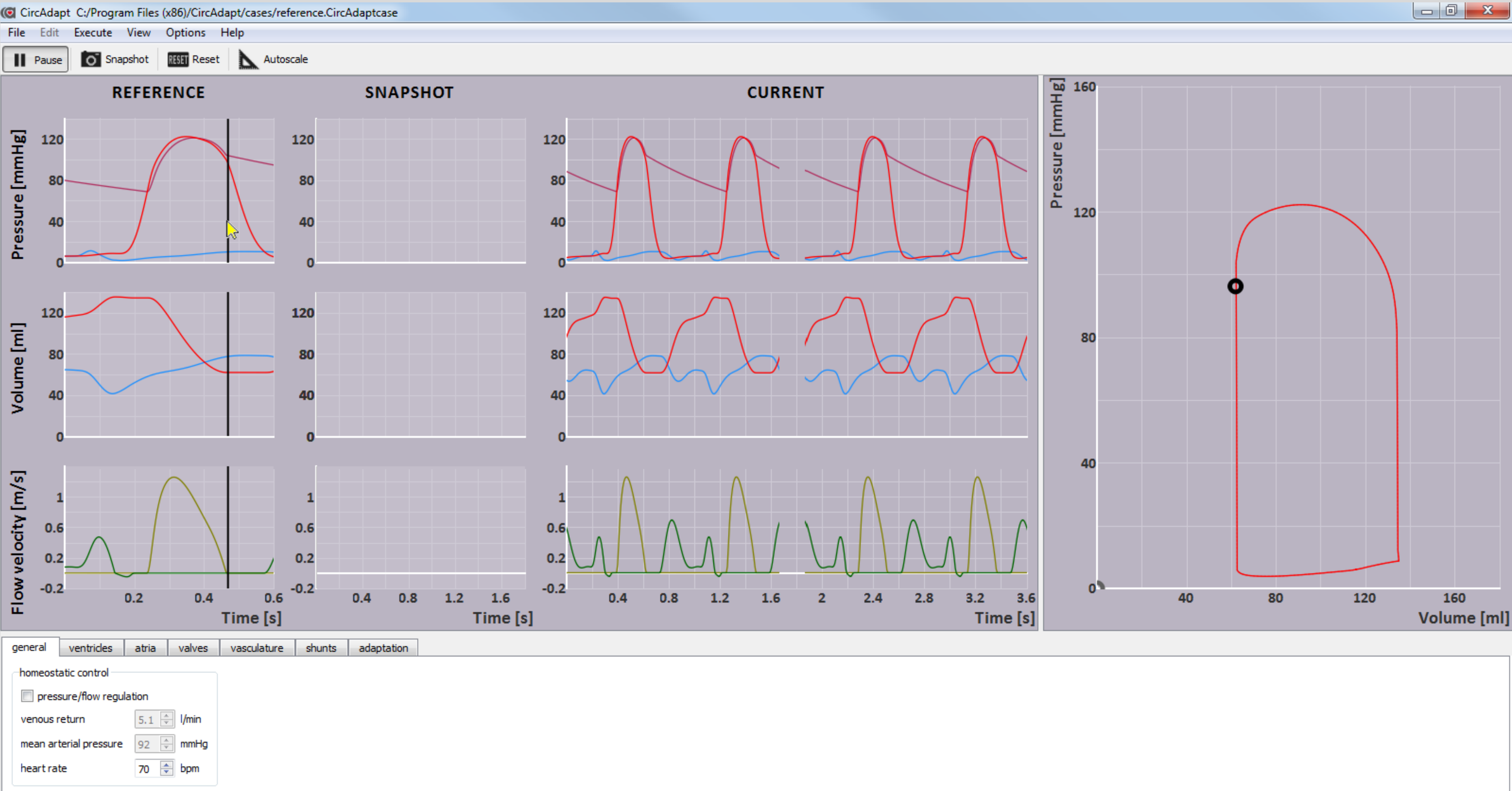
Timing of valve opening and closure

- Display all left heart signals as shown below and click in the REFERENCE column to show marker.
- Drag time marker (black line) and determine moments of aortic and mitral valve closure/opening.
- Example exercise: start with only LV or aortic pressure and let student reason which next signal is required for determining timing of valve events. Finally, display LV pressure-volume relation and follow the marker (circle).



