A 0D-1D global, closed-loop model of the cardiovascular system

Stefano Costa [1], **Federica Caforio** [2,3,4], **Caterina Dalmaso** [1], **Christoph Augustin** [3,4], **Lucas Omar Müller** [1]

[1] Department of Mathematics, UniTrento, IT;   [2] Department of Mathematics and Scientific Computing, UniGraz, AT;   [3] Division of Biophysics, MedUniGraz, AT;   [4] BioTechMed-Graz, AT

CONTEXT

Understanding the **complex interactions** between the heart and the arterial and venous networks remains a significant challenge in cardiovascular research.

In this work we coupled the **ADAVN model**, a 1D anatomically accurate model of the vascular system, with the **CircAdapt model**, a 0D model of the cardiac function and pulmonary circulation.

The coupled model enables an in-depth study of the interplay between the heart and the vascular system.
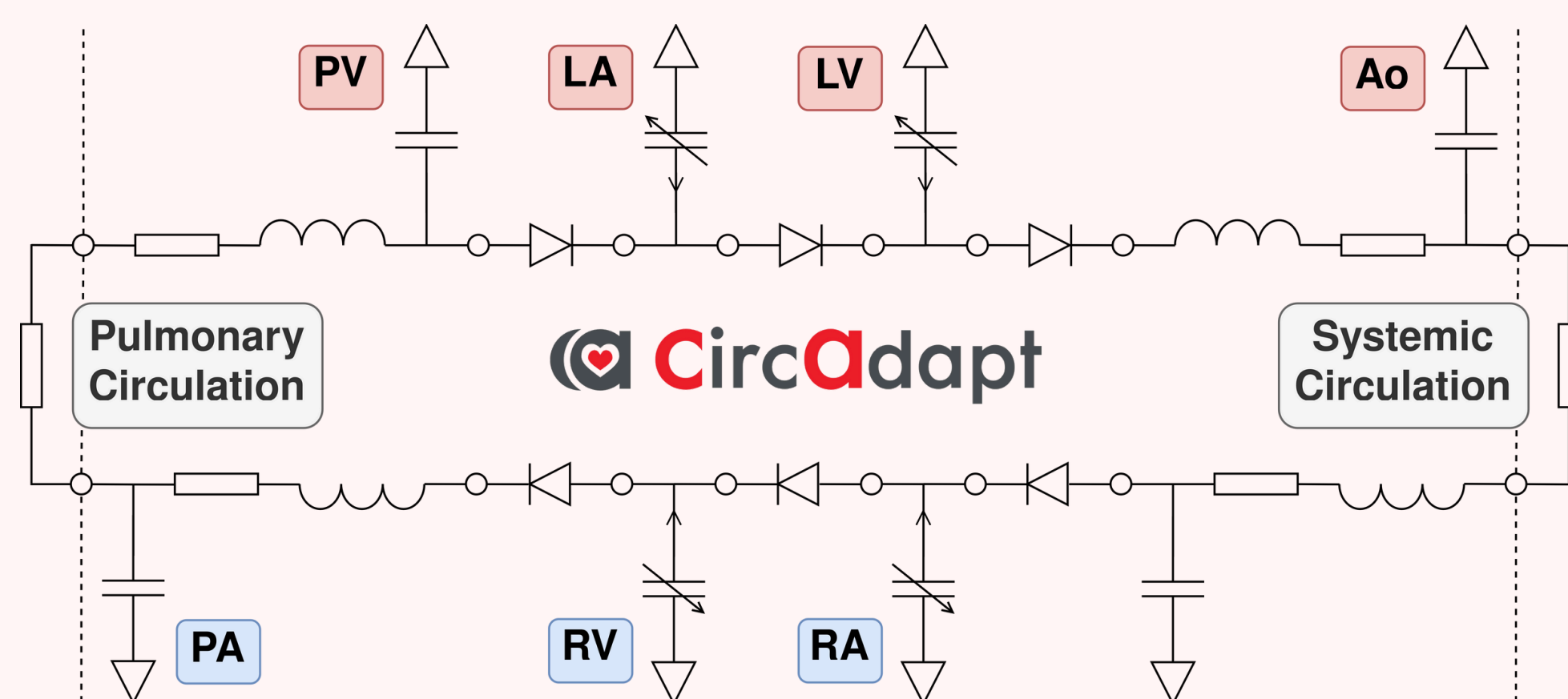
Electrical equivalent circuit of the CircAdapt model
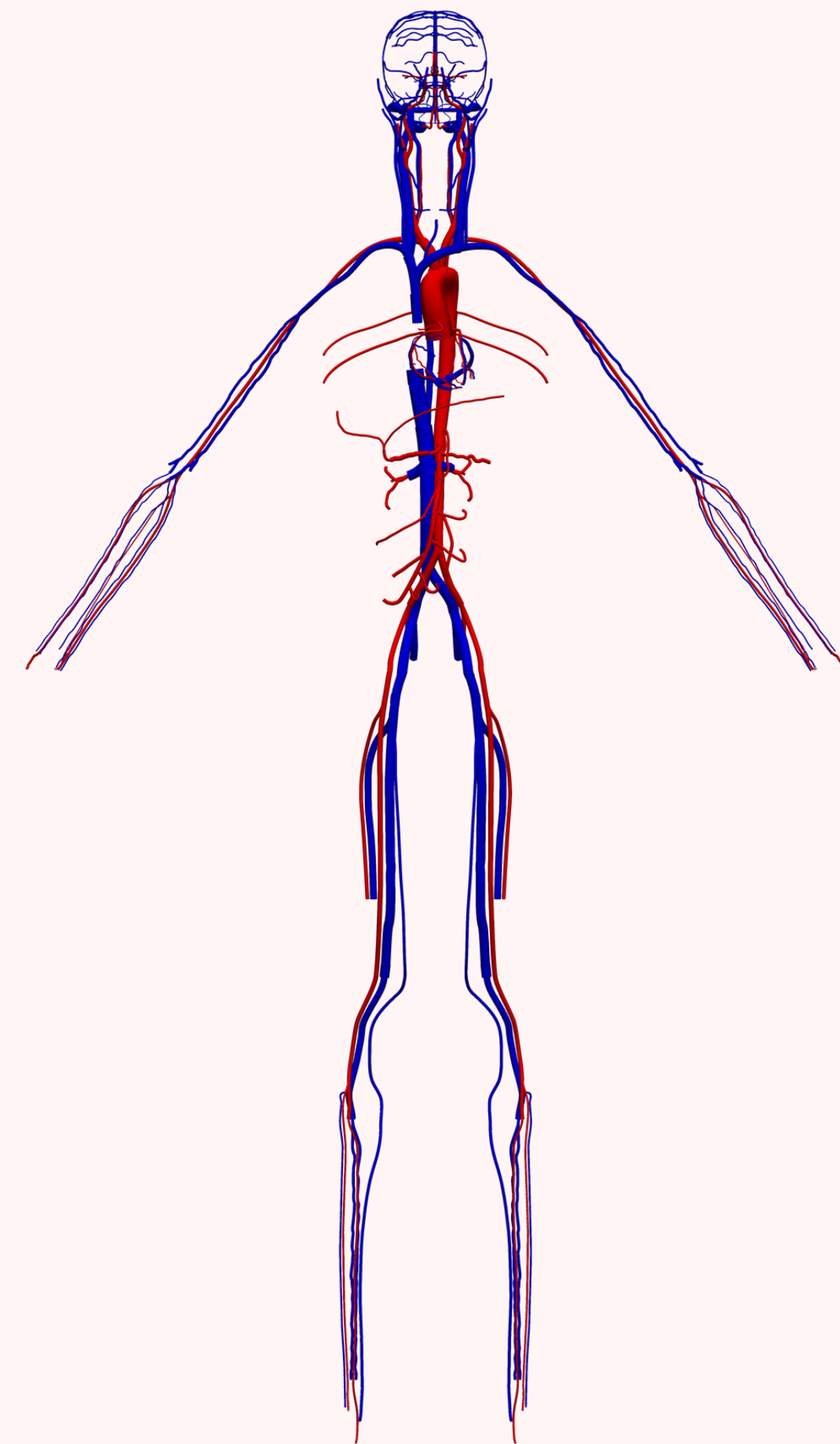
Arterial and venous vascular anatomy of the ADAVN model

CIRCADAPT

CircAdapt is a **0D hemodynamic model**, i.e., it simplifies the cardiovascular system to a set of ordinary differential equations.

It is **modular**, consisting of components for vessels, heart chambers, pericardium, sarcomeres, tubes, and valves.

