3D acoustic wave modeling with the MUMPS direct solver: application to seismic imaging.

Seismic imaging is one of the main geophysical method to image the subsurface of the earth at diffferent scales (near surface, oil exploration scale, deep crustal and lithospheric scales, global scale). Among the seismic imaging methods, the so-called full waveform inversion aims to exploit the full-information content of the seismic data by minimization of the residuals between the recorded and the modeled full wavefields. The related inverse problem is solved by local optimization such as Newton or gradient methods while the forward problem consists of the resolution of the wave equation for a large number of seismic sources.

When the forward problem is performed in the frequency domain, seismic modeling reduces to the resolution of a large and sparse system of linear equations, the right-hand side of which is the source and the solution is the wavefield at each node of the computatiional domain. This sparse linear system can be solved with direct solvers, iterative solvers or hybrid solvers. Alternatively, time-marching explicit algorithms can be used to perform seismic modeling in the time domain and monochromatic wavefields are computed by discrete Fourier transform in the loop over time steps.

After a review of the pros and cons of each approach, I shall present numerical results of 3-D frequency-domain acoustic wave modeling with the MUMPS direct solver. One key advantage of the direct-solver approach for seismic imaging applications is the efficiency of the solution phase when a large number of right-hand sides must be considered. The drawback is the memory and time complexity of the LU factorization which prevents large-scale applications involving more than 10 millions of unknowns.

The time-harmonic acoustic wave equation corrisponds to the generalized Helmholtz equation. A finite-difference method has been designed to minimize the numerical bandwidth of the impedance matrix and hence the fill-in during the LU factorization, while maintening a good level of accuracy in terms of numerical dispersion and anisotropy. A complexity and scalability analysis of MUMPS performed on the SGI supercomputer of CINES will be presented for simulations involving up to 7.5 millions of unknowns.

To tackle larger problems, we also implemented, in collaboration with L. Giraud and A. Haidar, a domain decomposition method based on the algebraic Schur complement approach and a hybrid direct/iterative solver. A complexity and scalability analysis of the hybrid approach performed on the IBM Blue Gend and IBM Power 6 of IDRIS will also be presented. Problems involving up to 30 millions of unknowns have been solved with the hybrid solver.