SPOTLIGHT : Radial Focus and Context Visualization and Orthogonal Plane Cutting for 3D Reservoir Simulation Post-Processing Models

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ABSTRACT

This paper describes a set of interactive 3D visualizations designed to explore the oil/gas reservoir simulation post-processing models. The visualizations that have been presented here are : Orthogonal 3D cutting of the post-processing models(along all the 3 planes, i.e XY plane, YZ-plane, XZ-Plane), and a Focus + Context visualization technique that helps in focusing and analyzing a specific area of the 3D post-processing model.In the remaining sections of the paper, an introduction to the reservoir simulation,related work, and technical implementation of the implemented visualizations are presented. Results of the implemented visualizations are then presented in the end.

Author Keywords

3D Reservoir Visualization, Reservoir Engineering, Interactive Visualization, 3D Graphics.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Interactive Visualization,Reservoir Visualization

INTRODUCTION

Oil and gas reservoirs are sub-surface portions of the earth which contain hydrocarbons. The fundamental goal of reservoir engineers is to analyze, assess and evaluate these entities so that they can optimally extract oil and gas. However, reservoir data acquisition is costly and therefore engineers have only limited access to the spatio-temporal information about the reservoirs[4]. The major part of the available information comes from the sensor measurements (e.g. seismic geophones, pressure transducers) and experimental results of rock samples(e.g. core measurements). These are combined with multi-disciplinary experts' advice to develop a realistic 3D geological model[4]. However, complexity, size, and multi-resolution data are some of the many challenges that exist for proper data integration and efficient analysis. These require advanced visualization tools to better understand and access the data.[5,6]. In practice, the oil and gas exploration and production(E & P) cycle consists of several stages of data gathering, simulation, and data analysis. Of those many stages, this work is situated at one of the last phases of the E&P cycle called the post-processing stage. A post-processing stage of the reservoir studies includes the simulations of various different scenarios of the reservoir models for history matching, prediction and forecasting[M.J.Pyrcz et al].At the history matching state, the reservoir engineer needs to manipulate some of the uncertain reservoir properties and run multiple simulations in order to provide a better match with the real production data.This will add further complexity as the size of the data increases rapidly. The simulation data are time varying and multi-attribute in nature, requiring techniques that support adequate exploration of those many parameters.

At the post-processing model, an approximation of the real reservoir, is used for exploring the various parameter configurations and fluid flows. The structureof this 3D reservoir model is usually represented by irregular corner point 3D grid[7](irregular hexahedron geometries) consisting of thousands to millions of cells, each of which is associated with a some static and dynamic properties.Therefore, the complexity of the models arising from multiple cells and the numerous attributes they possess motivates the need of visualization that helps the reservoir engineers to analyses and assess the models effectively so that they can gain a clear picture of the relationship that exists between these data attributes.

RESERVOIR MODEL

Reservoir post-procesing models are the end result of multiple simulation scenarios. The model employed in the experiment consists of the following types of information : (a)Structural information (b) time steps (c) cell specific information(geology property values - both static and dynamic). The structure of the 3D model consists of corner point cells[7], irregular hexahedron geometries, arranged along the three dimensions(i,j,k). The i&j dimensions correspond to the cells in the x and y directions of the 3D space and k corresponds to the layers of the 3D model. For example the

model used in the experiments contains 7500 cells, 30x50x5 in i,j and k directions respectively.The arrangement of the cells represents both spatial continuity as well as discontinuous to accommodate geological geological structures such as faults.The model used in this experiment consists of 25 properties including the static and dynamic ones.

