# A COMPUTATIONAL FRAMEWORK FOR PATIENT–SPECIFIC MODELING OF THE CARDIOVASCULAR SYSTEM

## * Pablo J. Blanco[1] and Raúl A. Feijóo[1]

[1] Laboratório Nacional de Computação Científica
Av. Getúlio Vargas 333, Quitandinha, 25651-075,
Petrópolis, RJ, Brasil, {pjblanco,feij}@lncc.br

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## ABSTRACT

During the last decade there has been an increase in the number of scientific papers dedicated to applying computational techniques to model the main physical phenomena in the cardiovascular system. This trend was a direct consequence of the growth of the computational power, what came alongside with the development of more complex models, techniques and algorithms, all those capable of pre–processing data, performing simulations and post–processing results in an even more effective and efficient fashion.

Fairly strong evidence about the importance of these developments has been presented throughout several landmark works [4,8]. As aforesaid, effectiveness and efficiency in handling large data-sets obtained in addition to the highly complex numerical simulations and the possibility of correlating mechanical aspects with cardiovascular diseases have given rise to new paradigms in the computational modeling. Hence, promising results have brought to light the need to perform patient–specific modeling. Such kind of patient-oriented modeling engages several challenging stages like medical image processing, mesh generation, FEM data pre-processing, numerical simulation, FEM data post-processing and visualization. Nonetheless, there still is a lack of available computational tools devoted to handle the whole process in a single environment. This kind of unifier computational system is crucial not only to provide a common language capable of holding all the important steps in the modeling process, but also as a tool to speed up research time, helping to stay ahead of the field.

Several works have dealt with each one of the stages present in the modeling pipeline, making significant progresses in cardiovascular modeling. For instance, different numerical techniques have been applied successfully in image processing [7]. In this respect, processing medical images entails several issues such as image restoration, region identification, image segmentation and finally geometry reconstruction. Therefore, the finite element mesh generator can be properly fed with an initial guess so as to build, for instance, a surface mesh of triangles and, afterwards, the corresponding volume mesh of tetrahedra [3]. In this way we are able to set up the finite element model. Concerning computational models of the cardiovascular system several approach could be chosen. The first generation of models is based on the use of simplified 1D/0D models to represent the wave propagation phenomena and to simulate the arterial pulse and the blood flow distribution along the major arteries of the network [1,5]. The

second generation, in turn, is based on the use of 3D models which are able to reproduce with considerably good accuracy the local blood flow patterns in isolated arterial districts [4,8]. A third generation can be mentioned and it is founded on the coupling between 1D and 3D models in order to take into account the interaction between local and global phenomena [2]. After the simulation step the results have to be post-processed and visualized to obtain all the information from the computed solution. In order to do this, the computational environment and the architecture provided by the ParaView framework allows an easy and efficient way to manage the data post–processing [6]. However, the potentialities of this framework go beyond the data visualization tools, and the pipeline–like filtering structure provided by ParaView is proving to be very useful for our application.

The purpose of this work is to present the advances concerning the development of a computational tool that embraces the whole process in the patient-specific modeling. This computational environment consists of the following five modules: (i) **1D model Module:** here it is possible to build, edit, simulate and visualize the results of a 1D model of the arterial tree; (ii) **image processing module:** with this module the user is able to extract information from medical images so as to build 3D finite element models; (iii) **3D model module:** in this stage a 3D finite element model is constructed, the partition of the domain is constructed, the boundary conditions can be easily incorporated and finally the simulation can be carried out; (iv) **3D–1D coupled model module:** with the tools provided in this module the relation existing between 1D and 3D models is straightforwardly set up, together with the configuration of the coupled simulation; (v) **visualization module:** this module exploits the visualization possibilities and other general data post-processing potentialities of Paraview, but also several others CFD visualization techniques, such as particle tracking, can be included in the environment.

It is also worthwhile to remark that this tool is not restricted to the cardiovascular system although this was the first step in our research group. Other possibilities such as organ modeling, transports modeling or human airway modeling can be incorporated using the same concepts.

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