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(54) METHOD FOR GENERATING DETAIL DIRECTED VISIBILITY ELEMENTS FOR A GRAPHICS MODEL

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(51) **Int. Cl.**^{7} **G09G 5/00**; G09G 5/30

(52) **U.S. Cl.** **345/645**; 345/629; 345/428; 345/427; 345/630; 345/621; 345/136

(58) **Field of Search** 345/629, 136, 345/645, 427, 621, 630, 627, 428

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,373,489	B1	*	4/2002	Lu et al.	345/428
6,396,492	B1	*	5/2002	Frisken et al.	345/420
6,407,748	B1	*	6/2002	Xavier	345/672
6,429,864	B1	*	8/2002	Schwarzer	345/419
6,466,227	B1	*	10/2002	Pfister et al.	345/619
6,504,535	B1	*	1/2003	Edmark	345/419
6,545,678	B1	*	4/2003	Ohazama	345/427
6,639,596	B1	*	10/2003	Shum et al.	345/427
6,639,597	B1	*	10/2003	Zwicker et al.	345/427
2002/0033835	A1	*	3/2002	Sowizral et al.	345/645
2002/0130864	A1	*	9/2002	Perry et al.	345/421

OTHER PUBLICATIONS

Hongbin Zha; Makimoto, Y.; Hasegawa, T; 3–D digital imaging and modeling, 1999. Proceedings. Second International Conference on, 1999, Page(s): 321–330.*

Bradley A. Payne and Arthur W. Toga; Distance Field Manipulation of Surface Models; Jan. 1992. pp. 65–71.*

Frisken et al., "Adaptively Sampled Distance Fields: A General Representation of Shape for Computer Graphics", Proceedings for SIGGRAPH 2000, pp. 249–254, 2000.

Michael Garland, "Multiresolution Modeling: Survey & Future Opportunities"; Eurographics '99, State of the Art Reports, pp. 111–131, 1999.

Hugues Hoppe, "View–Dependent Refinement of Progressive Meshes"; Proceedings of SIGGRAPH 1997, pp. 189–198, 1997.

Luebke et al., "View–Dependent Simplification of Arbitrary Polygonal Environments"; Proceedings of SIGGRAPH 1997, pp. 199–208, 1997.

