Recent advances in numerical methods for solving the wave equation in the context of seismic depth imaging

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For several decades, the Oil and Gas industry has been committed to produce more and more hydrocarbons in response to the growing world demand for energy. Always seeking deeper and farther, exploration and development has become economically challenging as a result of increased geological and above ground complexity, stronger environmental constraints and pressure on costs. Seismic reflection is the main technology used for exploration in O&G, providing huge amount of geophysical data. Seismic depth imaging is the main tool used to extract information describing the geological structure of the subsurface from the recorded data. It is is an inverse problem with main objective to find the best model of the subsurface explaining the recorded data. In other words, finding the best model which minimizes some distance between the observed data and the predicted data. The process to estimate the predicted data is known as the process of forward modeling and is based on the resolution of the wave equation for some sources, initial conditions and boundary conditions. Efficiency for solving the forward modeling is crucial for geophysical imaging as one needs to get solutions of the PDEs for many sources and many iterations as we progressively improve our image and, therefore, the model we consider. Constant progresses in data acquisition and in rocks physics labs, more powerful computers and integrated team including physicists and applied mathematicians have greatly contributed to the development of advanced numerical algorithms integrating more and more complex physics. For the last 20 years, our industry has been very active in the definition and introduction of different wave equation approximation and corresponding numerical methods for solving forward problem. But the real change came 10 years ago with the implementation of the full wave equation, thanks to the petascale era, giving access to a complete representation of the wave-field. It allowed geo-scientist to re-design imaging algorithm both in time dynamic and time harmonic domain. The most popular numerical scheme used, nowadays by the industry, is based on finite difference methods (FDM) on regular grids. Very efficient on modern computers, FDM, are the main numerical methods used for seismic depth imaging. However, despite their efficiency FDM have some limitations for approximating irregular topographies in foothills exploration, for coupling different physics (acoustic-elastic) or are strongly constrained in the case of explicit time marching algorithm by the CFL condition. Discontinuous Galerkin (DG) methods have been increasingly studied for the resolution of differential models of linear wave propagation problems, particularly in the time domain where they proved to be accurate and efficient when they are combined with explicit time integration schemes. DG methods present a lot of advantages such as a high flexibility with regards to the mesh used for discretizing complex geometrical features, hp-adaptivity (i.e. local adaptation of the discretization parameter and interpolation degree) and easy parallelization. In time-domain, DG can be coupled with local-time stepping strategy to relieve the CFL condition. In harmonic domain, we use Hybridizable Discontinuous Galerkin (HDG) methods in order to decrease the size of the linear system to be inverted. The principle of HDG consists in introducing an auxiliary unknown defined only on the faces of the element and in expressing all DG variables as functions of this new unknown. Hence, HDG inherits all of the advantages of DG methods, without the drawback of the increase of degrees of freedom. In this talk, we will present the recent advances in using DG for solving wave equation in the context of seismic depth imaging and full wave inversion. We will show some examples and the way forward to some more advanced scheme coupling different numerical approximations we believe will provide the necessary tools for building the next seismic depth imaging generation codes for TOTAL E&P.

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