Scalable Parallel Domain Decomposition for Mixed Finite Elements: Application to Analysis of Convective Mixing in CO2 Storage

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SCALABLE PARALLEL DOMAIN DECOMPOSITION FOR MIXED FINITE ELEMENTS: APPLICATION TO ANALYSIS OF CONVECTIVE MIXING IN CO_2 STORAGE.

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Abstract

Accurate prediction of the long-term fate of carbon dioxide in saline aquifers is a numerical and computational challenge. High permeability rocks are ubiquitous in many sedimentary bassins targeted by this technology. In many of such cases, convective mixing of dissolved supercritical CO_2 rich waters with the initial saline waters is likely to occur involving a multiscale time-space dependent problem. Spatial resolutions needed to capture dissolution fingers for practical applications like the first commercial CO_2 injection project in Sleipner (North-Sea) are in the orders of few centimetres. Therefore, efficient and highly scalable parallel decomposition methods need to be developed, hopefully as a black-box simulator, to advance scientific knowledge for such applications in as much to demonstrate the long-term safety of future storage sites. To this end, we implemented a balancing domain decomposition mixed finite elements for second-order elliptic partial differential equations. Problems in this form arise in many other applications including single-phase and multiphase subsurface flow, electrostatics, implicit discretisations of parabolic and hyperbolic equations, and as a subproblem in the application of operator-splitting techniques to advection-dispersion-reaction transport equations. The Balancing Domain Decomposition method, is a substructuring method that involves at each iteration the solution of a local problem with Dirichlet boundary conditions, a local problem with Neumann boundary conditions, and a coarse grid problem to propagate information globally (over all domain processors) and to ensure the consistency of the Neumann problems. Our numerical experiments show that the condition number, consistently with theory, grows at worst like $O\left(1 + log\left(\frac{H}{h}\right)^2\right)$ in both two and three dimensions, where H is the characteristic subdomain size, and h the characteristic mesh size. Computational results from an MPI message passing parallel implementation on IBM CLX/1024 Linux cluster machine at CINECA demonstrate the scalability properties of the method and show almost optimal linear speed-up for up to 128 processors.

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