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# Leveraging Geostatistical Seismic Inversion: Enhancing Genetic Algorithms for Sequential Reservoir Characterization

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## Abstract

Geostatistical seismic inversion methods typically rely on stochastic sequential simulation and iterative workflows, such as genetic algorithms, to optimize correlations between synthetic and real seismic data. However, these methods often involve high computational costs, particularly when applied to regular grids that inadequately represent complex subsurface geological features. This study introduces two optimized methodologies—Historic Genetic Algorithm (HGA) and Evolutionary Algorithm (EVO)—to enhance the potential of geostatistical seismic inversion. These approaches integrate local and global sequential inversions, aiming to reduce computational expenses while maintaining strong alignment between seismic and well data. HGA utilizes the best results from previous iterations as trends and input data for subsequent simulations, improving correlation outcomes. EVO builds on HGA by incorporating evolving parameter adjustments across iterations, further enhancing correlations. Both methodologies can be applied to stratigraphic and regular grids, addressing limitations of traditional regular grids in representing geological complexity. By leveraging stratigraphic grids, these methods ensure improved geological consistency and more accurate property simulations. The obtained results demonstrate significant advancements in computational performance, achieving higher correlation and reduced processing times. This work represents an important step forward in geostatistical seismic inversion, offering a robust framework for optimizing workflows while aligning geological models with seismic data.


## Introduction

In seismic inversion and reservoir characterization, approaches to model subsurface properties can be broadly categorized into linear and nonlinear methodologies. Linear approaches, such as deterministic inversion, rely on simplified assumptions like linearized Zoeppritz equations or Bayesian linear AVO inversion (Buland & Omre, 2003).

Nonlinear approaches, by contrast, address intricate and non-proportional relationships. For instance, rock physics models incorporating porosity, saturation, and mineralogy often exhibit nonlinear behaviors due to fluid substitution effects, stress responses, and anisotropies. Stochastic methods are commonly used in these cases, minimizing discrepancies between synthetic and real seismic data through iterative simulations. Despite being computationally intensive, these methods have been refined over the years with the implementation of techniques like geostatistical approaches (Penna & Lupinacci, 2024), and genetic algorithms (Maurya et al., 2019) trace-by-trace optimizations (Haas & Dubrule, 1994), global sequential inversion (Soares et al., 2007), and stratigraphic genetic approaches (Nascimento et al., 2023).

Stratigraphic grids play an essencial role in geostatistical inversion, particularly in structurally complex reservoirs where regular grids fall short in capturing geological features such as faults and anisotropies. To develop this type of grid, Mallet (2004) introduced the UVT-transform, which separates structural and property models, allowing independent geostatistical modeling. These grids preserve spatial correlations, align seismic inversion results with geological frameworks, and integrate multi-source datasets, including seismic, well, and geological data (Nascimento et al., 2021). By doing so, they minimize structural distortions, ensure geological consistency, and improve the accuracy of reservoir characterization.

This study further consolidates and advances these concepts into geostatistical inversion with the Historic Genetic Algorithm Seismic Inversion (HGA), which integrates high-correlation data from all simulation iterations. The Evolutionary Genetic Algorithm (EVO) extends HGA optimization by adapting parameters over successive iterations. The adaptive strategy consistently yields the highest correlation by the final iteration, demonstrating high accuracy and computational efficiency in complex reservoirs.

**Method and Dataset**

The proposed workflow integrates geological modeling and seismic data inversion into a cohesive and iterative process, enhancing both accuracy and geological consistency. It begins with the construction of a detailed stratigraphic and structural framework that captures spatial correlations of reservoir properties, hence, setting the stage for effective property simulations. Sequential Gaussian Simulation (SGS), combined with co-kriging techniques, generates impedance realizations by zone, which are seamlessly mapped onto a regular grid aligned with the seismic data scale.

These realizations serve as inputs for creating synthetic seismic data, where reflectivity coefficients are computed and convolved with wavelets representative of real seismic signatures. Correlation between synthetic and observed seismic data is achieved through a trace-by-trace sliding window technique. Samples showing strong correlations surpassing a defined threshold are incorporated as additional simulation input data, reinforcing the geological integrity of successive iterations.

Further refinement is driven by the ranking of properties based on correlation quality, considering data from all preceding iterations rather than relying solely on the most recent iteration. As simulations progress, velocity models can provide initial trends for impedance estimation, which are replaced by correlations emerging from accumulated simulation data in the subsequent iterations. This adaptive approach continuously integrates high-correlation samples into variogram analyses, ensuring alignment between geological and seismic representations.

To apply this approach to real data, a reduced dataset from an offshore siliciclastic play was chosen. The dataset includes several regional horizons and a single well containing a complete set of well logs, providing sufficient data for conducting all the analyses to demonstrate the feasibility of both methods.

Several analyses were performed to evaluate the improvements introduced in the new workflow by comparing results with default parametrizations. These evaluations assessed how each implementation improved the workflow, including varying correlation windows, incorporating correlations above thresholds as inputs, and comparing stratigraphic versus regular grids. Results were analyzed based on data-driven correlations.

