A dimensionally heterogeneous coupled HPC cardiac-vascular model using a black box decomposition approach

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ABSTRACT

In this article, a first version of an HPC-ready dimensionally heterogeneous cardiovascular coupled model is presented. Two codes are used to achieve this goal: Alya Red, the BSC in-house tool for biomechanical simulations; and a 55-artery reduced model of the highly detailed ADAN model (called ADAN55), from the LNCC hemodynamics simulation software. Alya Red is a three-dimensional, multiscalar, multiphysics, patient-sensitive, HPC-optimized code, that allows modeling and solving the electromechanical problem involved in the heartbeat [1,2,3]. The ADAN55 model employs a one-dimensional FSI model to solve the flow inside deformable pipes [4]. Both codes are coupled by a black-box decomposition approach; this technique enhances the inclusion of a third coupling software that, by a Jacobian free solver, allows strong iterative coupling among the models. Alya Red solves three sets of equations: the electrophysiology model, which governs the propagation of the action potential in the solid domain; the solid model, that predicts the deformation of the solid domain; and the fluid dynamics equations for the blood, which are solved in a region contained and deformed by the solid domain. The blood flow in ADAN55 is modeled by the condensed one-dimensional Navier-Stokes equations in compliant vessels and complemented with a constitutive relation for the arterial wall, which relates the pressure with the cross sectional area. The black-box decomposition approach used to couple the models in this work is presented in [4,5], where state variables such as pressure and flow are sent and received between black-boxes at connecting points. Due to the excellent scalability of Alya system [6], and the low computational cost given by ADAN55 model, the whole coupled model is capable to run in HPC machines, allowing to solve complex models in high-resolution heart geometries.

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