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High Quality Acoustic and Elastic Modeling

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Summary

Seismic modeling is pervasive in the exploration and exploitation of hydrocarbons, however the real physics of the earth interior exceeds our capacity to model. In this paper we present the Interior Penalty Discontinuous Method (IPDG) (Grote, et. al., 2007) which allows for extremely high quality seismic modeling of acoustic and elastic data. The challenge of quality modeling is to match the actual seismic earth response with synthetic data that honors all the physics of the earth. This is a hard problem and the IPDG method has a mathematical basis for high quality acoustic and elastic modeling with an-elastic and anisotropic material properties, a rugose topographic upper surface, a finite computational domain, and an interior model structure that mimics the actual geology. The use of finite difference, finite element, finite volume, and discontinuous Galerkin methods for seismic modeling accomplishes our goal of using the complete wave equation. But all of these techniques are compute intensive and much effort is required to make them efficient using new and innovative algorithms and computer hardware. These methods are the heart of inversion algorithms as they can generate synthetic seismic data with much of the character of real data, (Colis, et. al., 2010, Shin, et. al. 2008, and Shin and Min, 2006). The use of a discontinuous Galerkin scheme is illustrated with numerous examples to demonstrate the techniques of producing high quality synthetic seismic data sets.

Introduction

The use of linear approximation functions within triangles (2D) and tetrahedra (3D) provide the bases for finite element (FEM) and finite like methods, (Marfurt, 1984). This technique accurately models the displacement of the earth at the approximation points of the area or volume – the nodal points. If the change in properties across element surfaces is included as a flux (a function derivative) we have the discontinuous Galerkin method (DG), (Etienne, et. al., 2010). The difference in the two methods is the inclusion of this derivative approximation. The wave field is modeled with a displacement or pressure field and a spatial flux field. This improves the local accuracy of the wave propagation everywhere at the expense of doing more work everywhere. The alternative which we have been doing for a long time is to reduce the grid spacing metric by factors of 2 or more to increase the number of “grid points “ per wave length. Examples are provided to show the benefits of using these functions and derivative functions to model waves.

The use of the DG theory for seismic modeling is critical to building a useful tool for studying exploration and exploitation problems. Full wave form inversion is dependent on the modeling process to generate seismic traces with all the character of the real trace. To illustrate the power of this method we consider 2D and 3D modeling examples of different complexity. The first study compares the DG to the FEM method with different levels of grid resolution. The topography model is presented next, the Marmousi model is used to make a rugose model by removing the water layer. The acoustic and elastic DG results for this modified two dimensional model are presented. A three dimensional result using the SEG salt model is computed using the 3D elastic and acoustic DG codes.

Theory and/or Method

The wave field for acoustic or elastic waves can be approximated with area triangles or volume tetrahedra, in two or three dimensions respectively. The continuity of the mathematical approximation determines the character of these wave fields as they move from element to element. This is different from finite difference methods (FDM) for acoustic and elastic wave equations. The FDM typically uses a fixed Cartesian grid with local derivative operators. The actual geological model is sampled for each "cell" in the grid to find the local material properties. The derivative approximation extends across several of the cells and averages over this distance. The FEM schemes use the element structure to match the geological model better with non-Cartesian coordinates as needed. The element sizes are controlled to have approximate and consistent size, similar to controlling the grid spacing in FDM methods.

We see spurious reflections in finite difference schemes because the stair step matching of parameters to geology. In the finite element and IPDG methods the element to element shape change can cause similar spurious reflections if the meshing is too coarse. A finer mesh or better approximations like the flux terms in the IPDG greatly improve the quality of the method results as illustrated.

Examples

Using the model shown in Figure 1, a comparison was computed using two finite methods, the traditional Galerkin FEM and the newer IPDG scheme. Comments about the model, it is constant velocity, at 1.5 km/sec. The different color shades are placed in the model just to illustrate the complex structure of the element mesh and elements, (Shewchuk, 2002). The source frequency is 12 Hz., the model size is 5 km by 3 km, and a sponge boundary condition is used.

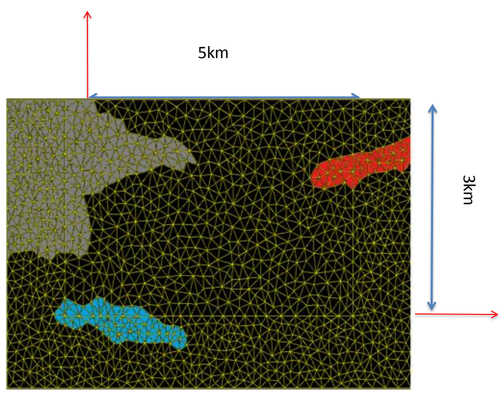

Figure 1: Model used for Finite Element and Discontinuous Galerkin Comparison.

