Performance Analysis of a High-Order Discontinuous Galerkin Method Application to the Reverse Time Migration

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Abstract. This work pertains to numerical aspects of a finite element method based discontinuous functions. Our study focuses on the Interior Penalty Discontinuous Galerkin method (IPDGM) because of its high-level of flexibility for solving the full wave equation in heterogeneous media. We assess the performance of IPDGM through a comparison study with a spectral element method (SEM). We show that IPDGM is as accurate as SEM. In addition, we illustrate the efficiency of IPDGM when employed in a seismic imaging process by considering two-dimensional problems involving the Reverse Time Migration.

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1 Introduction

Oil exploration is still an ongoing activity in spite that the new target regions are difficult to access (hostile climate and geography). Prior to drilling, it is thus very important to have a reliable prediction tool such as depth imaging. This produces an image in the manner of an ultrasound using artificial seismic waves caused by explosive sources. The

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waves that are reflected by heterogeneities of the medium are then recorded by receivers which are positioned in advance to cover a reasonable area to explore. The receivers are capable of recording both the arrival times and amplitudes of the reflected waves. Arrival time, which are directly associated with medium velocities, are used to produce a map of the reflectors depicting the interfaces between different media. Amplitudes are related to the properties of the materials constituting the subsurface. In most cases, the map obtained by depth imaging represents only the interfaces and the produced image is called the velocity model. The initialization of the imaging process is carried out in a campaign of acquisition that records the reflected waves generated by the propagation of seismic sources. The image is then obtained by reproducing the propagation of seismic wave fields numerically. Producing an accurate image may require several iterations of this process. Seismic imaging can therefore be viewed as an iterative method which requires, at each step, solving the wave equation twice (propagation and back propagation). Therefore, seismic imaging techniques depend on both the wave equation model and on the numerical method. When using the full wave equation, the imaging method is called Reverse Time Migration (RTM). For years, the RTM has been neglected mainly due to algorithmic issues and computing platforms limitations.

To alleviate this difficulty, various methods based on approximated wave equations have been suggested (see for example [11, 14, 18]). These methods do not require significant computing resources. The Phase-Shift method [11, 14] provides an exact solution of the one-way equation when the velocity does not vary laterally. The Split-Step Fourier method [18] can be applied even when the velocity varies in all directions. It uses the phase-shift operator that is corrected at each iteration to account for changes in the environment. The Split-Step Fourier method is more accurate than the Phase Shift method but requires applying Fourier transforms, which greatly increases the computational burden. In addition, the solution is actually accurate when the velocity variations are small enough, which can be a serious restriction for most situations. With the impressive progress made in the area of scientific computing, it is now possible to apply the RTM using advanced numerical methods such as finite element methods (FEM). Most numerical codes that have been designed for RTM are based on finite difference approximations. Finite differences (FDM) are very popular because they provide an explicit representation of the solution, which avoids the inversion of the mass matrix at each time step. They are efficient but they lead to prohibitive computational cost in the case of complex areas with strong heterogeneities and topography. Consequently, FDM methods can not be candidates for RTM when requiring the solution of the wave equation in an iterative scheme.

Based on unstructured meshes, FEM have all the flexibility required to reproduce correctly the topography of the environment and the geometry of the various subsurface's interfaces. FEM approximations are not only very accurate but they are also able to easily combine different orders of approximations. This important feature reduces the computational cost while maintaining the level of accuracy. Note that FEM methods have been so far rarely used because they often deliver an implicit representation of the solution.