CIGVis: an open-source python tool for real-time interactive visualization of multidimensional geophysical data

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Summary

As Python's role in processing and interpreting geophysical data expands, the need for a Python-based tool tailored for visualizing geophysical data has become increasingly critical. In response, CIGVis was developed - a fully open-source Python tool optimized for researchers and licensed under the MIT. It specializes in real-time, interactive visualization of multidimensional geophysical data, including 3D seismic, faults, horizons, geological bodies, and well logs. CIGVis enables users to interact with data through operations such as rotation, movement, zooming, and dragging slices. It also supports a multi-canvas functionality, allowing simultaneous visualization across multiple sub-canvases with a unified camera perspective. Its ease of use allows for effective visualization with just a few lines of code across all major operating systems, and extends to both desktop and Jupyter environments, facilitating code execution in various settings. The core functionalities of CIGVis are exemplified using straightforward datasets, such as the F3 dataset. The source code of CIGVis is hosted on GitHub at: https://github.com/JintaoLee-Roger/cigvis.

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In the field of geophysics, data visualization is not merely a means of data representation but a key to deeply understanding the subterranean world. It is the third type of resolution beyond temporal resolution and spatial resolution (Lynch, 2008). With the rise of artificial intelligence, machine learning and deep learning are being widely used in geophysics for many tasks. Therefore, Python, a premier language in deep learning, has significantly advanced the processing, analysis, interpretation, and inversion of geophysical data. As more workflows shift towards Python, there is a growing expectation for a Python-based geophysical data visualization tool, avoiding the need to import processed data back into commercial softwares.

In this work, we introduce CIGVis, a python tool developed by the Computational Interpretation Group (CIG), for real-time interactive visualization of multidimensional geophysical data. Designed primarily for researchers, CIGVis enables the rapid visualization of multidimensional geophysical data with just a few lines of code. This encompasses data such as 3D seismic, horizons, faults, well logs, and geological bodies, allowing researchers to concentrate more on the analysis and interpretation of geophysical data. A key strength of CIGVis is its interactive features, which allow users to engage dynamically with the data through operations like rotation, movement, zooming, and dragging slices. Besides, CIGVis supports multi-canvas functionality, allowing for simultaneous visualization on multiple sub-canvases with a unified camera perspective. This capability is crucial for comparative analysis between different dataset.

CIGVis has been optimized for compatibility across major operating systems and supports both desktop and Jupyter environments, ensuring wide accessibility and flexibility for researchers. As a fully open-source software, CIGVis adheres to the MIT license. Its source code is available on GitHub at `https://github.com/JintaoLee-Roger/cigvis`, and we also maintain detailed documentation at `https://cigvis.readthedocs.io/en/latest/`, where users can find a wealth of demos. CIGVis is continuously evolving, with regular updates to its source code, documentation, and demos to cater to the expanding needs of users.

