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A vascular model of cerebral arteries generated by constrained constructive optimization

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Cardiovascular diseases are among the highest causes of death, and although much is known about their effects, [1] deeper aspects of their onset and progress are still a matter of study.

Modeling of arterial networks in living organisms is often aimed at by researchers in the medical field as a tool to investigate these phenomena or to study how certain controlled effects might evolve in an organism. Due to the difficulty of experimental research in vivo, artificial models [2] are of great value in investigating the behavior of these interactions in the system under physiological or pathophysiological conditions.

Particularly, the study of hemodynamics in small vessels, such as those found in peripheral beds, encounters serious limitations concerning the degree of invasiveness in acquiring in vivo data. Vascular territories responsible for perfusing organs are fundamental for the study of mechanisms involving blood flow and organ function. In this sense, data extracted from medical images is severely limited to large and medium-sized vascular vessels, while the remaining vasculature [3] cannot be visually accessed.

Towards completing vascular models through the construction of vascular networks, the most common methods used to generate these networks are either based on space-filling methods or fractal methods. One of the space-filling methods is the Constrained Constructive Optimization (CCO) [3]. The CCO algorithm is used to create a tree of vessels by the minimization of a given cost function, which in this case is generally associated with the intravascular volume of vessels in the organ.

In this work, we use an adaptive version of the CCO algorithm (DCCO) [4] to generate a tree of vessels along a domain of interest. The domain of interest is the pial surface of the occipital and parietal regions of the left hemisphere of the brain, plus the regions located within the gray matter underneath the convexity.

As input data we employed the major cerebral vessels as described by the ADAN model [2] as initial arteries, which served as baseline network from where the automatic vascularization is produced. In addition, we employ a geometric 3D model of the brain extracted from magnetic resonance imaging. The baseline model was registered to the pial surface of the brain model. The first stages in the vascular generation targeted the pial surface as seen in Figure 1, while the subsequent stages targeted the vascularization of the gray matter.

The adaptive nature of the DCCO enabled the staged generation of the vascular network by changing the parameters that characterize the algorithm through the different stages. Moreover, the fact that a massive vascularization was produced, required the use of a parallel version of the DCCO, called PDCCO [5]. The output of the vascularization procedure also allows us to

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investigate the blood pressure and the flow rate distribution across the different regions of the model.

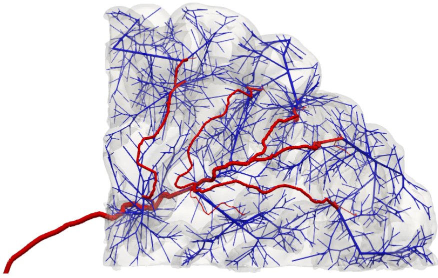

Figure 1: Early development of arterial network initial stage in the occipital and parietal region of left hemisphere, side view. ADAN model [2] is in red and generated network in blue. Image generated with ParaView version 5.10.

This work is the first step towards the modeling and simulation of whole brain hemodynamics by employing massive vascular networks that perfuse the different cerebral regions in a realistic and anatomically consistent manner. Such a model will be of the utmost importance in the study of hemodynamic anomalies such as obstructive lesions and stroke extension, drug delivery, patient-specific optimization of blood pressure levels, among others.

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