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Three-dimensional Visualization and Integration of Geophysical, Geological and Cultural Data in Python

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Abstract Summary

Geophysics has several methods for obtaining information in the subsurface, which will result in a variety of data used to investigate and understand the Earth's interior. The use of three-dimensional visualization allows data to be integrated, resulting in a more complete visual representation. However, existing commercial solutions for this purpose are expensive and often inaccessible to students and researchers. To this end, this work aims to use the Pyvista library in Python, an open-source tool that makes it possible to build a three-dimensional visualization of these geophysical data. Three-dimensional visualization has already established itself as a widely used tool in science, including in the field of geophysics, with some commercial programs. However, when using a Python library, in addition to being a free tool, it also stands out for its adaptability and reproducibility.

Introduction

Geophysics investigates the Earth's subsurface to obtain information about the interior of the planet. Methods such as gravimetry, magnetometry, refraction and reflection seismic, electro-resistivity, among others, help in the investigation process. Integrating the results of these methods with geological and cultural data is essential for a complete analysis and the reduction of ambiguities.

There are commercial software packages in this area, such as PETREL, OpendTect and Paleoscan, which use 3D visualization in their analysis and interpretation flows. According to Bullejos and Martín-Martín (2023), commercial software has advantages such as ease of use and technical support, but the cost of acquisition tends to be high. Open source tools are cheaper to purchase and more adaptable, but they can be more complex to use and do not provide specialized technical support. In this way, Python has become a tool for reproducing 3D visualizations using lines of code, products obtained from software, in an adapted way that allows you to adjust whatever is necessary according to the problem to be solved.

According to Paiva et al. (1999) visualization is a term related to methods that allow the extraction of relevant information from complex data sets. It is called scientific visualization when these data sets represent complex phenomena and when the aim is to extract relevant scientific information. Thus, we can associate the construction of a 3D scene with scientific visualization, as integrating products generated by geophysical methods enables the construction of this visualization and facilitates the scientific analysis of the subsurface.

This type of visualization is already widely used in science, as a 2D view can often limit the understanding and interpretation of certain data, although 2D data can also be added to a 3D visualization. In addition, Fitzpatrick and Hedley (2024) mention the concept of geovisualization, in which they focus on the development of multidimensional and interactive methods to meet the analytical needs of 3D and 4D spatial data analysis and visualization.

The aim of this work is to use the integration of products obtained through geophysical methods for three-dimensional (3D) visualization, which provides a wealth of detail, promotes the visualization of a set of information, and is interactive. In this sense, it is possible to interact with the 3D scene and select the object to be visualized. The Python programming language will be used to build this scene, mainly using the Pyvista library, within the context of analyzing geodynamic processes in southeastern Brazil.

Method and/or Theory

The methodology used in this study was implemented using the Pyvista library, developed by Sullivan et al., which generates three-dimensional models from an open source tool, enabling geoscientists to obtain this type of visual representation. Pyvista processes different types of data, contributing to the integration of objects in 3D visualization. According to Sullivan et al. (2020), Pyvista has classes that represent each type of structure, which represent what are generally called meshes and/or grids. Among them, *Polydata* represents point clouds, *RectilinearGrid* represents implicit geometries along the directions of rectangular and regular axes, *UniformGrid* when implicit geometries have cell dimensions uniformly assigned along each axis, *StructureGrid* represents a regular grid of points aligned with a coordinate axis, and *UnstructuredGrid* represents the most varied data sets.

In addition, Pyvista's compatibility with other Python libraries provides various possibilities for using and manipulating the library. According to Kaszynski and Sullivan (2017), all these classes are used to generate a mesh that represents any spatially referenced information that has a geometric representation of a surface or volume in 3D space.

To create a three-dimensional visualization with Pyvista, you need to follow a basic workflow after installing the libraries and packages required to use Python code. This workflow consists of the following steps:

- Reading the desired object/structure;
- Create a mesh with this object;
- Plot the mesh.

As mentioned earlier, this is a basic flow for dealing with a piece of data in Pyvista and creating the plot that will generate the three-dimensional visualization. Some of the data needs to go through additional treatments before it becomes a mesh. This is the process that will be repeated several times until a final visualization is built by integrating all the meshes into a single visual representation.

