QUALITY PERCEPTION OF SIMPLIFIED MODELS: NSA *VS.* QSLIM

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Abstract: Quality perception of simplified models is an important aspect for several applications. But, it is normally evaluated only based on the analysis of geometrical errors of the simplified models. However, the analysis of geometrical errors is not enough to evaluate the quality of the simplified models. The quality of the simplified models and the execution times are the main aspects that distinguish the simplification algorithms. These algorithms are of great interest in a variety of areas, since they allow the replacement of large models by approximations with far fewer cells for manipulation and visualization purposes.
This paper presents a comparison between two simplification algorithms, NSA and Qslim, and shows the difference between geometrical and graphical quality of the models. The comparison of results was made using the PolyMeCo tool, which enables the analysis and comparison of meshes by providing an environment where several visualization options and metrics are available and can be used in a coordinated way.

1 INTRODUCTION

The sophisticated modeling systems and 3D data acquisition technologies enable us to create complex and detailed geometric models. But in several application fields these models are approximated by polygonal meshes for manipulation purposes because of their mathematical simplicity. However these models have normally redundant information that can be removed.

Simplifying a polygonal mesh M_i consists in generating another mesh M_j with a lower number of cells. The resulting mesh obeys a target criterion, which is normally a measure of a maximum admissible error. This error can be evaluated using different metrics and the main difference between the algorithms is the metric chosen. This metric has an influence in the quality of generated meshes and also in the time performance of the simplification algorithm.

The quality of the model can be evaluated using different tools and metrics, and it is important to evaluate the geometric and graphical quality of the models. Normally, most works present only the results of geometric quality ignoring the graphical quality of the models. But quality perception of the simplified models depends both on geometrical and graphical quality. Note that the graphical quality (i.e., the visual quality of the model) depends on several factors and not only of the geometric quality of the model.

In this work the geometrical and graphical quality of the simplified models was compared for NSA and Qslim algorithms using the PolyMeCo tool. This tool provides an environment with several visualization options and metrics which allow their usage in a systematic and efficient way enabling a better perception of model quality.

Section 2 presents an overview of mesh comparison tools. The PolyMeCo tool is briefly described in Section 3. The NSA algorithm is presented in Section 4, and the experimental results are discussed in Section 5. Finally, Section 6 presents some conclusions.

2 MESH COMPARISON TOOLS

Mesh comparison is usually carried out with the help of dedicated software tools that provide a numerical and visual representation of the data, for example, the

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minimum, mean and maximum value for a metric and a model colored according to the obtained values at each mesh vertex/face.

A few tools allowing features evaluation and comparison are described in the literature. The Metro (Cignoni et al., 1998b) tool, allows comparing two polygonal meshes by computing the geometric distance between them and by depicting the results using a colored model. It also provides the computation of the Hausdorff distance. According to the literature, this is the most used tool for mesh comparison. Another tool, proposed by Zhou et al. (Zhou and Pang, 2001), introduces some additional measures (e.g., surface curvature) and provides a few different visualization options (e.g., side-by-side view of models). The MESH tool, developed by Aspert et al. (Aspert et al., 2002), uses the Hausdorff distance to measure the difference between two models and presents a model colored according to the obtained results. The MeshDev (Roy et al., 2004) tool allows the computation of geometric, normal, and other mesh attribute deviations such as color and texture. Its output is a VRML model depicting the obtained results.

However, these tools provide a small amount of quality measures and lack several features which would enable a more systematic comparison process. To evaluate the results obtained, for example, with different simplification methods, it is often necessary to compare many models in order to reach a conclusion. So, it is desirable that the mesh comparison tools used support several models simultaneously for an efficient comparison of the results.

PolyMeCo is such a tool, and an overview of its main features will be presented in the next Section.

3 POLYMECO TOOL

PolyMeCo (Silva et al., 2005) is a tool under development, which provides an integrated environment where mesh analysis and comparison can be performed using several quality measures. Besides, the results are properly presented to the user using different visualization options. These options include, among others:
- Original vs Processed vs Colored Model, which allows the simultaneous view of both models being compared and a model colored according to the data obtained with a particular measure;
- Features Comparison which allows the visualization of data distributions obtained with the same computational measure for several processed models. This can be very useful in situations where the purpose is to study different processing algorithms and compare the obtained results. In order to allow a proper comparison using colored models, PolyMeCo allows using a common color map for all compared models, i.e., the maximum data value across all models is obtained and all models are colored according to it. To the best of our knowledge, this feature is not available in any other tool for mesh analysis and comparison and can significantly improve the way how users explore the results. This option enables a better perception of what is really happening with the analysed models by inspecting the colored models only.

