Semi-Automatic Simplification of Interval Volumes Taking into Account Shape and Color Distribution Features

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Abstract: The triangle decimation algorithm presented by Schroeder, et al. in 1992 is extended to make efficient the transmission and rendering of triangle patch datasets for large scale interval volumes. The extended algorithm accounts for color distribution as well as geometric features to select best edges to be collapsed. Although analogous concepts can be found in the literature, what distinguishes the algorithm from the others lies in its auxiliary mechanism to optimize the combination ratio of the color/geometry components in an error metric automatically by considering the coherence structure of a given two-scalar volumetric dataset.

1 Introduction

Parallel volume visualization has been exploited to provide the users with an intuitive and effective means to explore the inner structures and complex behavior of various unstructured volumetric datasets arising in *GeoFEM*, which is known as a large-scale finite element analysis platform for solid earth simulation [1].

Interval volumes [2] allow the users to represent a three-dimensional subvolume for which associated scalar field values lie within a specified closed interval. Interval volume fitting can be viewed as more effective tool for exploring volumetric ROIs, compared with the traditional isosurface fitting. As in the case with isosurfaces, interval volumes can represent the mutual relationship with another associated scalar field by retaining it as their color attribute.

In order to make efficient transmission and rendering of polygonal patch datasets for large-scale interval volumes, a simplification scheme to decimate triangle patches [3] is extended. The extended algorithm accounts for color distribution as well as geometric features to select best edges to be collapsed. Although analogous concepts can be found in the literature [4, 5, 6], what distinguishes our algorithm from the others lies in its auxiliary mechanism to determine the combination ratio γ $(0 \leq \gamma \leq 1)$ of the color/geometry terms in a local feature metric automatically by considering the coherence structure of a given two-scalar volumetric dataset [7, 8].

2 Simplification of Polygonal Datasets

2.1 Accounting for Color Attribute

The decimation algorithm [3] reduces the number of triangle patches based on a quantitative evaluation of geometric features. We extend the algorithm so as to account for the color attribute as well. The extended algorithm uses an edge collapse operation [5] (Figure 1) for re-triangulation. It selects best edges to be collapsed using a local feature metric $D(\mathrm{V}_1, \mathrm{V}_2)$, which is defined by the distance of two vertices V_1 and V_2, and the difference of their color attributes:

$$D(\mathrm{V}_1, \mathrm{V}_2) = \gamma \frac{col(\mathrm{V}_1, \mathrm{V}_2)}{col(all)} + (1-\gamma) \frac{dist(\mathrm{V}_1, \mathrm{V}_2)}{dist(all)},$$

where $col(all)$ denotes the difference between the maximum and minimum values of the color attribute, and $dist(all)$ the length of the longest edge of the smallest rectangular box that covers all the triangle patches.

2.2 Geometric/Color Attribute Errors

Our geometric error is defined as the average of distances from all vertices of the original dataset to their projection points on the set of triangle patches of simplified datasets. On the other hand, our color attribute error is defined as the average of deviations between

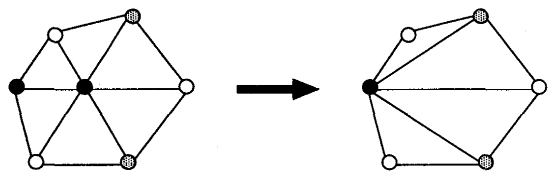


Figure 1 Edge collapse.

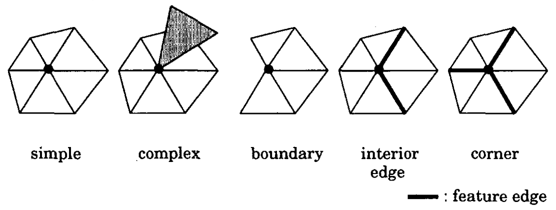


Figure 2 Classification of vertices.

colors of all vertices of the original dataset and the colors interpolated on the triangle patches at those projected points.

2.3 How to Determine Ratio γ

A polygonal dataset must have its proper value for the ratio γ of color attribute to geometric features. We herein propose one way to seek the value.

First, we compute a value F_s that measures the complexity of the geometric features as follows:

$$F_s = \frac{N_v - N_{simple}}{N_v},$$

where N_v denotes the number of all vertices, and N_{simple} the number of *simple* vertices. That classification of vertices is given in [3] (Figure 2).

