Cutaway Applied to Corner Point Models

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***Abstract*—This work proposes the use of the *Cutaway* technique to improve the inspection and analysis of dynamic properties in *Corner Point Models*. This approach places objects (or parts) of interest in focus by removing occluders. One important aspect is the notion of keeping the focused object in context within the whole scene. This is specially challenging in reservoir investigation since features are usually tracked not only by spatial (geometrical and topological) information, but also by their containing geological properties (ex. pressure), and hence, shifting the paradigm of traditional illustrative techniques. Here, we propose a first investigation on how to adapt the cutaway approach to track reservoirs' dynamic properties.**

***Keywords*-corner point geometry;cutaway view;**

I. Introduction

The main goal of the oil and gas industry is the search for hydrocarbon deposits beneath the earth's surface. Among its many sectors there is the upstream oil sector, also known as the exploration and production sector. Due to its complexity, it requires professionals from many different domains (e.g., petroleum engineering, reservoir engineering, geology, geophysics) to collect, analyze and interpret the available data. In order to have an effective reservoir characterization the following are required: a detailed geological description (from static data); the analysis of the dynamic behavior of the reservoir (from well testing); and thorough geological modeling and numerical simulation to integrate these two aspects. A 3D geological model improves understanding of the reservoir providing a better presentation and visualization of its architecture and fluid behavior. The main purpose of the geological model is to evolve an actual field development and future reservoir management in order to ensure the maximum hydrocarbon recovery [1].

A common data structure used to hold the geological model is the corner point grid, also known as distorted grid or flexible grid (Figure 1-left). It can represent complex reservoir geometries by specifying eight corners of each grid block. It is widely used by the petroleum industry as it can better adapt the grid to reservoir boundaries and some internal features (e.g., faults, horizons, wells, and flow pattern) [2]. Besides, this data structure improves the quality of the flow simulations by reducing the numerical error. Apart from the geometry, the cells of corner point model (CPM) also contain dynamic properties coming from the flow simulations, allowing for the analysis of dynamic attributes of the reservoir. However, if the cells with specific dynamic properties to be tracked are inside the model, it is difficult to observe them in time and interpret the data set using the existing approaches. Despite recent works proposing novel computational techniques to investigate CPMs, there is still a lack of tools that provide a set of cells to be tracked in time and/or in regards their properties [3]. The aim of this project is to allow domain experts (e.g. reservoir engineers, petroleum engineers, geologists) to visualize and create a correlation between properties and geometry. More specifically, in this work we propose the use of the Cutaway illustrative technique to enhance the concepts of focus and context in the visualization of CPMs.

The aim of this project is to provide a tool with which domain experts can visualize not only the reservoir model (with its static and dynamic properties), but also the well testing data and interact with them (Figure 1). The representation of the geological model, as well as the knowledge that well testing is a relation between pressure and/or pressure derivative through time, have been extensively investigate; therefore, the chosen approach is to create a visual correlation between them. The

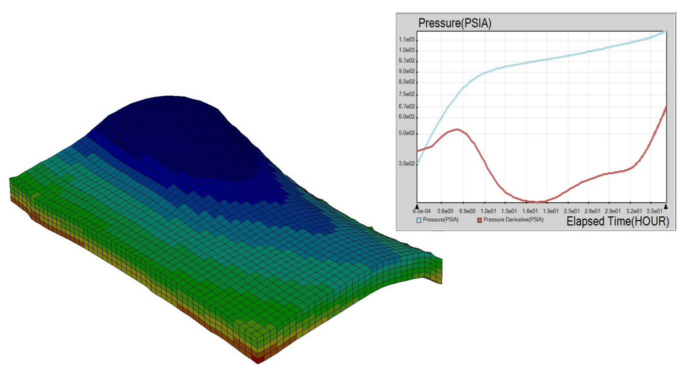

Fig. 1. The corner point model (reservoir model) is loaded as well as the graph for the actual field data (well testing data).

