Matrix-free Discontinuous Galerkin Solvers for the Cardiovascular System

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The coupling of incompressible fluid and solid phases remains a challenging application especially in the medical context. Such problems frequently arise in medical device design, surgery planning or clinical support, but similar difficulties are encountered in more general settings as well, when the density of the involved fluid and structure are similar. Standard fluid-structure interaction algorithms suffer from a high added-mass effect in addition to the large number of spatial and temporal unknowns to accurately represent the physical processes. Hence, robust and efficient numerical tools reducing the computational burden and the required time to solution are urgently needed.

Adopting monolithic solvers, which are traditionally applied in this field, preconditioning the linear system presents major difficulties. Following the partitioned approach, on the other side, a strong added-mass effect leads to increased iteration counts in the coupling algorithm. However, recently developed methods [1] combining Robin coupling conditions, interface quasi-Newton methods and semi-implicit coupling strategies offer an attractive alternative to monolithic schemes. Within this contribution, we present recent developments combining matrix-free Discontinuous Galerkin solvers within the open-source software framework ExaDG [2] with accelerated partitioned schemes in practical applications to patient-specific cardiovascular models. Higher-order discretizations for the three-dimensional structure and fluid are considered, comparing various alternative formulations of the fluid subproblem leading to monolithic velocity-pressure systems or, as an alternative, pressure-correction schemes splitting the problems governing fluid velocity and pressure, see, e.g., Kronbichler et al. [3].

We present results demonstrating the robustness of the solution with respect to the Robin parameter and investigate its interplay with the semi-implicit variants of the strongly coupled and accelerated partitioned solver. Practical relevance is demonstrated in a clinical scenario of blood flow through an iliac bifurcation, including relevant modeling aspects such as physiological boundary conditions and realistic problem parameters.

References:

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