Timing of valve opening and closure

- **Zoom in on LV and aortic pressure signals by placing the mouse in the pressure-panel of the REFERENCE column and holding CTRL-button while scrolling up and down. Note that one can also zoom in the other dimension by only scrolling.**
- **Example: let student figure out that the trans-aortic pressure gradient reverses before the aortic valve closes due to inertia of the previously accelerated blood.**



Some examples of simulations

1) Physiology 1:

basal knowledge about haemodynamics

2) **Physiology 2:**

left ventricular filling and the role of the atrioventricular delay

3) Pathophysiology:

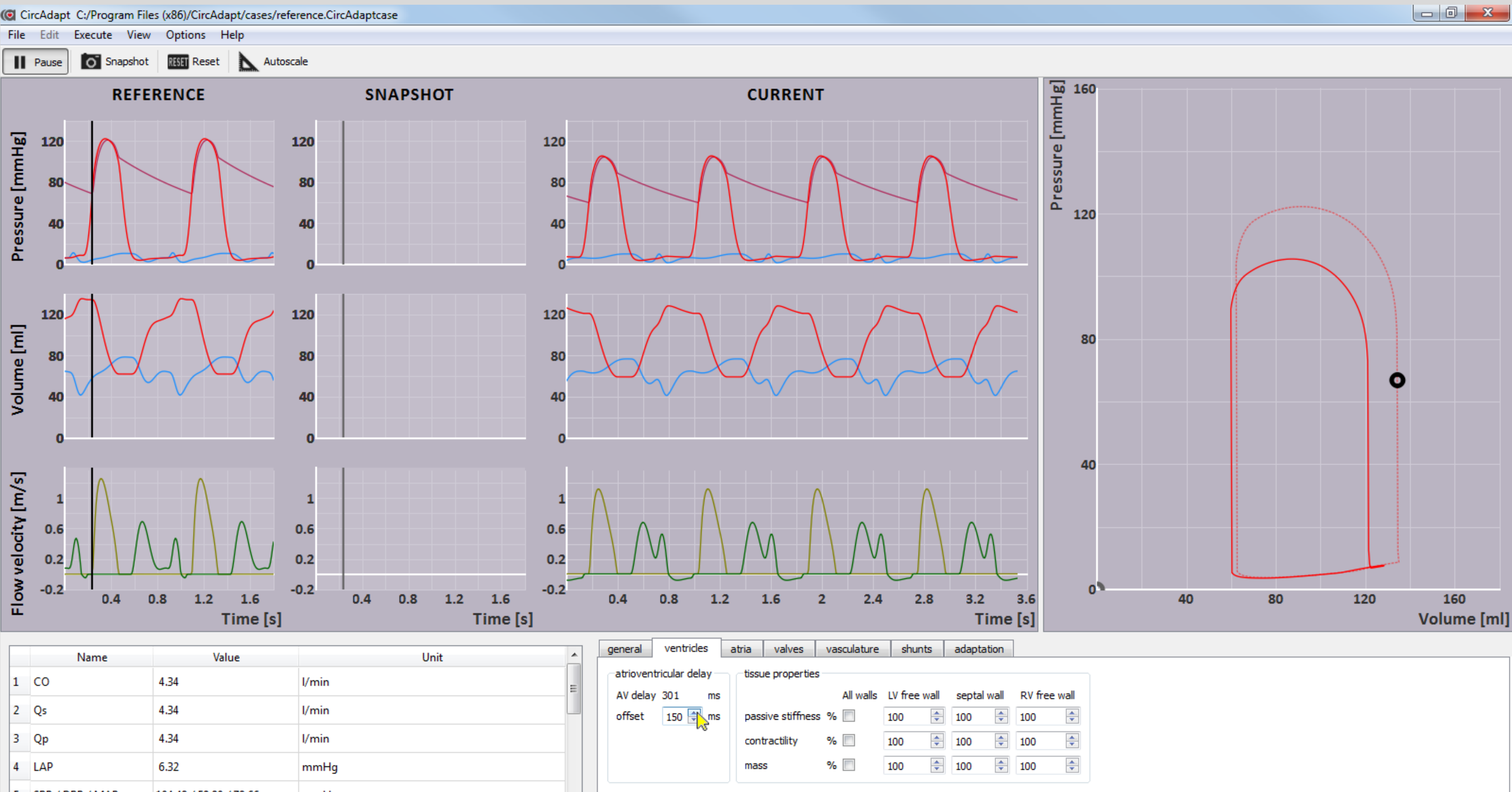
mitral insufficiency / aortic stenosis

Visit www.circadapt.org for more information.