This modularity allows it to be **easily coupled** with more detailed models of specific compartments.
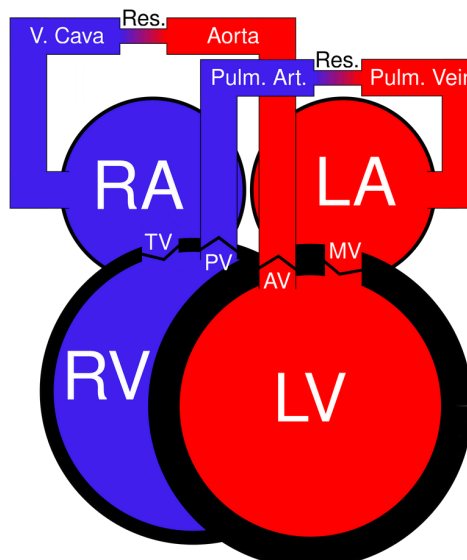
Anatomy of CircAdapt

ADAVN

"ADAVN" stands for **A**natomically **D**etailed **A**rterial **V**enous **N**etwork

Several **boundary conditions** are used to couple vessels, and **high-order finite volume solver** are used to approximate the solution.

One-dimensional blood flow equations

$$\begin{cases} \partial_t A + \partial_x q = 0 \\ \partial_t q + \partial_x \left(\frac{q^2}{A} \right) + \frac{A}{\rho} \partial_x p = -\frac{f}{\rho} \end{cases}$$

ADAVN network

86 systemic arteries

23 coronary arteries

189 systemic veins

COUPLING

To enable the coupling, the ADAVN model is included as an additional tube in the CircAdapt model.

At each time step, ADAVN receives the AoV flow and the RA pressure from CircAdapt, and returns the pressures and the average flows in AAo, CS and VCs. To update the coronaries, CircAdapt sends cavity pressures and volumes to ADAVN.

Before the coupling, the ADAVN model is pre-initialized to reach convergence.
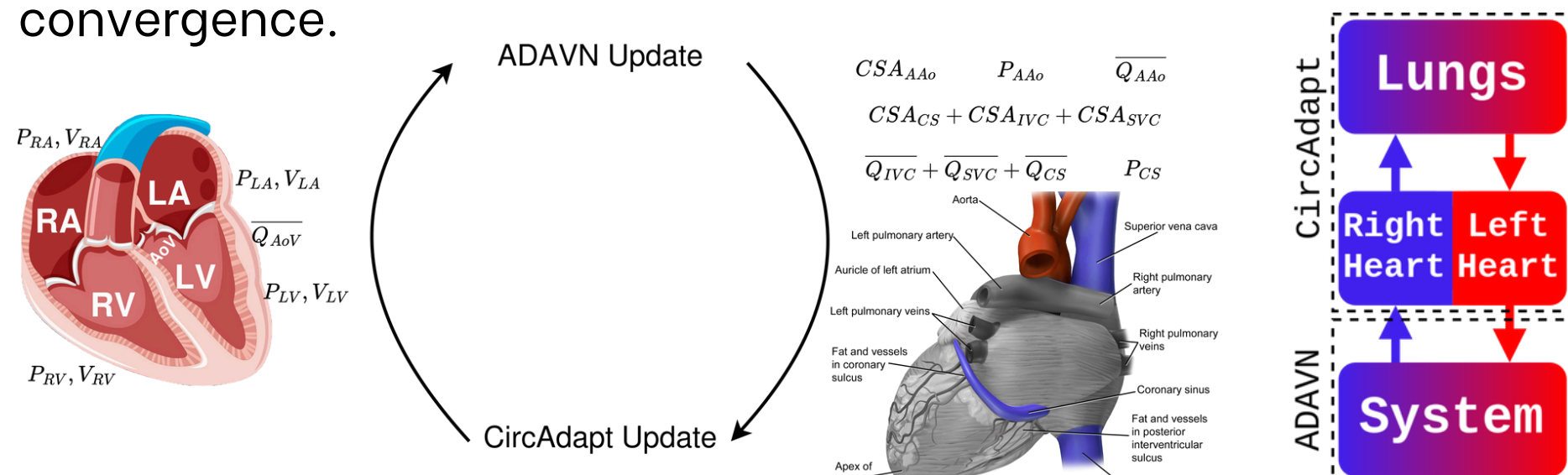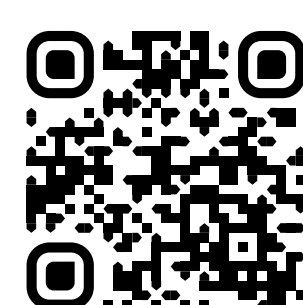

