Flat MPI and Hybrid Parallel Programming Models for FEM Applications on SMP Cluster Architectures

Kengo Nakajima

The 21st Century Earth Science COE (Center of Excellence) Program
Department of Earth and Planetary Science, The University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo 113-0033, Japan
nakajima@eps.s.u-tokyo.ac.jp

In this presentation, results of performance analysis of flat MPI and hybrid parallel programming models for FEM applications with preconditioned parallel iterative solvers on various types of SMP cluster architectures (Earth Simulator, IBM SP-3, Hitachi SR8000) will be demonstrated. Basically, flat MPI and hybrid parallel programming models are competitive over most of the applications, preconditioning methods, and computers, but optimization strategy, such as reordering technique is different in each application and computer.

The author has developed parallel iterative solvers with preconditioning in GeoFEM project (http://geofem.tokyo.rist.or.jp), which is a national research project for parallel FEM platform in solid earth simulation on the "Earth Simulator". In GeoFEM, an efficient parallel iterative method for FEM has been developed for SMP cluster architectures with vector processors such as the "Earth Simulator". The method is based on a three-level hybrid parallel programming model, including message passing for inter-SMP node communication, loop directives by OpenMP for intra-SMP node parallelization and vectorization for each PE. In order to achieve efficient parallel/vector computation for applications with unstructured grids, a special reordering technique has been integrated with parallel iterative solvers developed in the GeoFEM project. In ILU and MG type preconditioning method, reordering technique based on multicoloring is required in order to avoid dependency. The PDJDS/CM-RCM reordering method developed in the project provides excellent vector and parallel performance in SMP nodes. Simple 3D linear elastic problems with more than 2.2×10^9 DOF have been solved using 3x3 block ICCG(0) method on 176 nodes of the Earth Simulator, achieving performance of 3.80 TFLOPS (34% of the peak performance). A three-level hybrid parallel programming model outperforms flat MPI in the problems involving large numbers of SMP nodes due to the effect of communication latency.

Same benchmarks were applied to IBM-SP3 and Hitachi SR8000. On IBM-SP3, performance of flat MPI and hybrid programming model is very close. On Hitachi SR8000, hybrid programming model provides slightly better performance.

This study is a part of the project on "Solid Earth Platform for Large-Scale Computation" funded by MEXT, Japan. Author would like to thank the Earth Simulator Center, the Information Technology Center (University of Tokyo) and NERSC/LBNL (Lawrence Berkeley National Laboratory) for use of the Earth Simulator Center, Hitachi SR8000 and IBM SP-3, respectively.

References

[1] GeoFEM: http://geofem.tokyo.rist.or.jp/
[2] Earth Simulator Center: http://www.es.jamstec.go.jp/
[3] Nakajima, K.: "Parallel Iterative Solvers of GeoFEM with Selective Blocking Preconditioning for Nonlinear Contact Problems on the Earth Simulator", *SC2003 Technical Paper*, Phoenix, AZ, USA, 2003.
[4] Nakajima, K.: "OpenMP/MPI Hybrid vs. Flat MPI on the Earth Simulator: Parallel Iterative Solvers for Finite Element Method", *WOMPEI 2003*, Tokyo, Japan, Lecture Notes in Computer Science 2858, pp.486-499, Springer, 2003.
[5] Liou, J. and Tezduyar, T.E.: "Clustered Element-by-Element Computations for Fluid Flow", *Parallel Computational Fluid Dynamics (Implementations and Results)*, edited by H.D.Simon, The MIT Press, 1992. pp.167-187.