Quantifying Uncertainties in Variational Bayesian Machine Learning: Application to Seismic Imaging

Yuke XIE, Nicolas DESASSIS, Hervé CHAURIS (Centre of Geosciences, Mines Paris - PSL)

Introduction

Seismic imaging is a crucial tool for various applications such as natural resource exploration, geothermal energy development, and earthquake hazard assessment. Full Waveform Inversion (FWI) is a powerful technique for subsurface imaging, but it requires significant computational resources and is sensitive to uncertainties and data noise. The primary challenge in FWI is to quantify uncertainties accurately in the inversion process. Current approaches rely on deterministic optimization algorithms that do not adequately account for uncertainties, leading to biased or incomplete results.

Challenge

The primary challenge in FWI is to quantify uncertainties accurately in the inversion process. Current approaches rely on deterministic optimization algorithms that do not adequately account for uncertainties, leading to biased or incomplete results.

Method

To address these challenges, this research project proposes a novel FWI algorithm that uses Variational Bayesian machine learning techniques and incorporates a Gaussian prior to model uncertainties. The proposed approach seeks to optimize the posterior distribution of the model parameters given the observed data by integrating over the prior distribution of the model parameters, enabling the quantification of uncertainties and the exploration of multiple solutions.

The Gaussian prior framework is used to model uncertainties in the model parameters, which can be defined based on prior knowledge of the subsurface structure or through a data-driven approach using machine learning techniques. The use of Variational Bayesian machine learning techniques ensures efficient computation of the posterior distribution of the model parameters, reducing the computational complexity of the inversion process.

The proposed approach's effectiveness will be demonstrated through numerical simulations and real-world data applications, and it will be compared with existing FWI methods, including deterministic optimization algorithms and Bayesian methods that use Markov Chain Monte Carlo (MCMC) sampling. Evaluation criteria will include accuracy, computational efficiency, and uncertainty quantification.

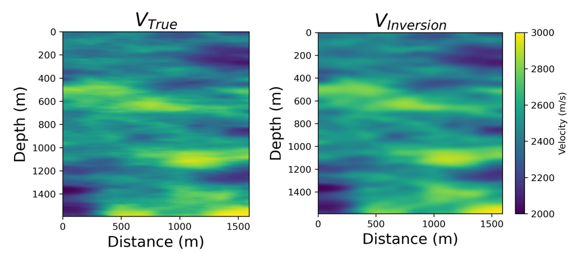

Fig. Gaussian Prior in FWI

Conclusion

This research project's proposed method has the potential to significantly advance our ability to accurately image the subsurface structure from seismic data by introducing a new framework that combines machine learning and optimization techniques.

Reference

[1] Bottero, A. et al. (2016) “Stochastic seismic tomography by interacting Markov chains,” Geophysical journal international, 207(1), pp. 374–392. doi: 10.1093/gji/ggw272.

[2] Calvetti, D. and Somersalo, E. (2018) “Inverse problems: From regularization to Bayesian inference,” Wiley interdisciplinary reviews. Computational statistics, 10(3), p. e1427. doi: 10.1002/wics.1427.

This project is co-funded by the European Union