Topological Reconstruction of Oil Reservoirs from Seismic Surfaces[1]

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Abstract

This paper describes the main aspects of Project Geosis. It is an ongoing three year project between the Brazilian oil company Petrobras and the Pontifical Catholic University of Rio de Janeiro, Brazil. Its main objective is to extract information from seismic data through the use of geometric and topological modeling, as well as scientific visualization.

Introduction

The characterization of oil reservoirs has as one of its components the study of their geometry and topology. While the geometry deals with spacial distribution of points and its associated properties, e.g. permeability and porosity, the topology handles its connectivity. To determine the topology of the reservoir is then an essential ingredient for its characterization.

One of the main characteristics of seismic processing is the generation of large data sets. Computationally intensive powerful techniques are needed to extract meaningful information from these data.

The main objective of the talk will be to show how to reconstruct geological objects (channels, lobes, etc.) directly from seismic data. The data is piled up in offset groups in such a way as to get information from the seismic aiming at the geological modeling.

This papers focuses on:

1. Topological surface reconstruction from seismic data and its corresponding visualization;
2. Surface simplification in order to deal with large data sets.

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Isosurface extraction

The seismic data obtained by physical measures can be interpreted, after the signal processing step, as a sampling of a continuous function $f:(x,y,z)\varepsilon R^3 \rightarrow f(x,y,z) \varepsilon R$ over a cuberill grid (x_i, y_j, z_k) i=1..m, j=1,...,n, k=1,...,p. The function f models the property function, such as permeability and porosity. The reser voir corresponds to the portion of space R where the value of the property is included in a certain range [v,w]: $Res = f^{-1}[v,w]$.

Any method that computes this volume *Res* needs to extrapolate from the sampled data. For example, we could induce the function f from the sampled data, and then compute analytically the pre--image *Res*. This extrapolation would envolve a geological model of the terrain. However, this method is computationnally expensive, renders interpreted data and does not guarantee the topology of the reservoir in general. We will use a different but classical strategy, and enhance its robustness.

We will compute the reservoir surface directly from the sampled data. We aim at controlling and minimizing the artifacts induced by the extrapolation. In particular, we are concerned with the topology of the resulting surface, i.e. preserving the connections between or inside the reservoirs. Moreover, in order to improve the quality of the result, we will include in our process the global information we already know, such as the data representation of section

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Missing data

The main problem we encountered with the seismic data is its incompleteness: some of the grid points do not have an (x_i, y_j, z_k) associated property value $f(x_i, y_j, z_k)$. Those points can be isolated, or form entire volumes inside the grid. We implemented three strategies to handle this deficiency, which corresponds to different quality/reliability and quality/computational costs trade--off:

1. No interpolation: the grid point is discarded, and none of the triangles of the final surface will intersect a cube containing a discarded point. This ensures a more reliable output, but leads to many holes in the surface.
2. Linear interpolation: the value of a missing grid point is computed as the barycenter of its nearest valid points.
3. Radial--basis interpolation: all the valid point of the grid contributes to the missing value proportionnally to their distance. It does give nice results, but induce a modeling of the data which is not always accurate. Radial--basis methods have been extensively studied, and would offer many possibilities of including accurate geophysics models (Carr and others, 2001).

We will use an extension of the Marching--Cubes' algorithm (Lorensen, 1987) to extract the surface of the reservoir from the preprocessed seismic data. The Marching Cubes method produces a triangular mesh of the preimage $g^{-1}(0)$, given by samples over a cuberille grid. To convert the test $f(x_i, y_j, z_k) \in [v,w]$ into $f(x_i, y_j, z_k) \geq 0$, we will test a grid point with $g = (f - v)(w - f)$. The original method sweeps the grid, and tiles the surface cube per cube. Each point of the grid is classified into positive and negative vertices. Thus, there are $2^8 = 256$ possible configurations of a cube. The usual implementation stores those 256 in a lookup table that encodes the tiling of the cube in each case.

