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Geological information retrieval using tetrahedral meshes

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ABSTRACT : Structured grids like Cartesian or stratigraphic grids are state-of-the-art for three dimensional modeling of the subsurface and a set of advanced visualization and modeling tools are available for these types of grids. However, tetrahedral meshes are becoming more and more important for geo-modeling applications since they can conform to complex geometries and provide more flexibility in terms of mesh resolution. Therefore, techniques for visualizing and modeling tetrahedral meshes need to be developed. Geological models are rich in information of different nature like topology of fault blocks, geological properties, geophysical data (e.g. seismic), stratigraphic layers or distances to geological interfaces like faults or to artifacts (e.g. wells). For an optimal interpretation, these layers of information can be combined into a single image using multi-texture capabilities of modern graphics hardware. An image consists of a set of user-defined iso-value surfaces and cross-sections. Boolean operations of Constructive Solid Geometry with constant complexity are directly performed on the graphics hardware and allow complex geological and geometrical conditional queries. The computation and rendering of the iso-value surfaces is performed in real time on models with up to several hundred thousand cells on normal consumer hardware.

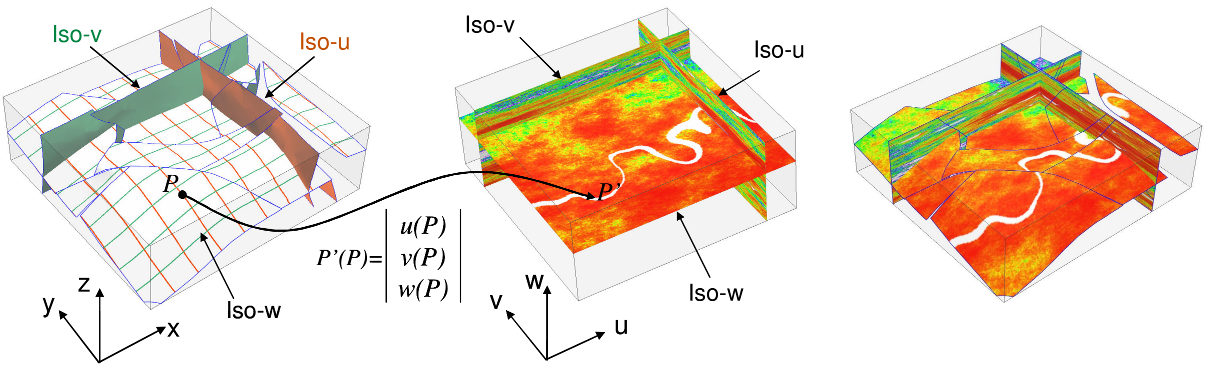
KEYWORDS : Visualization, tetrahedral meshes, geological co-rendering .

1. Introduction

Nowadays, visualization of volumetric data is no longer restricted to dedicated graphic workstations, because of advances in consumer graphics hardware, driven by the multimedia industry. Tetrahedral meshes are more and more used for geo-modeling applications. When dealing with visualization of volumetric data one can distinguish in general three methods: slicing, iso-value surface interpolation and volume rendering. This work is based on iso-value surfaces combined with geological information. An iso-value surface is built by extracting a level set where a property takes a constant value. The polygonization of this subset is performed on the CPU (Central Processing Unit). The intersection computation between an iso-value surface and the tetrahedral mesh is accelerated by an octree in a parametric value-space. Further improvement of the performance is gained on symmetric multiprocessing or multi-core systems, respectively, by a parallelization of the iso-value surface extraction algorithms. The model (geometric information) and the view (rendering information) are separated into different display lists, which are dynamic high-performance interfaces to the graphics hardware.

2. Geological co-rendering

Textures are one, two, three or four-dimensional patterns. Their primitive elements are called texels. Texture mapping paints the pixels (screen coordinates) of polygons with the content of the texels. Therefore, for each point P of a polygon (world coordinate), a corresponding point P' in the texture map is defined. In fact, texture coordinates are defined per vertex and are interpolated by the rasterizer for every fragment of the polygon. Measurement data are often scattered over the *3d*-geometrical space (e.g. seismic surveys). To map this kind of data, the world coordinates of a polygon can be directly mapped onto the data in the Euclidean space. Simulations are often performed in a so-called computational (parametric) space. To paint a polygon with this kind of data, the parametric coordinates have to be known. Figure 1(a) shows the mapping between the world coordinates of a geological model and the texture/parametric coordinate system of the texture map and computational space, respectively. The result is shown in figure 1(b).