Design Philosophy and Framework

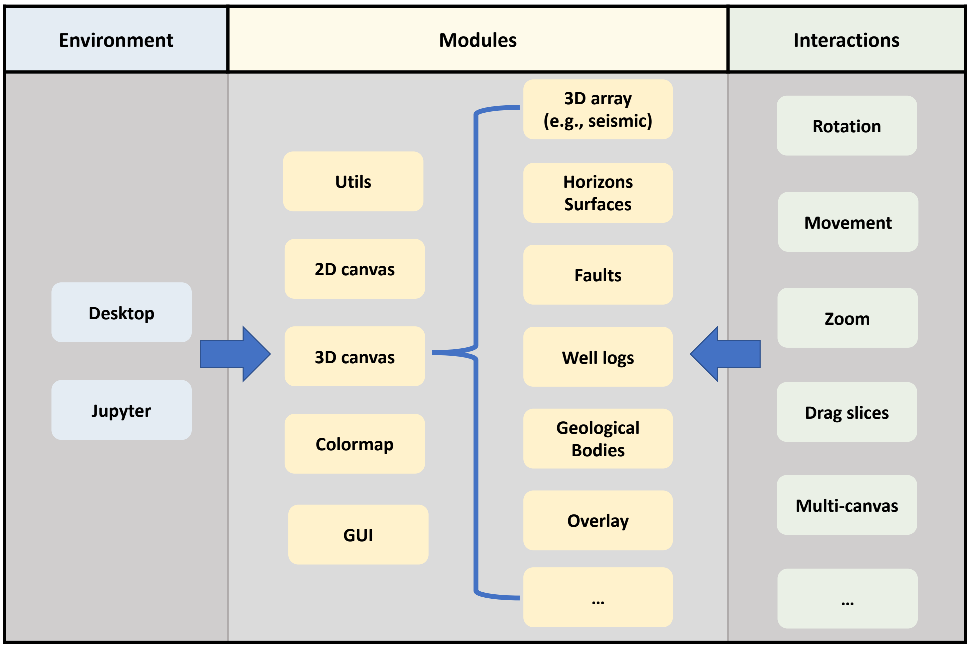

Figure 1 *The Design Framework of CIGVis.*

CIGVis is a software specifically crafted for the visualization of geophysical data, tailored for researchers. Its architecture and features are illustrated in Figure 1. CIGVis's design philosophy embraces simplicity, professionalism, and real-time interactive 3D visualization, while ensuring that the software maintains excellent extensibility and the freedom of open-source code.

Simplicity is reflected in the ease of installation and user-friendly interface of CIGVis. Leveraging Python's cross-platform capabilities, CIGVis can be seamlessly run on any major operating system and Jupyter environments. This ease of use empowers researchers to efficiently visualize 3D data with just a few lines of code. CIGVis provides advanced APIs for geophysical data visualization, allowing researchers to focus on the data's characteristics without getting bogged down in technicalities. It supports real-time interactive visualization of 3D data, such as 3D seismic data, enabling users to freely move slices within the data to deeply observe internal features.

CIGVis is composed of several modules, each serving a specific purpose. The Utils module provides essential functions for handling geophysical data, including reading and writing various data formats, processing coordinate systems, and providing common functionalities. The 2D canvas module is specifically for visualizing data on a 2D canvas in research. The 3D canvas is the core of CIGVis, encapsulating high-level APIs for visualizing geophysical data within a 3D canvas. The Colormap module offers commonly used colormaps in the geophysical domain, widely used in commercial software but not always included in Matplotlib. And it also provides functions for users to adjust colormaps as needed. The GUI module provides some limited but functional simple GUIs.

Core Features

The core feature of CIGVis lies in its 3D Canvas functionality. Users can visualize various types of geophysical data through simple code on this canvas. As shown in Figure 2, we demonstrate CIGVis's key features using the F3 dataset. Notably, in the 3D Canvas, all elements (or called nodes) are independent of each other. By progressively adding new elements to the canvas, we illustrate the powerful capabilities of CIGVis.

