Progressive 3D Animated Models for Mobile & Web Uses

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Abstract

To date, more high resolution 3D animated models are required to present important details and fine structures, however, sometimes such high resolution models are unnecessary and undesired, especially on web and mobile phone environments. Though there are many well-known algorithms dealing well on simplifying 3D models, most of them are limited to static ones. Applying these mesh simplification methods to 3D animated models, a good simplified model in a specified pose can be obtained. However, some features of the original animated model, which can be shown in other poses, may be destroyed. In this paper, we propose an automatic method to simplify a 3D animated model which takes the features shown in every poses into account and preserves the geometry details of them. Therefore, a progressive 3D animated model can be generated for mobile or web uses.

Keywords: Progressive Animated Models, Animated Model Simplification, Level-of-Details.

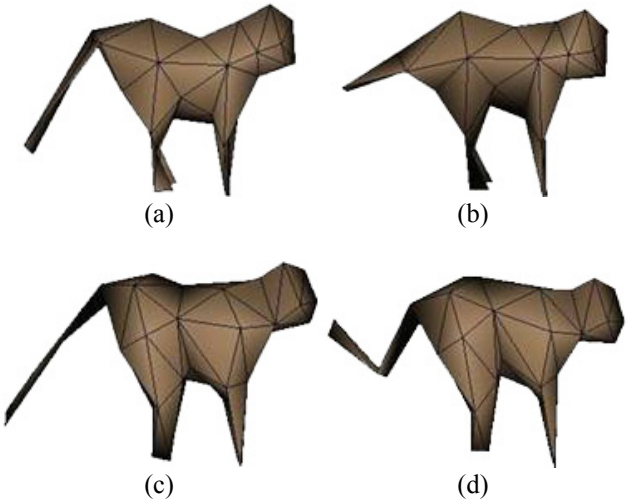
1. Introduction

Progressive Meshes (PM) [9] is a famous method for constructing a sequence of 3D models with continuous level-of-detail (LOD) based on recursive *edge collapse* operations. It can be used widely not only for displaying a 3D model with continuous LOD, but also for transmitting the 3D model over the Internet. The 3D model here only means a static 3D model without motion data. However, the 3D model with motion data, or so-called 3D animated model, is more widely used in many fields, like on-line games, animations, etc. Therefore, how to provide a method similar with PM but for the 3D animated model is necessary. In this paper, we present a novel scheme to construct a sequence of 3D animated models with LOD based on PM and the mesh simplification method presented by Garland and Heckbert [6], which is known as the Quadric Error Metric (QEM) method. The generated progressive 3D animated model can be used for web presentation or showing on hand-held devices.

In general, most of the mesh simplification methods are based on the error approximation of a 3D model in a single pose, since most of the 3D models are static. These methods can result good simplified models in a neutral pose. However, when applying these methods to an animated 3D model, like the 3D cat animation shown in Figure 1, it may destroy some features of the cat model in some particular poses. As an example shown in Figures 2 (a) and (b), which are the first and third frames of the simplified animated model of Figure 1. The simplified animated model is obtained by using the QEM method which only references the first pose of the animated model and applies the simplification process to all of the poses. Hence, the features which can be detected at the first frame can be reserved, but the features which are hidden at the first frame are ignored.

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

Figure 1. Five poses of an original 3D animated model, which is composed of 31 3D models and every model is deformed from the same cat model. (a) ~ (e) shows the poses at the first, third, sixth, eighth, and tenth frame, respectively.



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

Figure 2. (a) (b) The simplified models of the first and third frames when simplifying the animated model by only considering the first frame. (c) (d) The simplified models of the first and third frames when using our method. Obviously, the shape of the cat's tail shown in (b) and (d) are different. The carved shape of the cat's tail is preserved in our method.

The simplified models shown in Figures 2 (c) and (d) are obtained by our method. By comparing the tail parts of

Figures 2 (b) and (d), although the two models have the same number of triangles, the curved shape of the tail part is preserved in Figure 2 (d) as Figure 1 (b), but that is not preserved in Figure 2 (b).