To analyse and compare polygonal meshes several computational measures are available in PolyMeCo and they can be divided in two groups: intrinsic properties and difference measures. Intrinsic[1] properties allow the measurement of a particular property of a mesh. Difference measures allow the comparison of properties between two meshes, in general, the original mesh and a processed version (e.g., through simplification or compression).

For more details about the intrinsic properties and difference measures available in PolyMeCo tool see (Silva et al., 2005). A version of PolyMeCo for test purposes is available in `http://www.ieeta.pt/polymeco/`.

4 THE NSA ALGORITHM

There are several types of algorithms for simplifying a polygonal mesh (see (Cignoni et al., 1998a), (Puppo and Scopigno, 1997) and (Luebke, 2001)). They can be broadly categorized into three classes: cell decimation, vertex clustering and edge collapse.

The edge collapse algorithms simplifies a mesh by iteratively collapsing edges into vertices. They tend to preserve the topology but they may change it by collapsing pairs of vertices that are not connected by an edge (i.e., a ghost edge). The edge collapse operation has the disadvantage that it may cause local surface inversion.

The edge collapsing operation is standard. The main difference between the various edge collapsing-based simplification algorithms is the criterion used to choose the next edge to collapse. A different criterion implies different mesh quality, as well as a distinct processing time. Generally, all simplification algorithms make a trade-off between speed and the quality of the resulting mesh.

QSlim algorithm follows a geometric criterion that is based on the minimization of the error associated with each new vertex. This error is defined as the

[1]Meaning a property which can be obtained from a mesh regardless of any other mesh.

sum of the squared distances to the set of planes surrounding the pair of the original collapsing vertices. Thus, this algorithm produces simplified meshes with a very good geometric quality since it minimizes the error associated with each new vertex.

The simplification criterion used by NSA algorithm is guided by the normal angle metric that is very simple to compute. Thus, an edge is only collapsed if the variation of the face normals around the target edge (i.e., the faces that are incident on both vertices adjacent to the edge) are within a given tolerance ε. The value of ε is the threshold for the angle between the current normal and the new normal after the edge collapse operation.

In NSA algorithm the value of ε is adjusted automatically according to the desirable reduction of the number of faces of the mesh. A severe simplification of the model, i.e., a great reduction in the number of faces, implies a large value of ε. A small simplification of the model implies a small value of ε. Note that the number of faces of the mesh that will be created is a input parameter to the NSA algorithm.

The normal angle criterion implies that the region around the collapsing edge is nearly coplanar. In these circumstances, we say that a region is quasi-coplanar. But, the contrary is not true, i.e., the coplanarity does not ensure a minimal variation of the face normals because we can have coplanar faces with opposite orientations.

NSA algorithm guarantees the quasi-coplanarity of the region to simplify and, at the same time, prevents possible local folding or partial face overlapping of the resulting mesh, because the edge collapse operation is only allowed if the variation of the normals is less than ε. Note that these situations have a great variation of the face normals (see (Silva, 2007)).

Most authors distinguish between the simplification criterion (i.e., the criterion to choose the next edge to collapse) and the criterion that validates the edge collapse operation. On the contrary, NSA algorithm uses the same normal-based criterion to simplify and validate the edge collapse operation.

NSA algorithm preserves the mesh boundaries because the collapse operation is not allowed whenever at least one edge neighboring the collapsing edge has only a single face incident on it. This means that the boundary edges are never collapsed, so the boundaries are always preserved. Thus, it produces very good approximations preserving the original visual shape and the boundaries of the original model.

Note that the NSA algorithm was developed initially for multiresolution purposes. But a new implementation of the NSA algorithm alone was created as a general simplification algorithm of meshes (Silva, 2007) and it is available for test purposes in `http://www.di.ubi.pt/~fsilva/nsa/`.

5 EXPERIMENTAL RESULTS

The comparisons are made with QSlim algorithm (Garland and Heckbert, 1997) because it is referred in the literature as the algorithm that produces better results quickly. Besides, QSlim is available from `http://www.cs.cmu.edu/~garland`, which enabled running both algorithms in the same machine for the same models.

