Towards a Parallel-in-Time Multigrid Solver for Fluid-Structure Interaction Problems

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ABSTRACT

Fluid-structure interaction (FSI) phenomena are present in many different fields of application, such as biomedical engineering. Even with simplistic mathematical models, numerical simulations of a studied time-dependent system may yield significant computational cost. For example, simulating periodic FSI problems usually requires running multiple cycles to achieve periodic steady-state. For real-world engineering problems, the time-to-solution may often be undesirably large and conflict with required fast turn-around. Thus, parallelization techniques are the key to decrease the wall clock time of a given algorithm.

Spatial parallelization techniques, such as domain decomposition methods, are commonly used to speed up computations by distributing the work load per time step amongst a number of available processors. However, spatial parallelization saturates with increasing communication tasks and an optimum number of processors (for example, with respect to parallel efficiency or minimum runtime) may not fully utilize the available resources. A further reduction of the time-to-solution may be achieved by, for example, parallelization in the temporal domain.

In this talk, we will present a multigrid-reduction-in-time (MGRIT) algorithm [1] for the solution of a time-dependent and generally nonlinear system. The MGRIT algorithm is a true multilevel approach based on multigrid techniques applied to the temporal domain and thus introduces a grid hierarchy of fine and coarse time grids. It solves the global space-time problem iteratively by employing multigrid cycling (e.g. V- and F-cycles), FC relaxation and coarse-grid updates. The algorithm uses multiple temporal levels and allows re-use of optimized and efficient solvers. Further, temporal parallelization may be complemented with spatial parallelization to solve the spatial problem for each time point more effectively. The MGRIT algorithm provides a non-intrusive way to achieve speedups beyond the speedups that are observed for purely space-parallel methods.

To provide a thorough basis for further investigations of multi-physics problems, we study the application of the MGRIT algorithm to single-physics problems, such as flow over a moving domain. Here, we focus on properties of the space-time solver (e.g. scalability) and demonstrate that traditional time stepping schemes (i.e. direct temporal solvers) and the MGRIT solver (i.e. iterative temporal solver) solve the same system of equations. We further extend this approach in the context of FSI, demonstrating efficacy using FSI benchmark problems.

REFERENCES

[1] R.D. Falgout, S. Friedhoff, Tz.V. Kolev, S. MacLachlan and J. Schroder, "Parallel Time Integration with Multigrid", *SIAM J. Sci. Comput.*, Vol. **36**, pp. C635-C661, (2014).