Second, we compute a value F_c for representing the complexity of color distribution. The larger the color deviation and dispersion become, the larger this value becomes. We employ the following statistic for three-dimensional textures (volumes) accounting for their contrast and entropy [9, 10]:

$$F_c = -\sum_{i=0}^{N_c-1}\sum_{j=0}^{N_c-1}\frac{(i-j)^2}{N_c^2}P(i,j)\log\{P(i,j)\},$$

where P denotes co-occurrence matrix, and N_c the number of field levels.

Then, the ratio γ of color attribute to geometric features is defined as:

$$\gamma = \frac{F_c}{F_c + F_s a\{\log_{10}(N_v)\}^b}(1.5 - R_s), \qquad (1)$$

where R_s denotes the reduction ratio. The user-specifiable parameters a and b are introduced for equalizing the effects of F_s and F_c, and these values are currently defined on the basis of empirical knowledge.

3 Results

Experiments were performed on an SGI OCTANE system (CPU:R10000×2, Clock:195MHz, RAM:2Gbytes). Timings for decimation process are measured by averaging ten times of trials except for the maximum and minimum values. The parameters a and b are commonly set to 200 and 2, respectively in Equation (1).

Figure 3 shows the geometric error and color attribute error for simplifying the mechanical part (Figure 4(a)) under variable conditions on γ and R_s. The original dataset of interval volume for modeling a mechanical part has 6,705 patches. 50% of the patches are reduced under three different conditions on γ (Figures 4(b)-(d)). Figure 4(c) shows a simplified dataset by accounting for both geometric features and color distribution. The value for $\gamma\,(= 0.63)$, determined according to Equation (1), is judged to be qualitatively most desirable. The errors of the simplified dataset in Figures 4(b)–(d) are tabulated in Table 1, from which it is seen that the superiority of the case in Figure 4(c) is also proven quantitatively in terms of rendering time.

Figure 5(a) shows an original dataset of interval volume for modeling a carbon block. It has 1,123 patches. Figure 5(b) shows the 50% simplified carbon block dataset by accounting for both geometric features and color distribution. In this case, γ is 0.42.

Figure 6(a) is an original dataset of interval volume for modeling a fault. It has 5,180 patches. Figure 6(b) visualizes the 50% simplified dataset. The recommended γ is 0.23, a relatively lower value, because it includes a complex geometrical feature, i.e., two plates contacting with each other.

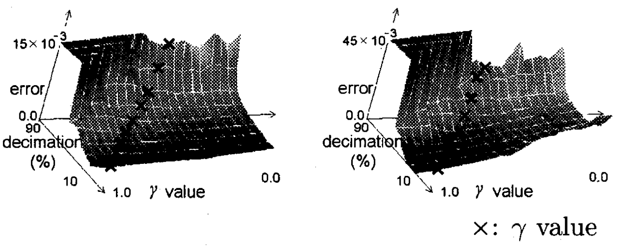
Figure 7(a) shows an original dataset of interval volume for modeling a water permeability. It has 194,358 patches. As the geometric features are very complex with relatively simpler color distribution, γ becomes a value near 0.0. Figures 7(b)-(d) show three cases of simplified datasets with different γ and R_s values.

The errors of simplified datasets in Figures 5–7 are summarized in Table 2.

4 Summary and Future Work

We have described a simplification technique for interval volumes accounting for color attribute as well as geometric features. We have presented a formula to determine a proper contribution ratio of color attribute to geometric features.

Further evaluation for optimized simplification of interval volumes should be performed using various kinds of larger scale datasets, including affordable setting of the parameters a and b in Equation (1).



(a) Geometry (b) Color

Figure 3 Error analysis of mechanical part in Figure 4.

Table 1 Errors and timings in simplifying mechanical part in Figure 4.

γ	Geometric error	Color attribute error	Timing (CPU second)
0.00	3.20×10^{-3}	21.3×10^{-3}	1.99
0.63	4.15×10^{-3}	11.2×10^{-3}	4.72
1.00	5.24×10^{-3}	23.7×10^{-3}	71.7

Table 2 Errors and timings in simplifying datasets in Figures 5, 6, and 7.

