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Feature Preserving Polygonal Mesh Simplification Using Mesh Salience

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***Abstract*—In this paper, we proposed a feature preserving polygonal mesh simplification method based on vertex salience. Our approach adopted a simple and effective vertex salience estimation to capture the features and a linear-time algorithm based on our earlier works. Compared with existing works, our novel approach not only has better run-time efficiency at generating level-of-detail meshes but also is capable of preserving visually important details.**

Keywords: feature preserving, mesh simplification, vertex salience.

1. Introduction

Polygonal mesh as a dominate representation for the 3D objects has been intensively applied to a great number of 3D multimedia applications including animation, virtual reality, and games. To maintain interactivity by providing trade-off between rendering efficiency and visual quality, a technique called level-of-detail(LOD) is commonly applied in the aforementioned applications, which derives a set of polygonal meshes of various details by applying polygonal mesh simplification iteratively. Depicted in Fig. 1, it is clear to see that the farther the mesh is located, the lesser level-of-detail, namely, the number of faces, is required.

Moreover, with the rapid improvements on model acquisition, deriving level-of-detail meshes from highly detailed meshes of very large size proposed a bigger challenge in designing a proper simplification algorithm that not only is highly efficient but also is capable of preserving important visual features. To address on such issue, we proposed a novel approach to feature-preserving level-of-detail generation. The new approach proposed using a simple and effective vertex salience estimation developed in [1] to preserve the visual features; on the other hand, the linear-time simplification framework proposed in [2] is adopted to maximize the runtime efficiency. According to our experimental results, our new approach outperforms existing methods in preserving salient features..

2. Related Works

Lee et al. define mesh saliency in a scale-dependent manner using a center-surround operator on Gaussian-weighted mean curvatures, which is able to capture visually interesting regions and yields visually appealing results from mesh simplification [3]. In a later work, Shi et al. proposed a perceptual metric based on global perceptual structural degradation for the measurement and evaluation of the degradation caused by the simplification of polygonal meshes [4].

Zhao et al. estimates the salience of a vertex by voxelizing the model and samples points in terms of the entropy of the shape index of vertices in voxels [5]. With the estimated salience map, visually significant local details can be located and preserved. In a more recent work, Wu et al. proposed another approach for computing saliency [6]. Their approach considered both local contrast and global rarity at once captures local rotational invariant geometric features by introducing a multi-scale local shape descriptor.

3. Preliminaries

Given an orientable 3D mesh $M = (V, F)$ defined by a set of vertices V defined in R^3 and the set of faces F defined by a subset of distinct vertices of V, a vertex $v \in V$ is commonly represented by a 3-tuple of real, say (x, y, z), where $x, y, z \in R$;whereas, a face f of F, in particular, a triangle face, is usually represented by a 3-tuple of vertex indices. Furthermore, to facilitate the computations on the local geometry a vertex v, a number of terms are defined on neighbourhood of v as follows.

- $R(v)$, the *ring* of v, is the set faces adjacent to v.
- $S(v)$, the *star* of v, is the set edges incident on v.
- $C(v)$, the *crown* of v, is the set vertices on the boundary of $R(v)$, i.e., the set $\{v_j | \overline{vv_j} \in S(v)\}$.

4. Our Approach

To preserve visually significant features, our salience computation is based on the maximum normal variation approach proposed in [1]. The process flow of our approach to mesh simplification is illustrated by Fig. 2, which comprises three major procedures, namely, the salience computations, heap operations, and full edge collapses. We will give the algorithmic details of each parts with the following subsections.

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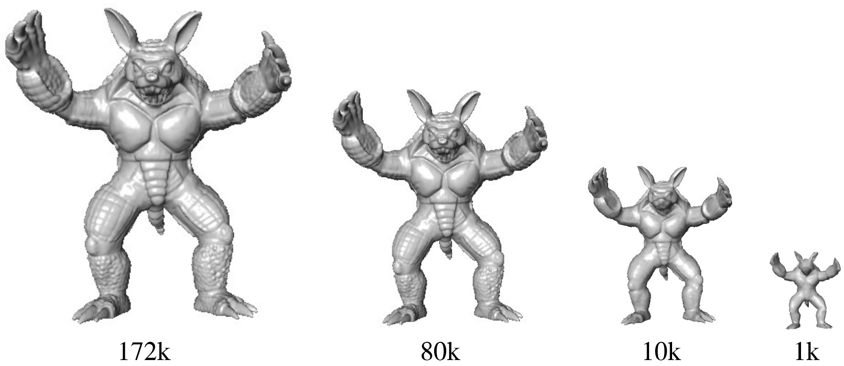

Figure 1. The Armadillo mesh in various level-of-details.

