3D object-oriented image analysis with applications in 3D geophysical modeling

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Abstract: The interpretation of 3D geophysical data is a challenging task. The process continues to be often done manually and remains limited by subjective choices that render the process unrepeatable.
3D object-oriented image analysis (OOA) has recently been used successfully in the biomedical field, where it was shown to constitute a robust and semi-automatic tool to extract objects from 3D image stacks.
In this research, 3D OOA was used to interpret 3D geophysical data. The approach was first tested on a synthetic 3D model, and later applied to areal 3D seismological data.
The results showed that 3D OOA is a promising tool that can provide a semi-automatic and repeatable approach to interpret 3D geophysical data. However, the approach needs further research to automate the process of threshold selection.
Keywords: OOA, 3D, Geophysics.

1. Introduction

3D geophysical data are the main source of information about the subsurface. They describe the subsurface based on different physical properties e.g., seismic wave velocities, electric resistivity, and density, which can be measured using different sensors. However, this distribution of the physical properties needs to be interpreted into subsurface structures (objects), which is the general aim of any geophysical survey. The data used in this research are 3D shear wave velocity model of the central part of the African rift system. The data describes the 3D subsurface structures (objects) in terms of shear seismic velocity distribution. The model was produced by 3D seismic tomography inversion of the earthquakes recorded in the study area.
The interpretation of geophysical data is a challenging task since the subsurface images are always fuzzy. Moreover, the process needs expert opinion, which makes it subject to subjective choices that render the process largely unrepeatable, and that limit its use for different datasets and geological settings.
In this research, 3D OOA was used to interpret and extract 3D objects from 3D geophysical data.

2. 3D OOA

The utility of 3D OOA has recently been explored in the biomedical field to extract 3D objects from 3D image stacks, e.g., 3D X-Ray computed tomography images (Schönmeyer et al., 2006). A similar approach was recently used in the geo-scientific community to process 3D LiDAR point cloud data (URL 1).

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3D OOA, similar to any OOA, consists of two steps, starting with data segmentation followed by the classification step. However, the main difference is the third dimension, in which additional spatial attributes can be used.
In this research eCognition software (8.7) package was used.

3. Methodology

The methodology can be divided into two steps:

- The first step was testing 3D OOA using a synthetic example, which was designed to simulate the objects existing in the real data model, describing seismic wave propagation in the subsurface. It is consisted of a central object in the middle surrounded by two vertical objects and three vertically aligned layers surround all of them (Fig. 1). Underneath all of these objects lies a deep-seated object that continues to the end of the model. The model includes both vertical and horizontal boundaries that describe the gradual transition between the different objects. The objects have sharp and crisp boundaries, which made the analysis more straightforward.
- The second step was using 3D OOA to extract objects from a real 3D seismological model that describes the seismic wave propagation in the subsurface of Tanzania Craton and its surroundings. The model consists of the Tanzania Craton surrounded by two rift branches, and all surrounded by vertically aligned layers. These objects are underlain by a low velocity anomaly. The extracted objects are crucial to understand the tectonic framework of the study area. I was also further used to constrain the inversion of the satellite gravity inversion of the study area (for more details see Fadel et al. (in press-b)).

3.1. Synthetic test

The synthetic test started by preparing the data. The model was converted into a 3D image stack, which was imported into eCognition. Then, the 3D image stack was analysed using the segmentation and classification algorithms in eCognition in the following steps:

- Multi-threshold segmentation was used to define the different pixel clusters in the model.
- Then the different objects were classified based on a combination of thresholds using their depth and pixel values.
- A finalization steps in which the segments of each object were merged and the objects were fully constructed in 3D.

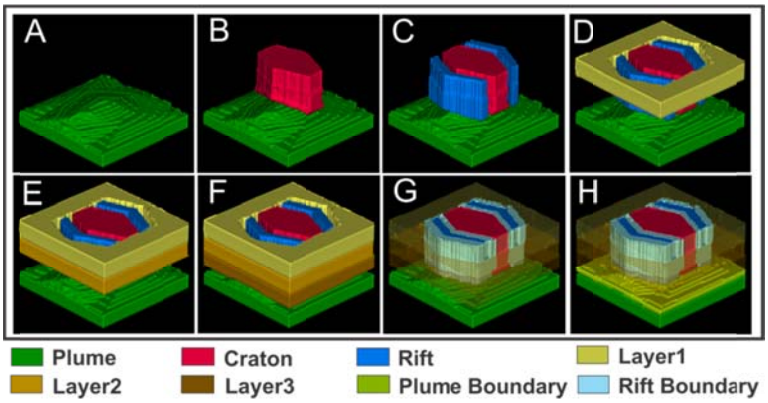

Figure 1. 3D OOA of the synthetic model. Figures (A:H) show the 3D OOA extraction process with the plume, craton, rifts, layers L1, L2, and L3 (D, E, and F, respectively, and displayed with 50% transparency), the rift boundary, and the plume boundaries (adapted from Fadel et al. (in press-a)).