* cited by examiner

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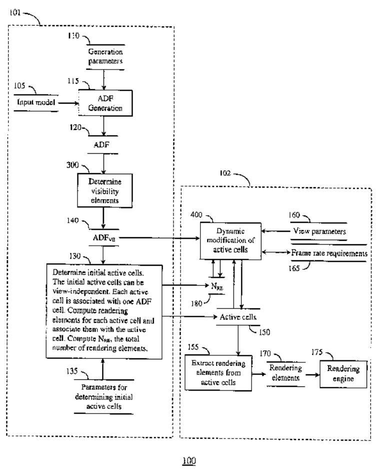
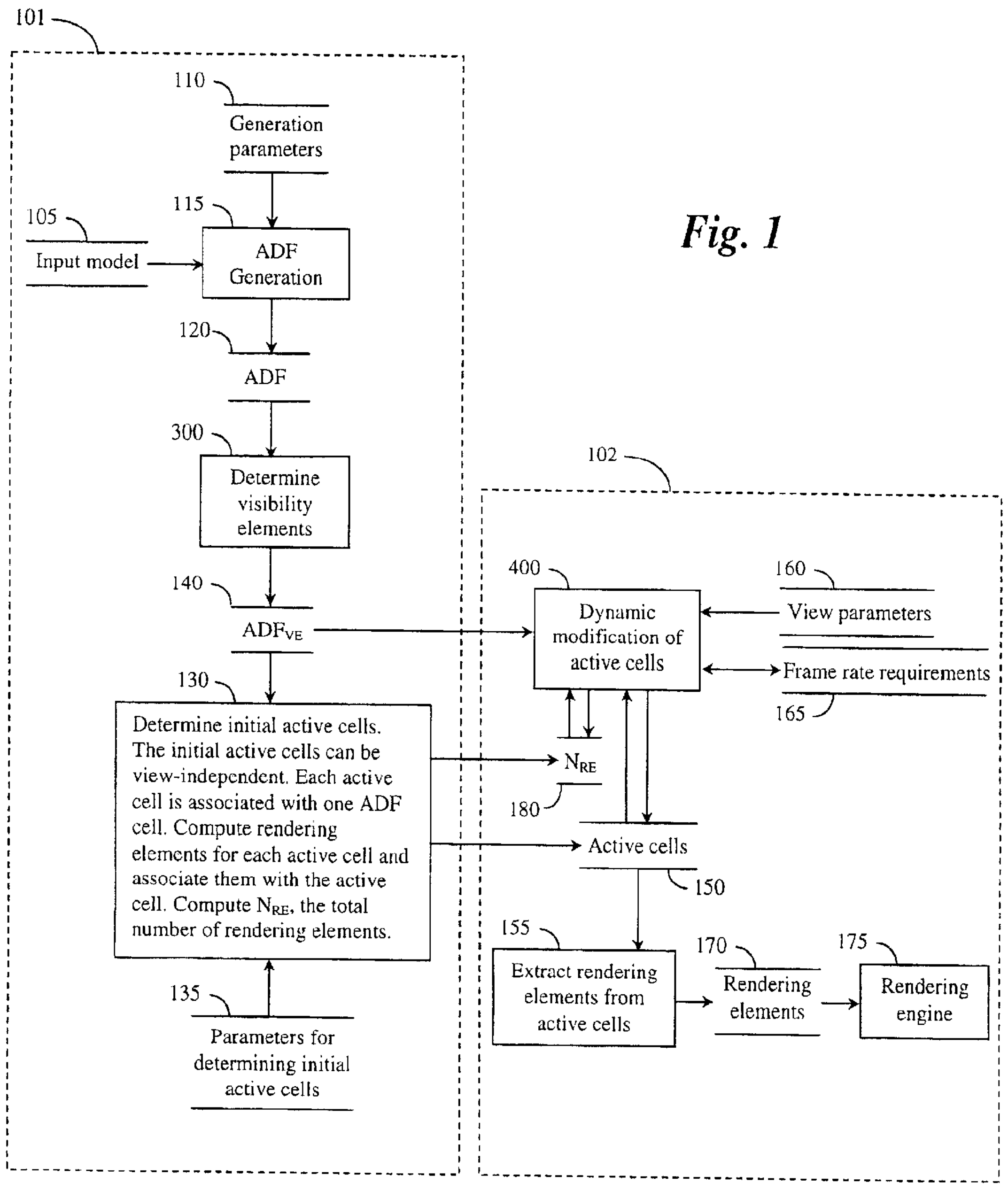
(57) ABSTRACT

A method generates a detail directed hierarchical representation of orientations of a surface of a graphics model. The surface of the graphics model is partitioned into surface cells, each surface cell enclosing a portion of the surface. The surface cells are stored in a hierarchical data structure having levels, wherein the number of levels for a particular portion of the surface is determined by surface detail of the particular portion. A visibility element of the enclosed portion of the surface is determined for each surface cell, the visibility element specifying an axis and a spread defining a range of normal values of the enclosed portion of the surface. The visibility element is stored with the associated surface cell. The surface detail of the particular portion can be determined by a degree of curvature and shading parameters of the surface of the particular portion.

28 Claims, 5 Drawing Sheets


101
110
Generation parameters
105
Input model
115
ADF Generation
120
ADF
300
Determine visibility elements
140
ADF_{VE}
130
Determine initial active cells. The initial active cells can be view-independent. Each active cell is associated with one ADF cell. Compute rendering elements for each active cell and associate them with the active cell. Compute N_{RE}, the total number of rendering elements.
135
Parameters for determining initial active cells
102
400
Dynamic modification of active cells
160
View parameters
Frame rate requirements
165
N_{RE}
180
Active cells
150
155
Extract rendering elements from active cells
170
Rendering elements
175
Rendering engine
100



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View parameters
Frame rate requirements
165
N_{RE}
180
Active cells
150
155
Extract rendering elements from active cells
170
Rendering elements
175
Rendering engine