RESULTS
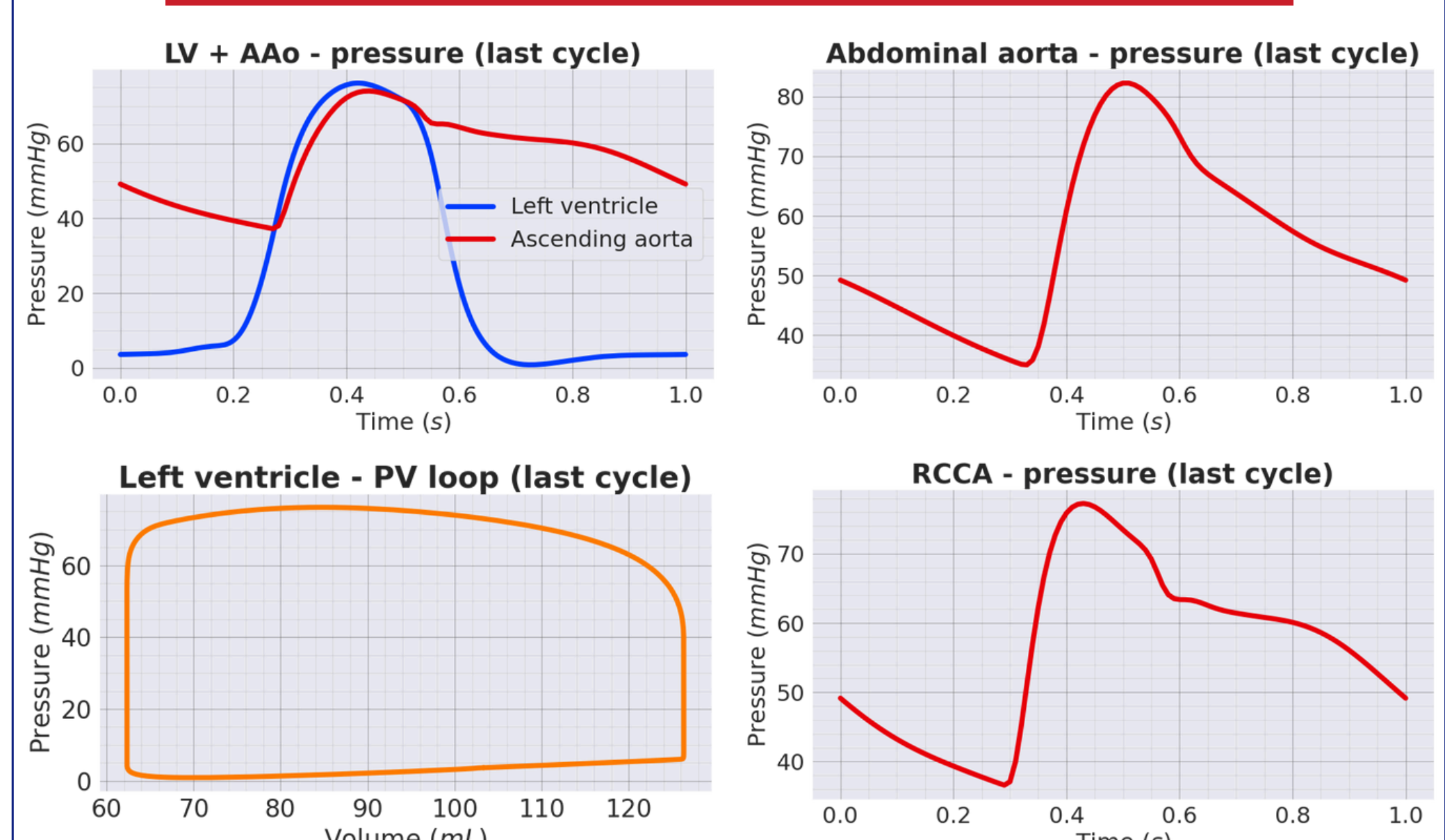
CONCLUSION + FUTURE WORK

We obtained a 0D-1D model which provides insight into **cardiac biomechanics** thanks to the CircAdapt model and **wave propagation dynamics** thanks to 1D formulation for the vascular system.

In the future we want to apply the coupled model to several pathologies, e.g., system hypertension and pulmonary hypertension.

LET'S KEEP IN TOUCH

Personal website

More on this work

st-costa.github.io

bit.ly/3X0Y6Sn