AN EFFICIENT APPROACH TO RENDER 3D MESHES BY MANAGING MULTIRESOLUTION TRIANGLE STRIPS

Francisco Ramos, Jesus Gumbau and Miguel Chover
Institute of New Imaging Technologies, University Jaume I of Castellon, Campus Riu Sec s/n, Castellon, Spain

Keywords: Real-time Rendering, Multiresolution Model, Level of Detail, Triangle Strips, Hardware Acceleration.

Abstract: Visualization of large 3D scenes is a problem often solved by means of multiresolution modeling or level of detail. In this paper, we present a uniform resolution model that noticeably improves existing models, in terms of storage and visualization cost. The model is entirely based on optimized hardware primitives, triangle strips. Management of triangle strips coherence, on a multiresolution mesh, is key to achieving optimum performance. This model is able to take advantage of coherence in a software level as well as directly on the graphics hardware, integrating part of the model in that hardware. Use of stripification techniques, oriented to exploit vertex cache, has been taken into account to minimize vertex reprocessing. Comparisons to existing multiresolution model implementations show improvements of approximately 25% in storage space cost, 40% in level-of-detail extraction cost and visualization as much as 5 times better by applying hardware acceleration techniques.

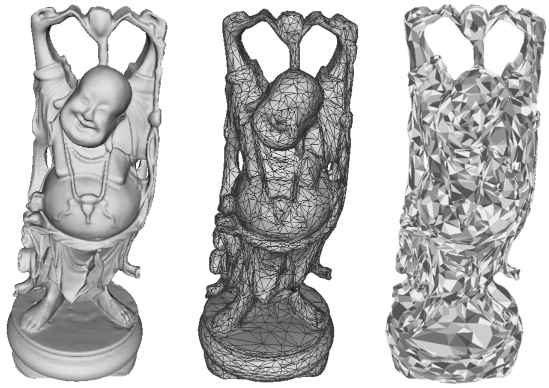
1 INTRODUCTION

Increasing complexity of 3D applications requires processing of vast amounts of graphic information for rendering, which often becomes in no more than a few pixels when introduced into the output device. With the purpose of solving this situation, multiresolution models have been created. According to (Ribelles et al., 2002), these models can be classified in two important groups: discrete models and continuous models. Within the latter, we can distinguish between uniform resolution models and variable models.

Discrete models have been widely used, however modern graphic application requirements are becoming more demanding. Thus, continuous models are required because they have more exact approximations, less storage cost and they are fast in visualization.

In recent years, continuous variable resolution models have evolved considerably (El-Sana et al., 1999); (Stewart, 2001); (Shafae and Pajarola, 2003). Important applications, like terrain renderers use this kind of models, although level-of-detail extractions quite penalize its performance.

At the present time, important 3D game engines, such as Torque, CryEngine or CodeCreatures, implement continuous uniform resolution models. Recently, some advances have been reached (Belmonte et al., 2003); (Ramos et al., 2004); (Hoppe, 1996); (Ribelles et al., 2000); (Ramos and Chover, 2004), but for one reason or another, none satisfies all the key requirements in a model of this type: facility of implementation, low level-of-detail extraction cost, appropriate spatial cost and simple integration with graphics hardware.



a) b) c)

Figure 1: Happy_buddha model. a) The highest level of detail: 543699 vertices and 31596 triangle strips. b) The lowest level of detail: 5438 vertices. c) Strips at the lowest level of detail.

In this paper, we present a continuous uniform resolution model that efficiently manages algorithms

Ramos F., Gumbau J. and Chover M..
AN EFFICIENT APPROACH TO RENDER 3D MESHES BY MANAGING MULTIRESOLUTION TRIANGLE STRIPS.
DOI: 10.5220/0003943203950403
In *Proceedings of the International Conference on Computer Graphics Theory and Applications* (GRAPP-2012), pages 395-403
ISBN: 978-989-8565-02-0

and data structures for real-time rendering of multiresolution polygonal meshes. The model is conceived in such a manner that mesh updating be fast and efficient. Thus, some data structures are ordered in accordance with the level of detail, it is also possible to integrate part of these into the graphics hardware, providing a hardware orientation to the model. Moreover, the model has been designed to facilitate the application of any hardware and software acceleration technique: coherence, vertex cache optimized stripification, OpenGL extension, and so on.

The model has been implemented on multiresolution meshes, initially generated by means of vertex cache static stripification techniques (NVIDIA, 2003) and based on progressive edge collapses (Garland and Heckbert, 1997). Certain data structures have also been implemented on the graphics hardware (NVIDIA, 2002).

