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Full Waveform Inversion via Optimal Transport with Sign-Sensitive Signal Decomposition

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Introduction.

Full Waveform Inversion (FWI) plays a critical role in seismic imaging by enabling the recovery of subsurface properties through the use of waveform data collected on the surface. Despite its potential, conventional FWI techniques face significant challenges, including nonlinearity, sensitivity to noise and initial models, and the frequent entrapment in local minima due to the use of classical least-squares misfit functions. All these drawbacks are not of surprise, since FWI is an inverse problem whose solution involves the whole model of the subsurface while the input data involves only data on the surface.

Recent advances have explored alternative formulations based on the theory of Optimal Transport (OT), which offer improved convexity and robustness to amplitude variations and noise. However, OT theory traditionally assumes positive mass distributions, which poses a fundamental limitation when applied to seismic data — seismograms inherently contain both positive and negative values. To address this mismatch, various signal transformation strategies have been proposed, yet no consensus has been reached.

In this work, we propose a novel OT-based FWI framework that operates by decomposing seismic signals into their positive and negative parts. This separation allows for a physically meaningful application of OT theory without discarding important waveform information. To address the non-differentiability introduced by this decomposition, we incorporate smoothing techniques that ensure compatibility with gradient-based optimization methods. Additionally, we are exploring proximal-type algorithms to further improve the convergence and stability of the inversion process. Preliminary results suggest that our approach enhances the quality of the reconstructed models while maintaining computational tractability.

Method and/or Theory

We developed a theoretical framework that encompasses a broad family of misfit functions between real and simulated seismogram data, including well-known examples such as the least-squares criterion. Within this framework, we are exploring several proximal-type algorithms to improve the solution of the inverse problem. Misfit functions based on Optimal Transport (OT) are formulated as specific instances of our general approach. All computational experiments are implemented in Python, using the Devito package for high-performance finite difference modeling.