High-order adaptive multistep coupling scheme for multiphysics applications

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In the context of multiphysics simulations, partitioned methods enable the reuse of existing solvers while preserving modularity. However, achieving high-order accuracy in time and providing adaptive time step-ping remains a challenge, especially when dealing with strong coupling conditions. We address these issues by developing and analyzing a high-order multistep coupling scheme tailored for multiphysics applications [2, 3, 1]. Contrary to classical staggered coupling schemes, where the coupling terms are held constant between two successive coupling time points, this new technique uses high-order polynomials in time to predict the evolution of the coupling conditions during a coupling time step. An explicit and an implicit variant arise naturally, and error estimates can be built to dynamically drive the coupling timestep.
We first present the numerical analysis of convergence and stability of the multistep coupling scheme. The objective of this contribution is to present how convergence acceleration algorithms can further improve the efficiency of the implicit multistep coupling approach. Fixed-point acceleration techniques will be discussed, with particular attention to how the structure of the multistep coupling influences their effectiveness. Several benchmarks will be provided, with emphasis on an unsteady conjugate fluid-solid heat transfer configuration, with metrics on iteration counts, achievable time step, and overall efficiency.

[1] B. Dias, L. François, M. Massot, A. E. Simon. *High-order adaptive flow-material coupled simulation of uranus orbiter and probe entry.* In *AIAA SCITECH 2026 Forum*, p. 2937, 2026.

[2] L. Francois, M. Massot. *Multistep interface coupling for high-order adaptive black-box multiphysics simulations.* In *10th edition of the International Conference on Computational Methods for Coupled Problems in Science and Engineering.* CIMNE, 2023.

[3] A. E. Simon, L. François, M. Massot. *High-order multistep coupling : convergence, stability and pde application.* Comptes Rendus. Mécanique, **353(G1)**, 1159–1184, 2025.

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