Using a 5% clip the resulting seismograms are illustrated next as four different case studies. Figure 2.a is the traditional FEM code result using 251,126 elements, Fig. 2.b has 4,346,832 elements, Fig. 2.c has 28,973,514 elements The resulting quality improvement is clearly illustrated. The mesh size metric is the area per element, which ranges from approximately 60 m^2 to 4 m^2 to 0.5 m^2. This is equivalent to decreasing the FDM grid spacing from 8 meters to 2m to 0.7m for the three Fig. 2 a,b,c results. These grid spacing's might seem high but they are typical for quality elastic modeling to get accurate surface waves.

As said, in Figure 1, the velocity model is constant; no spurious reflections should exist in the seismogram. Yet we show in Case 1 and Case 2 in Figure 2, a low level of real mesh generated noise unsuitable for effective seismic modeling.

The final IPDG result is shown in Figure 2.d, where element mesh is the same as in Fig. 2.a, using 251,126 elements. What has happened is the higher quality approximation has greatly reduced the spurious element reflections. This allows the use of an economical grid to match the geological model.

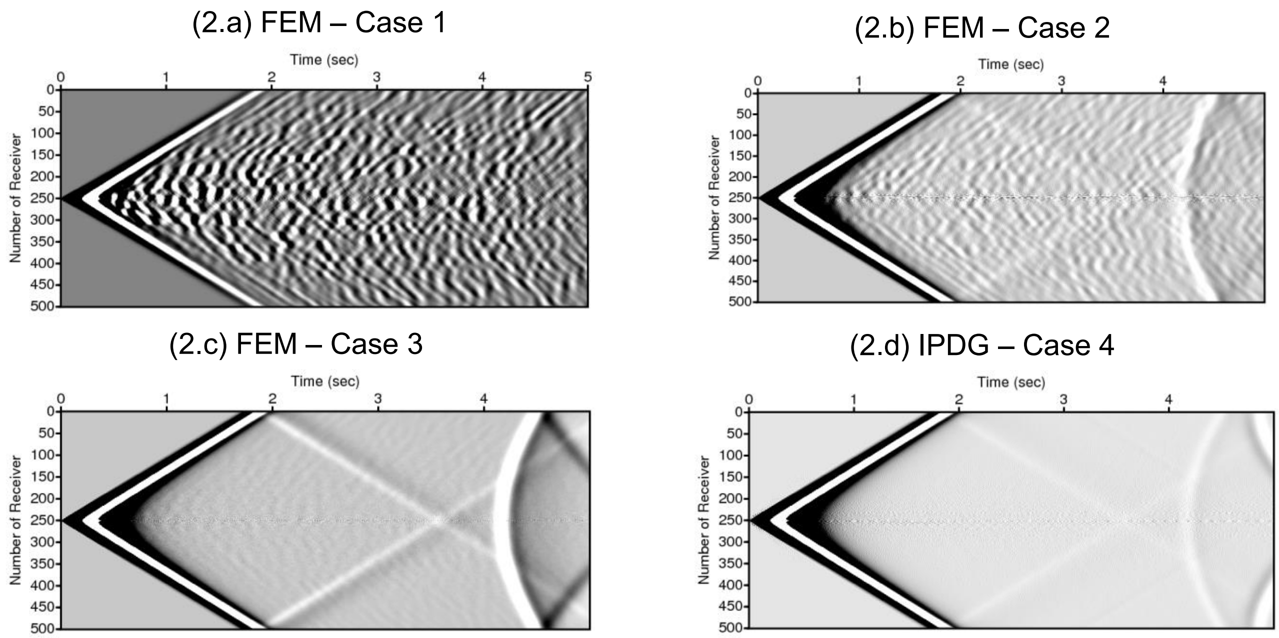

Figure 2: Finite Element and Discontinuous Galerkin Comparison with different number of elements.

Next shown in Figure 3 are the shot records for acoustic modeling from topography. The model is the well known Marmousi model where the water layer has been removed. This creates very complex model topography. The seismograms were computed using the IPDG acoustic code written by the first author. The model is not shown to due to space limitations in the abstract.

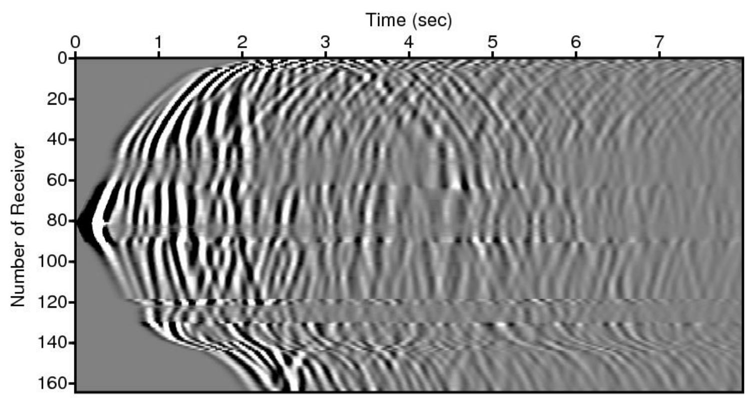

Figure 3: Modified Marmousi Topographic Model Example Acoustic Shot Records

The final example is a 3D elastic synthetic result using the same idea of modifying a well known model. The SEG 3D Salt Model is used without the water layer, the source frequency is 10 Hz, and again the model displays are not shown due to space limitations. In the presentation these models will be displayed. In Figure 4.a the x-axis displacement wave field is shown, Fig. 4.b has the corresponding z-axis wavefield. A similar y-axis wavefield was also computed.