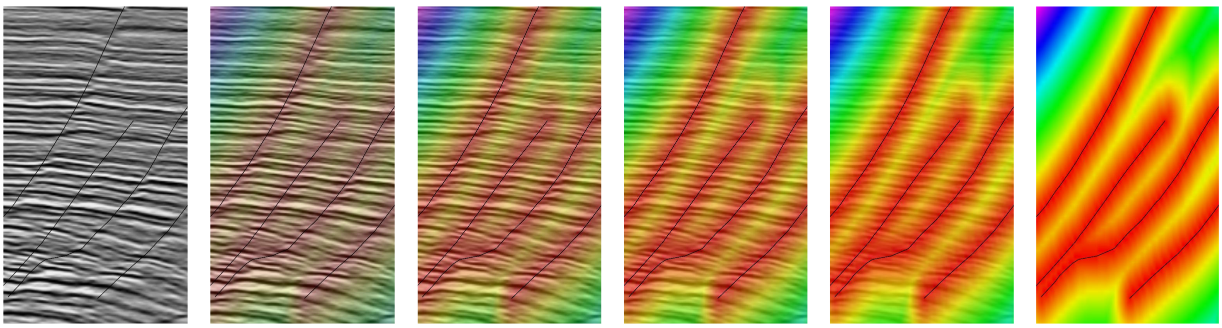


(a) shows the mapping between the world coordinates (left) and the parametric coordinates (right) of a texture map.

(b) Geological model painted with a 3d-texture map.

Fig. 1. Texture mapping with coordinate transformation. The texture map is based on a channel simulation [Alapetite et al., 2005]. Data courtesy of Total.

To co-visualize several attributes, the colors defining these attributes have to be blended for each fragment (figure 2). This operation is performed on the fragment unit of the OpenGL graphics pipeline [Segal and Akeley, 2003] and can be customized by user defined fragment shaders.

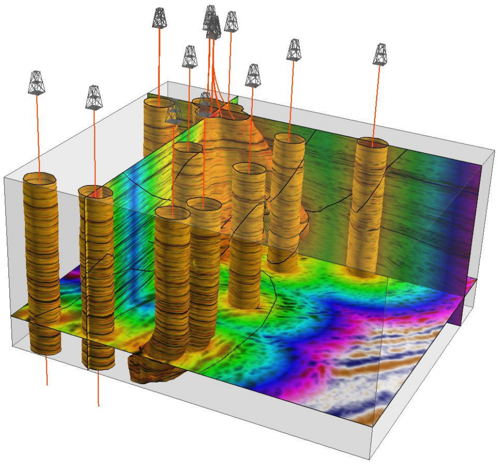


(a) 0.0 (b) 0.2 (c) 0.4 (d) 0.6 (e) 0.8 (f) 1.0

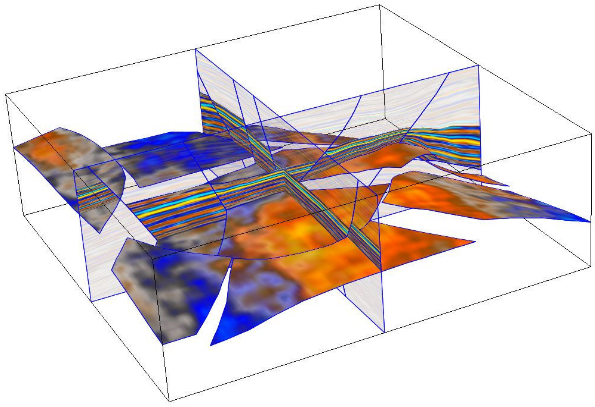
Fig. 2. This series of figures shows a cutaway of a cross-section through a tetrahedral mesh, co-visualized with seismic data and a distance function to the faults. The color channels of the two attributes where interpolated linearly and the bias (weight of the distance function) of the interpolation is given.

2.1. Distance maps

Distance transforms have been widely investigated for morphological image processing applications. An Euclidean Distance Transform (EDT) can be used to represent the distance to geological objects like faults or fractures. Also non-natural objects like wells can be considered. Common algorithms for the calculation of *n*-dimensional distance transforms were developed on Cartesian grids [Meijster, 2004]. The basic idea to compute distances on unstructured tetrahedral meshes is to compute an EDT on a regular background grid and to use this background grid as a 3d-texture map on the unstructured domain (figure 3(a)). For the computation of the EDT on a Cartesian grid, an adaption of [Ledez, 2002] was used.



(a) shows cross-sections and iso-value surfaces extracted from a tetrahedral mesh. The iso-value surfaces are defined by an iso-distance to the wells. The distance function and seismic data are co-visualized. Fault traces are highlighted by black outlines. Data courtesy of Earth Decision.

