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Block-structured preconditioners for equal-order finite element discretization of coupled fluid problems

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Many important engineering and scientific systems require the solution of extensions of standard incompressible flow models, whether by coupling them to other processes or by incorporating additional nonlinear effects. Finite element methods and other numerical techniques provide effective discretizations of these systems, and the generation of the resulting algebraic systems may be automated by high-level software tools such those in the Sundance project, but the efficient solution of these algebraic equations remains an important challenge.

Frequently, the nonlinear equations are linearized by a fixed point or Newton technique, and then the linear systems are solved by a preconditioned Krylov method such as GMRES. We have extended the methodology and analysis of preconditioning such systems, in particular, extending existing block-structured preconditioners (such as those of Elman, et al.) to address coupled systems, showing how an effective preconditioner for Navier-Stokes combined with a process such as convection-diffusion of temperature to obtain a preconditioner for the Newton linearization of a nonlinearly coupled system such as Bénard convection. We examine these preconditioners in the case of inf-sup stable finite element discretizations as well as equal-order finite elements with pressure stabilization.