Main contributions of this model are:

- Spatial cost. Simple data structures, oriented and built for easy application of acceleration techniques and for fast removal of degenerate triangles. This provides improvements of approximately 25% in this aspect.
- Complete exploitation of coherence. At an extraction level, we base level-of-detail extraction on information that changes from one LOD to another. At a visualization level, it uses efficient and fast-access data structures. Extraction cost is improved by approximately 40%.
- Hardware integration: Allocation of the model data structures into the graphics hardware and complete exploitation of the most modern techniques in hardware acceleration for current GPUs. Thus, visualization speed improvement can be as high as 5 times faster.

2 RELATED WORK

Garland (Garland, 1999) defines a multiresolution model as a model representation that captures a wide range of approximations of an object and which can be used to reconstruct any one of them on demand. Ribelles (Ribelles et al., 2002) presented a characterization of multiresolution models. This work classifies the models taking into account other criteria. A classification obtained from the same work separates continuous multiresolution models into uniform and variable models.

Variable resolution models are able to concurrently render two or more resolutions on the same multiresolution mesh, although these models consume a great deal of rendering time in level of detail extraction. This is mainly due to the use (on models based on triangle strips) of dynamic stripification, which requires new rendering primitive calculations in real-time, in addition to the cost of maintaining various resolutions on the same mesh. This type of model has advanced considerably, and there are many solutions available: (Hoppe, 1997); (El-Sana et al., 1999); (Stewart, 2001); (Shafae and Pajarola, 2003).

In general, continuous uniform resolution models have lower extraction times and allow a total rendering time that is more competitive than variable resolution models. After the appearance of progressive meshes, a model based on triangles and implemented in the DirectX graphics library, some models of this type were presented.

The first multiresolution model to use the triangle fan primitive in their data structures, taking advantage of the connectivity information between triangles in a mesh, is the model by Ribelles et al. called MOM-Fan (Ribelles et al., 2000). The main drawback of this model is the high number of degenerate triangles used in representation, although they are purged before the rendering stage. Another drawback of the model is that the average number of triangles in each triangle fan is small. Furthermore, rendering primitives are triangle lists, which have lower performance than triangle strips.

Figure 2: Some objects with triangle strips generated by NvTriStrip utility.

As regards strips, the first multiresolution model to take advantage of the triangle strip on the whole model is that of Belmonte et al., called MTS (Belmonte et al., 2003). Its main drawback is the high spatial cost, and its level-of-detail extraction time, although that loss is minimized by means of rendering with triangle strips.

Recently, LodStrips (Ramos and Chover, 2004) was presented, as an evolution of (Ramos et al., 2004). This model is wholly based on triangle strips, however it does not present simple data structures either to implement or to integrate them into the graphics hardware. Moreover, its spatial cost is considerable.

In general, this kind of models, either offer such a high level of detail extraction cost that they compensate rendering by means of implicit connectivity primitives, or have low extraction cost but without efficiently using these primitives. Furthermore, in certain cases, storage cost becomes excessive. In some models, another point to take into account is that of difficulties in applying existing acceleration techniques.

Nowadays, varied acceleration techniques have appeared, which integrated into a multiresolution model would become key to improve its performance. Basically, we can notice: stripification techniques oriented to exploit vertex caches (NVIDIA, 2003) and hardware acceleration techniques by means of graphics library extensions (NVIDIA, 2002).

There also are works that intend to exploit new GPUs characteristics. Chow presented a method for geometry compression (Chow, 1997), Hoppe developed an algorithm for generating triangle strips taking into account vertex cache (Hoppe, 1999) and Bogomjakov and Gostman presented a method for vertex cache optimization applied to progressive meshes (Bogomjakov and Gostman, 17).

3 MODEL CONSTRUCTION

Our model is built from a polygonal mesh, usually composed of triangles on which a sequence of processes is applied in order to obtain a multiresolution representation in the model data structures.

In figure 3, we can observe the data flow diagram associated with the global construction process.

3.1 Simplification

Simplification process allows us to obtain versions, at different levels of detail, of the input polygonal mesh. This algorithm is based on iterative contractions of vertex pairs.

The fundamental information that supplies this process consists of a sequence of collapses necessary to simplify the polygonal mesh.

3.2 Stripification

The model is wholly based on triangle strip primitives, which are generated at the highest level of detail.

The stripification process consists of converting a polygonal mesh, geometrically composed of triangles, into triangle strips.