The optimization for each proposed method is focused on achieving higher global correlations while minimizing processing time. Key parameters, such as the number of realizations, iterations, thresholds, and variograms, were tested to identify optimal configurations. Additionally, EVO results showcased significant correlation improvements, followed by efficiency analyses summarizing all the scenarios generated.

**Results**

Figure 1 presents the evaluation of correlation and processing time across all analyzed scenarios, emphasizing the differences in efficiency and accuracy. The analysis encompasses several workflow configurations: scenarios utilizing only the previous iteration to refine the next (1–3), those verifying sampling effects on correlation coefficients (4–7), varying the number of realizations in simulations (8–12), examining variograms before (13–16) and after (17–20) the implementation of the HGA algorithm, the impact of correlation thresholds values in turning properties into new input data for subsequent iterations (21–26), and the performance of stratigraphic (27–29) and regular (30–31) EVO algorithms.

The regular EVO scenarios delivered the highest correlations, though at the expense of significant computational resources. In contrast, both HGA scenarios and stratigraphic EVO configurations achieved correlations above 0.8 with superior efficiency, successfully balancing accuracy and processing time. By comparison, the default scenario (1)—using a regular grid with only the previous iteration's input, 10 realizations, and no correlation threshold—demonstrated one of the least efficient performances, yielding lower correlations and extended processing times. This analysis highlights the clear advantage of proposed workflows, such as HGA and EVO, in optimizing correlation while reducing computational effort.

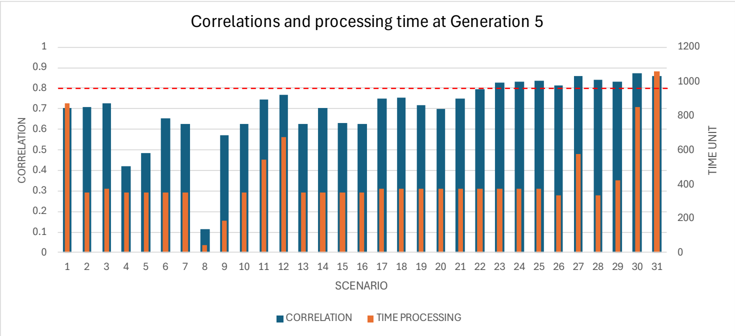


**Figure 1:** Correlation and processing time for each analyzed scenario were evaluated.

The EVO inversion results demonstrated strong alignment between real and synthetic seismic data, characterized by low residual amplitude and high final correlations. The final simulated input data effectively covered nearly the entire section, as illustrated in Figure 2, highlighting the consistency and accuracy achieved through this methodology.

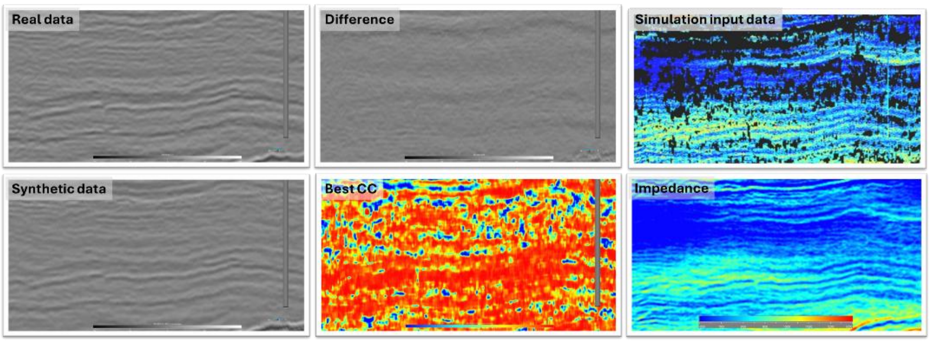


**Figure 2:** Evolutionary Algorithm: Inversion Results. The small residual amplitude between synthetic and real data demonstrates excellent adjustment in the inversion process. Correlation values consistently exceeded the threshold of 0.9, as reflected in the simulation input data.

**Conclusions**

This study introduces two innovative methodologies for geostatistical seismic inversion: the Historic Genetic Algorithm (HGA) and the Evolutionary Genetic Algorithm (EVO). Both approaches aim to optimize the inversion process, reducing computational costs while improving alignment between seismic and well data.

The use of stratigraphic grid demonstrated superior efficiency compared to the regular grid, reducing processing time with three times fewer cells while preserving geological accuracy. Although the regular grid achieved slightly better correlations, it approximately doubled the processing time. Optimization tests identified ten realizations and five iterations as the ideal balance for correlation improvements and computational efficiency. A threshold of 0.75 yielded the highest global correlations, while variogram analysis showed better results in scenarios with limited well influence. The Evolutionary Genetic Algorithm (EVO) further improved the workflow, delivering higher correlations and refined geological alignment while maintaining reasonable cost-benefit compared to HGA.

Overall, HGA and EVO represent significant advancements in the use of geostatistical seismic inversion, delivering improved correlations and cost-benefit outcomes. Future work could explore further parameter optimizations and strategies to address low correlation regions, increasing the effectiveness when performing seismic inversion techniques and geological modeling.

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