FreeFEM with PETSc - easy and efficient large-scale finite element simulations

Jolivet Pierre[1]
[1]Sorbonne Université, CNRS, LIP6
e-mail : pierre@joliv.et

1 Abstract

FreeFEM is a domain-specific language used for finite element analyses with a high abstraction, coupled with PETSc, a backend used in scientific libraries that has been deployed on various architectures, from laptops to large exascale systems.

2 Introduction

On the one hand, FreeFEM [1] is a domain-specific language (DSL) used to perform finite element analyses with a high level of abstraction. Once the weak (or variational) form of a partial differential equation is known, users are not bothered by cumbersome tasks inherent of the finite element method such as vector or matrix assemblies, mesh adaptation, and such, as these can be performed efficiently within FreeFEM DSL with an expressive syntax. On the other hand, PETSc [2] is an algebraic backend used in many scientific libraries around the world that has been deployed on various architectures, from laptops to large exascale systems such as Aurora@ALCF and Frontier@OLCF, currently number #2 and number #1, respectively, of the TOP500. In this talk I will present some new features of FreeFEM and its interface to PETSc and SLEPc (its sister library for eigenvalue computations [3]). Coupled together this ecosystem offers a flexible infrastructure to deal with coupled and/or high-dimensional systems of equations using MPI for distributed-memory parallelism. I will showcase some examples from fluid dynamics (Schur complement preconditioners [4] for Oseen or Navier—Stokes equations, see left-hand side figure below), computational mechanics (smoothed-aggregation algebraic multigrid methods for elasticity [5]), radiative transfer (matrix-free solver with user-defined preconditioning, see right-hand side figure below) and boundary integral equations (nonlocal — a priori dense — operators with hierarchical matrices and on-the-fly compression [6]). The presentation will also include live demos, including (but not limited to) discretizing and solving the 3D Poisson equation, computing some eigenmodes using shift-and-invert spectral transformations, and this translates to nonlinear problems.

Acknowledgement The help and support of Hiroshi Fujiwara (Kyoto University), Takeshi Takaishi (Musashino University), and Atsushi Suzuki (RIKEN R-CCS) is greatly appreciated.

参考文献

[1] F. Hecht, "New development in FreeFem++" Journal of Numerical Mathematics, vol. 20, no. 3-4, 2012, pp. 251-266, doi: https://doi.org/10.1515/jnum-2012-0013.

[2] S. Balay et al., "PETSc/TAO users manual." Argonne National Laboratory, Illinois (2024).

[3] J. E. Roman, F. Alvarruiz, C. Campos, L. Dalcin, P. Jolivet, and A. Lamas Daviña, "Improvements to SLEPc in Releases 3.14–3.18" ACM Transactions on Mathematical Software, vol. 49, no. 3, Article 29, 2023, doi: 10.1145/3603373

[4] J. Brown, M. G. Knepley, D. A. May, L. C. McInnes, and B. Smith, "Composable Linear Solvers for Multiphysics," 2012 11th International Symposium on Parallel and Distributed Computing, Munich, Germany, 2012, pp. 55-62, doi: 10.1109/ISPDC.2012.16.

[5] M. F. Adams, H. H. Bayraktar, T. M. Keaveny, and P. Papadopoulos, "Ultrascalable Implicit Finite Element Analyses in Solid Mechanics with over a Half a Billion Degrees of Freedom," SC '04: Proceedings of the 2004 ACM/IEEE Conference on Supercomputing, 2004, pp. 34-34, doi: 10.1109/SC.2004.62.

[6] P. Marchand, X. Claeys, P. Jolivet et al., "Two-level preconditioning for h-version boundary element approximation of hypersingular operator with GenEO" Numerische Mathematik, vol. 146, 202, pp. 597–628, doi: 10.1007/s00211-020-01149-5