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Traveltime tomography on the triangular mesh based on automatic differentiation

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Traveltime tomography recovers the background velocity field by minimizing the difference between observed and theoretical traveltime. Due to its computational efficiency and robustness, this method has been widely applied in studies of Earth's internal structure, oil and gas exploration, and other fields. However, most existing studies rely on regular rectangular grids for tomography, which exhibit limited adaptability when dealing with irregular topography and subsurface interfaces. The utilization of unstructured triangular meshes are more suitable for handling such complex study areas, and the development of traveltime tomography based on triangular meshes is necessary.

Compared with rectangular grids, the inversion method based on triangular meshes faces more complex gradient computation formulas, which has, to some extent, hindered the development of traveltime tomography. To address this challenge, we introduce automatic differentiation (AD) method to calculate the gradients more automatically, enabling the implementation of traveltime tomography based on triangular meshes. After building the forward computational graph, AD method can compute the gradient using the chain rule, thereby saving a lot of manpower in theoretical derivation, coding, and other processes. In this study, we used a finite difference method based on triangular meshes to solve the eikonal equation, accurately and efficiently calculating the traveltime in complex structural areas. Then, we integrate the eikonal solver into the current deep learning framework (e.g. pytorch), and update the velocity model with its built-in optimization algorithm after calculating the gradient in AD method. The process of traveltime tomography is completed on GPU, which can fully utilize the computing power of GPU and efficiently calculate inversion. Numerical tests indicate that the method can achieve promising inversion results and provide a suitable initial model for the full-waveform inversion. Our research provides a new approach for seismic inversion with unstructured grids, which is helpful for high-precision imaging of complex structural areas.