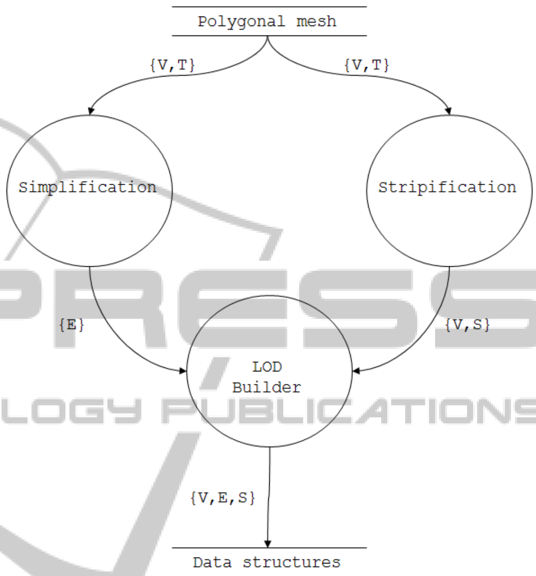


Figure 3: Model construction.

3.3 LOD Builder

Once obtained from the simplification process, the information about vertices to be simplified for each level of detail, and, from the stripification process, triangle strips at the highest level of detail, we proceed to the initial construction of the model.

In this process vertices are reordered in a simplified way, that is, the first vertex to be collapsed will be the zero; the second will be one, and so on. Once completed, it is necessary to modify the strips to reflect the changes realized. Finally, this process stores the ordered vertices into the model data structures and the triangle strips at the highest level of detail. With this information, it is already possible to build a multiresolution model that traverses through the levels of detail. However, whenever a change of level of detail occurs, it will be required to search among the strips for the vertices to be collapsed, and this operation has a high cost in real-time. So, another process is required that pre-computes and stores this information into another data structure.

Moreover, this process computes, for each level of detail, the strips that change and where exactly, in every strip, the vertex to be simplified is located. It permits to quickly traverse between levels of detail of the model, offering optimum performance.

4 MULTIRESOLUTION MODEL

This model represents a mesh as a set of multiresolution triangle strips (figure 4). It is an evolution of models (Ramos and Chover, 2004) (Ramos et al., 2004). Data structures were noticeably improved, reducing their size and integrating part of them into the graphics hardware. Moreover, with these new data structures it is easy to apply varied hardware acceleration techniques. All this, results in lower level of detail extraction times, lower visualization times and more efficient storage cost compared to the recently published uniform resolution multiresolution models.

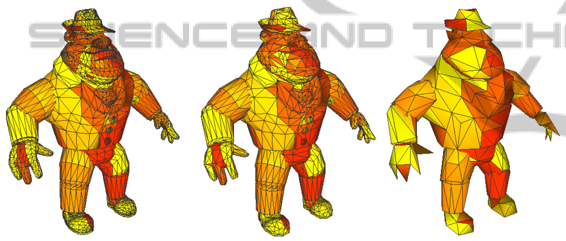


Figure 4: Three levels of detail from AL model.

At the beginning, data structures are informed by the pre-process that constructs the model. All this information is loaded at runtime and, afterwards, depending on application parameters, collapses, splits or resizes into multiresolution strips are performed.

4.1 Basic Data Structures

In order to visualize a polygonal mesh at the highest level of detail, we only need two data structures: hStrips and hVertices. hVertices stores the 3D coordinates for each vertex in the mesh, and hStrips, a set of triangle strips, where each strip contains a sequence of indices to hVertices. Figure 5 shows a simple representation of those data structures.

After the construction process, we know where collapses each vertex. This information is essential for level of detail management because it will determine collapses and splits onto the mesh, obtaining the LOD demanded by the application.

All this information in managed by the hVertexLOD data structure, storing for each LOD, the index to the vertex to collapse when that LOD is traversed.

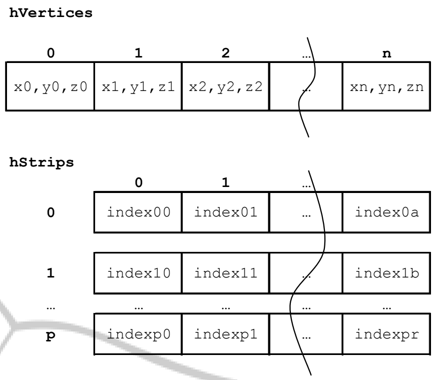


Figure 5: hVertices and hStrips representation.

Thus, with these three data structures, we can build a simple multiresolution model. However, this initial idea has a problem: to move across levels of detail is necessary to update strips looking for the vertex to collapse in every one. This task would imply a no competitive multiresolution model in some aspects, overall, in level of detail extraction cost.