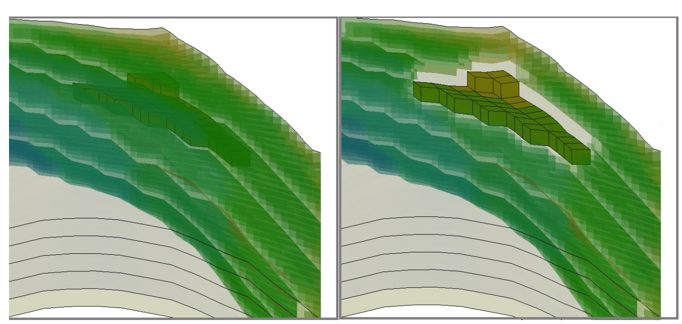

Fig. 2. The filters applied in the data set of Figure 1.

user can select a range from the well log and a respective range will be shown in the geological model. There are two levels of selection where each selection is being called as a filter, where these two filters have a hierarchy between them. Each filter relates a range of pressure and time-step with properties of the reservoir's cells, and the goal of each one is to keep the selected (i.e filtered) cells focused while keeping the unselected ones just as part of the context (Figure 2).

This paper is divided as follows. Section II presents an overview of the cutaway technique. In Section III we provide a background of corner-point in the context of geological models. In Section IV more details about how the selection process works are described. Our first results are presented in Section V, and finally, Section VI brings our conclusion and highlights directions for future works.

II. Cutaway

Illustration techniques have been created to enhance the understanding of complex scenes by, for example, exposing internal structures and highlighting important features. The generation of ever-larger 3D datasets on various applications domains, such as architecture, engineering and manufacturing, has created a need for effective visual communication techniques that allow the user to intuitively and interactively explore and comprehend the data. *Cutaway* is one of these techniques that visually aid the inspection of 3D models, and is specially useful when the model in question has a volumetric character, contains multiple layers, or has interconnecting pieces.

A simply and efficient cutaway approach is to just remove occluding objects (of secondary importance) to expose the object of interest (of primary importance). However, in this way, the user is forced to mentally "fill the gaps" of the removed material and estimate its spatial relation. A better approach that increases comprehensibility, is to selectively discard portions of these overlapping objects while still rendering some of their outlines in order to, at the same time, minimize occlusion and provides effective visual depth and spatial cues of the interior. This approach produces a visual appearance as if someone had carved a piece of the object.

Diepstraten et al. [4] define cutaway for technical illustration as the main motivation, and also justifie its categorization into NPR (i.e. non-photorealistic rendering) and discuss different methods to apply this technique in a computer. They provide some rules for the described methods in order to help the reader to choose one of them for a specific purpose.

When manually selecting and tracing cuts, an artist can carefully reason about the visibility issue; however, an interactive system faces the challenge to somehow achieve this goal respecting performance constraints. One obvious approach is to try to simulate the craft of the illustrator as best as possible, where the user can manually delimit cuts by visually tracing paths over the model. The top shell is then removed exposing the underlying parts. An implementation of this technique is proposed by Li et al. [5].

Another approach involves the paradigm of primary and secondary objects, where the former are regions or objects of interest that one would like to keep visible throughout an investigation session. In other words, the goal is to automatically clip secondary objects to maintain the primaries in focus in a view dependent manner. Burns and Finkelstein [6] describe a real-time algorithm to adaptively generate cutaway illustrations by only selecting what are the primary and secondary objects, as well as an aperture angle defining the size of clipped regions around the primaries.

Lidal et al. [7] also apply Cutaway in a 3D geological model. However, instead of working with a postprocessing model they work with models which have mainly stratigrafic information. In other words, the data is a grid model which has already been simulated and thus has not only static but also dynamic properties. On the other hand, their data is basically a set of layers and their rock properties. While our proposal is to work with corner point grids and their dynamic properties, their approach was developed over a horizontal layer-based geometry.