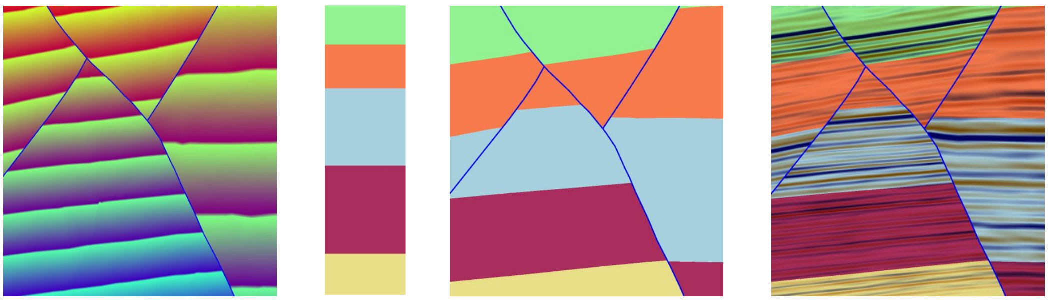


(b) shows two cross-sections and an iso-T surface in a tetrahedralized model. The surfaces were texture-mapped with a synthetic seismic cube and co-rendered with a stratigraphic column. One stratigraphic layer is highlighted, the other parts have a higher transparency. Data courtesy of Total.

Fig. 3. Two examples of geological information retrieval using tetrahedral meshes. The cross-sections and iso-value surfaces are illustrated with multiple attributes and outlined faults.

2.2. Stratigraphic column

A stratigraphic column is an image that assigns distinct colors to a model according to given geological time intervals. These markers can easily be combined with stratigraphic grids where the borders of a stratigraphic layer are aligned to the cell boundaries of this grid. The extension of the stratigraphic column to unstructured grids like the tetrahedral mesh – investigated in this work – is more complex. As precondition we need the definition of a geological time function on the nodes of the simplicial 3d-complex. This is realized with the GeoChron [Mallet, 2004; Moyen et al., 2005] parametrization. A stratigraphic column can be considered as a step function over geological time (figure 4). As this rendering is performed on the GPU (Graphics Processing Unit) there is no loss of performance compared to ordinary rendering. The stratigraphic column and its color values are user-defined parameters.



(a) (b) (c) (d)

Fig. 4. (a) shows a GeoChron time function painted with a periodic colormap. (b) shows a colorbar computed from a step function over the GeoChron time. (c) shows the model rendered with the step function. The stratigraphic layers are outlined in different colors. (d) combines the image of (c) with a 3d-texture map extracted from a seismic cube. Data courtesy of Total.

2.3. Visual solution of Boolean queries

Let us consider a step function over the domain of the function φ_A. This function takes zero values in the interval [min(φ_A),b[and is one in the interval [b,max(φ_A)] where b is an arbitrary value of the range of φ_A and defines the clipping threshold. The values of this step function can be treated as alpha values of a texture map, and rendering an iso-value surface of the function φ_B with this texture map will paint all parts of the iso-value surface that take values less than b of φ_A transparent. This is a graphical solution for a clipping algorithm with constant complexity *O(1)* for implicit surfaces of arbitrary size and complexity. This method can be extended to compute complex *3d*-Boolean queries in real time on the GPU (figure 5).

(a) A (b) B (c) A∪B (d) A\B (e) B\A (f) A∩B

Fig. 5. This series of figures shows the results of Boolean queries computed by implicit clipping on the GPU. The two attributes bunny (a) and the sphere (b) are defined as implicit functions on an unstructured tetrahedral mesh.

3. Conclusions

The developed methods reach interactive frame rates even on models with several hundred thousand tetrahedrons on standard consumer hardware. Common models can be explored at interactive frame rates. Beside the geometric information of iso-value surfaces, the rendering of heterogenous geological information was investigated. Hereby, different kinds of information – stored in texture maps or retrieved from topology – are blended and combined on the GPU. In both cases the image is created in one rendering path without additional computations on the CPU. Information like stratigraphic columns, distance maps, iso-contours and geological/geophysical data are combined. Further, multitexturing is used for boolean CSG (Constructive Solid Geometry) operations – performed on implicitly defined models. The developed method has constant complexity *O(1)* independent from size and complexity of the models. These high-performance boolean operators can be used for complex conditional 3d-GIS queries. The outline of faults and fault block boundaries are computed on the fly from the micro-topology of the tetrahedral mesh.

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