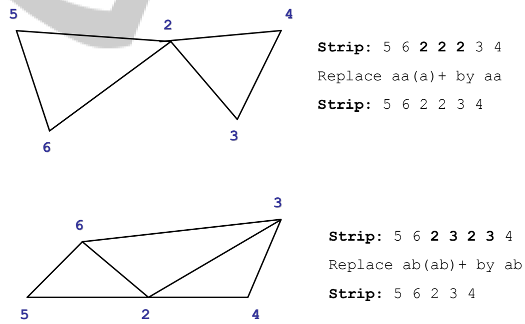


Figure 6: Type of patterns removed by model data structures.

A possible solution to this problem, above mentioned, that improves very much the model performance, consists of storing, in the data structures, what strips change, and for each strip in what position is located the vertex to be collapsed. It allows us to quickly locate information to be modified from a LOD to another. This approach offers a good performance, but as model moves to coarse LODs, an accumulation of identical vertices is produced. Sending these vertex repetitions to the graphics hardware does not contribute at all to the final scene, because it is equivalent to send degenerated triangles.

We have checked that most vertex repetitions, which can be removed, follows patterns like aa(a)+ or ab(ab)+. Patterns aa(a)+ are replaced by aa, and ab(ab)+ by ab. Figure 6 shows an example for each kind of pattern, we can observe that final geometry of strips do not change after removing these patterns.

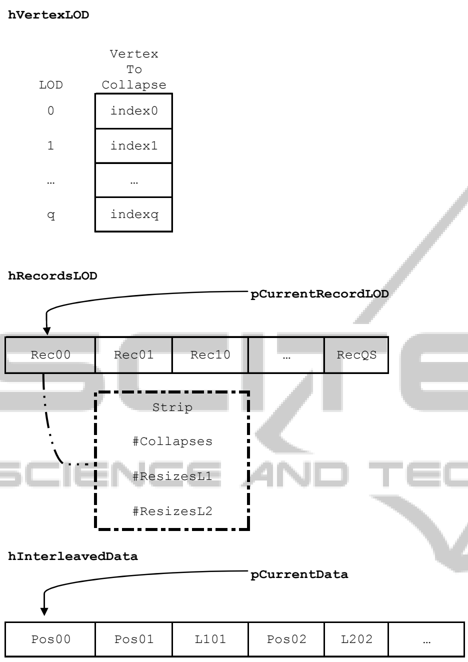


Figure 7: Model data structures.

In summary, we need additional data structures in order to support the aspects before mentioned: to index vertex to be collapsed and to remove more frequent patterns. These functions are performed by hRecordsLOD and hInterLeavedData.

hRecordsLOD data structure is managed by pCurrentRecordLOD, which is always positioned on the first record of hRecordsLOD to be applied in the next level of detail to the current one. Every record of this data structure contains the minimum information required to change a strip in a specific LOD. Concretely:

Strip	Strip to be modified
#Collapses	Number of collapses
#ResizesL1	Number of aa(a)+ patterns to be removed
#ResizesL2	Number of ab(ab)+ patterns to be removed

In this record, strip field will determine over what strip we are operating, and next fields let find in hInterLeavedData the type of operation to perform.

On the other hand, hInterLeavedData contains this information:

Collapses	Positions in a strip where a vertex will be replaced by another.
ResizesL1	Composed of position and number of aa(a)+ patterns in this position.
ResizesL2	Composed of position and number of ab(ab)+ patterns in this position.

In figure 7, we show a representation for every data structure.

Construction Example. Model construction starts from the information obtained from the simplification and stripification processes. This information is stored in hVertexLOD, which saves, for each level of detail, what vertex collapses. In this case (figure 8), and due to the model organization, in LOD 0, vertex 0 is collapsed to 7, in LOD 1 vertex 1 to 2, and so on. From the stripification process we obtain hStrip, which contains indices to vertices.

With this data, transition calculations sub process starts. It pre-calculates the changes to be produced into strips from the highest level of detail to the lowest one.

In figure 8, we can observe the model construction process saving information to the data structures.

From the highest level of detail (LOD 0), we can observe that to move to LOD 1, we must replace vertex 0 by 7, in every strip where it appears. Once collapses are performed, we proceed to detect vertex repetition patterns. In this case, a pattern 4 7 is detected in position 5. In brief, we have in strip 0, one collapse and one pattern ab(ab)+, so [0,1,0,1]. Furthermore, the collapse is located in position 6, and the pattern in position 5 and it repeats once, so [6,5,1]. Thus, we are building the model until the lowest level of detail.

4.2 Coherence

In this model, we have applied coherence at two levels: coherence at an extraction level and coherence at a visualization level.

Coherence at an extraction level means taking advantage of information obtained from the last level of detail extracted. Use of this kind of coherence noticeably improves time consumed by level of detail extraction algorithm, avoiding extractions already computed. Thus, if we are visualizing certain LOD, to move to the next or previous LOD will only need a few operations over strips. These operations will require a data structure, hStrips, with constant time in insertions and deletions, although access is penalized.

