UNIVERSITÀ DEGLI STUDI DI PADOVA

EXAMG - EXtreme-scale Algebraic MultiGrid for next-generation nuclear simulations

Nuclear fusion has long been promised to deliver safe, cost-efficient, and sustainable energy production, but significant technical challenges remain in tokamak design, such as sustaining the extremely high required temperatures and effectively confining the hot plasma with magnetic fields. Conversely, nuclear fission provides large quantities of carbon-free energy and has critical medical applications but poses serious safety challenges, including reactors' limited life and nuclear waste management. In this context, Computational Fluid Dynamics (CFD) and Magnetohydrodynamics (MHD) are key to accelerating nuclear innovation. However, tokamak and nuclear reactor thermal hydraulics simulations remain elusive due to the vast range of relevant scales involved, which demand an exceptional mesh resolution. As a result, advancing these applications requires very accurate CFD and MHD simulations, whose main bottleneck is the solution of extreme-scale sparse linear systems. The EXAMG project addresses such challenges through a novel Algebraic Multigrid (AMG) preconditioner whose design involves a multidisciplinary team with experts in numerical linear algebra, high-performance computing and computational physics. The resulting linear solver combines multigrid's optimality with AMG's flexibility and GPU's capabilities to deliver a lightweight yet very effective method enabling unprecedented extreme-scale CFD and MHD simulations of nuclear applications. In this sense, EXAMG targets several key research areas of the EU's energy research and innovation strategy, directly supports the European Green Deal and closely aligns with Euratom research domains by fostering the extreme-scale simulations required to develop safer fission reactors and advance the European fusion roadmap. Furthermore, deploying advanced software for exascale supercomputers contributes to the EuroHPC JU major initiative of establishing a world-class European HPC ecosystem.

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