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Optimum blended spectral element operators for forward modelling

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The study of wave propagation phenomena in complex media requires accurate numerical simulations. The wavefield interpolant basis and the related discrete wave operator are the main sources of the numerical errors that must be avoided. High order techniques have attracted the interest as a mean for improving both the accuracy and the overall computational efficiency of the numerical codes.

In particular, the spectral element methods, which combine high accuracy of spectral methods and the flexibility of finite elements, have been applied successfully to the acoustic and elastic cases. They are based on high-order orthogonal polynomials, but in order to retain computational efficiency, very high order polynomials cannot be used and numerical errors such numerical dispersion and numerical anisotropy cannot be totally avoided.

In the present work we devise an approach for reducing such errors by considering modified discrete wave operators. We analyze consistent, lumped and blended operators. Consistent operators are derived by the standard finite element approach, while mass lumping is a technique that decouples the equations of the finite element formulation. Since consistent operators overestimate the wave propagation velocity, while the lumped operators underestimate it, a blending of lumped and consistent operators could balance the approximations towards the correct solution.

In the present work, we introduce a new dispersion analysis methodology that is simpler than the standard approach and holds for any operator order and it is easily extended from 1D to 2D and 3D dimensions, moreover, it allows for a fast optimal blending selection.

Our 2D and 3D blended operators significantly differ from standard operators, which only modify the mass matrix. The present approach is based on the tensor product decomposition of the element matrices into one-dimensional factors. The lumping is then applied to a 1D factor common to the mass and the stiffness matrices.

The numerical results show that the optimal blending produces operators of moderate order that are as accurate as high order regular operators. The approach is general and valid for solving both the time dependent and the stationary (Helmholtz) wave equations. The blending parameter is independent of the mesh refinement and the polynomial order, and provides an additional means to increase the computational efficiency of high-order methods.