Coherence at a visualization level means using auxiliary data structures that provide a fast access

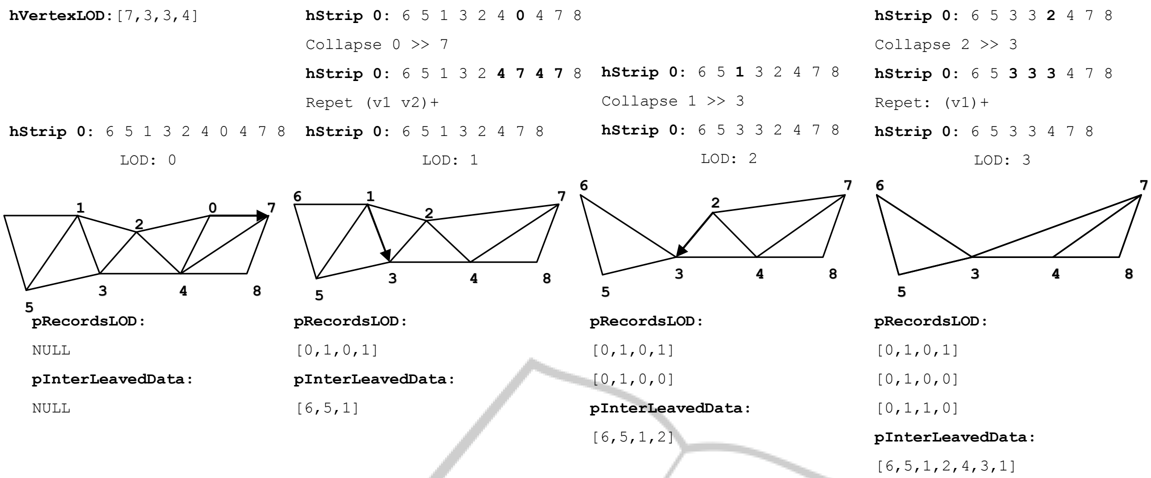


Figure 8: Model construction example.

and, thus, accelerates visualization. This kind of coherence can be applied at a software level and at hardware level. At a software level, the most efficient solution consists of using a fast data structure, in terms of sequential data access containing strips to be visualized for each moment. Thus, while a LOD is maintained during certain time, meshes are rendered at the maximum possible performance. Moreover, maintenance of these strips can be directly realized on the graphics hardware by means of specific buffers in its memory. It improves visualization very much, as shown in the results section.

Algorithm 1: Level of detail extraction from a LOD to a coarse one.

```
for(lod=currentLOD;lod<demandedLOD;lod++) {
  for(i=0;i<totalRecs[lod];i++) {
    strip=pCurrentRecordLOD->Strip;
    stripChanged[strip]=1; //for visualisation
    //Collapses
    for(n=0;n<pCurrentRecordLOD->Collapses;n++){
      hStrips[strip,*pCurrentData]=hVertexLOD[lod];
      pCurrenData++;
    }//aa(a)+ Patterns
    for(n=0;n<pCurrentRecordLOD->ResizesL1;n++){
      hStrips[strip].Erase( *pCurrentData ,
                            *(pCurrentData+1) );
      pCurrenData+=2;
    }//ab(ab)+ Patterns
    for(n=0;n<pCurrentRecordLOD->ResizesL2;n++){
      hStrips[strip].Erase( *pCurrentData ,
                            *(pCurrentData+1) );
      pCurrenData+=2;
    }
  }//End for i
} //End for lod
```

Visualization. To exploit coherence in visualization, every multiresolution strip has two representations: hStrips, a data structure with constant time in insertions and deletions, which corresponds with model geometry at the current LOD, and another representation, efficient and fast in access, which contains the same strips ready to render. This representation can be allocated in main memory or directly in the graphics hardware, which produces a great acceleration, as shown in results section. Depending on the type of coherence in visualization applied, the algorithm is also different.

Algorithm 2: Visualization algorithm with coherence at a software level.

```
//visStrips: strips visualisation data structure
for(s=0;s<hStrips.size();s++) {
    //Update visStrips when proceed
    if (stripChanged(i)) {
        visStrips[i]=hStrips[i];
        stripChanged[i]=0;
    }
        //Send strips to GPU
    glBegin(GL_TRIANGLE_STRIP);
    for(v=0;v<visStrips[i].size();v++)
        glVertex(hVertices[visStrips[i][v]);
    glEnd();
} //End for s
```

In the visualization algorithm shown above, we apply coherence at a software level. It uses visStrips, which stores strips ready to render guaranteeing an optimum access time. stripChanged data structure is informed by extraction algorithm, indicating what strips have changed in transitions between levels of detail, thus we know when to update visStrips data structure.