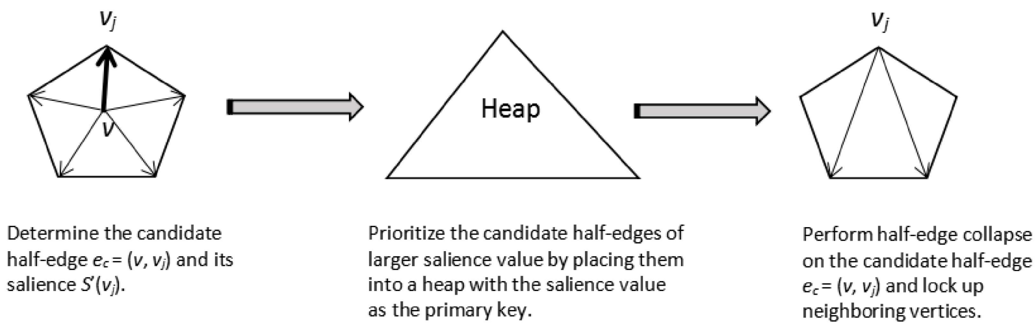

Figure 2. A flow diagram of our salience preserving approach to mesh simplification.

4.1. Salience Computation Based on Maximum Normal Variation

In our previous work [1], we have developed a simple and effective estimation to vertex salience by considering the maximum normal variations. A brief review of the related terms and formula is given as follows.

Given two adjacent faces, say f_a and f_b, of an edge $e_{i,j} = (v_i, v_j)$, the dihedral angle α of the faces f_a and f_b is determined by

$$\alpha = \cos^{-1}\left(\frac{\vec{n}_a \cdot \vec{n}_b}{|\vec{n}_a||\vec{n}_b|}\right). \tag{1}$$

where $\vec{n}_a$ and $\vec{n}_b$ respectively are the face normals of face f_a and f_b. An example is given in Fig 3.

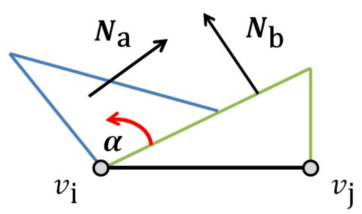

Figure 3. An example of two adjacent triangular faces.

For a 1-ring neighbourhood $R(v)$, the maximum variation angle α_{max} of v is given by

$$\alpha_{max} = \mathbf{max}\{\cos^{-1}\left(\frac{\vec{n}_a \cdot \vec{n}_b}{|\vec{n}_a||\vec{n}_b|}\right)\}, \tag{2}$$

where $\hat{n}_a$ and $\hat{n}_b$, respectively are the unit normals of any two distinct faces f_a and f_b of $R(v)$.

The vertex salience $S(v)$ of a vertex v with respect to $R(v)$ is determined by

$$S(v) = \frac{1 + \cos\alpha_{max}}{2} \tag{3}$$

Note that, for flatten surfaces, the vertex salience $S(v)$ is nearly 0; on the other hand, for concave and convex regions, salience value approaches 1.

Alternatively, the value of $S(v)$ can be normalized by

$$S(v) = \frac{|\alpha_{max} - \pi|}{2} \tag{4}$$

As an example, the results on the vertex salience computation for the Armadillo, the head of the David, and the Dragon meshes are presented in Fig. 4(a)-(c), respectively.

With such metric, we modified the simplification framework of [2] by incorporating the consideration of the vertex salience. Hence, for each vertex, we choose from its stars,

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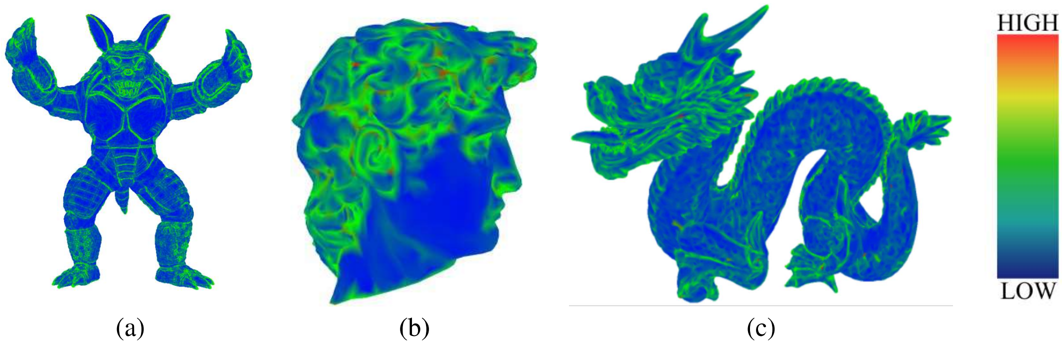

Figure 4. The distributions of the vertex salience for the head of (a) the David mesh and (b) the Dragon mesh.

i.e., the out going edges, an edge that resulted in the maximum salience and minimum quadric error. Namely, we find the candidate edge e_c from the vertex ring of a vertex $v \in V$ by

$$e_c(v) = \max_{\forall v_j \in C(v)} \{S'(v_j)\}, \quad (5)$$

where $S'(v_j)$ is the salience after collapsing the half edge $v \to v_j$.