Several models are used in the comparisons between NSA and QSlim, however, due to limited space the results presented in this paper are based only on the four models pictured in Figure 1. The tests were performed with both algorithms on the same machine, a PC Pentium(R) D at 3.20GHz with 4GB of RAM running XP operating system.

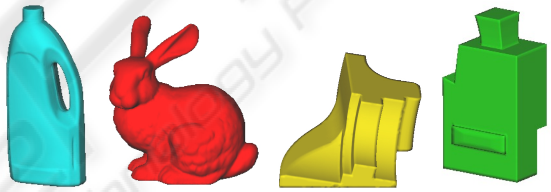


Figure 1: The four models used in this work. The FLASCHE. model has 85524 faces (left); the BUNNY model has 69473 faces (middle left); the FANDISK model has 12946 faces (middle right); and the BLOCKFS model has 25542 faces (right).

5.1 Time Performance

Table 1 shows the time performance for both algorithms, NSA and QSlim. As we can see, the NSA algorithm is always the fastest algorithm for all tested models. However, the difference of times is more significant for CAD models (i.e., models with planar regions as FANDISK and BLOCKFS). For example, with the BLOCKFS and FANDISK models the NSA algorithm is on average 8 to 10 times faster than QSlim algorithm. But, with the BUNNY and FLASCHE models it is only on average 1.1 to 1.5 times faster than QSlim algorithm.

The type of the model is important for the performance of simplification algorithms. For example, the QSlim algorithm spends much more time to simplify CAD models (see Table 1) than for other models. However, the run times for NSA algorithm show us that NSA algorithm is more sensible to the number of cells than to the type of model. Besides, the NSA algorithm produces models with high graphical quality (i.e., a more regular mesh) compared with QSlim algorithm, in particularly for CAD models as we will see in the next Section.

Table 1: Simplification times for NSA and QSlim.

Models	# of faces	NSA times	QSlim times
Fandisk	8000	0.047 sec	0.687 sec
Fandisk	6000	0.062 sec	0.702 sec
Fandisk	4000	0.093 sec	0.717 sec
Fandisk	1200	0.125 sec	0.733 sec
BlockFS	15000	0.094 sec	1.421 sec
BlockFS	12000	0.125 sec	1.609 sec
BlockFS	8000	0.171 sec	1.749 sec
BlockFS	4000	0.203 sec	1.765 sec
BlockFS	2000	0.234 sec	1.796 sec
Bunny	34999	0.438 sec	0.702 sec
Bunny	24999	0.532 sec	0.843 sec
Bunny	14999	0.657 sec	0.952 sec
Bunny	5999	0.750 sec	1.030 sec
Flasche	45000	0.515 sec	0.702 sec
Flasche	35000	0.657 sec	0.796 sec
Flasche	20000	0.829 sec	0.937 sec
Flasche	8500	0.954 sec	1.046 sec

5.2 Model Quality

Model quality can be evaluated using different tools and by different metrics. However, it is important evaluating the geometric and graphical quality of the models. Normally, most of the works present only the results of geometric quality and ignore the results of the graphical quality of the models. In this work the geometrical and graphical quality was compared using the PolyMeCo tool (Silva et al., 2007a). This tool enable us a more systematic perception of the results, for example using a side-by-side viewing with a equalized color scale.

5.2.1 Quality Metrics

There are several metrics available in PolyMeCo tool to compare the obtained models, but for this work we only use the most important of them to compare the geometrical *vs*. graphical quality. Thus, we select six metrics, three that compute the intrinsic properties and the other three that compute difference measures. Thus, the metrics used to evaluate the results are the following: Geometric Deviation (GD), Normal Deviation (ND), Composed Deviation (COMP2), Smoothness Analysis (SA3), Mean Curvature Analysis (MCA) and Angle Analysis (AA).

The geometric deviation is the most commonly used metric in the literature to compare polygonal meshes. But, as said before, the results obtained do not necessarily express the perceived quality of the simplified models.

The normal deviation relates with the shape of the model and particularly with how the model is viewed due to the strong relation between surface normals and light computation.

The composed deviation is a quality metric being developed based upon perceived quality results obtained using observer studies. Even though it still needs to be further enhanced it proved to be a very good estimator of user perceived quality in some specific conditions (Silva et al., 2007b).