Manual & example tutorial:
http://www.circadapt.org/documentation

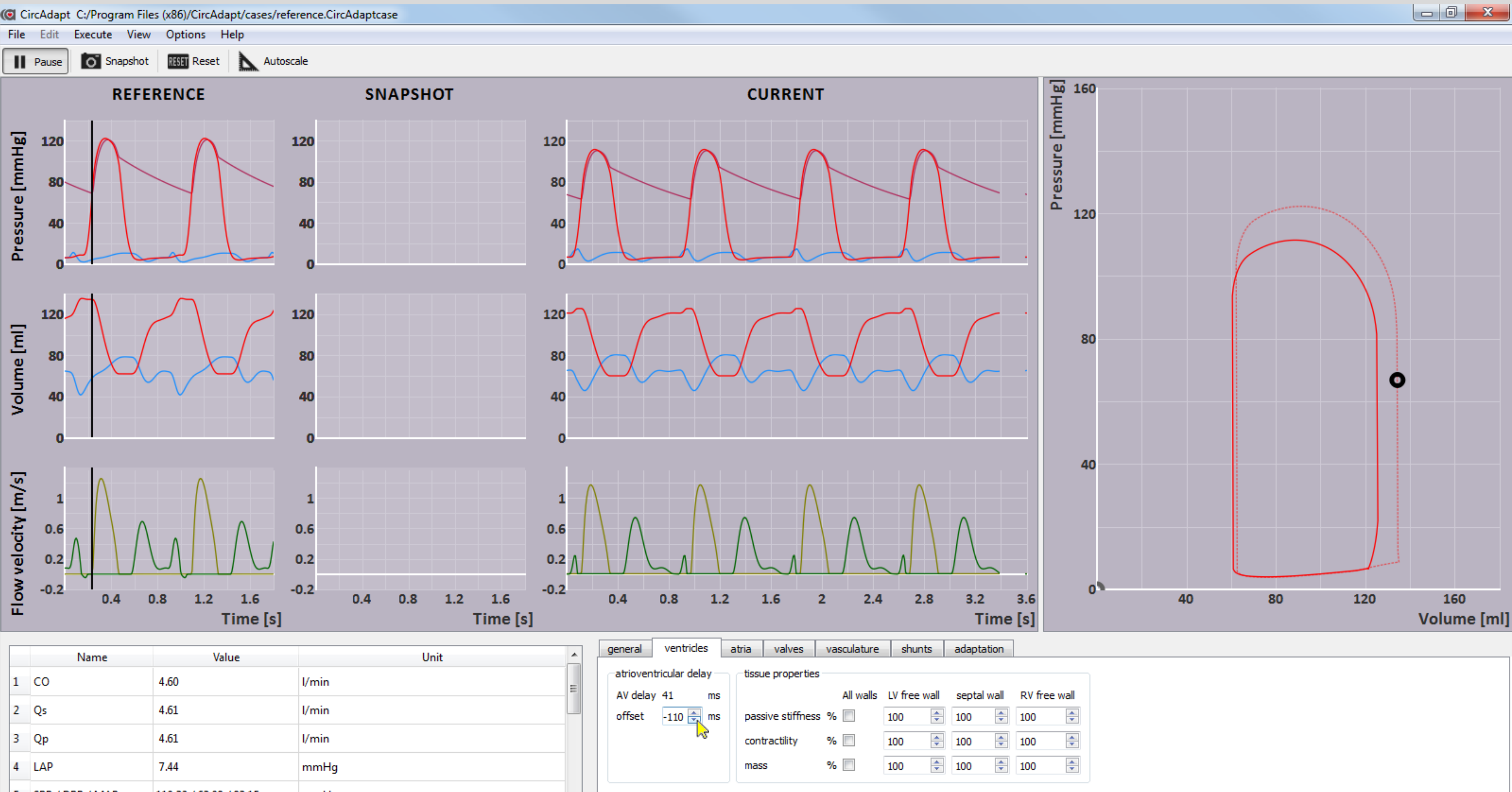
LV filling and the AV delay

- Go to the “ventricles” tab and prolong the AV delay gradually from its normal reference value (151 ms) to 301 ms.
- While gradually increasing the AV delay, observe the following changes of the mitral blood flow velocity signals:
  1) fusion of the passive E-wave and the active A-wave, and lengthening of the “isovolumic” contraction phase;
  2) development of functional mitral regurgitation due to delayed papillary muscle activation.
- Also observe the acute deterioration of global LV pump function (pressure-volume relation) due to compromised filling.