Fig. 1

100

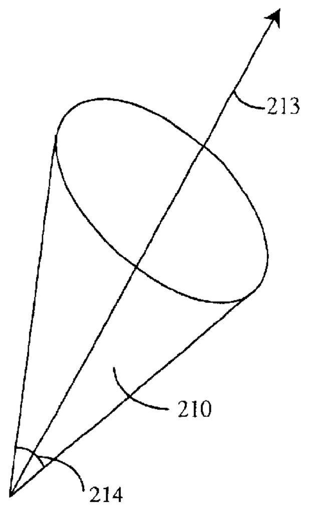


Fig. 2a

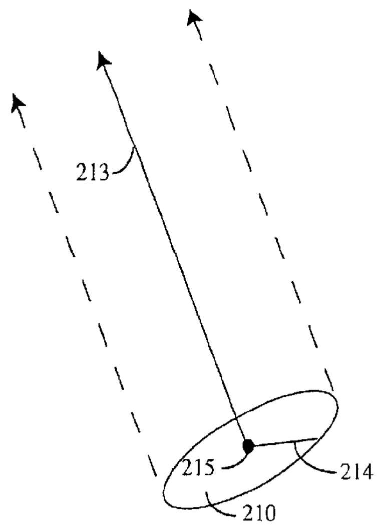


Fig. 2b