The smoothness analysis measures how smooth is a surface. It is considered as an important characteristic of a surface which influences how its quality is perceived (Karni and Gotsman, 2000).

The mean curvature is an important characteristic of a surface, related with its shape, smoothness and, consequently, surface normals.

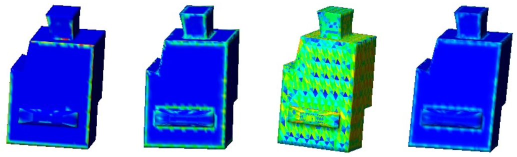
Finally, the quality of the triangles composing a mesh has been widely considered in Finite Element Methods in order to obtain meshes with good numerical characteristics. But, triangle quality (shape) is also important when rendering the models, because malformed (thin) triangles tend to result in visual artifacts which influence perceived quality.

Beyond all these quality metrics, PolyMeCo provides an additional (and important) feature to qualitatively evaluate perceptual quality. Its integrated environment, where all tested models can be loaded in a single work session, allows visually analysis/comparison of the models which helps to understand the meaning of the results obtained with the quality metrics.

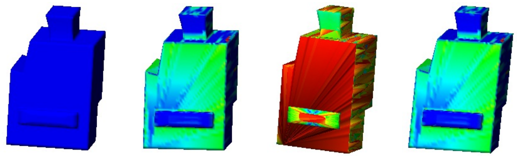
5.2.2 Analysis of Results

All the figures presented in this work use the same color scale with a common color mapping among all presented models, enabling us to see the real differences between the results of the algorithms.

Figure 2 shows the results of four metrics (GD, ND, AA, and COMP) for a 8000-faces simplified BLOCKFS model for both algorithms, NSA and QSlim. The Figures 2 a) to d) created by NSA and the Figures 2 e) to h) created by QSlim show the metrics for the simplified model. In this case only the geometric deviation is favorable to QSlim algorithm while normal deviation, angle analysis and composed analysis are favorable to NSA algorithm. Note that the simplified BLOCKFS model produced by QSlim has also geometric problems as show the Figures 3(b)

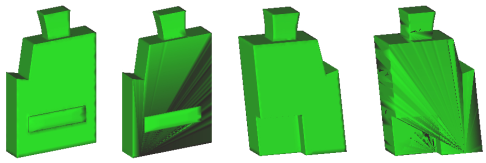


(a) GD (b) ND (c) AA (d) COMP



(e) GD (f) ND (g) AA (h) COMP

Figure 2: The simplified BLOCKFS. model. In the first row are the results of the NSA algorithm and in the second row are the results of the QSlim algorithm.



(a) NSA (b) QSlim (c) NSA (d) QSlim

Figure 3: A 15000-faces simplified BLOCKFS. model created by NSA and QSlim algorithms.

and (d) but, on the contrary, the simplified BLOCKFS model produced by NSA algorithm is correct as show the Figures 3(a) and (c).

Other model tested with both algorithms was the FLASCHE model which has planar regions. In this case only the angle analysis is favorable to NSA algorithm, i.e., the graphical quality of the model created by NSA algorithm is better than the graphical quality of the model created by QSlim algorithm. Thus, the model created by NSA algorithm is more adequate for visualization purposes because the mesh is more regular. On the contrary, the geometrical quality of the model created by QSlim algorithm is better than the geometrical quality of the model created by NSA algorithm, i.e., the model created by QSlim have smaller geometric errors (see (Silva, 2007)).

For the BUNNY model, all the results are favorable to QSlim algorithm. This fact is due to the simplification criterion of the NSA algorithm which is based on the planarity of the model surface. Since the BUNNY model has not planar regions the meshes produced by NSA algorithm have lower quality (see (Silva, 2007)).

Finally, the last model tested with both algorithms is the FANDISK which have planar regions. Figure 4 shows a simplified 4000-faces FANDISK model. The results for NSA algorithm are pictured in Figures 4 d), e), f), j), k) and l), and the results for QSlim algorithm are pictured in Figures 4 g), h), i), m), n) and o). The Figures 4 b) and c) show a 4000-faces simplified FANDISK model created by NSA and QSlim algorithms, respectively. As you can see in this case only the geometric deviation metric is favorable to the QSlim algorithm (see Figures 4(d) and (g)). All the others metrics (ND, COMP, AA, MCA, and SA) are favorable to the NSA algorithm. We can also observe that the simplified model created by QSlim (Figure 4(c)) have geometric problems. On the contrary, the model created by NSA algorithm have a correct geometry as shows the Figure 4(b).