LV filling and the AV delay

- Shorten the AV delay gradually from 301 ms to 41 ms and observe the changes of the blood flow velocity signals:
  1) truncation of the mitral A-wave;
  2) shortening of the isovolumic contraction phase.
- Also observe the acute deterioration of global LV pump function (pressure-volume relation) due to compromised filling.
- Try to find the AV delay leading to optimal LV pump function.



Some examples of simulations

1) **Physiology 1:**

   basal knowledge about haemodynamics

2) **Physiology 2:**

   left ventricular filling and the role of the atrioventricular delay

3) **Pathophysiology:**

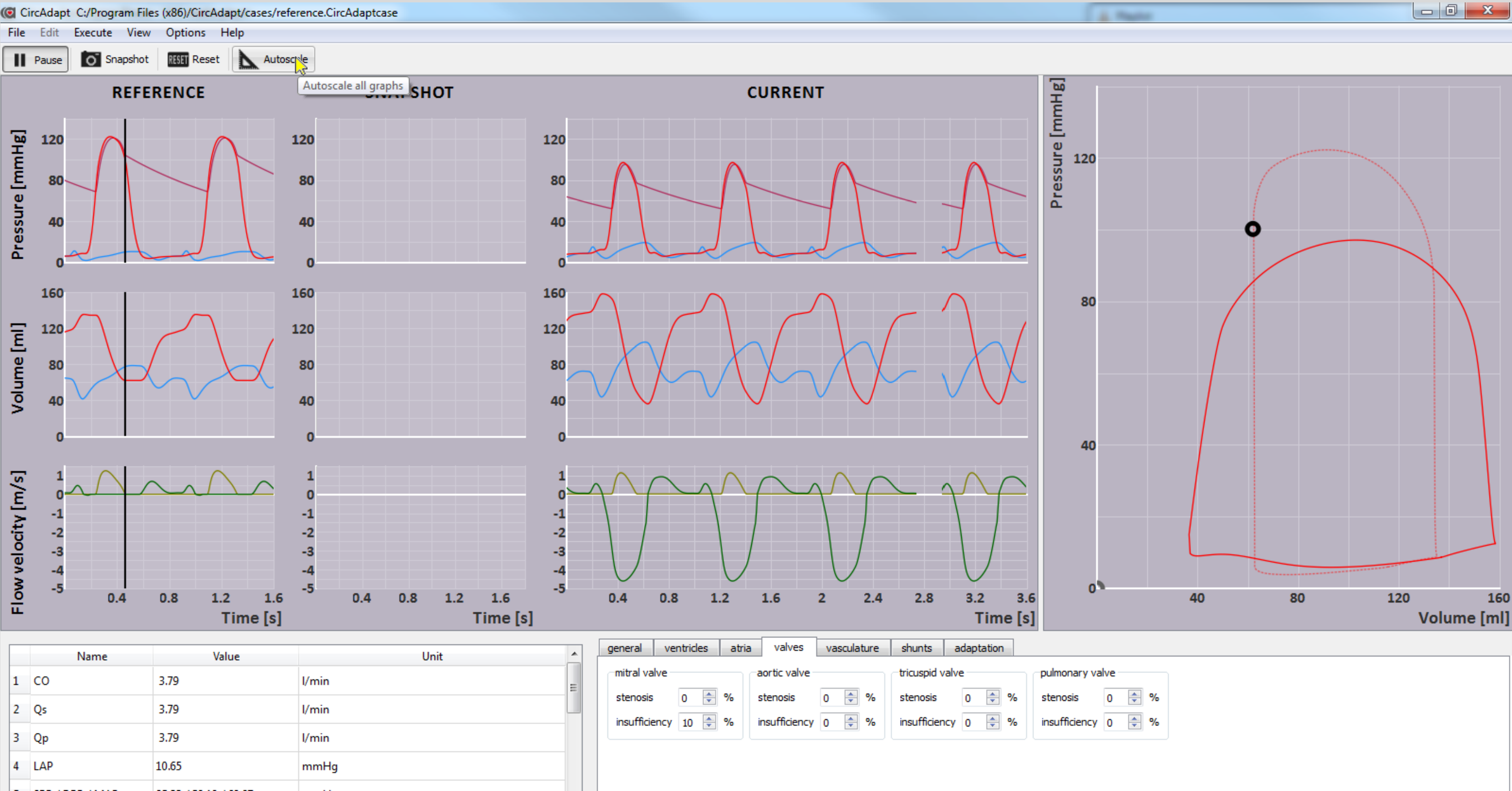
   mitral insufficiency / aortic stenosis

