GENERIC ATTRIBUTE DEVIATION METRIC FOR ASSESSING MESH SIMPLIFICATION ALGORITHM QUALITY

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ABSTRACT

This paper describes an efficient method to compare two triangular meshes. Meshes considered here contain geometric features as well as other surface attributes such as material colors, texture, temperature, radiation, etc. Two deviation measurements are presented to assess the differences between two meshes. The first measurement, called *geometric deviation*, returns geometric differences. The second measurement, called *attribute deviation*, returns attribute differences regardless of the attribute type. In this paper we present an application of this method to the Mesh Simplification Algorithm (MSA) quality assessment according to the appearance attributes. This assessment allows the appreciation of local quality and the computation of global quality statistics of a simplified mesh.

1. INTRODUCTION

Many applications (geometric modelers, 3D scanning, etc.) generate very complex meshes that contain geometric data as well as appearance data. Geometric data describe the surface and the dimension of the mesh. Appearance data, called *attributes*, represent information describing the aspect of the mesh such as colors, texture,... High quality meshes usually contain a high number of vertices and faces that cause non interactive rendering or high storage space. Some results have been presented in the last few years in order to reduce the mesh surface complexity. The methods proposed simplify meshes either by merging/collapsing elements or by re-sampling vertices. MSAs use different error criteria to measure the fitness of the approximated surfaces. Usually, MSAs do not return measurements of the error introduced while simplifying the mesh. A measurement tool would be useful to precisely compare different simplification algorithms or parameters. In literature some methods are presented to assess the quality of a simplified mesh compared with the original one. We present a new, generic metric to assess mesh attribute quality after a simplification process by comparison between the original and its simplified representation. The method is suitable for numerical models from real scenes and for synthetic models. It can be used for many applications: mesh simplification, multiresolution analysis (comparison between different levels of detail), reverse engineering (comparison between a CAD model and a numerical model of a real object), mesh segmentation, etc.

2. SIMPLIFICATION ALGORITHMS AND ERROR METRICS

MSAs use their own error metrics to guide the simplification process. These metrics are either local or global. Cignoni *et al.*[1] has presented the various techniques used to evaluate and bound the error introduced by the mesh simplification process.

Most of these metrics use geometric measurements of distance or curvature. Schroeder *et al.*[2] use a vertex-to-plane distance as decimation criterion. Reddy [3] uses a function based on curvature to guide its simplification process. Klein *et al.*[4] use an error metric based on the Hausdorff distance. Ronfard *et al.*[5] use two energy functions: local tessellation error and local geometric error. Guéziec [6] uses a tolerance volume as an error bound measure. Rossignac [7] uses an error bound metric based on distances to supporting planes. Lindstrom *et al.*[8] use an area and a volume metric.

These algorithms simplify the geometry and ignore the distortion caused due to surface attributes (colors, texture, normals,...). Thus, more complete algorithms are needed to manage mesh attributes during the simplification process. Hoppe [9] uses energy functions, which preserve surface geometry, scalar attributes and discontinuity curves. Cohen *et al.*[10] use no error measure but only a geometric construction, called simplification envelopes, to minimize the surface deviation. Garland *et al.*[11, 12] use a quadric error metric giving vertex-to-plane distances; this metric works for meshes with attributes. Hoppe [13] has improved this technique for meshes with attributes.

Toubin *et al.*[14] have presented a new method for simplifying numerical models from real scenes. This method works with multi-modal models containing several types of appearance information (such as several textures, one for each wavelength band). Mesh simplification is performed by the quicunx wavelet transform. This method allows the conservation of important data in terms of geometric or appearance data. Thus, the original mesh is simplified according to the pre-defined important data. If the important data are appearance attributes, we need a tool to verify that these data are conserved.

Cohen [15] has proposed a texture deviation metric to assess the texture coordinate distortion introduced during a simplification process. Given two meshes M_a and M_b, their respective surface S_a and S_b, and a point $p_i \in S_a$, the texture deviation $T(p_i, S_b)$ between p_i and S_b is defined as:

$$T(p_i, S_b) = d(p_i, F_b^{-1}(F_a(p_i))) \tag{1}$$

where $F_a(p_i) = (u, v)$ is the texture coordinates of the vertex p_i on the surface S_a, and $F_b^{-1}(s, t) = p_j$ the point on the surface S_b with the texture coordinates (u, v). The texture deviation is the distance between a given point on S_a and the point on S_b with the same texture coordinates. The measurement of texture deviation was made to guide a simplification process. However, it is not suitable for assessing simplification quality. We propose a more general method to assess surface attribute distortion after a simplification process. This method does not depend on the attribute type.