Both the models, FANDISK and BLOCKFS, have planar regions where the QSlim algorithm generates problems in the geometry as confirmed by the simplified models and by the angle analysis metric (AA) in Figure 4 and Figure 2. Thus for models without planar regions the QSlim algorithm generates good simplified models but always spends more time, as the case of BUNNY model.

Thus for the models with planar regions we can say that NSA algorithm produces better simplifications than QSlim algorithm. For models without planar regions normally the QSlim algorithm produces better simplifications than NSA algorithm, but some times with inferior graphical quality.

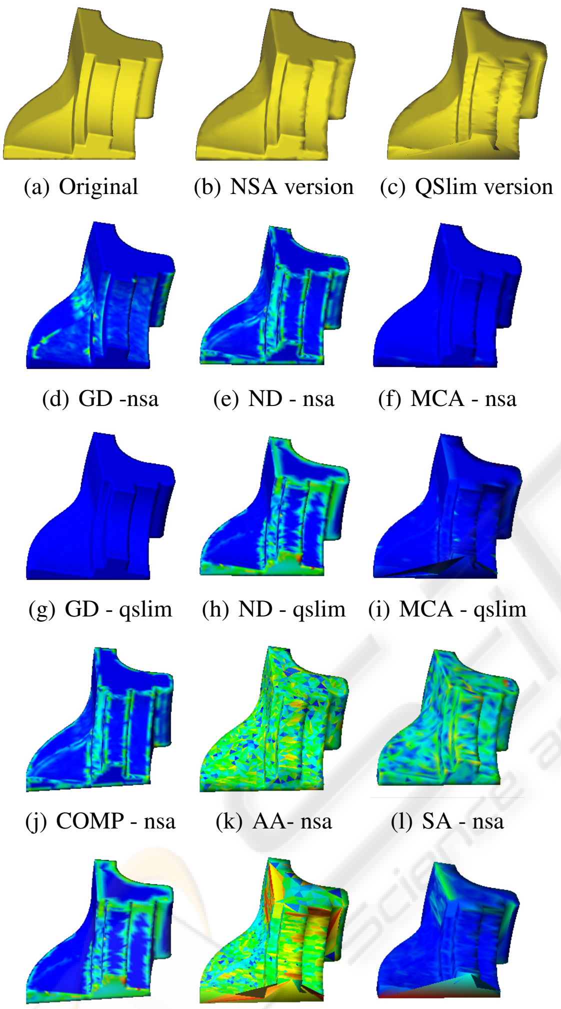
6 CONCLUSIONS

The PolyMeCo tool provided the possibility of analysing several simplified meshes using a large range of metrics, which allowed a more precise evaluation of the simplification algorithms. The available visualization options allowed a clearer understanding of the numerical values as well as the problems related to them. A clear example is the Angle Analysis metric that detects thin triangles which are not adequate for visualization.

The analysis and comparison of mesh properties can be performed with the help of 3D models. For example, a model is colored according to the value obtained for each vertex/face. This coloring can be performed by mapping the values range to a particular color scale and it is important to use common color maps among the compared models in order to attain a correct perception of the results.

The NSA algorithm is faster than the QSlim algorithm for all types of models, but in particularly for CAD models. Besides, for CAD models the QSlim algorithm generates simplified models with geometric/topological problems. On the contrary, the NSA algorithm produces always valid geometric models.

The results show that even though Qslim always created simplified models with high geometric quality they sometimes have inferior graphical quality. Thus, if the original model has a large number of planar regions, and visual quality is the most important criterion, then the QSlim algorithm might not be the algorithm of choice. For these cases the NSA algorithm is the right choice because it always creates valid models with a good graphical quality.



(a) Original (b) NSA version (c) QSlim version

(d) GD -nsa (e) ND - nsa (f) MCA - nsa

(g) GD - qslim (h) ND - qslim (i) MCA - qslim

(j) COMP - nsa (k) AA- nsa (l) SA - nsa

(m) COMP - qslim (n) AA- qslim (o) SA - qslim

Figure 4: The results of several metrics for a 4000-faces simplified FANDISK. model for algorithms NSA and QSlim.

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