To visualize the geological properties, reservoir models are mapped to different color maps corresponding to the range of the property value.The color maps are loaded dynamically based on the user input. The user can select one of the 25 properties and the system loads the appropriate color map based on the selected value. Figure 1 shows the tool that has been developed to visualize the various properties of the 3D reservoir post-processing model. The properties can be chosen from the drop-down list and the appropriate color map is loaded based on the property values. The image shows one such Color map that has been loaded for the property Bubble Point Pressure. Figure 2 shows the Color map that has been loaded for the property Water Saturation.
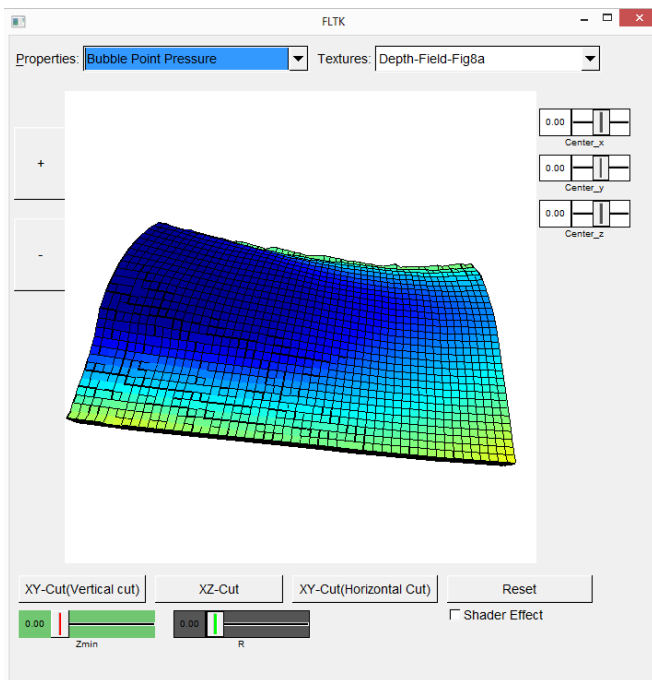

Figure 1. 3D Reservoir Model Loader Interface to visualize Bubble Point Pressure at each cell

RELATED WORK

Research in the field of Reservoir simulation is not new and has been going on since some time. There are also some commercially available software tools that provide visualization of the reservoir post-processing models[(1)].

"Point it, split it, peel it, view it"[2] is one of the papers which focuses on various aspect of 3D reservoir visualization techniques for tabletops. They provide some tools for the reservoir engineers that enable them to split the model, peel it and view it on a Multi-touch tabletops.
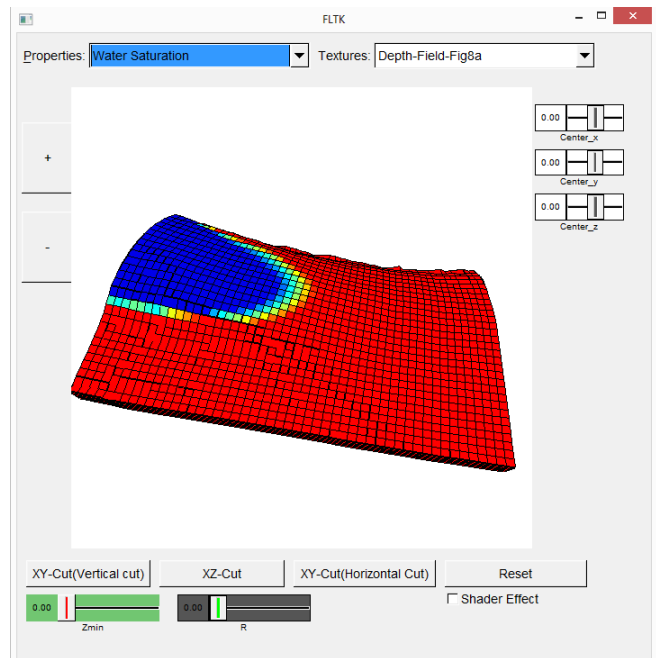

Figure 2. 3D Reservoir Model Loader Interface to visualize the Water Saturation at each cell.

