Submission code: 9Y48BDAVYV

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Andromeda: A Scalable and Extensible Python's Software for Seismic Data Inversion and Analysis

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Abstract Summary

Andromeda is an open-source Python software designed for efficient loading, visualization, and analysis of post-stack seismic data, well logs, and inversion products. It leverages the HDF5 format to handle large datasets with optimized memory usage, enabling responsive performance even on limited hardware. Built on a modular MVC architecture with a PyQt5-based GUI, Andrômeda ensures maintainability, scalability, and a smooth user experience. Its backend integrates robust scientific libraries like NumPy, SciPy, scikit-learn, and VisPy to deliver high-performance data processing and 3D visualization. Currently, the system supports seismic inversion workflows and real-time exploration of seismic volumes through a modern OpenGL canvas.

Introduction

Seismic inversion, interpretation and quantitative analysis are the main tools applied for reservoir characterization and those require large computing capabilities and complex software to be done taking in account the amount of data and the need for integrated visualization of the dataset acquired for the study area. For most companies and academic groups, the main issue lies at the software needed to run the required workflows applied to reservoir characterization, mostly due to the high costs for the licenses and plug-ins limiting the number of users depending on the financial capability of the company or academic group. Furthermore, traditional software often imposes steep learning curves, inflexible interfaces and shows limited options for customization and inclusion of new algorithms.

To address these challenges, we introduce Andromeda, a Python-based framework designed to enhance scalability and accessibility in seismic inversion workflows, developed using Model-View-Controller (MVC) paradigm, with simple scalability and customization of tools, workflows and algorithms. The software is being developed for use by an oil and gas company and academic institutions and is optimized to handle large seismic datasets efficiently. It features high-performance I/O operations, robust processing capabilities, advanced visualization tools, and supports real-time interaction through an intuitive graphical user interface.

This study aims to demonstrate Andromeda´s main functionalities using real world, large scale seismic dataset and well data to run viability study prior acoustic inversion, relative post-stack inversion and visualization of the results in the 3D viewer with user support for parametrization of viability study, seismic inversion and 3D visualization.

Method and Theory

Andromeda's architecture adopts a modular Model-View-Controller (MVC) paradigm (Figure 1). The Model layer leverages Segyio for SEG-Y data import (Robijns & Equinor ASA, 2020), h5py for efficient HDF5 storage (Collette, 2013), and SQLAlchemy for managing local database operations (Bayer, 2024). Performance and memory efficiency are enhanced through parallel processing with QThread (The Qt Company, 2024) and dataset chunking supported by HDF5.

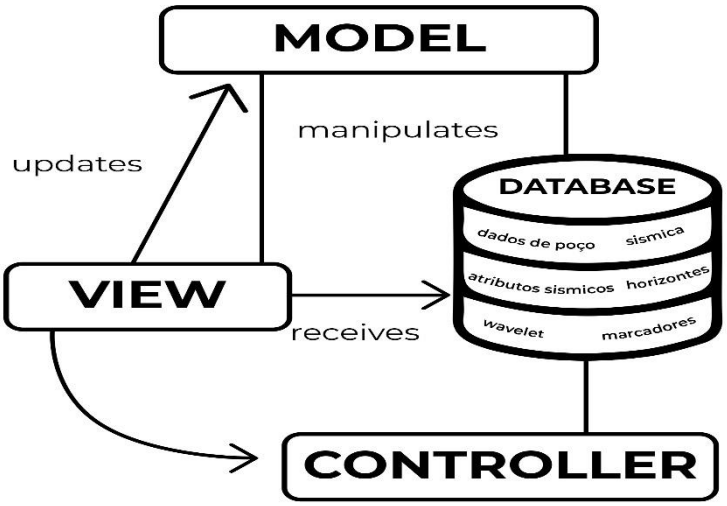

Figure 1 - Schematic figure representing Andromeda´s software architecture.

The View is built using PyQt (Riverbank Computing, 2024) and Vispy (Campbell et al., 2023), delivering a lightweight, GPU-accelerated interface for seismic data visualization and inversion configuration. The Controller orchestrates application logic, integrating computational and plotting functionalities supported by NumPy (Harris et al., 2020) and Matplotlib (Hunter, 2007). Andromeda supports a variety of seismic inversion algorithms—including trace-by-trace, regularized, and blocky inversion models—adaptable to different geological settings. These are implemented using the Pylops package for linear operator management (Ravasi & Vasconcelos, 2020).

The current release performs relative impedance inversion, with model-based inversion planned for future versions. The platform also supports feasibility studies using Bayesian inference (Figure 2), leveraging well data, and enables fast loading and seamless visualization of seismic volumes, well logs, horizons, markers, and other related datasets—without overloading CPU or GPU memory. All modules are thoroughly tested with pytest (Krekel et al., 2024) to ensure robustness, reproducibility, and maintainability.