III. Corner-Point Background

In order to create a computational model of the actual reservoir some different representations have been used. A rectangular Cartesian coordinate system was widely used as it has the advantage of familiarity; since the equations describing physical phenomena were traditionally described in Cartesian coordinates, for the reservoir engineer it was straightforward to construct rectangular grid systems as they appeared natural and intuitive. Unfortunately, these grids do not permit a good representation of the reservoirs geological features, since they impose a rectangular structure with possibly no physical relation to the reservoir being studied, and, therefore, may produce erroneous results [8]. Although any discretization mesh could be chosen to reduce simulation errors, this is often best accomplished using meshes derived from non-rectangular (but orthogonal) coordinate systems, that better adapt to geological features (e.g., reservoir boundaries, faults, horizontal wells). Furthermore, another major application of flexible grid is well modeling. Among non-rectangular grids (also known as distorted or flexible grids) there are triangular grids, Voronoi grids and corner point grid. The latter has become specially popular because it has a straightforward implementation in standard reservoir simulators (even in complex full field studies), while achieving a performance gain due to its regular matrix structure.

Corner point geometry is composed of three main elements: corners, pillars, and cells (Figure 3). Cells are defined by eight vertices (corner points) and are the smallest volumetric element in the grid. Each corner point cell contains 3D information (x; y; z) and is identified by integer coordinates (i; j; k), where i and j span each layer, and the k coordinate runs along the pillars. During the modeling stage pillars are represented by 3D curves (usually splines), however, this information is lost upon model completion. Since we focus on applications at later stages, for our purposes, the integer coordinates (i;

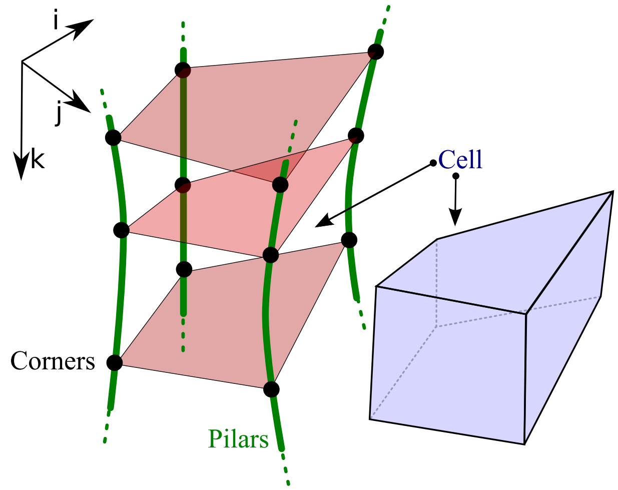

Fig. 3. The three main elements of a corner-point geometry: corners, pillars, and cells.

j; k) has only a structural (topological) meaning, as the 3D coordinates of the corner points have neither to be regularly spaced nor spatially continuous [2].

When there is a fault (i.e., a displacement within one or more rock layers as a result of earth movement), more than one corner will be sharing the same (i; j; k) while they will have different spatial positions (Figure 4).

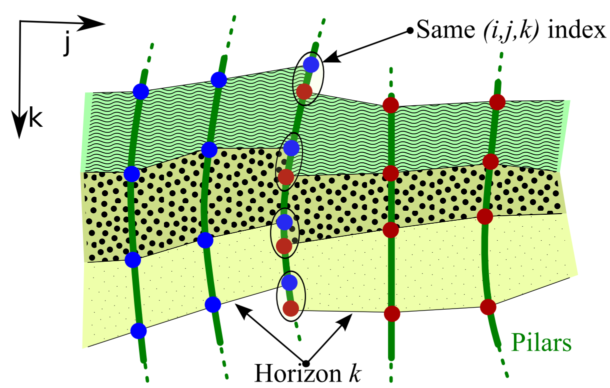

Fig. 4. Typical corner point grid discontinuity. Circulated corners have the same (i, j, k) index, but they have different coordinates.