With respect to the spatial splitting data structures, a number of algorithms and data structures have been designed. Octree is one such data-structure in which each node has exactly eight children[11].A k-d tree is another commonly used space-partitioning data-structure for organizing points in a k-dimensional space[8]. Binary Space Partitioning(BSP) is a method for recursively subdividing a space into convex sets by hyperplanes. This subdivision gives rise to a representation of objects within the space by the means of a tree data structure known as BSP tree[9]. These BSP trees can be considered as a generalization to the k-D trees the only difference being that, in a BSP tree the hyperplanes can have any orientation while in a k-d tree the hyperplanes are generally oriented with the co-ordinate axes. In this experiment, a k-d tree has been used for implementing the splitting the 3D reservoir post-processing model.

Depth of Field [13] is one of the rendering effects which gives a focus and context visualization. For a given focal region, all the objects that are within this focal area appear sharp and have high resolution while the objects that are out of focus appear blurry. The blur factor for the object is calculated based on the Circle of confusion, which is calculated in the first pass. In the second pass, the blur factor is applied so that the objects far from the focus area are more blurry and objects near the focal area are less blurry.Although this is a very handy technique that can be applied for 3D reservoir simulation, one of the drawbacks of this technique is that it blurs out the objects out of focus. Hence if the reservoir engineer has to analyse an object outside the focus area, he can get the property value because it is blurry. He has to re-adjust his focus area again. Another issue with this method is that since it is a two-pass algorithm it can some times be very slow on large models which have millions of triangles.

A number of radial focus and context visualizations have been developed in the field of information visualization. Moire-Graphs[10] is one of the visualization that provides radial focus+Context graph layout. PolarEyes[12] is another information visualization that has been developed for visualizing multi-Dimensional functions.

Though radial focus and context visualizations exist in the field of information visualization, their application to the field of reservoir engineering visualization and simulation has not been explored.The goal of this experiment has been to explore these focus and context visualization techniques on the 3D reservoir simulation post-processing models.

IMPLEMENTATION

The implementation can be divided into two parts : (a) Splitting of the 3D model (b) focus and context visualization. All of these parts have been implemented in C++ using OpenGL on Windows Operating System running on computer having Intel Xeon CPU E5-2620 clocked at 2Ghz and Nvidia Quadro 4000 graphics card.Both the parts are discussed in detail in the upcoming sections.

3d Reservoir Model Splitting

As explained in the previous section the, a k-d tree has been used to split the reservoir model. A "hypePlane" in n-dimensional space is a n-1 dimensional object which can be used to divide the space into two half-spaces. For example in the three-dimensional space(which is our case) the hyper plane is a plane. In a 2-D space, a line becomes a hyperplane.

For splitting the model in the i,j,k direction, an appropriate hyperplane has to be used. For example to split the model horizontally, the hyper plane should be parallel to YZ plane as shown in figure 3. Similarly, to split the model vertically the hyperplane should be parallel to the XY plane as shown in figure 4.

The algorithm for performing the split is as follows :

(a)Firstly the hyperplane corresponding to the Cut has to be defined.

(b) Find the origin, center and the normal of the hyperplane.

(c) compute the difference = center - origin; where center is the centroid of the cells in j, j-1, k-1 direction and origin is the centroid of the hyperplane.

(d) find the dot product of (center - origin), normal; where normal refers to the normal of the hyper plane.

(e) using the sign of the dot product , we can determine what lies to the left and right of the plane.

(f) Once this is determined, all the triangles that are to the left of the plane are rendered, then a translation is done based on the hyper plane selected and then all the triangles that are to the left of the hyperplane are rendered.