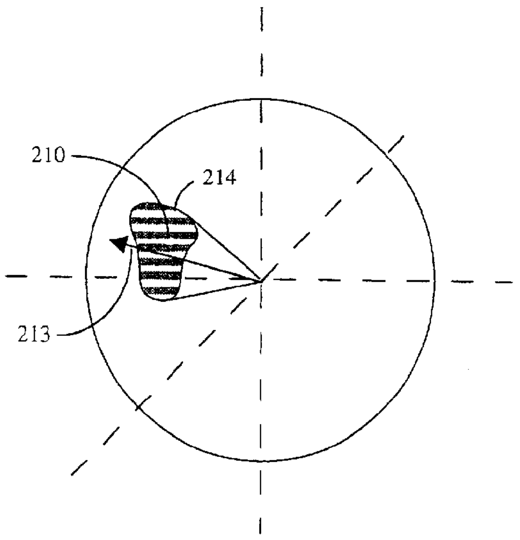


Fig. 2c

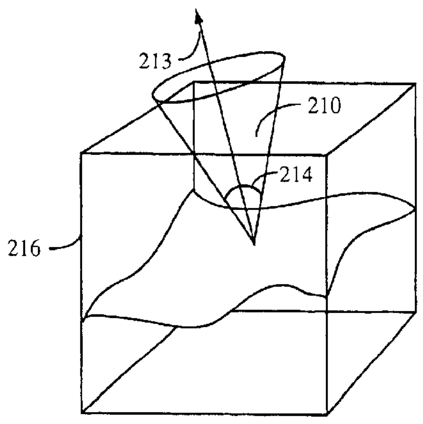
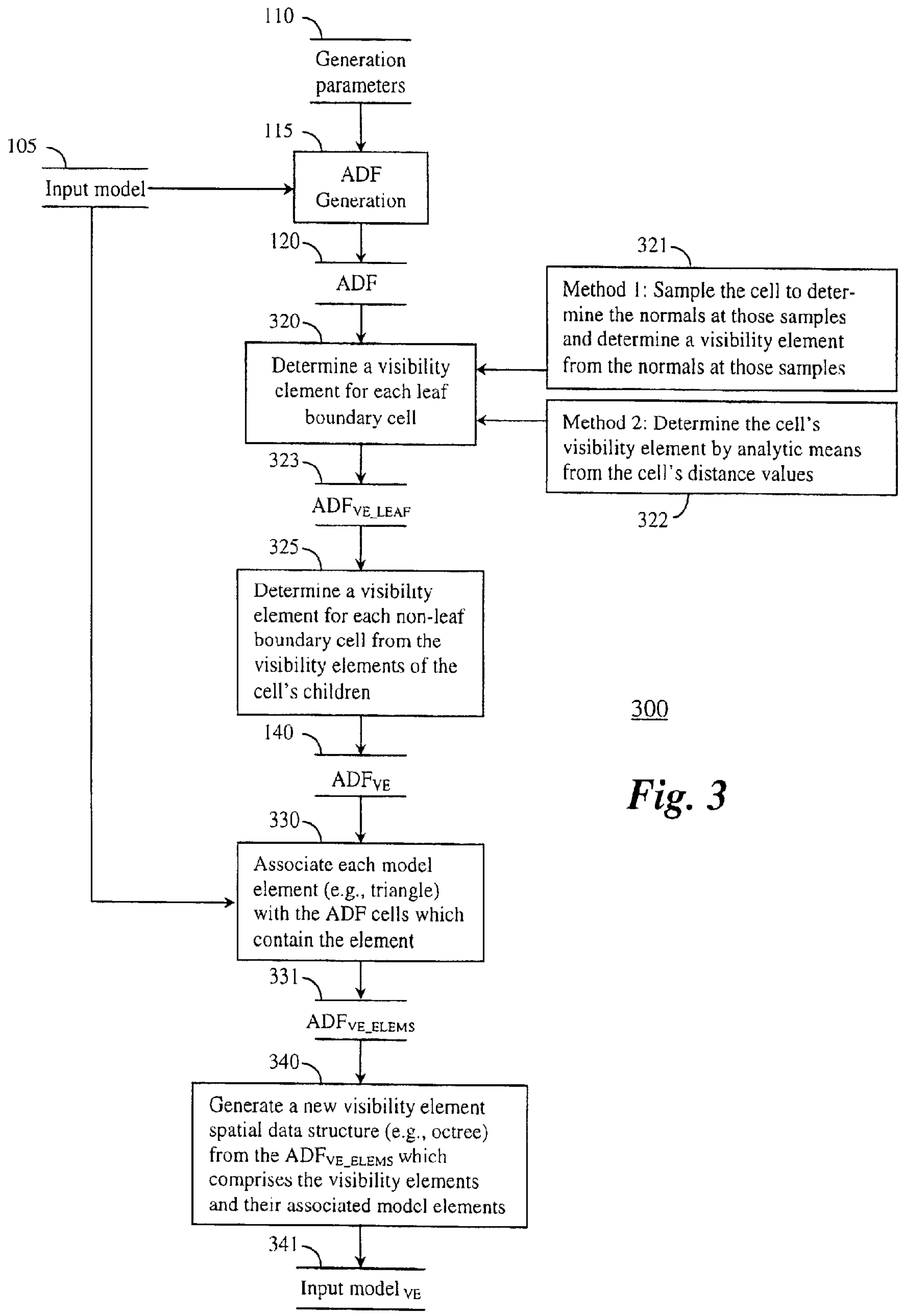


