EG07

Phase-space imaging of 3-D seismic reflection data

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Modern seismic exploration often operates in complicated geologic areas in presence of complex overburden such as salt bodies. Reflection seismic data recorded on the surface in such cases contain wavefields that are impossible to use directly for geologic interpretation. Those data need to be imaged to provide any useful information to explorationists.

Seismic imaging maps data from acquisition and time coordinates to depth coordinates, thus allowing identification of geologic features in the subsurface. One popular way of achieving this, known as Kirchhoff imaging, treats such features as secondary sources (scatterers), which generate reflection data during seismic acquisition. Relationship between pieces of surface reflection data and subsurface scatterers is established through ray tracing.

Ray tracing is a numerical simulation of wave propagation from the scatterers that needs to be computed for every possible subsurface location to achieve the most accurate imaging results. Unfortunately, the computational cost of such procedure for a sizeable seismic survey can be prohibitive. However, there is a different mathematical framework for describing ray tracing that allows for a more robust and flexible computation of wavefield arrivals to surface from subsurface. In this framework, extra dimensions are added to depth and lateral axes. This higher-dimensional space (phase-space) brings new computational possibilities for simultaneous estimation of neighboring ray trajectories.

In this work, we outline the principles of an efficient algorithm for computing multi-arrival traveltimes in the above framework. We demonstrate that this algorithm can be used for Kirchhoff imaging of 3-D reflection seismic data. We show results for a synthetic benchmark model as well as for a real exploration dataset.

Keywords: computational seismology, depth imaging, Kirchhoff migration, multi-arrival traveltimes, angle gathers