The major contribution of our method is that we propose a mesh simplification method for 3D animated model while preserving the features of the model, even the features are only shown in a few frame. This paper has been presented in NICOGRAPH International 2005. [4]

2. Related Work

PM provided by Hoppe [9] is a famous method for 3D mesh simplification and is based on the *edge collapse* or *edge contraction* operation. Although this method could result in an almost optimized simplified model, it is well known to be time-consuming. A derived method, QEM [6], has been provided to make the calculation faster. Instead of using *edge collapse* or *edge contraction* operation for edge or vertex removal, it uses *vertex-pair collapse* operation which is also similar with *edge collapse* or *edge contraction* operation. The heuristic function used by QEM is geometry-based, since it calculates the geometric distance between the newly generated vertex and the faces which are deformed before generating it. Both of them are good methods for simplifying static 3D models for continuous LOD.

For simplifying 3D animated models, Alexa and Müller [1] proposed an approach to represent time-varying geometry by principal components. Through their method, a matrix composed of consistent meshes of original key-frames is build at first. The vertices of each frame of this matrix are then decomposed to the bases and weights after a Singular Value Decomposition (SVD) operation. By adapting different number of the basis, the LOD can be achieved. It also supports progressive animation compression with spatial, as well as temporal. However, the computational time for SVD decomposition is expensive and the view-dependent property cannot be fulfilled with this approach. Kircher and Garland also provide a method for this problem [11].

Houle and Poulin presented a very similar algorithm as ours on skeletal meshes [10]. They combined the PM concept and skeletal models to produce animation with continuous LOD. Their contribution is major for game industry, especially on-line games; however, it is limited to the models with skeleton, e.g. human or animals. Furthermore, they simplify the articulated mesh by taking only one single static model into account without considering the all poses contained in the animation sequences, so they had to adjust the model to a special pose by hand for better simplification effect.

Shamir and Pascucci proposed a scheme for creating LOD models for time-dependent meshes [12]. It supports both temporal and spatial LOD. They divided temporal variation into factors with low and high frequencies. In their definition, low-frequency factor stands for global affine transformation while high-frequency factor stands for local vertex deformations. They had different and good LOD effects by applying different updates (e.g. spatial and temporal); however, the size of the encoded data is much larger than the original mesh.

Based on "Geometry Images" [7], Briceno et al. proposed "Geometry Videos" [3] as a new representation for 3D animation. For each key-frame model, it uses global cut algorithm and parameterization method to create consistent geometry images. It inherits many advantages from Geometry Images and provides meshes in each frame with regular connectivity, LOD, and allows for applying numerous processing and compression methods targeted at videos to animated models. Though it has several advantages over previous techniques; however, for models with high-genus, it will cause high distortion due to the defeats of Geometry Images.

3. Animated Model Simplification

3.1 3D Animated Model

In this paper, we describe an animation comprised of a sequence of 3D animated models which are denoted as $\hat{M}_i = \hat{M}_0 + \Delta M_i$ for the i-th key-frame, where $\hat{M}_0$ is a generic triangle mesh; each animated model is deformed from it, and it can also be the model at the first key-frame, i.e., $\hat{M}_1 = \hat{M}_0$. ΔM_i means the geometric difference of the i-th key-frame between $\hat{M}_i$ and $\hat{M}_0$, which is generated by the object's skeleton or other deformation methods like other animation generating methods. Then, the state of the object can be calculated by interpolating two in-between models on two consecutive key-frames. Therefore, if the number of polygons of the object is large, to generate the model sequence is a time-consuming task.