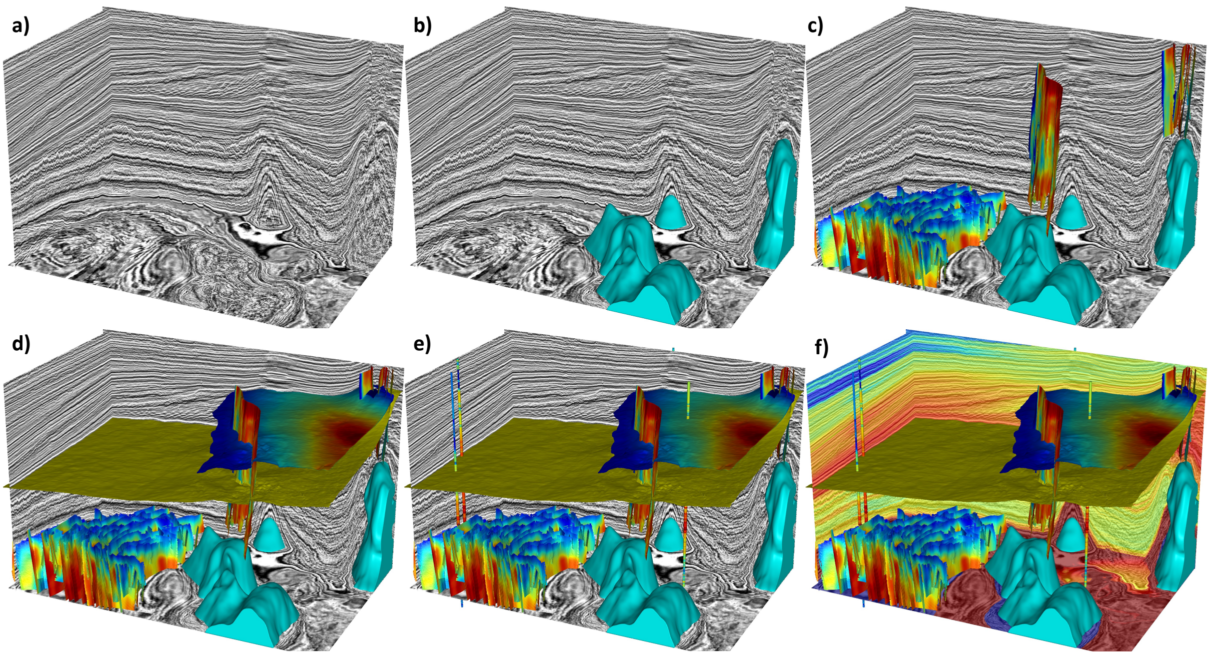

Figure 2 *Demonstrating core features of CIGVis using the F3 dataset. We sequentially add geophysical data to a 3D canvas, showcasing (a) 3D seismic data, (b) salt body, (c) fault surface, (d) horizons in various colors, (e) well logs, and (f) an overlay of seismic data with its impedance.*

CIGVis represents 3D volume by displaying multiple 2D slices in different orientations. Figure 2a shows an example of a 3D volume represented by multiple 2D slices in the X, Y, and Z directions.The basic real-time interactions with the 3D canvas, such as rotation, movement and zoom, can be performed with the mouse and keyboard. Moreover, each slice is presented as an image, allowing for rapid rendering. Users can move any 2D slice in real-time by clicking and dragging the mouse, conveniently observing data at any point in 3D space.

For 3D geological bodies, CIGVis uses the Marching Cubes algorithm (Lorensen and Cline, 1987) to extract their and displays them using a closed mesh constructed with triangular grids. Figure 2b shows a 3D representation of a salt body in F3 dataset. CIGVis conveniently visualizes fault planes, not only displaying their location but also superimposing fault attributes (such as the fault displacement fields) in an intuitive manner, as shown in Figure 2c. Additionally, the results of AI fault identification, which are often binary or discrete 3D arrays, can also be overlaid on seismic data for visualization.

Visualizing horizons is one of the most basic and vital requirements in geophysical visualization. CIGVis can process depth matrices of the same size as seismic horizons, as well as handle 3D spatial coordinates, whether ordered or not. Users can display depth or seismic amplitude data on horizon surfaces and customize colors for each point. Figure 2d shows two horizons: the lower horizon displays a full spatial distribution in yellow, while the upper horizon is an unconformity surface with colors representing its displacement field, and Figure 3c visualizes seismic amplitude on the horizons.

A well log typically contains multiple curves, such as gamma, velocity, and density curves. As shown in Figures 2e and 3a, CIGVis can display well logs as tubes of varying sizes, where the tube's color and radius size reflect the relative magnitude of the curve values. Other curves can be displayed as individual mesh pieces attached to the tube walls, their color and width of the mesh indicate the magnitude of those well log curve values. CIGVis can display both vertical and deviated wells, facilitating comparative analysis of well logs with seismic data.

Overlaying two or more types of 3d data helps understand the correspondence between different datasets and verify the consistency of the results with reality. CIGVis easily achieves the overlay display of various data types. For example, Figure 2f shows the effect of overlaying 3d seismic data with its impedance. This display method not only retains the basic information of the seismic data, such as horizons, but also clearly examines the accuracy of the impedance through the contrast with the foreground color. Additionally, geological formations such as faults and channels can be overlaid on seismic images to analyze the distribution of these geological structures (Figure 3b).

A distinctive feature of CIGVis is its support for Multiple Canvas. This feature allows users to divide a single canvas into multiple sub-canvases, each hosting independent nodes. As shown in Figure 3b, the 3D canvas is divided into four sub-canvases. A key functionality in this setup is the unified camera perspective across all canvases. This means any action, such as rotation, movement, or zooming, applied to one canvas affects all others in a synchronized manner. For instance, if a slice is dragged in a specific direction in the first canvas of Figure 3b (indicated by the red arrow), corresponding slices in other sub-canvases will also move synchronously. This multi-canvas display is particularly valuable for conducting comparative analysis between different datasets, offering an efficient way to compare various results and explore relationships between different types of data.

The 3D canvas of CIGVis also offers APIs to support Jupyter environments. Given that Jupyter is a web-based tool, it has certain performance limitations, such as the ability to drag slices in real-time and rendering speed. In the Jupyter environment, CIGVis is developed based on Plotly, and its rendering results may differ from those in the desktop environment, but this does not imply a reduction in quality. Figure 3c shows the visualization result of F3 data in the Jupyter environment. CIGVis in Jupyter also supports some features not yet available in the desktop environment, such as axis display and real-time display of 3d coordinates when hovering the mouse. In the future, we aim to improve functionalities in the Jupyter environment and strive for a unified API across both environments.

