Performance of preconditioned linear solvers and matrix characteristics in cardiovascular simulations in high-performance computing

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Cardiovascular simulations are widely used to aid in surgical planning and disease diagnostics. Patient-specific modeling and simulation typically proceeds through a pipeline from anatomic model construction from medical image data to blood flow simulation and analysis. Cardiovascular blood flow simulations typically solve the incompressible Navier Stokes equations with physiologic boundary conditions. To provide confidence intervals on simulation predictions, we use an uncertainty quantification (UQ) framework to analyze the effects of numerous uncertainties that stem from clinical data acquisition, modeling, material properties, and boundary condition selection. However, UQ poses a computational challenge requiring multiple evaluations of the Navier-Stokes equations in complex 3-D models. For efficient uncertainty propagation, we use reduced order modeling coupled with a 0-D lumped parameter network which consists of circuit elements to model. In addition, to achieve efficiency in UQ problems with many function evaluations, we implement and compare a range of iterative linear solver and preconditioning techniques in our flow solver. We then test the performance of these techniques on typical patient-specific cardiovascular simulations. Characteristics of the matrix arising from the linear system and its relation to the solver performance will be discussed. First, we introduce a preconditioning technique to resolve the ill-conditioning of resistance boundary condition. Additionally, we propose a preconditioning technique that takes advantage of block-structure of the matrix from fluid domain. Lastly in the case of FSI we discuss different matrix characteristics arising from solid and fluid domain and discuss the performance of linear solvers.