3.2 Simplification Scheme

To decrease the number of polygons of the object is a good idea to solve the problem. However, if we simplified the 3D animated models by simplifying each pose separately using traditional mesh simplification method, the interpolation of two in-between models may be an artifact. To make the simplified animated models consistent as the original model sequence, we only simplify the initial mesh $\hat{M}_0 = M_0^n$ into a coarser mesh M_0^0 by applying a sequence of n successive edge collapse operations. Since edge collapse operations are invertible, $\hat{M}_0$ can therefore

be denoted as its simplified mesh M_0^0 with a sequence of n vsplit records as described in [9], where vsplit is a vertex split operation which is the inverse operation of edge collapse. Hence, $\hat{M}_0 = M_0^n$ can be denoted as

$$\hat{M}_0 = M_0^n = M_0^0 + \sum_{j=1}^{n} vsplit_j .$$

Then, the pose of the animated model at the i-th key-frame can be defined as

$$\hat{M}_i = \hat{M}_0 + \Delta M_i = M_0^0 + \sum_{j=1}^{n} vsplit_j + \Delta M_i$$
$$= M_i^0 + \sum_{j=1}^{n} vsplit_j = M_i^n .$$

Therefore, by applying some vsplit records to M_i^0, we can get multiresolution animated models for each key-frame.

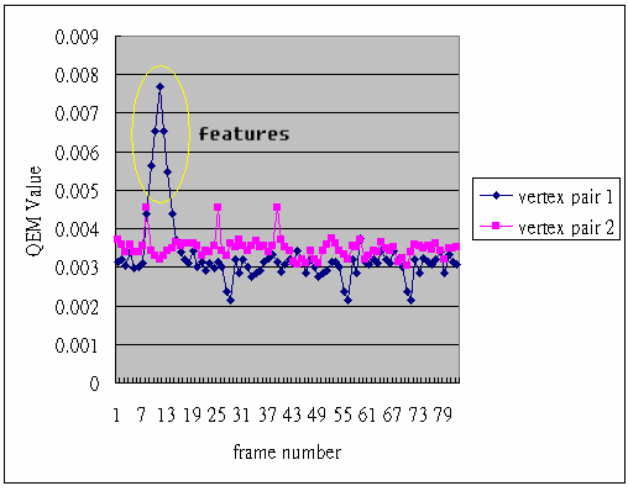


Figure 3. The features which are only appeared in some certain frames can be detected by considering their QEM values.

3.3 The QEM Function

To simplify the initial mesh $\hat{M}_0$, we use the algorithm modified from the QEM method. The original QEM method simplifies the mesh by considering the quadric error metrics $\mathbf{Q}(v)$ of each vertex v of the mesh. If $\mathbf{Q}(v)$ is large, that means the vertex v is located at a bumpy surface and it might be a feature and will be removed later. Otherwise, it will be removed earlier. Since the initial mesh $\hat{M}_0$ is deformed to be other poses to perform the animated model, to simplify it, it is necessary to take other poses of the animated model into account at the same time.

In Figure 3, we show the variance of two QEM values of two vertex-pairs along the time. During the animation playing, the QEM values of some vertices might be changed. That means a vertex will be the feature at certain frame, but it can be removed at other frames since it is not the feature in these frames. If we do not consider this situation and just remove it since it is not the feature in most frames, the feature will be disappeared like the curved shape of the tail part shown in Figure 2 (b).

Hence, we modified the quadric error metrics $\mathbf{Q}(v)$ of each vertex v of the initial mesh $\hat{M}_0$ to be $\mathbf{Q}(v) = \max \mathbf{Q}_i(v)$, where $\mathbf{Q}(v)$ is the quadric error metrics of the corresponding vertex v of the animated models $\hat{M}_i$ for the i-th key-frame. The value of $\mathbf{Q}(v)$ is used to select a proper vertex v with the minimum $\mathbf{Q}(v)$ to remove. Hence, we use the maximum $\mathbf{Q}(v)$, among the key-frames to guarantee the removed vertex is the proper one for all of the models which composed the animated model. To drive M_0^j by adding ΔM_i, i.e., $M_i^j = M_0^j + \Delta M_i$, a deformed model at the i-th key-frame and j-th level can be achieved. The geometric difference ΔM_i is generated by the model's skeleton or some deformation methods, so when applying ΔM_i to M_0^j, if some parts or vertices of the model has been simplified, this geometric difference will be ignored. That means if a part of the model has been removed, the motion of this part should also be ignored.