Figure 5 shows one of the splits, in which the hyperplane is parallel to the XZ plane and has a normal that is in the positive Y direction. As can be observed the dot product separates
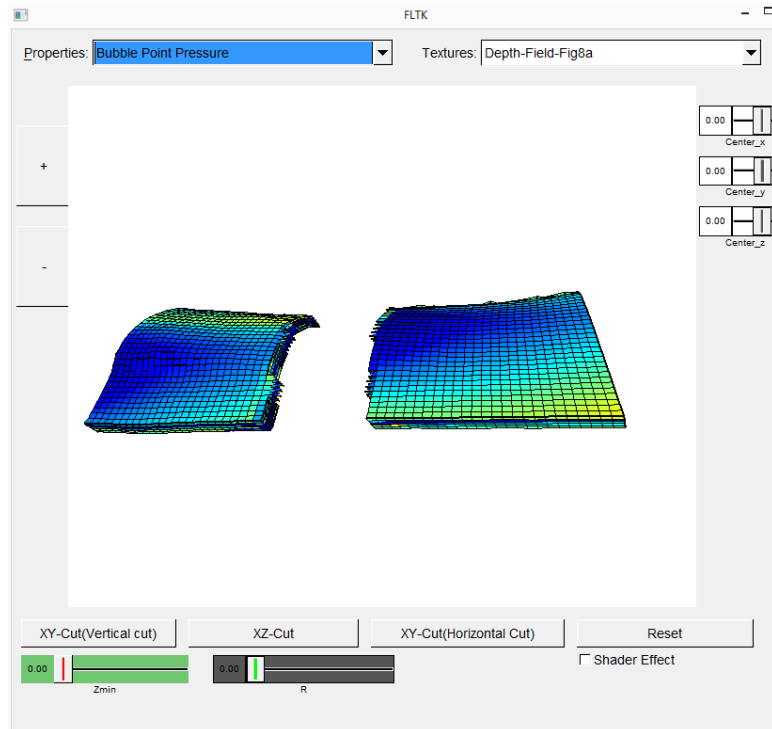

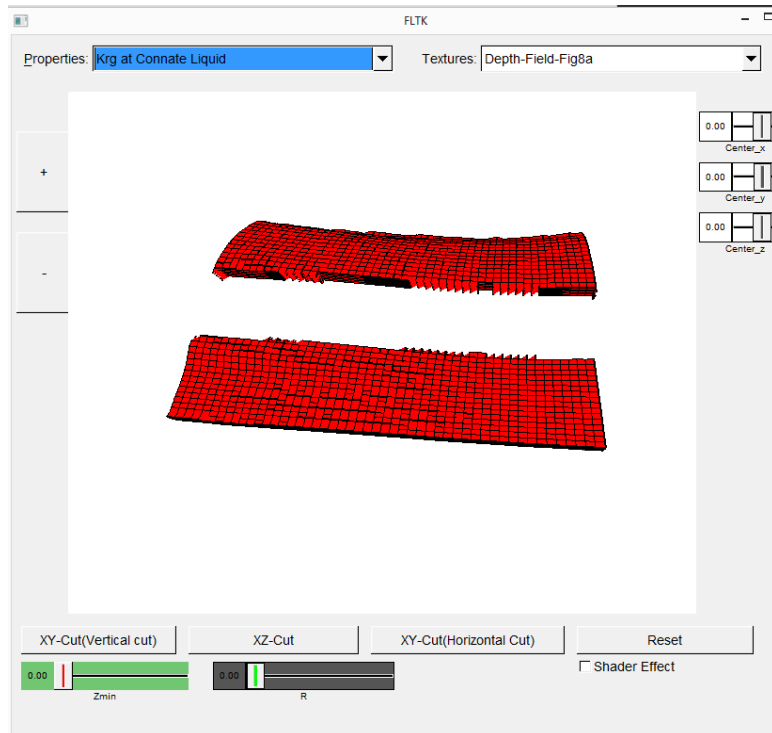**Figure 3. Horizontal splitting of the Model. The hyperplane is paralles to the YZ plane.**

Figure 4. Vertical splitting of the Model. The hyperplane is paralles to the XY plane.