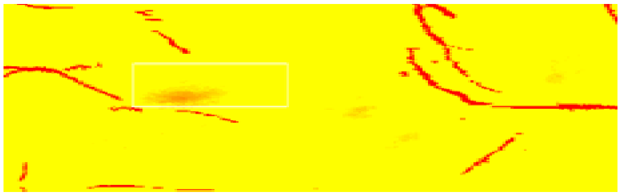
However, the original implementation can lead to cracks (incoherent surface) and could not respect the topology of the trilinear interpolation of f. We thus need to add further test on ambiguous cubes. This distinction has been done by Chernyaev in its Marching Cubes' 33 algorithm (Chernyaev, 1995), and has lead us to the complete lookup table of 730 cases.

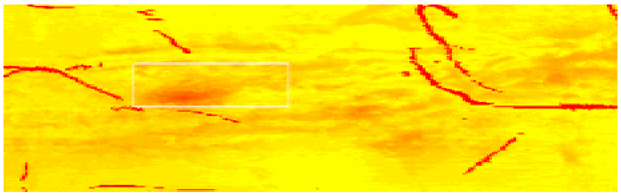
This enhanced algorithm has been implemented in (Lopes and Brodlie, 2003). However, their implementation needs a recomputation when tiling an ambiguous cube, which is computationnally expensive. Their computation allows a more accurate geometry inside each cube by the addition of extra vertices inside some of the cubes. For our purpose, we needed a faster algorithm which would not produce too many vertices. Therefore, we implemented the 730 cases of Chernyaev's lookup table (Lewiner and others, 2003). The tiling of a cube is then done by only a checking the lookup table.

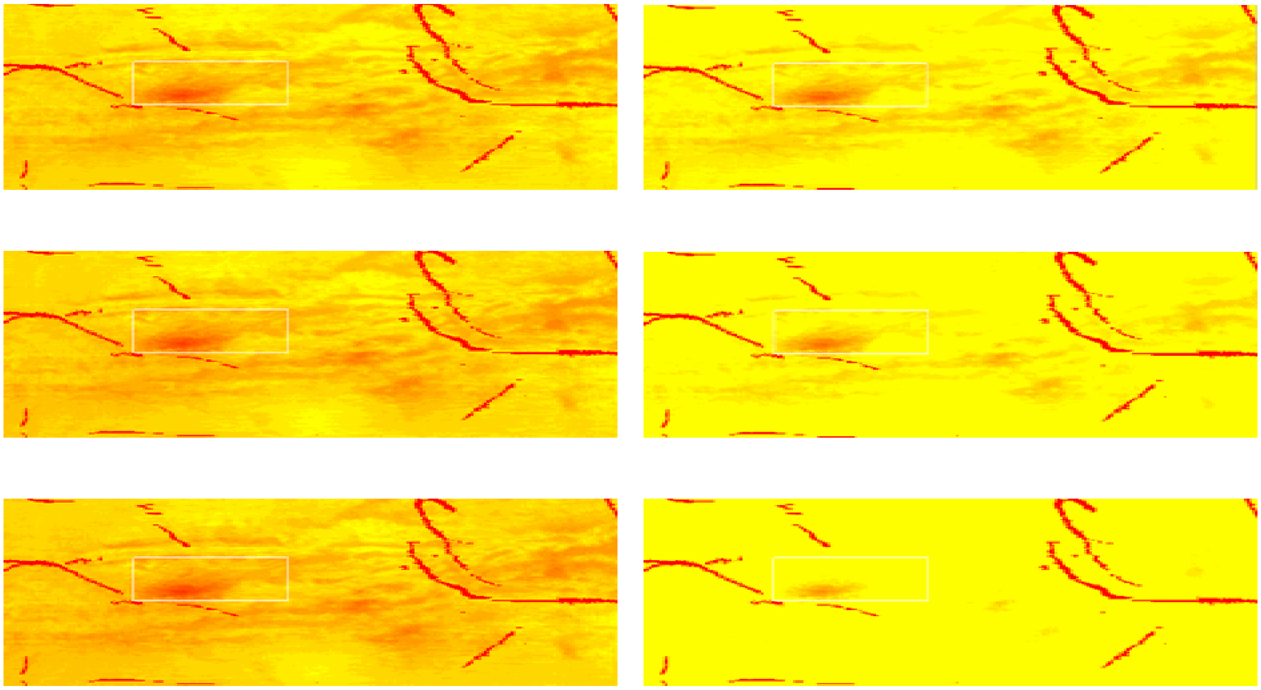
The Marching Cubes' algorithm offers many extensions, in particular in pre-visualization, view-dependant rendering, hardware acceleration and so on. Some of those enhancements need an expensive pre-computation (n log (n) for topology pre-visualization, for example), others presuppose parts of the results (the ability of having one seed per connected component in order to avoid parsing all the cubes). All those extensions are possible to implement with our enhancements.