γ	Geometric error	Color attribute error	Timing (CPU second)
Carbon block data (reduction ratio: 50%)			
0.00	8.25×10^{-3}	28.1×10^{-3}	0.870
0.42	11.1×10^{-3}	18.9×10^{-3}	1.04
1.00	12.7×10^{-3}	23.6×10^{-3}	82.3
Fault data (reduction ratio: 50%)			
0.00	20.3×10^{-3}	29.3×10^{-3}	0.721
0.23	21.5×10^{-3}	23.2×10^{-3}	0.703
1.00	30.9×10^{-3}	40.3×10^{-3}	298
Water permeability data (reduction ratio: 50%)			
0.00	3.12×10^{-3}	5.20×10^{-3}	60.8
0.04	3.13×10^{-3}	4.82×10^{-3}	61.0
1.00	3.90×10^{-3}	4.35×10^{-3}	85.2
Water permeability data (reduction ratio: 75%)			
0.00	4.52×10^{-3}	7.21×10^{-3}	89.8
0.03	4.59×10^{-3}	6.73×10^{-3}	90.0
1.00	5.45×10^{-3}	6.07×10^{-3}	252
Water permeability data (reduction ratio: 90%)			
0.00	8.88×10^{-3}	12.2×10^{-3}	355
0.02	8.99×10^{-3}	11.4×10^{-3}	371
1.00	10.9×10^{-3}	10.9×10^{-3}	1,860

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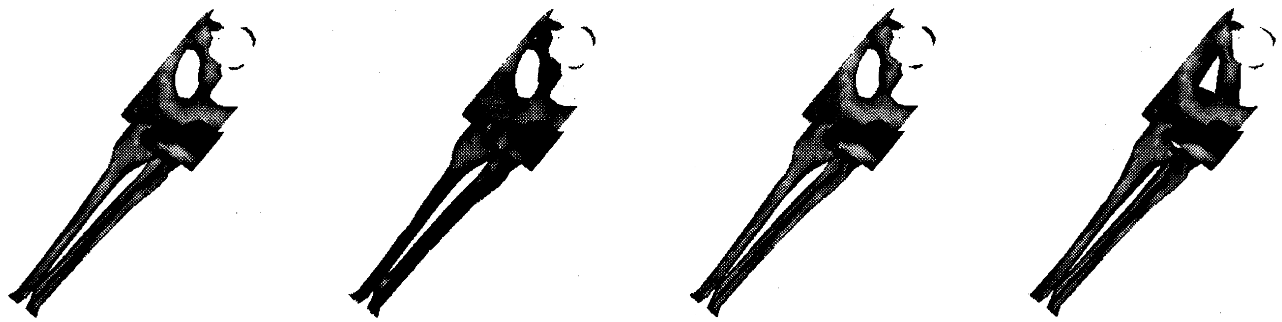
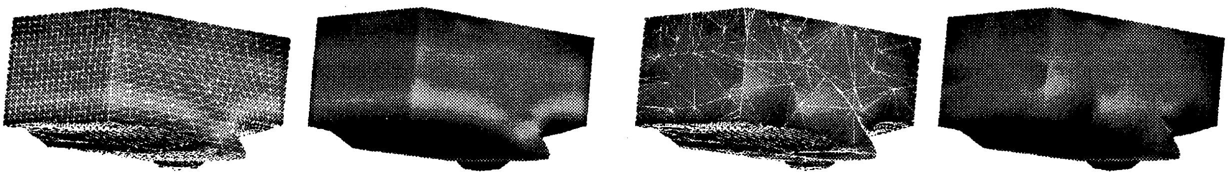


(a) (b) (c) (d)

Figure 4 Simplifying interval volume for mechanical part (reduction ratio: 50%). (a) Original interval volume (Number of vertices: 3,407; Number of patches: 6,706); (b) Simplified interval volume ($\gamma = 0.00$); (c) Simplified interval volume ($\gamma = 0.63$; semi-automatic); (d) Simplified interval volume ($\gamma = 1.00$).

(a) (b)

Figure 5 Simplifying interval volume for carbon block (reduction ratio: 50%). (a) Interval volume for carbon block (Number of vertices: 581; Number of patches: 1,123); (b) Simplified interval volume ($\gamma = 0.42$; semi-automatic).



(a) (b)

Figure 6 Simplifying interval volume for fault (reduction ratio: 50%). (a) Interval volume for fault (Number of vertices: 2,304; Number of patches: 5,180); (b) Simplified interval volume ($\gamma = 0.23$; semi-automatic).

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

Figure 7 Simplifying interval volume for water permeability. (a) Original interval volume (Number of vertices: 97,667; Number of patches: 194,358); (b) Simplified interval volume (reduction ratio: 50%; $\gamma = 0.04$; semi-automatic); (c) Simplified interval volume (reduction ratio: 75%; $\gamma = 0.03$; semi-automatic); (d) Simplified interval volume (reduction ratio: 90%; $\gamma = 0.02$; semi-automatic).