IV. Selecting Cells of Interest

The architecture was build around the concept of filters. In this context, a filter is a selection performed (through two sliders) in the well testing window which is reflected into the geological model. The grid blocks with property values falling inside the selected range will be visible, while others will be used for context. The well testing window has three states, both filters not activated (see Figure 5 (a)), first filter activated (see Figure 5(b)) and both filters activated (see Figure 5(c)).

In order to create the focus+context effects for the first filter, only the selected blocks are drawn while other are not. Therefore, to avoid losing the context the layers of the geological model are drawn with some degree of transparency

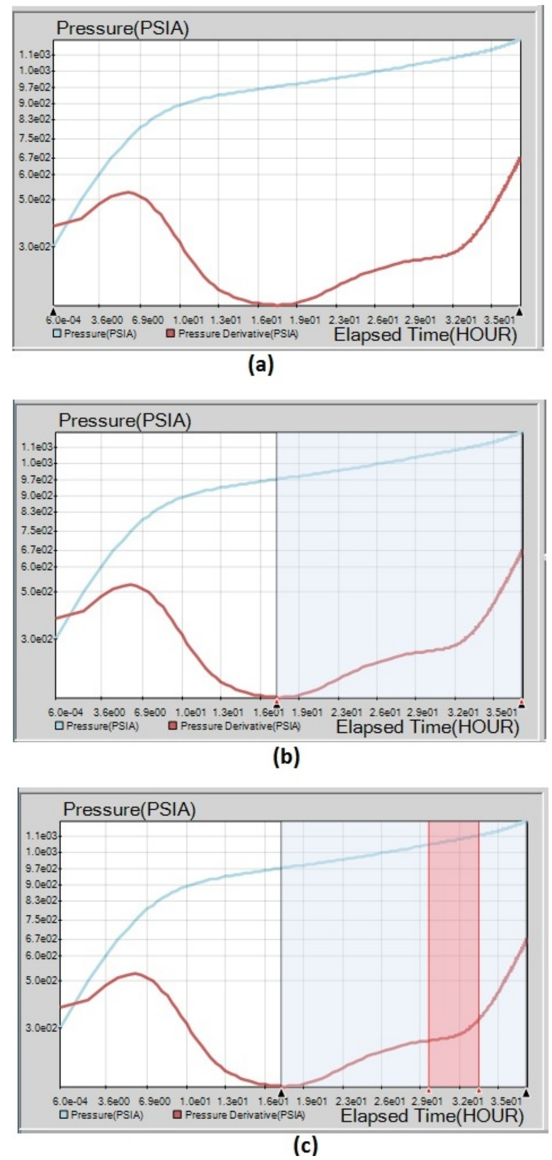

Fig. 5. Well testing window's states: (a) both filters deactivated, (b) just one filter activated, (c) both filters activated.

(see Figure 6). The second selection's context is primarily done by applying transparency into the unselected blocks while the selected ones are drawn with full opacity (see Figure 7). However, depending on the relation between the positions of the selected and unselected blocks the cells the regions in focus becomes unclear (see Figure 8(c)). To solve this issue a cutaway technique is applied (see Figure 8(d)). The main goal is to not draw the unselected blocks which are between the camera position and any selected block.

V. Cutaway for Corner Points models

A system was build in order to implement a cutaway implementation applied to the oil and gas domain, more specifically, to corner point models. We have adapted the techniques described in Section II to the data structures described in Section III. According to Diepstraten et al. [4]

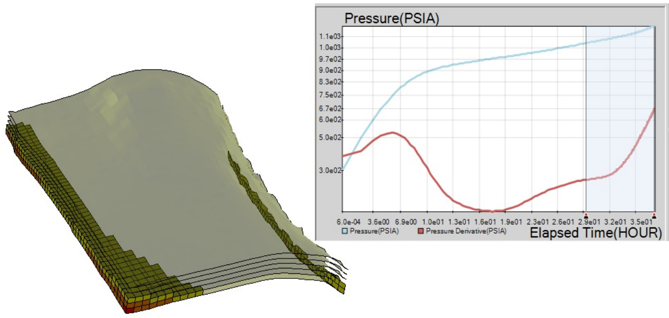

Fig. 6. After the first selection using the sliders the first filter is applied. Only selected blocks are visible.