Fig. 2d


110
Generation parameters
115
ADF Generation
105
Input model
120
ADF
321
Method 1: Sample the cell to determine the normals at those samples and determine a visibility element from the normals at those samples
320
Determine a visibility element for each leaf boundary cell
Method 2: Determine the cell's visibility element by analytic means from the cell's distance values
322
323
ADF_{VE_LEAF}
325
Determine a visibility element for each non-leaf boundary cell from the visibility elements of the cell's children
140
ADF_{VE}
330
Associate each model element (e.g., triangle) with the ADF cells which contain the element
331
ADF_{VE_ELEMS}
340
Generate a new visibility element spatial data structure (e.g., octree) from the ADF_{VE_ELEMS} which comprises the visibility elements and their associated model elements
341
Input model$_{VE}$

300

Fig. 3

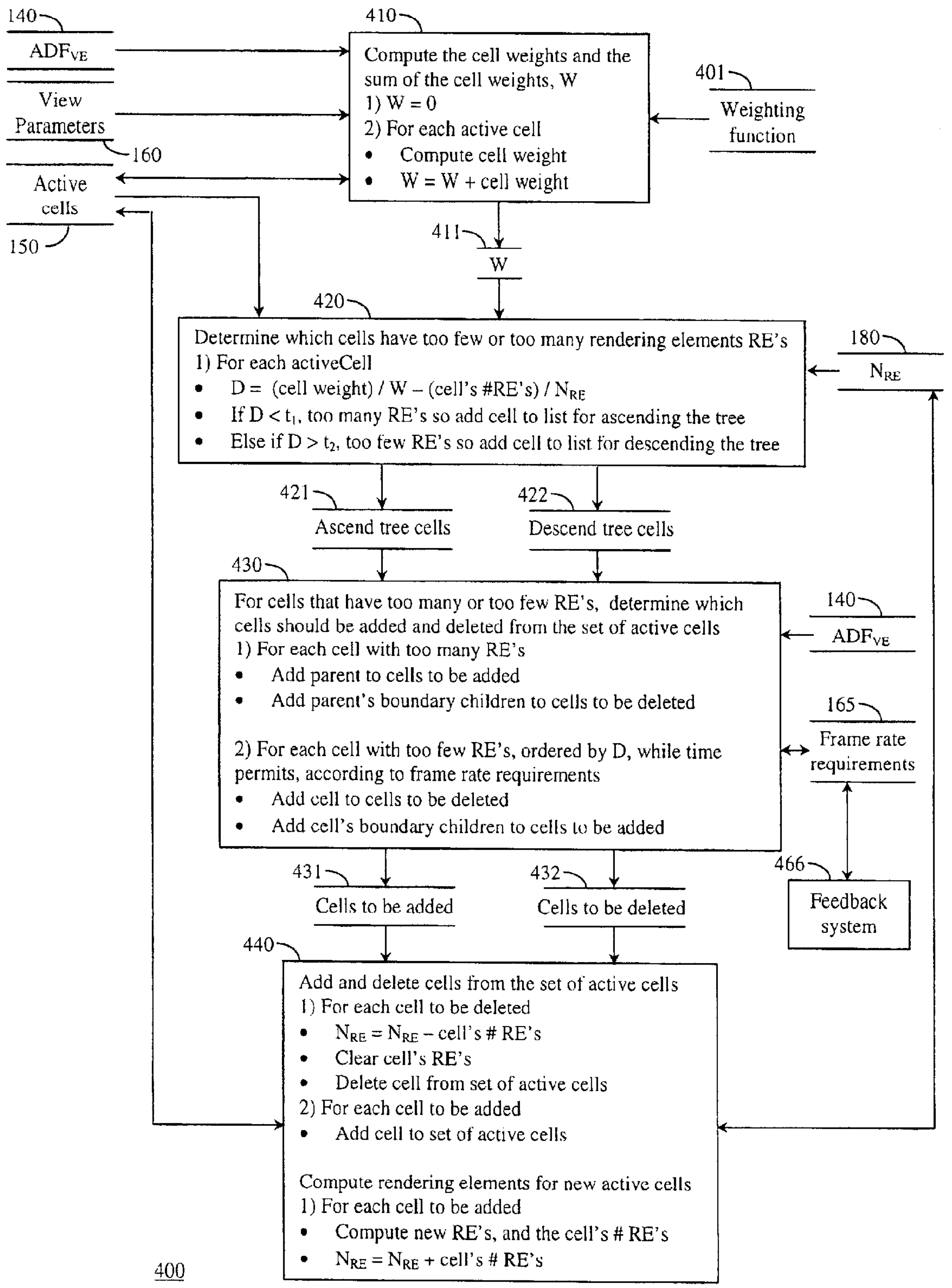

140
ADF_{VE}
View Parameters
160
Active cells
150
410
Compute the cell weights and the sum of the cell weights, W
1) W = 0
2) For each active cell
• Compute cell weight
• W = W + cell weight
401
Weighting function
411
W
420
Determine which cells have too few or too many rendering elements RE's
1) For each activeCell
• D = (cell weight) / W – (cell's #RE's) / N_{RE}
• If D < t_1, too many RE's so add cell to list for ascending the tree
• Else if D > t_2, too few RE's so add cell to list for descending the tree
180
N_{RE}
421
Ascend tree cells
422
Descend tree cells
430
For cells that have too many or too few RE's, determine which cells should be added and deleted from the set of active cells
1) For each cell with too many RE's
• Add parent to cells to be added
• Add parent's boundary children to cells to be deleted
2) For each cell with too few RE's, ordered by D, while time permits, according to frame rate requirements
• Add cell to cells to be deleted
• Add cell's boundary children to cells to be added
140
ADF_{VE}
165
Frame rate requirements
466
Feedback system
431
Cells to be added
432
Cells to be deleted
440
Add and delete cells from the set of active cells
1) For each cell to be deleted
• $N_{RE} = N_{RE}$ – cell's # RE's
• Clear cell's RE's
• Delete cell from set of active cells
2) For each cell to be added
• Add cell to set of active cells
Compute rendering elements for new active cells
1) For each cell to be added
• Compute new RE's, and the cell's # RE's
• $N_{RE} = N_{RE}$ + cell's # RE's
400