Visit www.circadapt.org for more information.

Manual & example tutorial:
http://www.circadapt.org/documentation

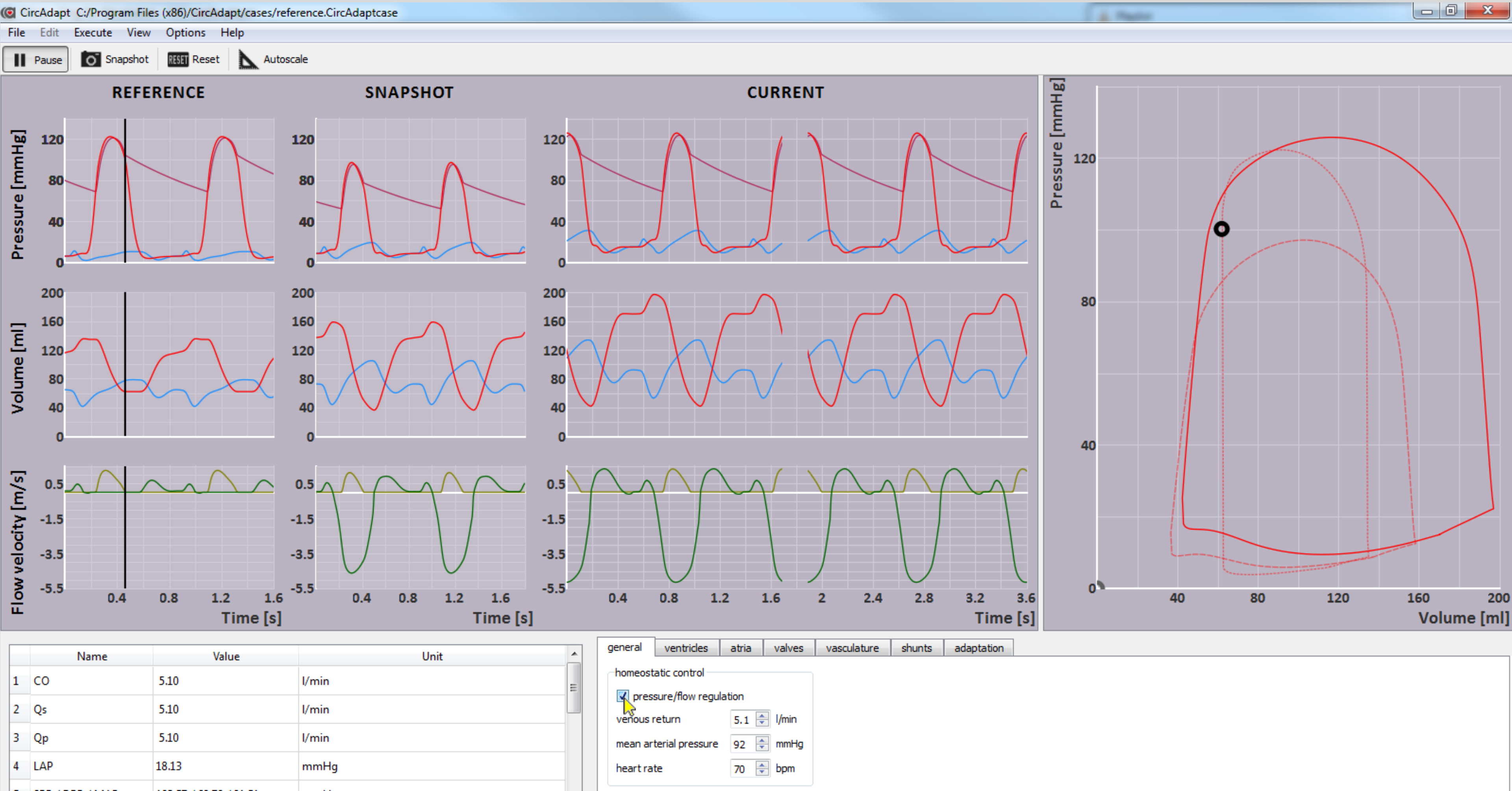
Mitral insufficiency

- Go to the “valves” tab and simulate a 10% mitral insufficiency. Press *autoscale*-button to automatically scale axes.
- Example exercise: let student determine what happened to cardiac output (Values-pane). Then, let them determine what happened to LV stroke volume by comparing the LV volume signals of the CURRENT simulation (10% MI) with that of the REFERENCE (no MI) simulation. Let them explain the discrepancy between the changes of stroke volume and cardiac output. Also point them at the loss of the isovolumic phases.