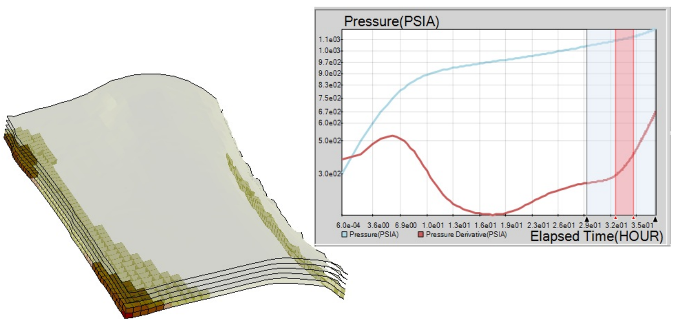

Fig. 7. After the second selection using the sliders the second filter is applied. Unselected blocks have some transparency and the selected ones have full opacity.

when employing cutaway (breakaway technique) the following conditions must be satisfied:

1) interior objects have to be distinguished from exterior ones;
2) from any given viewing angle all interior objects should be visible;
3) and a single hole in the exterior object should realize the breakaway.

It is important to mention that in the corner point grid, all objects are grid cells, and according to their properties they are classified as an interior or exterior object (analogous to the primary and secondary terminology) (Section IV). However, since this classification does not depend on the geometrical and topological structure, but only on the cells properties, interior objects are not necessarily close to each other; hence, the third condition (3) is not always being satisfied. Note that, it is possible to have interior cells located at opposite extremes of the grid, thus, by creating a single hole, a large amount of grid cells (exterior objects) would be culled. Even worst, the whole idea of preserving context would be lost.

In the current approach the grid cells are discretely classified, i.e., they are either entirely rendered or culled. From the domain point of view, a classification based on the grid properties is the most meaningful, so after defining the desired range of property values which should be visualized, all grid cells will be marked as selected (interior object) or unselected (exterior object). In order to define which unselected cells should be culled the following scheme is proposed. From the view point a ray is traced for each selected cell (targeting its centroid), and the distance between each unselected cell and the ray is computed. If the distance is greater than an user defined threshold the cell is drawn; otherwise, the unselected cell is culled (see Figure 9).

