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Interactive cutaways of oil reservoirs

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ABSTRACT

In the Oil and Gas industry, processing and visualizing 3D models is of paramount importance for making exploratory and production decisions. Hydrocarbons reservoirs are entities buried deep in the earth's crust, and a simplified 3D geological model that mimics this environment is generated to run simulations and help understand geological and physical concepts. For the task of visually inspecting these models, we advocate the use of Cutaways: an illustrative technique to emphasize important structures or parts of the model by selectively discarding occluding parts, while keeping the contextual information. However, the complexity of reservoir models imposes severe restrictions and limitations when using generic illustrative techniques previously proposed by the computer graphics community. To overcome this challenge, we propose an interactive Cutaway method, strongly relying on screen-space GPU techniques, specially designed for inspecting 3D reservoir models represented as corner-point grids, the industry's standard.

1. Introduction

The Oil and Gas industry is considered to be one of the largest industries of all times, involving many large-scale companies worldwide. The increasing demand for energy, along with the gradual depletion of the easy accessible hydrocarbons reservoirs, has motivated the industry to maximize the oil recovery of existing fields. This shift stimulated intensive research to better understand complex fluid flow mechanisms that occur inside the oil fields, as well as the development of advanced reservoir visualization and simulation techniques [1].

In order to understand the flow behavior of a reservoir, a 3D computational geological model is created by domain experts. This model represents the reservoir geometry, its intrinsic properties and its fluid content. Once the geometry is constructed, the other properties of the model should be filled, and a tuning process, known as *history matching*, is triggered. Based on sparse data the model is populated with static properties, then the flow is computed through a simulation, and the results are tested against observed data. If the computed result diverges from the observed data, the model parameters are manipulated and the simulation is restarted. This interactive process is repeated until an acceptable degree of accuracy is reached.

Visual inspection is an important asset for analysis in all steps of this interactive process, as well as when using the final model as a predictive tool. The standard representation for oil reservoirs is corner-point grids, and there are in the order of millions corner-point models employed by the industry nowadays. Traditionally, geologists use parallel cuts (a plane oriented with one of the axes) to see the interior of the grid, or manually set a range of cells to be removed from the visualization. Nonetheless, because these

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models have volumetric characteristics, and some important phenomena may occur in the interior cells that are usually occluded by several layers of outer cells, they are hard to visualize using naive methods. These simple methods do not preserve context, so it is difficult to have a clear insight of what is happening around the cells of interest. Furthermore, removing cells manually offer very little intuitive visual control. Wireframe also does not provide a good visualization choice, since it produces a lot of cluttering for large models.

Illustrative techniques are a natural way to solve this issue. A commonly used method is *Cutaways*, where the artist creates the illusion of the object being cut to expose its interior without losing the general context. Researchers have investigated solutions to generate these illustrations automatically using computational methods. Given that an object in focus (the part or object of interest) is selected or identified, the goal is to compute the appropriate cut surface that eliminates occluding parts.

In this paper, we present a method for generating cutaway visualizations of reservoir models. We follow suggestions on how to generate meaningful cutaways from previous studies (e.g., Lidal et al. [2] and Sigg et al. [3]), and transfer these good practices to corner-point models. However, due to the volumetric nature of reservoirs, a straightforward application of known methods performs poorly with these complex models. Our method works by selecting a subset of the volumetric cells from a range of attribute values, such as pressure or porosity. These are the *primary* cells, since they are the focus of the visualization. All other cells are *secondary* cells, and are either removed when occluding primary ones, or used to increase context perception.

Our cutaway visualization method is based on a flexible screen-space representation for clipping volumetric cells. The main contributions are:

- the cutaway surface is dynamically defined as the union of frustums that better preserves context by tightly adapting to the corner grid structure;
- the volumetric intersection is generated on-the-fly and on a per fragment basis, allowing for a precise cut of the grid structure;
- a local ray-casting procedure to render important edges;
- some feature emphasizing techniques to enhance the cuts and provide more visual clues during the inspection process, such as contour lines and shading techniques.

In Fig. 1 we illustrate a corner-point model and the proposed technique in action, while Fig. 2 shows an overview of our method. The method achieves interactive framerates even for complex topology and geometry.

Apart from the technical points above, we have carried an informal user study with domain experts that suggests that our visualization method applied to corner-point models can have a great impact in some important tasks in the petroleum exploration processes. It may help petroleum engineers answer one of the most critical questions by providing insightful visualizations: where should the wells be placed to maximize oil recovery.

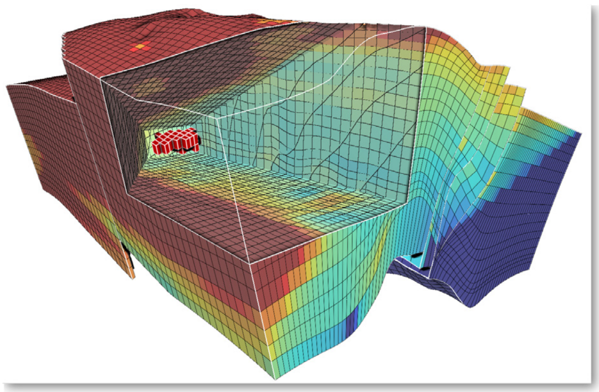

Fig. 1. Our cutaway method in action with a real reservoir model. The colors correspond to the Oil Saturation dynamic property. The reservoir volume is cut to visualize some selected cells of interest in its interior, while maximizing the visual comprehension of the context around them.

The remainder of this paper is as follows: in Section 2 we present a review of the related works that inspired our technique. A brief introduction to reservoir engineering is given in Section 3 to present our study domain and some terminologies. Our technique is detailed in Section 4, and in Section 5 we present some results. In Section 6 we describe a design critique carried out with two domain experts. In Section 8 we provide our final remarks and discuss some directions for future works.

2. Related works

Complex models arise in various domains, such as architecture, manufacturing industry, and medical imaging. The conception of even larger and more detailed models has brought challenges for visual comprehension and making inferences on the data. One important issue is occlusion, i.e., when key parts of the models are nested inside or hidden behind others. In this case, artists often make use of the cutaway technique, that removes less important parts of the object to reveal the most significant ones. Researchers in computer graphics have been inspired by these technical illustrations and have developed algorithms to automate the process of creating cutaway illustrations. Here we review some of these works that are most related to our approach.

2.1. Cutaway in volume rendering

Volume rendering methods create visualizations by employing opacity functions to reveal the interior structures, or by extracting iso-surfaces. However designing a suitable transfer function can be a challenging task. Some approaches have aimed at increasing the visual understanding of a selected region by using cutaways or similar techniques.

Bruckner et al. [4] describe a focus+context method to highlight regions of interest in volumetric models. They use the idea of lighting-driven feature classification, creating images that resemble artistic illustrations. In a previous work, Bruckner and Gröller [5] proposed a discrimination of interior and exterior parts by preserving