We have adopted the strategy II proposed in [2] to optimize the simplification result and avoids inconsistencies and overly localized simplifications. After the decision of candidate half-edge with respect to the vertex salience, the collapse of the candidates are prioritized using a heap with the salience value $S'(v_j)$ as its primary key.

5. Experimental Results

According to our experimental results shown in Fig. 5, by incorporating the vertex salience estimation [1], the visually significant regions of the original input meshes have been successfully reserved. In comparison with existing approaches, i.e., the QSlim by Garland et al. [7] and the mesh saliency approach by Lee et al. [3], our method outperforms the others significantly by better preserving visually interesting regions.

6. Concluding Remarks and Future Works

As interactive three dimensional graphics are extensively applied, the demand for a better level-of-detail technique that can not only release the workload of the rendering pipeline but also preserves the detail parts that is meaningful to the human vision system is increasing. With the method proposed in this paper, visually interesting parts are better preserved after an extreme simplification while comparing to the existing approaches. Therefore, we may conclude that our approach is successful and is very practical to the generation of LOD representation for the interactive 3D applications such as the virtual reality, 3D games, and 3D animation, etc.

In the future works, we expect to find a classification scheme for visibly meaningful features. According to which, we may further prioritize the features with respect to its visual importance so that the visual signals provided by such level-of-detail representation can be maximized.

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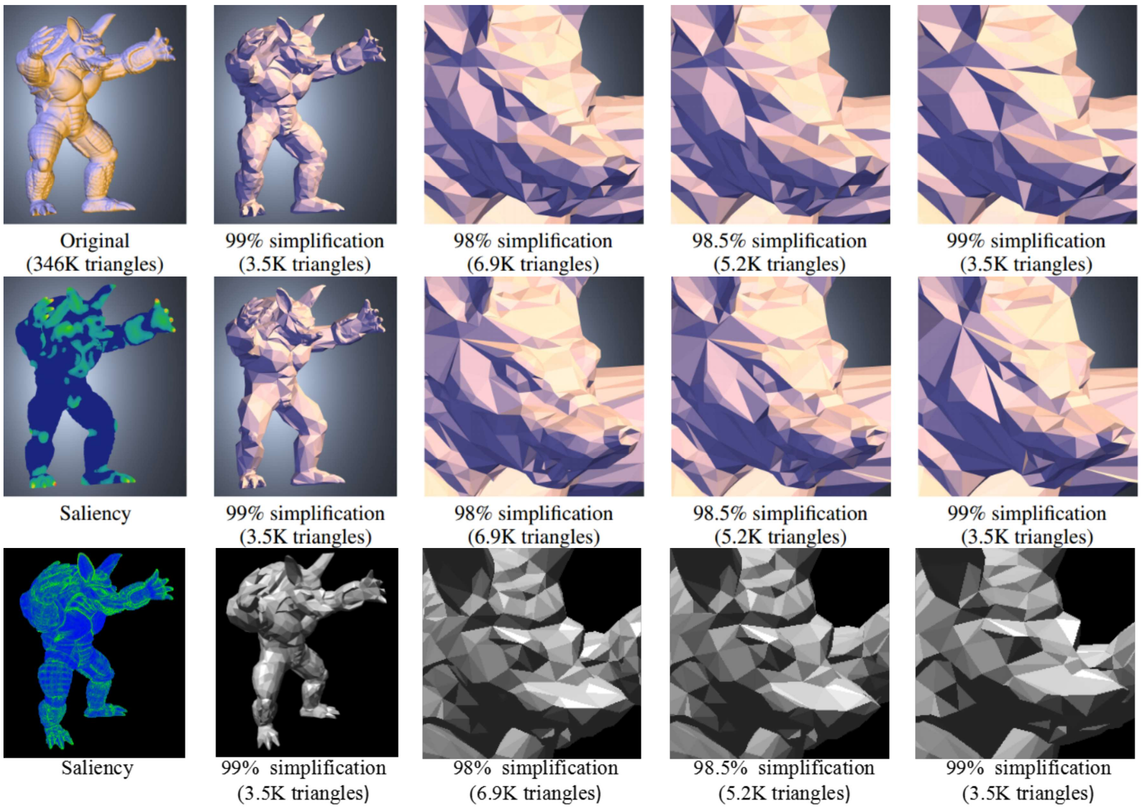

Figure 5. The simplified meshes using the QSlim (upper row) [7], the mesh saliency (middle) [3], and our approaches (lower).