The reasons that we use this QEM function are based on the following two heuristics: (1) The decimation cost of the original features of the initial model are certainly high within all frames. (2) Features caused by the deformation will introduce the peaks of the QEM value as shown in Figure 3. From the first heuristic, we can still preserve the original features of the animated model because those features are motion independent, and the second one takes the features caused by some specific motions into account whether those motions are frequent or not. If the motion is frequent in this animation, it will introduce many peaks of QEM value in the chart.

4. Result

Figure 4 shows the simplification result of an angry cat animation which is composed by 31 cat models with different poses. Obviously, even the number of triangles is much decreased; the features of the animation can still be recognized, such as the curved shape of the tail part and the variance of the cat's back.

The lower row of Figure 5 shows a dog walking animation which is generated by 20 deformed dog models. Since the entire animated dog models are generated by deforming the same initial dog model, these models are vertex-wise correspondence. Simplifying the initial dog model while

considering the quadric error metrics of the other poses, the multiresolution dog walking animation can be obtained as the upper and middle rows of Figure 5. Applying the deformation data to the simplified dog models, multiresolution dog walking animations can be obtained. To simplify the dog models, it costs about 3.76sec. on a desktop PC with an Intel Pentium 4 2.6GHz CPU. The performance of simplification depends on the number of vertices of the initial model and the key-frame number of the animation. To display our progressive 3D animated model, we provide the viewers on several platforms including web environments and mobile phones.

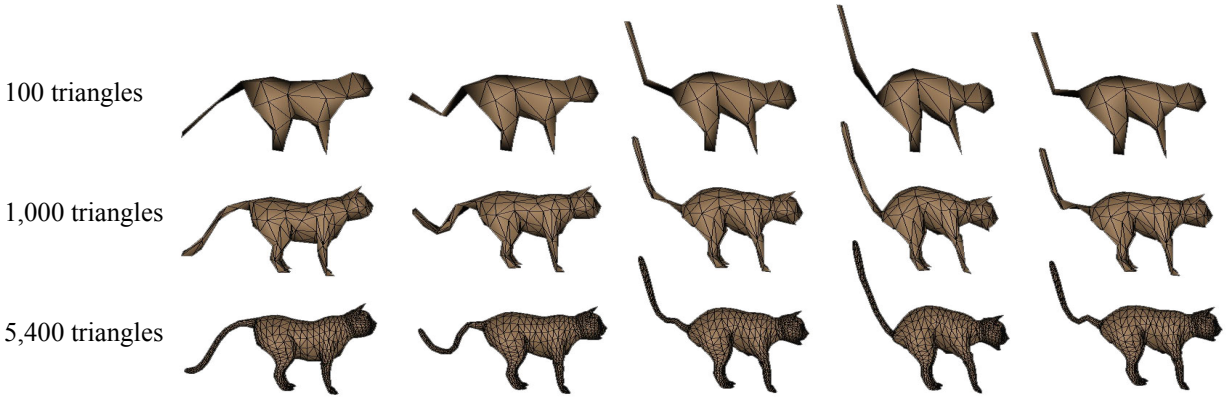


Figure 4. An angry cat animation. The lower row shows five poses of the original animated model. The model consists of 5,400 triangles. The middle and upper rows show the corresponding simplified results, which consist of 1,000 and 100 triangles, respectively.