those triangles that lie to the top of the plane from the ones that lie below the plane.
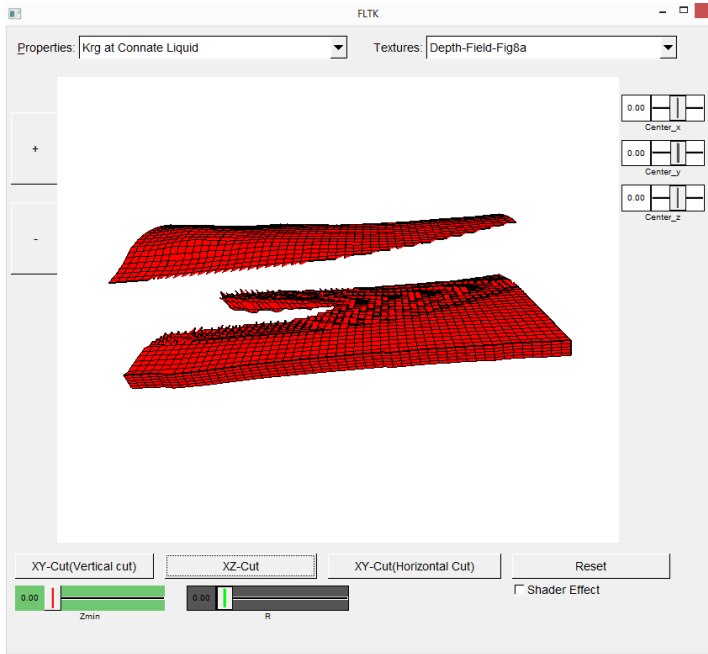
Figure 5. Splitting of the Model on XZ plane. The hyperplane is paralles to the XZ plane.
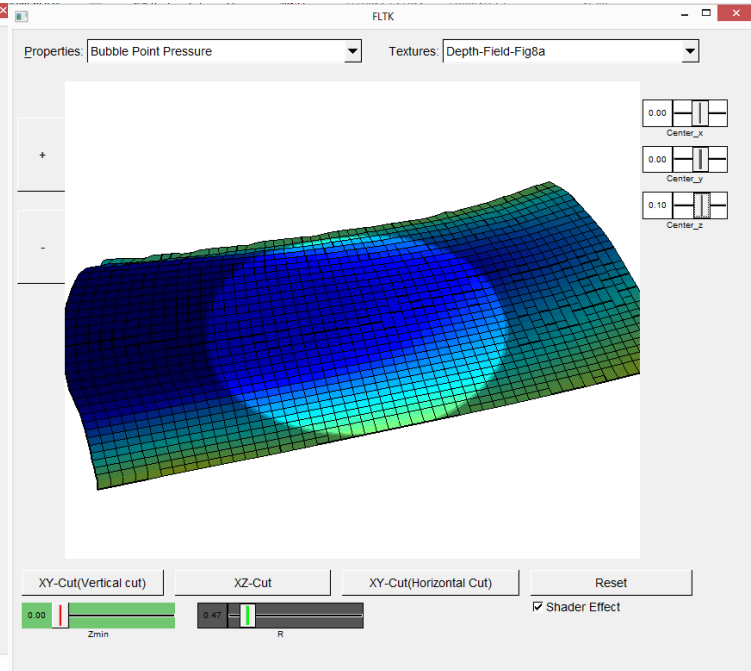

Figure 6. Splitting of the Model on XZ plane. The hyperplane is paralles to the XZ plane.

Radial Focus and Context Visualization

Radial focus and context visualization can be very useful in analyzing and assessing a particular cross-section or a part of the model.

In this experiment a simple radial focus and context visualization has been implemented. The inputs are : (a) a focal point and (b) and a focal radius. Based on the focal point given by the user and the focal radius, a radial focus is constructed with the given focal point as the center and the focal radius as the radius of the region of focus as shown in figure 6.

As shown in figure 6, the radial focus allows the reservoir engineers to focus and analyze on a particular region. The property vales and the cell colors in this region of interest is kept intact while for those cells that are outside, the cell color is multiplied with a grayscale factor.