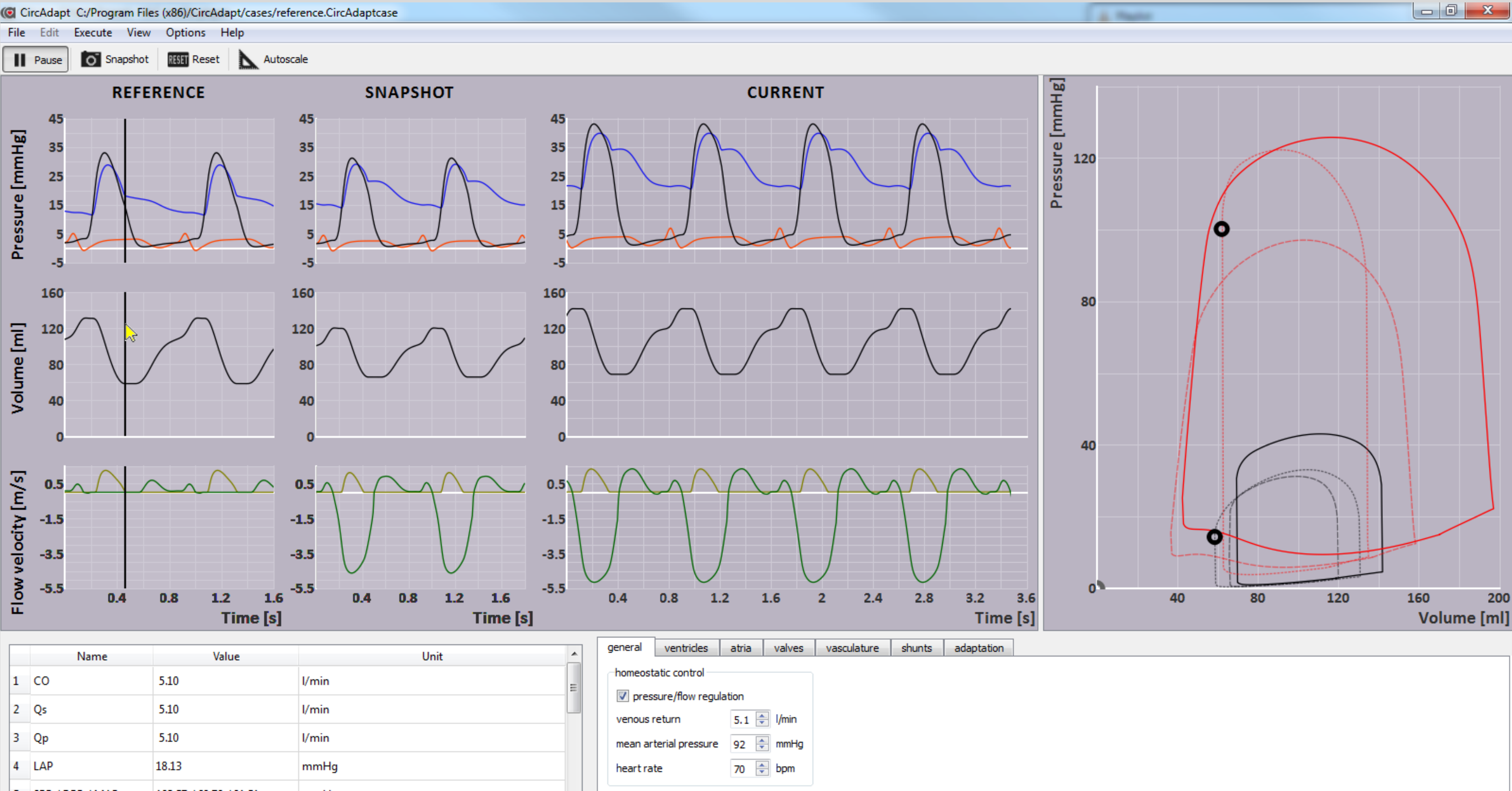
Mitral insufficiency

- Press the *snapshot*-button to save the current simulation in the SNAPSHOT column.
- Go back to the “general” tab and enable the pressure/flow regulation. The model will automatically restore venous return and mean arterial pressure by gradually changing the total blood volume and systemic vascular resistance.
- Press the *autoscale*-button regularly during this homeostatic control.
- Example exercise: let the student reason what happened with preload and diastolic LV pressure.



