2D/3D seismic modelling via a massively parallel structured approximate direct Helmholtz solver

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Abstract

We consider the discretization and the solution of the 2D/3D inhomogeneous acoustic wave equation in the frequency domain, which is known as the Helmholtz equation, including variable density, transverse isotropy (VTI & TTI), and attenuation scenarios. In particular, we are concerned with solving this equation on a large physical domain, for a large number of different forcing terms in the context of the 3D seismic modeling. The advantage of seismic modeling in the frequency domain lies on that for a single frequency all solutions share a common Helmholtz operator. We resort to a parsimonious mixed grid finite difference scheme for discretizing the Helmholtz operator equipped with the Perfect Matched Layer (PML) boundaries, yielding a pattern-symmetric but non-Hermitian matrix. We make use of 2D/3D nested dissection based domain decomposition, and introduce an approximate direct solver by developing a new parallel Hierarchically Semi-Separable (HSS) matrices compression, factorization and solution approach. We cast our massive parallelization in the framework of the parallel multifrontal method. The assembly tree is partitioned into local trees, which are stored and eliminated locally at each process, and a global tree, whose elimination arouses massive communications among processes. The entire Helmholtz solver is a parallel hybrid between the multifrontal and HSS structures. The computational complexity associated with the factorization is almost linear in the size, say N , of the matrix, assuming r is the maximum numerical rank of all off-diagonal blocks in the multifrontal procedure. We benchmark our Helmholtz solver with the state-of-the-art MUMPS solver, and show that our solver is at least one order of magnitude faster than MUMPS for the same problem and on the same computing platform. We demonstrate the efficiency and accuracy of our solver via displaying various 2D (BP2004 and BP2007 TTI models) and 3D (SEAM model) numerical examples.

Key words

Modeling, frequency domain, Helmholtz solver, multifrontal, HSS matrix, nested dissection