Figure 2 - Viability study summary window.

Results

A functional version of Andromeda has already been delivered to the partner oil and gas company, where it has been successfully tested using large real-world seismic datasets and well data. The platform demonstrated robust performance during data loading, parameter configuration, and inversion processing stages, maintaining responsiveness even when handling multiple seismic volumes. In comparative testing against proprietary platforms, Andromeda showed competitive results in terms of processing speed and visual rendering performance, despite running on modest hardware. Users from both industry and academia provided highly positive feedback, emphasizing the intuitive user interface, the seamless integration of preprocessing and inversion workflows, and the flexibility to incorporate custom algorithms and workflows. Additionally, the 3D viewer enabled detailed inspection of inversion results (Figure 3), facilitating interpretation and quality control.

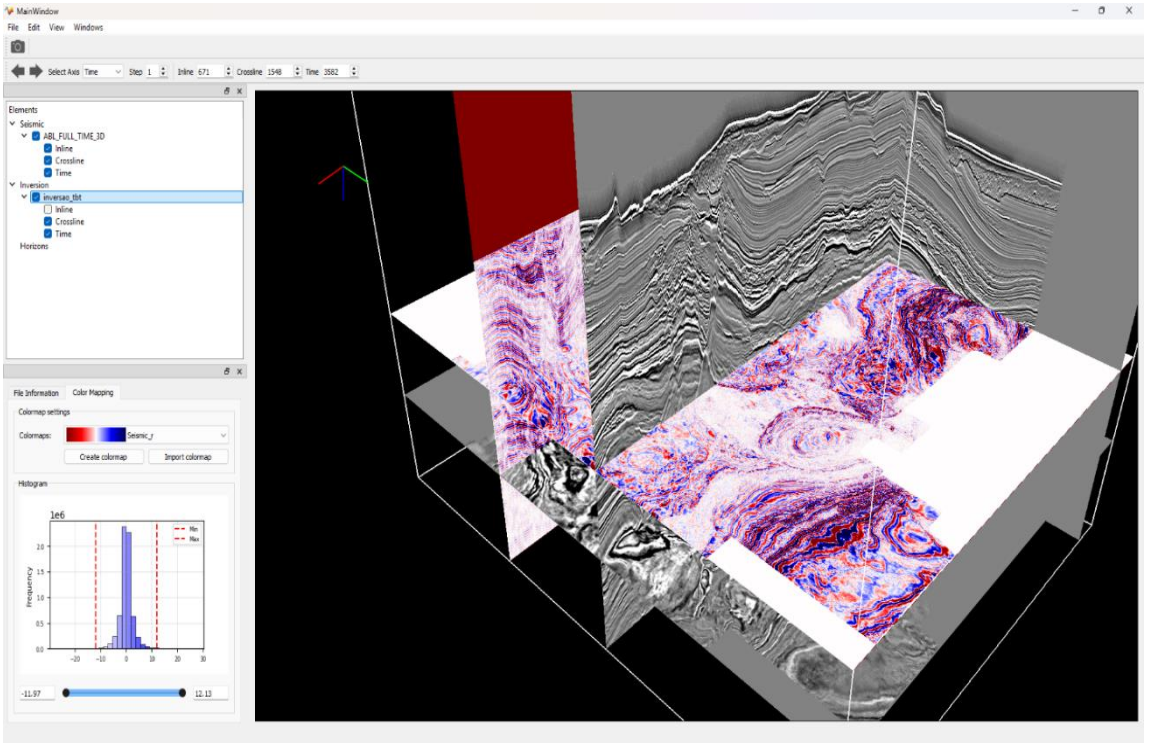

Figure 3 - 3D Canvas showing seismic data and computed relative acoustic impedance.

Conclusions

Andromeda effectively combines high computational performance with a modern, user-oriented interface, offering a compelling open-source alternative to expensive and restrictive commercial software. Its modular MVC-based architecture and support for HDF5-backed data access allow scalable handling of seismic and well data, while GPU-accelerated 3D visualization ensures a fluid experience during exploration and interpretation. The platform is already enabling advanced seismic inversion workflows, including feasibility studies and relative post-stack inversion, with more sophisticated inversion techniques, such as model-based and simultaneous inversion, in the development roadmap. By lowering the cost barrier and increasing accessibility to advanced geophysical workflows, Andromeda is positioned to support innovation and collaboration within both the academic and industrial geoscience communities. Future development will prioritize community engagement, plugin support, and comprehensive documentation to foster long-term adoption and contribution.

Acknowledgments

The authors gratefully thanks PRIO S.A. for providing part of the data used in this study and for funding the research project.

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