Algorithm 3: Visualization algorithm with coherence at a hardware level.

```
//visStrips: strips visualisation data structure
for(s=0;s<hStrips.size();s++) {
    //Update hardware buffer when proceed
    if (stripChanged(i)) {
        glBufferSubDataARB(. . .);
        stripChanged[i]=0;
    }

    //Send strips to the GPU using extensions
    glDrawRangeElements(. . .);
} //End for s
```

Algorithm 3 corresponds to visualization at a hardware level. This algorithm takes advantage of new GPU capacities. It directly store and manage strips to visualize from graphics hardware memory.

Different versions of this algorithm have been developed, storing only vertices in GPU, vertices and strips, and using two different OpenGL extensions too. We have checked the improvements achieved with this kind of visualization.

5 RESULTS

This model was submitted to several tests, all of which were aimed at evaluating the rendering time in a real-time application by applying different acceleration techniques.

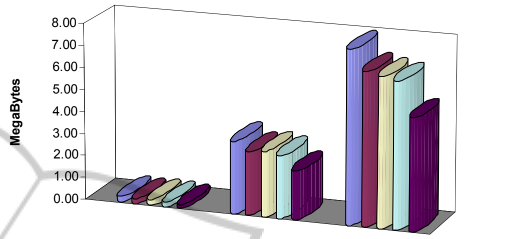
Tests designed to compare multiresolution models follow the ones introduced by (Ribelles et al., 1999) and those carried out in this study was the linear test: this consists in extracting a number of LODs of the model in a linear and proportionately increasing or decreasing way.

To carry out the tests, some well-known meshes from the Stanford 3D Scanning Repository were taken as a reference, so as to make it easy to compare this model with other well-developed models.

Tests were carried out using a NVIDIA GeForce graphics card. C++ was employed for the implementation, using the graphics library OpenGL, and it is completely portable.

5.1 Spatial Cost

Figure 9 shows a spatial cost comparative between the most important continuous uniform resolution models, at present time. As we can see, the presented model improves lodstrips, which had the best spatial cost among existing models, in around a 40%.

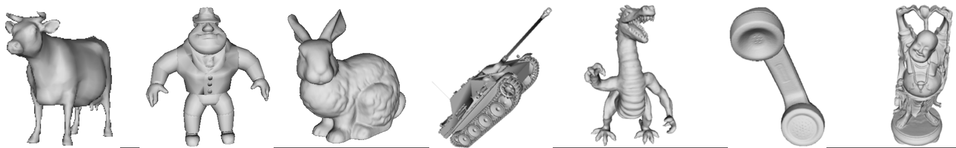


	Cow	Bunny	Phone
Vertices	2904	34834	83044
PM	0.27	3.28	7.86
MOM	0.24	2.88	6.94
MTS	0.25	2.96	6.77
LodStrips	0.22	2.83	6.64
hStrips	0.17	2.21	5.08

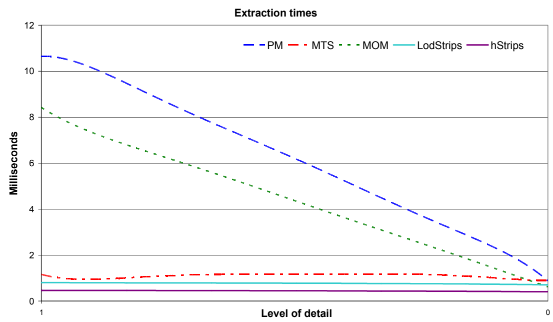
Figure 9: Spatial cost comparison.

5.2 Level of Detail Extraction Cost

In figure 10a, we can observe that the presented model, hStrips, offers the best extraction time from compared models. It is mainly due to the effect of using coherence in extraction algorithm and to the efficient data structures implementation that manage level of detail.



	Cow	AL	Bunny	Panther	Dragon	Phone	Buddha
Vertices	2904	3618	34834	38911	54294	83044	543699
Strips	551	177	6194	4368	8799	1747	31596
Storage MB.	0.17	0.20	2.64	2.00	4.01	5.08	35.51