Conclusions

The goals of high quality modeling in acoustic and elastic domain is best met using the IPDG method, it has intrinsic capabilities to manage the physics of the earth as demonstrated here. Accurate 3D seismic modeling will allow the methodology of full wave form inversion to be developed.

Fig 4.a, X-axis – displacement (Ux) | Fig 4.b, Z-axis – displacement (Uz)

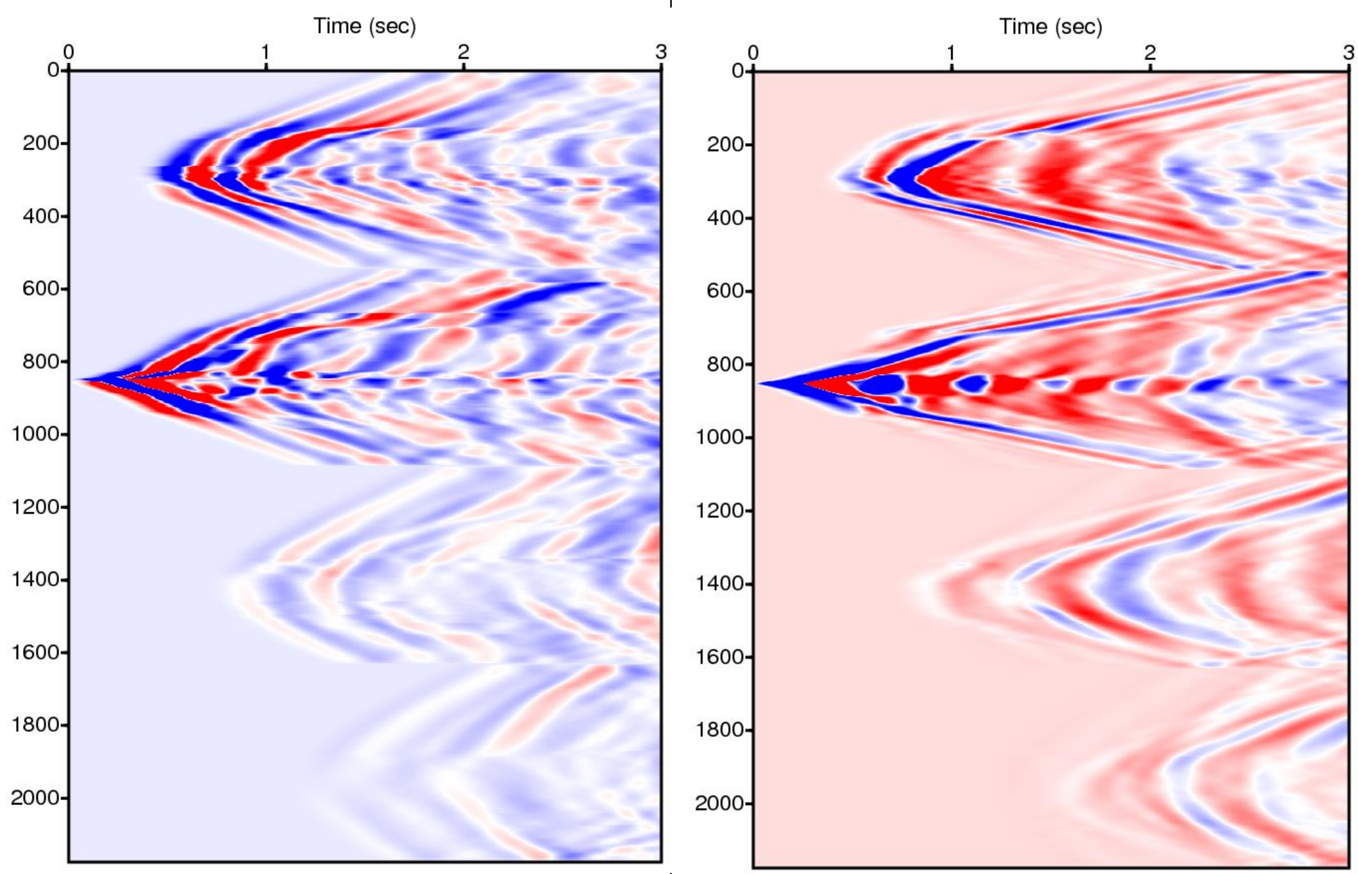

Figure 4: Modified SEG Salt Model Topographic Model Example Elastic Shot Records

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