Visualization of seismic surfaces

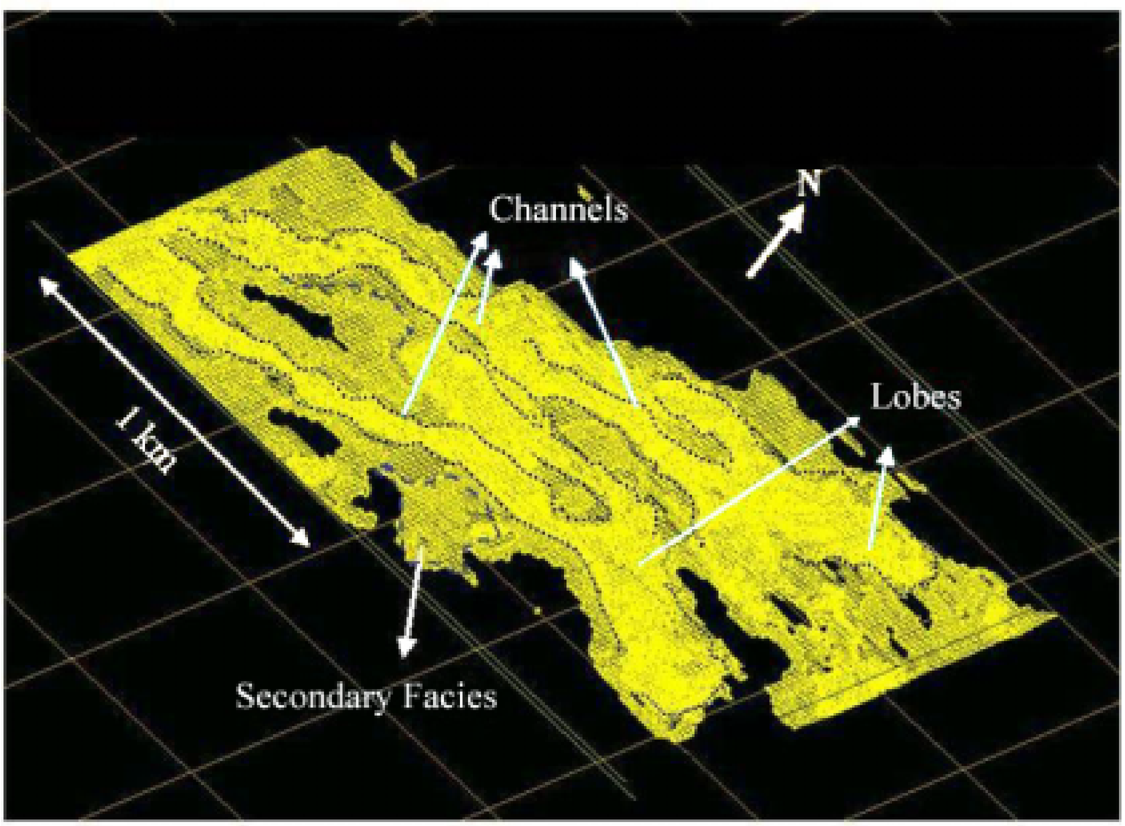
Given a seismic cube, parallel slices are extracted and piled up in such a way as to allow the 3D reconstruction of the reservoir using the amplitude of the seismic wave in a given interval. In the figures below domains on parallel slices were chosen.







In the next figure isosurfaces were extracted and geological structures like channels and lobes, were identified in a deep water reservoir.



3D topological reconstruction, from seismic data, of a deep water oil reservoir (2000 meters).

Surface simplification

Techniques for surfaces simplification, called surface decimation, for handling large data sets are at the core of nowdays research in geometric modeling and computer graphics. Several techniques have been implemented in the Project Geosis (see Cignoni, Montani and Scopigno, 1998) in order to visualize large data sets at an interactive rate while the original data is mantained intact for further analysis.

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