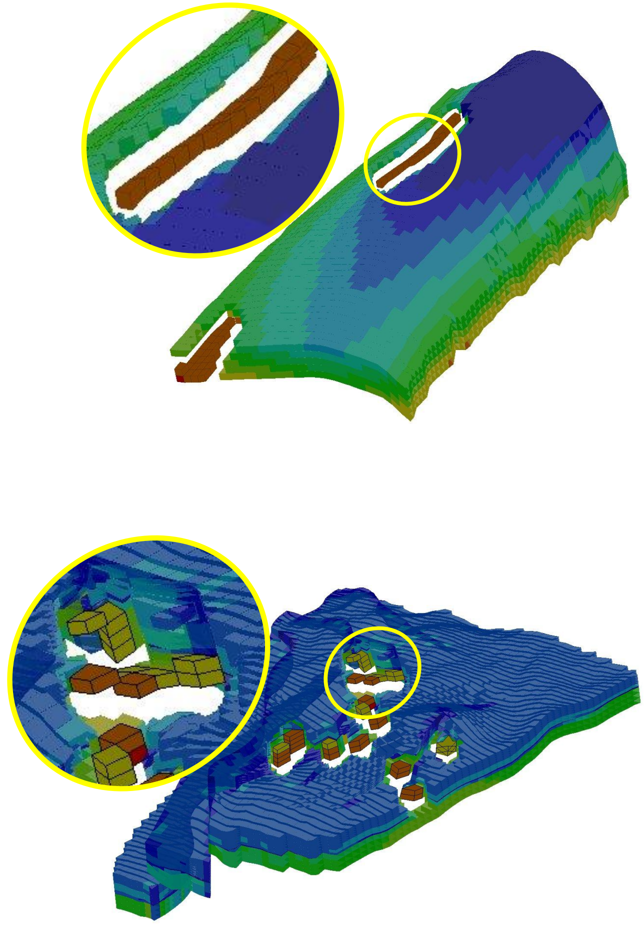

Fig. 10. Two corner point visualizations using cutaway. (a) Emerald, 72000 Cells; (b) Zmap, 7500 cells;

Our system starts with the complete corner point model where each cell is colored according to its property value (Figure 8(a)). The user defines a range of the property to be tracked during inspection, and the cells that fall within this range are considered as interior objects (Figure 8(b)), while the remaining ones are considered as exterior objects. Figure 8(c) illustrates that, when interior objects are not located on the boundaries, in most cases it becomes impossible to visualize them just by applying transparency. On the other hand, Figure 8(d) illustrates how the cutaway technique visually provides a clear path to the interior objects, and at the same time preserves context by drawing most of the exterior ones. In order to validate our proposal, we applied the discussed techniques to different reservoir models, as illustrated in Figure 10, which differ in shape and number of cells.

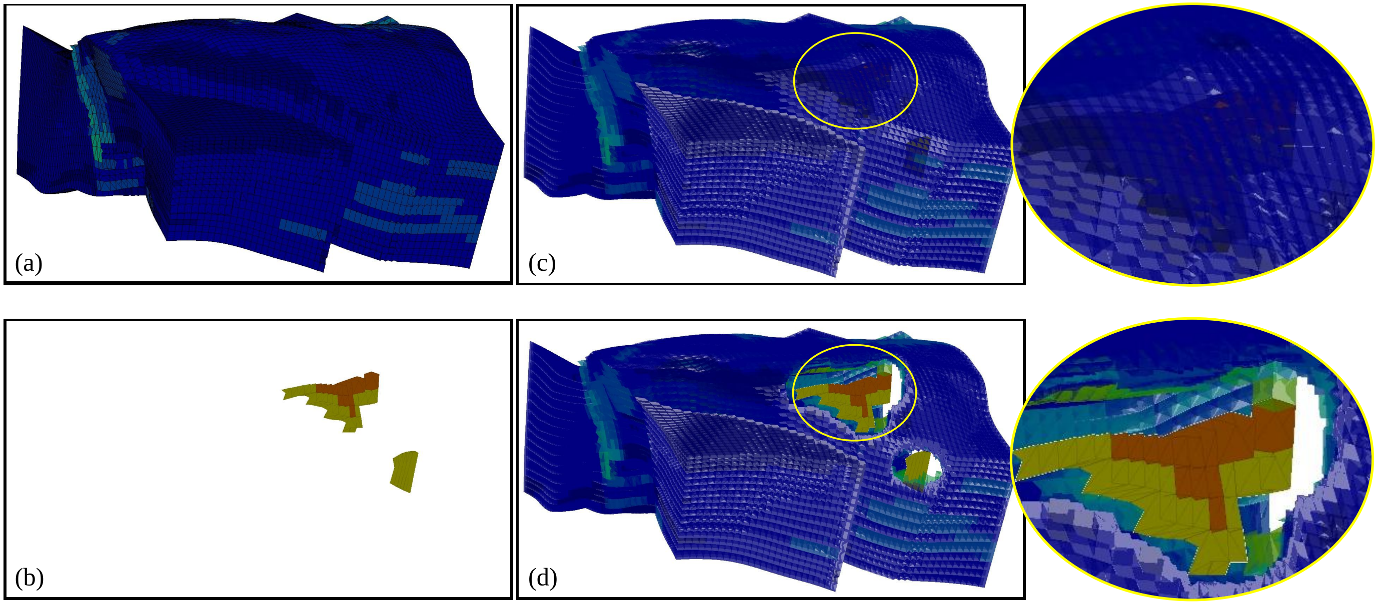

Fig. 8. Opnine corner point model: 76000 cells; (a) complete corner point model, (b) selected cells, (c) without applying cutaway, (d) applying cutaway.

