Efficient and scalable posterior surrogate for seismic inversion via wavelet score-based generative models

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Abstract

Seismic inversion poses significant computational challenges due to its high dimensionality and non-unique solutions. We propose a novel method integrating the Wavelet Score-Based Generative Model (WSGM) with Simulation-Based Inference (SBI) to enable efficient posterior sampling for full-waveform inference. Our approach reduces memory requirements (approximately 50%) and significantly decreases sampling time (approximately 73%) compared to standard score-based diffusion models, while preserving accuracy.

Introduction

Accurate subsurface characterization remains a fundamental challenge in geophysical exploration, with seismic inversion serving as the primary tool for reconstructing subsurface properties, such as the acoustic wave-speed. The inverse problem of estimating velocity models from seismic observations is inherently ill-posed due to its high dimensionality, non-uniqueness and sensitivity to noise (Virieux and Operto 2009; Tarantola 2005).

Theory

Seismic imaging

Seismic imaging aims to reconstruct a velocity model $\mathbf{x} \in \mathbb{R}^n$ from seismic observations $\mathbf{y} \in \mathbb{R}^m$ recorded at the surface, governed by the forward model $\mathbf{y} = \mathcal{F}(\mathbf{x}) + \epsilon$, where $\mathcal{F} : \mathbb{R}^n \to \mathbb{R}^m$ is a nonlinear operator solving the wave equation and ϵ represents noise (Virieux and Operto 2009).

Tarantola, Albert. 2005. *Inverse Problem Theory: Methods for Data Fitting and Model Parameter Estimation*. SIAM: Society for Industrial; Applied Mathematics.

Virieux, Jean, and Stéphane Operto. 2009. "An Overview of Full-Waveform Inversion in Exploration Geophysics." *Geophysics* 74 (6): WCC1–26.