Currently there is no tool to measure error introduced on attribute data by a simplification process. The purpose of this work is to define a method to assess MSA quality according to appearance attributes.

3. MESH COMPARISON METRICS

3.1. Geometric deviation

Simplification usually implies a local geometric difference between the original surface and the simplified surface. We call this difference: *geometric deviation*.

Given two meshes M_a and M_b, their respective surfaces S_a and S_b, and a point $p_i \in S_a$, the geometric deviation $d_g(p_i, S_b)$ between p_i and S_b is defined as:

$$d_g(p_i, S_b) = \min_{p_j \in S_b} d(p_i, p_j) \tag{2}$$

with $d(p_i, p_j)$ the Euclidian distance between two points. The geometric deviation is defined as the distance between a point p_i on the surface S_a and the nearest point on the surface S_b. This metric is based on the geometric error used by Metro tool [16].

3.2. Attribute deviation

Attributes are data defined at each vertex of a mesh (diffuse color, normal, texture coordinates). They are essential elements to numerical models of real scenes. The number of attributes per vertex changes according to the context. Geometric simplification of a mesh implicitly introduces a modification of the attributes. Thus, we can measure the local difference of the attributes between the original mesh and the simplified mesh. We call this difference: *attribute deviation*.

Given two meshes M_a and M_b, their respective surfaces S_a and S_b, and a point $p_i \in S_a$, the attribute deviation $d_a(p_i, S_b)$ between p_i and S_b is defined as:

$$d_a(p_i, S_b) = d(A(p_i), A(N(p_i, S_b))) \tag{3}$$

where $A(p)$ is the attribute at the point p and $N(p, S) = p'$ the nearest point to p on the surface S. The attribute deviation is defined as the distance between the attribute of the point p_i and the attribute of the nearest point to p_i on the surface S_b. There may be many nearest points on the surface S_b with the same distance to the point p_i. In that case, the attribute distance is the minimum distance between the attribute of p_i and the attribute of the nearest points. The attributes are considered as vectors in the Euclidian space.

3.3. Discussion

The deviation measurements are not symmetric. Given two meshes M_a and M_b, deviations are measured from a point p_i on the surface of M_a to the surface of M_b. If meshes are inverted, deviation measurement may give different results. For our investigation we measure the deviations both ways: from M_a to M_b and from M_b to M_a. Both measurements give different information but results are relatively close.

Geometric deviation is the main measurement because the mesh simplification process is essentially a geometric simplification. Attribute deviation is useful to assess appearance modification of the simplified mesh. When an important simplification is proceeded (90% or more reduced faces), we usually note important attribute modifications. Attribute deviation can be computed either for one attribute type or for all attribute types. If there are several attribute types (*e.g.* normal + diffuse color), the global deviation is a vector containing the deviation for each attribute type.

These two mesh simplification quality metrics (geometric and attribute deviations) are measured for a set of points p_i given on the surface of the mesh M_a. This allows great liberty for the choice of p_i points. Usually deviations are measured for the entire mesh. Thus, the p_i points may be the mesh vertices. The measurement resolution can be increased using a surface sampling technique.

4. RESULTS

Figure 1 shows geometric and texture deviation measurement. Figures 1(e) and 1(f) show results obtained with the texture deviation measurement proposed by Cohen *et al.*

[15]. With low texture deviation (Figure 1(e)), Cohen's texture deviation measurement has the same visual results as the geometric deviation measurement. Nevertheless, both measurements cannot be numerically compared. The geometric deviation is based on the nearest neighbor distance, whereas Cohen's texture deviation is based on the corresponding point distance. Figures 1(g) and 1(h) show results obtained with attribute deviation, where considered attributes are the texture coordinates. The attribute deviation gives better results than Cohen's texture deviation. If no real texture deviation does exist, Cohen's measure indicates a deviation coming from strictly geometrical distortion.

Figure 2 shows a comparison between the three simplification software programs for different face simplification percentages. *QSlim* is Michael Garland's simplification software using quadric error metric. *Jade* is simplification software developed by the Visual Computing Group using a global error metric. *ProgMesh* is an implementation of Hoppe's progressive meshes. Figure 2(a) shows mean geometric deviation in terms of simplification percent. Figure 2(b) shows mean deviation of normals in terms of simplification percent. QSlim software has obtained the best results on our test mesh.