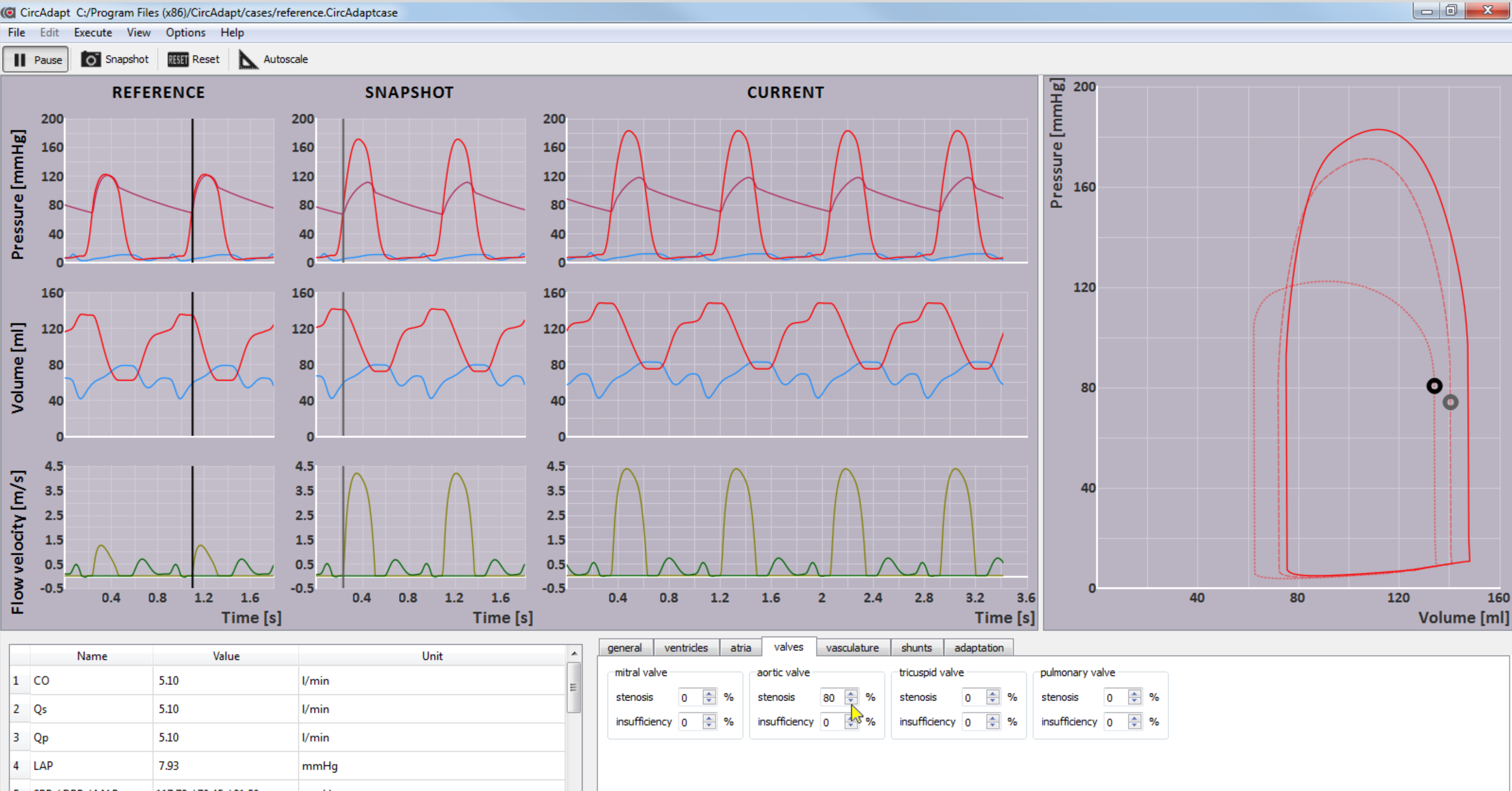
Mitral insufficiency

- Example exercise: let the student predict what would have happened to right ventricular (RV) haemodynamic loading in terms of preload and afterload.
- Display the RV pressure and volume signals and also the RV pressure-volume relation.
- Example exercise: let the student realise that RV loading conditions changed as a result of a left-sided problem (haemodynamic ventricular interaction: congestion could cause pulmonary oedema)



Aortic stenosis

- Press the *reset*-button to go back to the normal reference situation.
- Repeat the steps in slides 16 and 17 but now with simulating a 80% aortic valve stenosis instead of simulating mitral insufficiency.
- The result should look like the screenshot below.
- Note the increased transvalvular pressure gradient and the high blood flow velocity in the stenotic valve.



The CircAdapt Team: info@circadapt.org

Department of Biomedical Engineering
CARIM School for Cardiovascular Diseases
Maastricht University Medical Center

From left to right: Joost Lumens, Tammo Delhaas, Koen Reesink, Theo Arts and Willem Dassen.

CircAdapt Simulator is developed in close collaboration with Peacs (www.peacs.nl)
and its development is funded by Stichting IT Projecten (www.stitpro.nl).

Visit www.circadapt.org for more information.

Manual & example tutorial:
http://www.circadapt.org/documentation