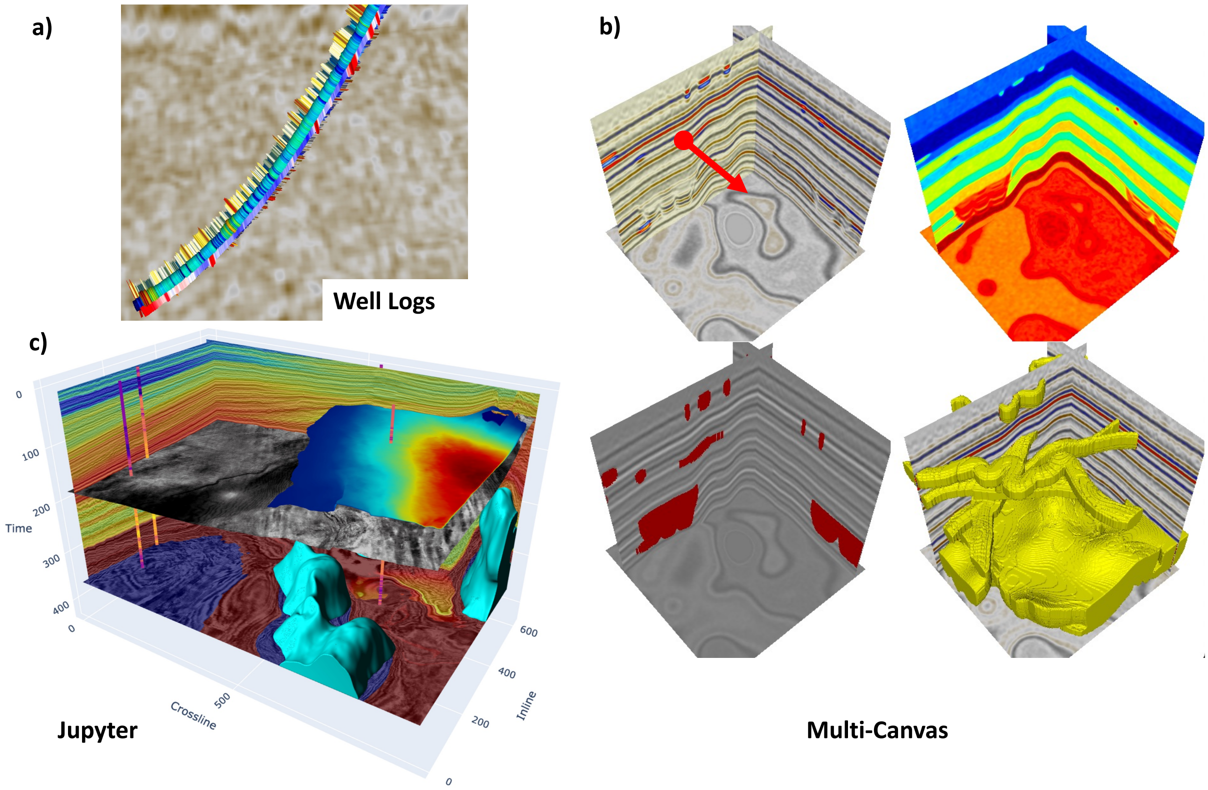

Figure 3 *Some examples of the core features. (a) the well logs, (b) the multi-canvas functionality, (c) the F3 dataset displayed in jupyter environment.*

Conclusions

This paper presented CIGVis, an open-source Python tool tailored for visualizing multidimensional geophysical data. Addressing the growing need within the geophysics community, CIGVis excels in real-time interactive visualization, making multidimensional data analyses more intuitive and accessible. Designed for wide accessibility, CIGVis is compatible with major operating systems and supports both desktop and Jupyter environments CIGVis's interactive features, including rotation, movement, zooming, and dragging slices, allow users to interact deeply with various geophysical data types such as 3D seismic, faults, horizons, and well logs. Its multi-canvas functionality, enabling simultaneous visualization across multiple sub-canvases under a unified camera perspective. This is particularly valuable for comparative analysis, offering enhanced insights into complex geological datasets.

Future enhancements for CIGVis include improving the coordinate system, expanding support for more data formats from various softwares, and refining visualization quality for a better user experience. Additionally, CIGVis aims to enhance its interactive capabilities, particularly by providing a visualization interface for interactive AI. This will involve developing features that allow users to interact with visualized data, facilitating direct communication between the user actions, AI model responses, and the visualization outcomes.

References

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