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Review

Geometric multiscale modeling of the cardiovascular system, between theory and practice

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Abstract

This review paper addresses the so called *geometric multiscale* approach for the numerical simulation of blood flow problems, from its origin (that we can collocate in the second half of '90s) to our days. By this approach the blood fluid-dynamics in the whole circulatory system is described mathematically by means of heterogeneous problems featuring different degree of detail and different geometric dimension that interact together through appropriate interface coupling conditions.

Our review starts with the introduction of the stand-alone problems, namely the 3D fluid–structure interaction problem, its reduced representation by means of 1D models, and the so-called lumped parameters (aka 0D) models, where only the dependence on time survives. We then address specific methods for stand-alone 3D models when the available boundary data are not enough to ensure the mathematical well posedness. These so-called "defective problems" naturally arise in practical applications of clinical relevance but also because of the interface coupling of heterogeneous problems that are generated by the geometric multiscale process. We also describe specific issues related to the boundary treatment of reduced models, particularly relevant to the geometric multiscale coupling. Next, we detail the most popular numerical algorithms for the solution of the coupled problems. Finally, we review some of the most representative works – from different research groups – which addressed the geometric multiscale approach in the past years.

A proper treatment of the different scales relevant to the hemodynamics and their interplay is essential for the accuracy of numerical simulations and eventually for their clinical impact. This paper aims at providing a state-of-the-art picture of these topics, where the gap between theory and practice demands rigorous mathematical models to be reliably filled.
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Keywords: Blood flow simulation; Fluid–structure interaction; 1D models; Lumped parameter models; Geometric multiscale coupling

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