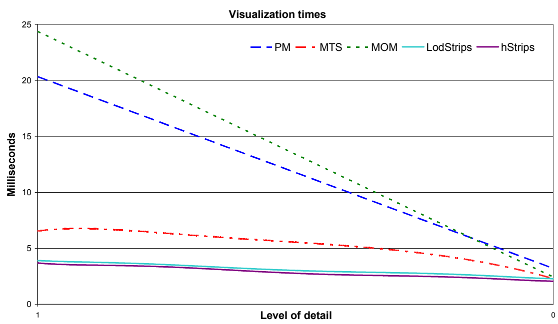
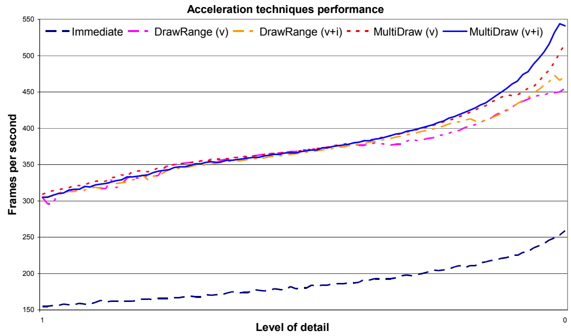


Figure 10: Extraction (a) and visualization (b) cost comparison for the bunny model with continuous uniform resolution models.

Bunny Model		
Vertices 34834		Strips 6194
Test	Hardware technique	Render (fps)
Linear Test	Immediate Mode	187
	VBO (v) DrawRange	371
	VBO (v+i) DrawRange	372
	VBO (v) MultiDraw	380
	VBO (v+i) MultiDraw	382

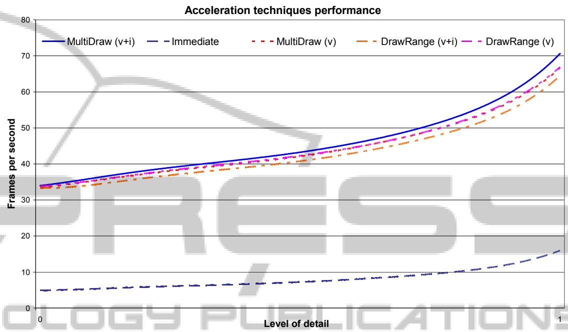
a) Bunny model frames per second average



b) Bunny model performance chart

Buddha Model		
Vertices 543699		Strips 31596
Test	Hardware technique	Render (fps)
Linear Test	Immediate Mode	8
	VBO (v) DrawRange	45
	VBO (v+i) DrawRange	43
	VBO (v) MultiDraw	44
	VBO (v+i) MultiDraw	46

c) Buddha model frames per second average



d) Buddha model performance chart

Figure 11: Bunny and Buddha model rendered by means of hardware acceleration techniques.

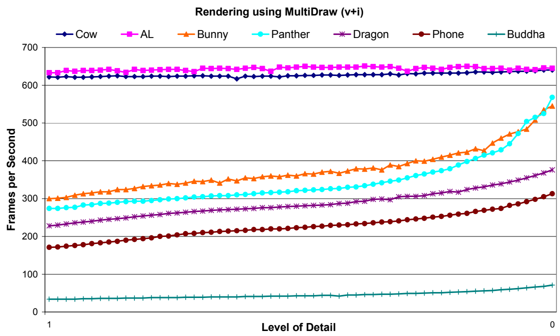


Figure 12: Multiresolution performance obtained from our model, rendering with MultiDraw extension allocating vertices and strips in the graphics hardware memory.

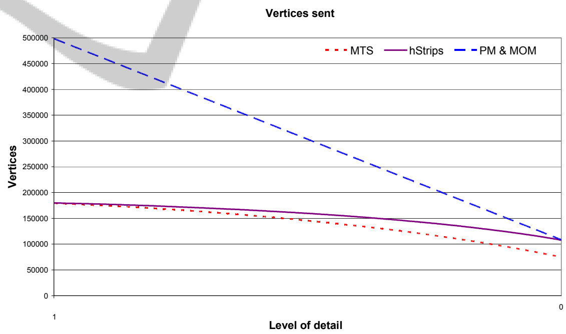


Figure 13: Vertices sent comparison for the phone model, from the highest lod (1) to the lowest (0).

5.3 Visualization

Results of visualization are shown in figure 10b, where it is compared to other models using immediate mode to render. It is possible to observe that our model offers the best visualization times. In spite of rendering in immediate mode, the coherence at a software level is exploited.

5.4 Hardware Acceleration

Rendering by means of hardware acceleration techniques noticeably improves models performance. On one side, we might upload different kind of information to special buffers in the graphics hardware memory. We have tested these buffers uploading only vertex information and uploading vertex and strips index information. It is shown at figure 11 as (v) and (v+i) respectively. On the other side, we can take advantage of those buffers by using OpenGL extensions, like glDrawRangeEXT and glMultiDrawsEXT. Thus, in figure 11, we can see the effect of combining these modern features offered by current GPUs, with a multiresolution model that exploits them to the maximum. Comparing immediate mode to VBO Multidraw (v+i) technique, improvements are considerable, on average, around 200% for the bunny model and 570% for the budhha model.