5. CONCLUSION AND FUTURE WORK

We have described two measurements for assessing MSA quality. Each measurement manages a specific data group: the geometry and the appearance attributes. The local measurement allows one to precisely view simplified regions on the mesh. As the simplification process is primarily a geometric simplification, geometric deviation measurement is the most important measure. Attribute deviation measurement is efficient to measure appearance modification. Our experimentation software is available online[1].

We are testing different simplification software packages including professional software using different kinds of meshes (digital elevation maps, synthetic meshes). This test will allow the comparison of MSA algorithm quality according to appearance attributes.

6. REFERENCES

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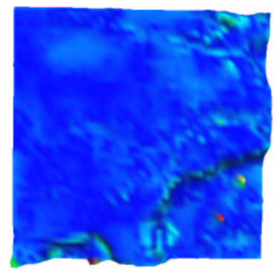
[1] http://meshdev.sourceforge.net

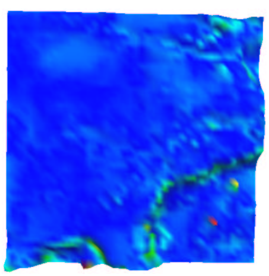
(a) Original mesh (3 972 faces)

(b) Simplified mesh (69 faces) (Low texture deviation)

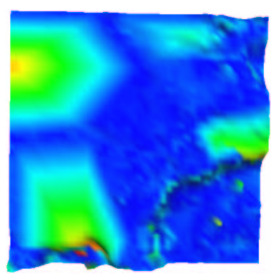
(c) Simplified mesh (69 faces) (High texture deviation)



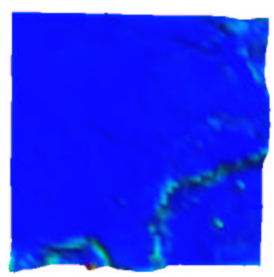
(d) Geometric deviation



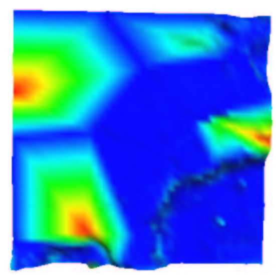
(e) Cohen's texture deviation from (b)



(f) Cohen's texture deviation from (c)

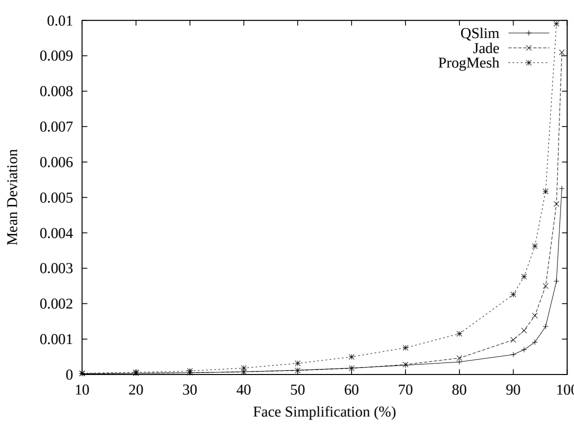


(g) Attribute deviation (Texture coordinates) from (b)

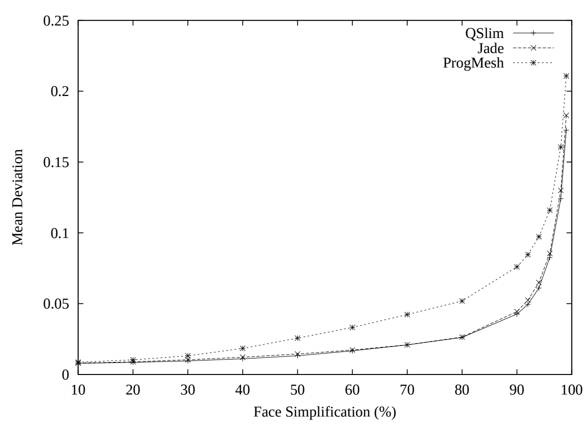


(h) Attribute deviation (Texture coordinates) from (c)

Fig. 1. Deviation assessment results. Comparison between results from the Cohen *et al.* algorithm [15] (e,f) and our algorithm (g,h).



(a) Geometric deviation



(b) Normal deviation

Fig. 2. Simplification software comparison.