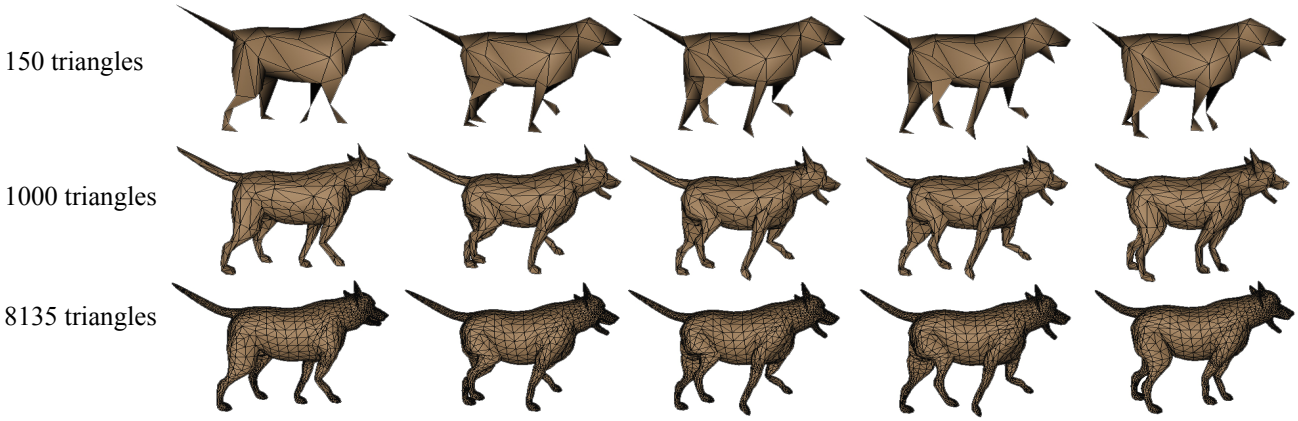


Figure 5. A walking dog animation. The lower row shows five poses of the original animated model. The model consists of 8,136 triangles. The middle and upper rows show the corresponding simplified results, which consist of 1,000 and 150 triangles, respectively.

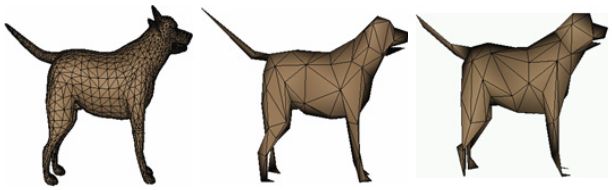
To compare our method with other simplification schemes, we use two kinds of quadric error metrics:

$$\mathbf{Q}(v) = \mathbf{Q}_0(v) \quad \text{and} \quad \mathbf{Q}(v) = \sum_{i=0}^{m-1} \mathbf{Q}_i(v) / m ,$$

where m is the number of frames and $\mathbf{Q}_1(v) = \mathbf{Q}_0(v)$. We call the two kinds of QEM functions as *single pose approach* and *average poses approach*. The result of using *single pose approach* is like the result of [10], since both of *single pose approach* and [10] only consider the features appeared in one certain frame. Hence, as shown in Figure 2 (b), the curved shape of the tail part of the cat model will be simplified since that part was not a feature at the initial model. Someone may want to use the average QEM value for simplification as *average poses approach*. As shown in Figure 6 (c), compare to Figure 6 (b), the back feet part of Figure 6 (c) becomes strange, since *average poses approach* makes the importance of that part decreased. This is because that part is not always the feature.

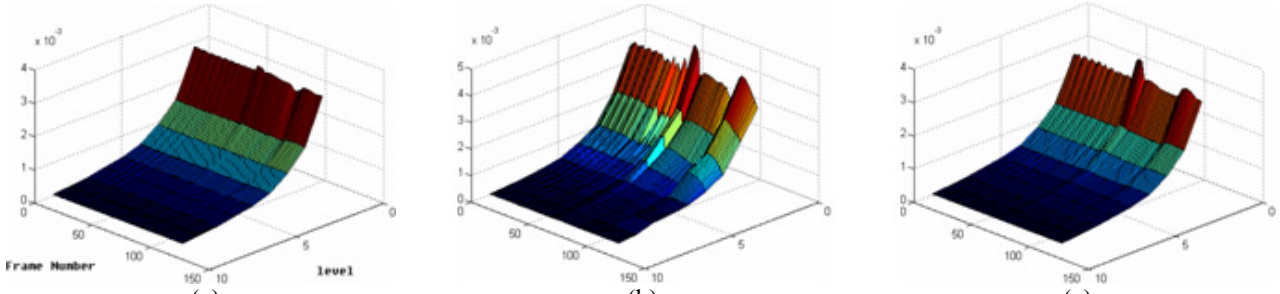
To measure the statistic differences of these simplifica-