To achieve the gradual transition of the color change from the region of interest to the end of the polygon, a 1D grayscale texture can used as shown in Figure 7. In the figure 7 it can be observed that color of the cells change radially, starting form the center of the region of interest. The color of the cells that are farther away from the region of interest tend to be "darker". This is because the grayscale weight in this case becomes) 0.2 which is closer to black.

For the implementation, GLSL(Graphics Library Shading Language) has been used to implement the rendering effect. All of the calculation happens in the fragment shader. The vertex shader sends the transformed vertices to the fragment shader. In the fragment shader, the distance of each and every vertex from the center of the focus region is calculated. If this calculated distance is less than or equal to the radius of the focus region then the original property color of the cell is rendered, otherwise the color of cell it multiplied based on its distance from the region of interest. For example, assuming that the radius of the region of interest is 0.35, if the distance of the cell from the center of focus region is 0.65,then the cell is outside the region of interest, and hence it is multiplied by a grayscale factor 0f 0.75.
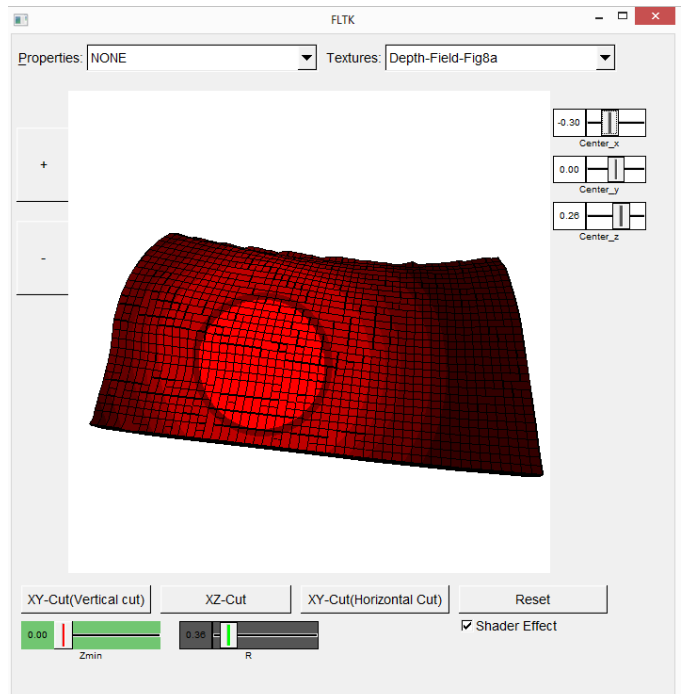

Figure 7. Radial focus with a grayscale weight added based on the distance of a given cell from the focus region.

FUTURE WORK

There are quite a few limitations to this work. Firstly, in the case of splitting the model, the hyperplane is fixed and user cannot change the hyperplane dynamically to visualize the splitting of the model. Providing the user the freedom to change the cutting planes would be an important value add it helps in visualizing various cross-sections. Secondly, with respect to the radial focus and context effect, it would be interesting to explore how this would be useful in the actual practical scenario. A user study with reservoir engineers and geologists would help in identifying potential directions for future research and based on their valuable input and feedback, necessary changes could be incorporated. Another interesting avenue would be compare this radial focus and context with the other commonly used focus+context visualization techniques such as the depth of field, magic lens, depth-based attribute mapping etc.

CONCLUSION

This paper, presented the various techniques that have been implemented for creating meaningful visualizations for the reservoir engineers and the geologists. An introduction to the field of reservoir engineering and the oil and gas Exploration and Production (E&P) cycle has been described which would be helpful for readers who donot have any background in the domain. The splitting and radial focus and context visualizations have been implemented on a real oil and gas reservoir post-processing simulation model which helped in gaining an insight into the layout of the digital version of the oil and gas reservoirs.

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