3.2. Real 3D seismic tomography model

Extracting the objects from the real model started, as in the synthetic test, by converting the model into a 3D image stack, which was imported into eCognition to start the 3D object extraction. Then, the 3D image stack was analysed using the segmentation and classification algorithms in eCognition in the following steps (Fig. 2):

- The multi-threshold algorithm was used to divide the 3D image stack into equally divided classes, since the objects boundaries were not clear.
- The different objects in the model were classified based on a combination of thresholds of their pixel values, based on the equally divided classes, and depths.
- A finalization step in which the segments of each objects were merged together and the objects were constructed in 3D.

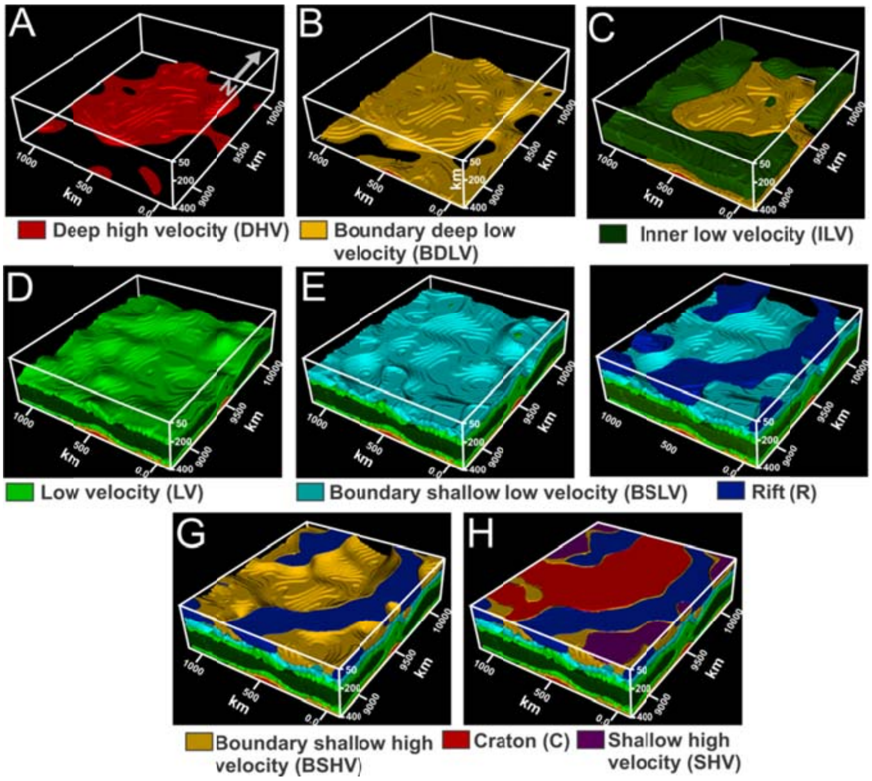

Figure 2. 3D OOA of the real model. (A:H) show the 3D OOA extraction process where (A) illustrates the deep high velocity object, (B) the boundary deep low velocity, (C) the inner low velocity zone, (D) the outer part of the low velocity zone, (E) the boundaries of the shallow low velocity, (F) the rifts, (G) the boundaries of the high velocity objects, and (H) the craton and the shallow high velocity objects (adapted from Fadel et al. (in press-a)).

4. Results and Conclusions

3D OOA of the synthetic model was a straightforward process, since the objects boundaries were crisp and clear. This made the threshold selection in the classification process easier and the results mimicked the original model perfectly. However, 3D OOA of the real model contains – and is limited by – a subjective selection of thresholds, since the objects boundaries were fuzzy and the model was blurred.

The usage of multi-threshold segmentation algorithm was not the optimum choice. The multi-resolution segmentation algorithm, combined with the and Estimating Scale

Parameter tool (ESP) (Drăguţ et al., 2010) to estimate the optimum scale parameter can be better choice, since they can deal with complex structures. However, further development is needed to be able to deal with 3D data since the 3rd dimensional needs further attention in the segmentation process.
In this work 3D OOA has shown the ability to extract 3D objects from 3D geophysical data. However, further research is needed to optimise the segmentation algorithms in 3D. Moreover, further development in needed to automate the threshold selection and reduce the human interaction.
The accuracy assessment of the extracted results is a difficult task since there is no ground data that exist at these depths. However, the extracted objects were evaluated by comparing the calculate gravity signal using them with the measured satellite gravity signals. The comparison showed the signal based on the extracted objects showed 70 % correlation with the measured signal (for more information see Fadel et al. (in press-b)). This can be an evaluation for the extracted objects, which showed an acceptable performance in further geophysical modelling steps.
3D OOA can be a useful tool for 3D geophysical modelling. It can provide the geophysical community with a semi-automatic and repeatable approach to interpret their data. However, the process needs further future research to be more automated and less dependent on human interaction.

References

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Useful links (accessed September 2012):

URL 1:
http://community.ecognition.com/home/ecognition-labs/3d-lidar-point-cloud-analysis/?searchterm=3D

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