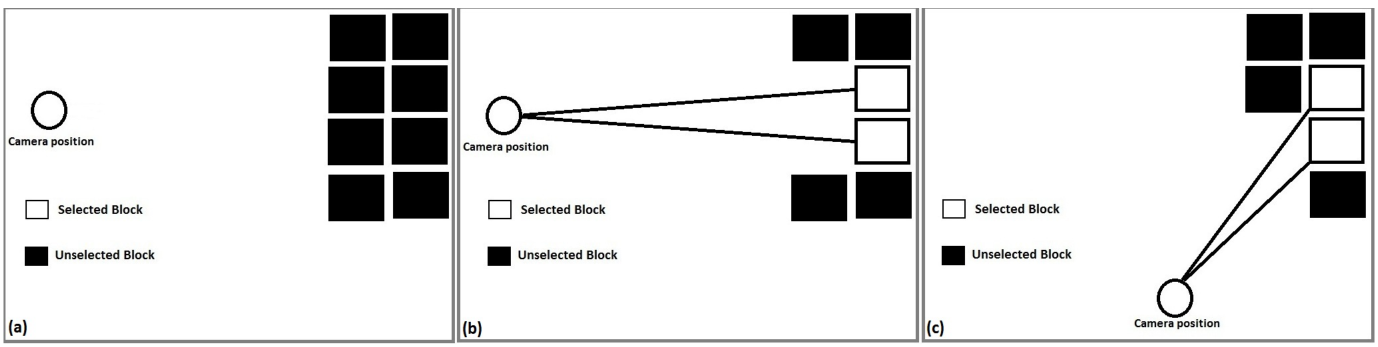

Fig. 9. Illustration of our cutaway algorithm. Scenarios: (a) When there is no selected cells, all will be drawn, (b) removal of occluding cells based on the ray intersection results and (c) dynamic update of visible blocks according to camera position.

Although the current implementation has achieved satisfactory visual results for different corner point models, there are still some limitations. The algorithm's complexity is $m \times n$ where m is the number of selected cells and n is the number of unselected ones. On a Windows 7 PC with Intel Xeon E5620 Processor and 12 GB RAM, the cutaway implementation works well when the total (selected and unselected) number of cells is up to eight thousand. For larger amounts, the increase in the number of comparisons compromise the visual effect. Furthermore, as a consequence of working with a discrete classification of the grid cells (either entirely drawn or culled), there is no way to refine and/or explore the cutting within the cell; in other words, there is no way to work with grid cells as a continuous object.

VI. Conclusion

We advocate the use of the cutaway technique to visually improve the inspection of geological data in the oil and gas domain, as well as other application areas that share similar geometrical structures.

We have described how to select regions of interest in a corner point model (simulated data), using the well pressure information (measured data). To visually correlate these representation we employ technical illustration methods to investigate the corner point model. More specifically, we show that cutaway is an efficient way to emphasize the desired cells without loosing context.

Even though the described implementation provided satisfactory results in regards to what was anticipated, we believe that there is an open avenue for research in this direction.

To overcome the main limitations (i.e. scalability and discrete cell representation) we propose the use of shader programming techniques as future work. Since the current implementation was validated mainly using static properties, the main future direction of this project is to investigate the tracking of dynamic attributes using cutaway. Moreover, other techniques, such as explosion diagrams, could be experimented and possibly a hybrid approach might render even better solutions.

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