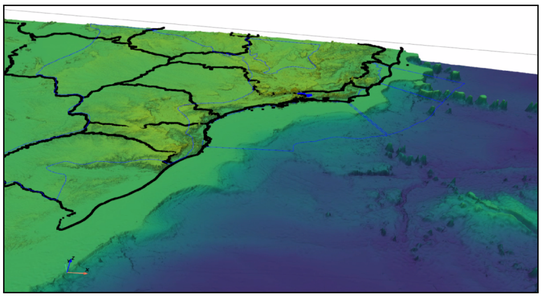
Results

To build the three-dimensional visual representation of this work, a portion of southeastern Brazil was used as the study area, with an emphasis on data for the region of the state of Rio de Janeiro. Among the meshes used in the 3D scene, we have:

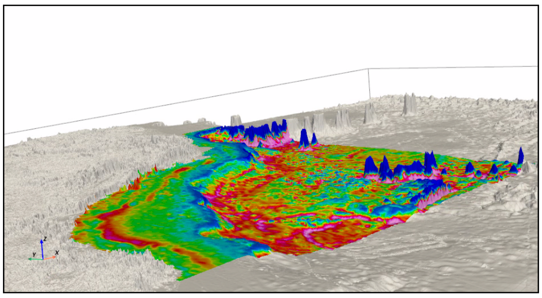
- A Digital Elevation Model (DEM) of the selected area;
- A mesh that represents the ocean;
- A mesh with gravimetric and magnetometric map textures;
- Base and top of the Búzios salt field;

- Meshes that demarcate basins and states.

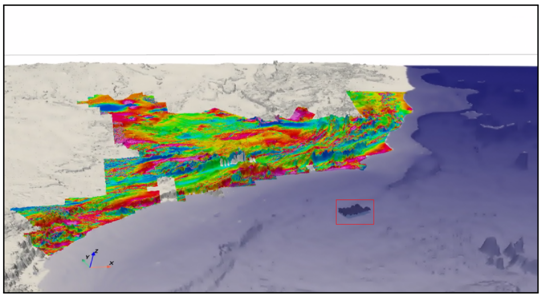
Below are some of these structures, which can be used to compose the visualization. The result is the figure 1. The figure 1a represents the topography, with the basins and states present in the study area demarcated, in figure 1b is the representation of a gravimetric map as a texture over the topography, 1c the representation of a magnetometric map, with the ocean and the top and bottom of the salt of the Búzios field, finally, 1d represents all the topography, states, basins, along with the basement and the base and top of the salt of the Búzios field. The figure 1 is an example of part of what can be achieved with this type of visual representation, since this tool is compatible with various geophysical data, given that Pyvista has a very high level of abstraction, precisely to deal with data of the most diverse natures and sciences.



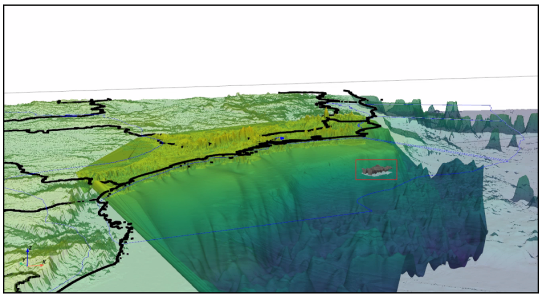
(a) Three-dimensional visualization of basins and states



(b) Three-dimensional visualization of the gravimetric map



(c) Three-dimensional visualization of the magnetometric map with the ocean, salt top and base



(d) Three-dimensional visualization of the basement and salt top and base marked in red

Figure 1: Three-dimensional visualizations.

Conclusions

The use of three-dimensional visualization in geophysics, as in other sciences, is a methodology that allows data to be studied in three dimensions, from various angles, as well as making it possible to interact with the image. The tool's capacity for customization and adaptability is a positive aspect, as it allows geoscientists to explore the other functionalities that 3D offers. In addition, the easy integration of data of various kinds makes it possible to interpret this data with the presence of other information that adds to the historical context of the area studied.

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