Figure 11 shows a chart with various models tested with the best performance technique: MultiDraw (v+i).

5.5 Tripification Techniques

As shown in figure 13, hStrips model sends more vertices to the GPU than MTS. When it moves to coarser LODs, degenerated triangles appear, it does not affect to visual mesh quality, but useless information is processed. hStrips model removes much of degenerated triangles, although some remain. This is an aspect to be improved in future work. Notwithstanding, hStrips is the best model in visualization cost.

6 CONCLUSIONS

We have presented a uniform resolution model that noticeably improves existing models, in terms of storage and visualization cost. This model features: optimized hardware primitives, coherence, vertex cache exploitation, graphics hardware integration and low spatial cost.

Comparisons to existing multiresolution model implementations show improvements of approximately 25% in storage space cost, 40% in level-of-detail extraction cost and visualization as much as 5 times better by applying hardware acceleration techniques.

ACKNOWLEDGEMENTS

This work was supported by the Spanish Ministry of Science and Technology (Project TIN2010-21089-C03-03) and Feder Funds, Bancaixa (Project P1.1B2010-08) and Generalitat Valenciana (Project PROMETEO/2010/028).

REFERENCES

Ribelles, J., López, A., Belmonte, O., Remolar, I., Chover, M., 2002. Multiresolution modeling of arbitrary polygonal surfaces: a characterization. In *Computers & Graphics,* ISBN/ISSN 0097-8493, vol. 26, num. 3, pp. 449-462.

El-Sana, J., Azanli, E., Varshney, A., 1999. Skip strips: maintaining triangle strips for view-dependent rendering. In *Proceedings of Visualization* 99. p.131-137.

Shafae, M., Pajarola, R., 2003. DStrips: Dynamic Triangle Strips for Real-Time Mesh Simplification and Rendering. In *Proceedings Pacific Graphics Conference*.

Stewart, A., 2001. Tunneling for Triangle Strips in Continuous Level-of-Detail Meshes. In *Graphics Interface,* p. 91-100.

Belmonte, O., Remolar, I., Ribelles, J., Chover, M., Fernández, M., 2003. Efficient Use Connectivity Information between Triangles in a Mesh for Real-Time Rendering. In *Future Generation Computer Systems, Special issue on Computer Graphics and Geometric Modeling*.

Ramos, F., Chover, M., Belmonte, O., Rebollo, C. ,2004. An approach to improve strip-based multiresolution schemes. *In proceedings of WSCG 2004*, Vol. 12, N. 2, p. 349-354.

Hoppe, H., Progressive Meshes. 1996. In *SIGGRAPH* 1996, p. 99-108.

Ribelles, J., López, A., Belmonte, O., Remolar, I., Chover, M., 2000. Multiresolution Modeling of Polygonal Surface Meshes Using Triangle Fans. In *Proceedings of 9th DGCI 2000*, 431-442.

Ramos, F., Chover, M., 2004. LodStrips: level of detail strips. *Lecture notes in Computer Science, Proceedings of Computational Science ICCS 2004* vol. 3039, pp. 107-114.

NVIDIA Corporation. NvTriStrip Library, 2003. *Available in http://developer.nvidia.com/object/nvtristrip_library.html*.

Garland, M., Heckbert, P., 1997. Surface simplification using quadric error metrics. In *Proceedings of SIGGRAPH '97* p. 209-216.

NVIDIA Corporation, 2002. ARB_vertex_buffer_object Specification. In http://oss.sgi.com/ projects/ ogl-sample/ registry/ ARB/ vertex_buffer_object.txt

Garland, M., 1999. Multiresolution Modeling: Survey & Future Opportunities. In *Proceedings EUROGRAPHICS'99,* p. 111-131.

Hoppe H., 1997. View-dependent refinement of progressive meshes. In *Proceedings of SIGGRAPH 1997. p. 189-198.*

Hoppe, H., 1999. Optimization of Mesh Locality for Transparent Vertex Caching, In *Proceedings of SIGGRAPH 1999,* p. 269-276.

Chow, M., 1997. Optimized Geometry Compression for Real-time Rendering. In *Proceedings of the IEEE Visualization 1997,* p. 347–354.

Bogomjakov, A., Gostman, C., 2001. Universal Rendering Sequences for Transparent Vertex Caching of Progressive Meshes. In *Proceedings of Graphics Interface 2001.*

Ribelles, J., Chover, M., Lopez, A., Huerta, J., 1999. A First Step to Evaluate and Compare Multiresolution Models, In *Short Papers and Demos of EUROGRAPHICS 1999,* p. 230-232.