tion schemes, we use Metro [5] as a measuring tool to compare the simplified models to the original ones. It is designed to compensate for a deficiency in many simplification methods proposed in literature. It allows one to compare the difference between a pair of surfaces (e.g. a triangulated mesh and its simplified representation) by adopting a surface sampling approach. It has been designed as a highly general tool, and it does no assumption on the particular approach used to build the simplified representation. It can also return both numerical results (meshes areas and volumes, maximum and mean error, etc.) and visual results, by coloring the input surface according to the approximation error.



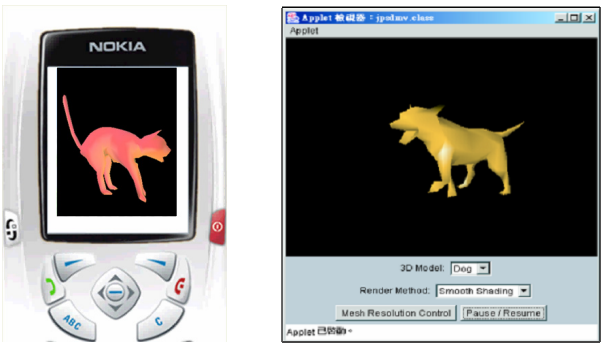
(a) (b) (c)

Figure 6. (a) The original dog model which is the first pose of a dog animation sequence. (b) The simplified dog model generated by our method. (c) The simplified dog model generated by using *average poses approach*.



(a) (b) (c)

Figure 7. RMS distance between the simplified animated model and the original one for (a) our method, (b) simplification due to the first frame as *single pose approach*, and (c) simplification using *average poses approach*.



(a) (b)

Figure 8. Progressive animated model viewer on (a) a mobile phone and (b) a Java-enabled browser.

For each simplified model (in different level and different frame), we measure the root mean square (RMS) distance from its surface to the corresponding model (in the same frame but full resolution). Then Matlab[1] is used to make charts for observation: *x*-axis stands for the level (from 10 to 1) of the simplified model, where level-10 is the full resolution and level-1 contains 10% faces of the original model; *y*-axis stands for the frame number, and *z*-axis stands for the measured error approximations.

[1] http://www.mathworks.com/

Figure 7 shows the RMS distance approximation of all simplified models generated by three different simplification approaches. RMS distance is a better measurement or metric than mean distance, because it is two-norm distances and it considers the space-relationship of distances between sampled points on original model and simplified model. From Figure 7, we find out that the RMS distance between the original model and the simplified model are smaller if we use our method or *average poses approach*. Another observation is that the surface of the chart created by our method is much smoother than those by other simplification approaches. That means some features are simplified in other two approaches, so at some certain frames, the differences between the simplified model and the original one become large and it makes the chart becomes bumpy.

Since the target of our method is to provide a progressive animated model for web and mobile uses, we therefore provide two kinds of viewers as shown in Figure 8. One is developed for mobile phones and the other is for Java-enabled browsers.

5. Conclusions and Future Work

In this paper, a fully automatic simplification scheme, which preserves the deformation features of objects, for animated models is proposed. 3D animated models, either key-framing or skeletal models, can be inputs of our sys-

tem, and a progressive animated model is generated. The scheme we proposed takes every pose of the animated model into account, and determines a better decimation sequence to simplify it. We can find out that our method really produce better simplified models than other schemes from the visualized results. Moreover, we can conclude that our method can generate a smooth animated model from the statistic results, though the evaluation of error approximation of our method is slightly higher than the average scheme.

Currently our simplification method does not consider the attributes of the vertices, like colors, textures, and even the binding weights of the skeletal models. Though the animated model is scalable, the storage space is huge. We would like to propose a well-organized data structure to store those data in the near future. The TDAG (Temporal Directed Acyclic Graph) structure used by Shamir and Pascucci in [10] is a good reference for us to start.

Acknowledgements

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