Fig. 4

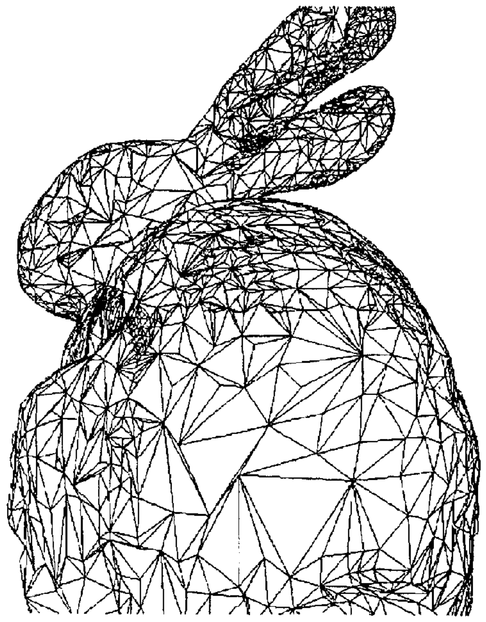


Fig. 5a

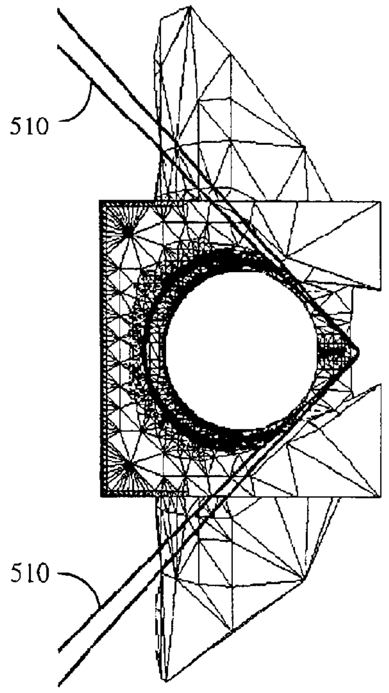


Fig. 5b

METHOD FOR GENERATING DETAIL DIRECTED VISIBILITY ELEMENTS FOR A GRAPHICS MODEL

FIELD OF THE INVENTION

The present invention relates generally to the field of computer graphics, and more particularly to determining the orientations of a surface of a model.

BACKGROUND OF THE INVENTION

In real-time graphics applications, such as games and physical simulations, numerous techniques are known to automatically generate models in the form of polygon meshes. Common generation techniques include laser range scanning and triangulation of implicit functions. Often, the resultant meshes include more polygons that can be rendered by standard rendering engines at real-time frame rates.

Therefore, in order to reduce the number of polygons in the models, multi-resolution triangle meshes are frequently used. These methods typically use two approaches for generating level-of-detail (LOD) meshes. In the static approach, a set of static LOD meshes are pre-computed before use in an application. At run-time, a member of the set is selected, based on viewing parameters and frame rate requirements, and displayed. In the dynamic approach, a single dynamic mesh is generated before use in the application, and then the mesh is adapted by a series of transformations according to the viewing parameters and the frame rate requirements, see Garland "*Multiresolution Modeling: Survey and Future Opportunities*," Eurographics '99 State of the Art Reports, pp. 111–131, 1999.

Known dynamic meshing methods, such as view dependent progressive meshes (VDPM), and hierarchical dynamic simplification (HDS), generate hierarchical data structures that can be refined and decimated to reduce the number of polygons in the meshes. The hierarchy in the VDPM is formed by generating a new parent vertex for every pair of vertices combined by an edge collapse operation, see Hoppe "*View-Dependent Refinement of Progressive Meshes*," Proceedings of SIGGRAPH 1997, pp. 189–198, 1997. The HDS hierarchy is formed by spatially subdividing a scene into cells, and grouping vertices in each cell into a single representative vertex, see Luebke et al. "*View-Dependent Simplification of Arbitrary Polygonal Environments*," Proceedings of SIGGRAPH 1997, pp. 199–208, 1997. In both methods, a screen space error and normal cones are used to determine when to refine and decimate the mesh.

However, these techniques can still produce more polygons than needed. Furthermore, their processing time is dependent on the number of polygons in the original model, which can be prohibitively slow for large models. Finally, these methods can produce poor quality models when the polygon count is small.

Therefore, there is a need to provide a method and system for automatically generating real-time dynamic meshes that match viewing parameters and desired frame rates.

The use of normal cones for determining visibility is known in the art, see Hoppe and Luebke et al. as described above. In both systems, normal cones are constructed from the initial geometry of the model and placed in a data structure such as an octree. There, the range, or spread, of normals in an octree cell is a function of where the geometry lies with respect to the octree grid. For example, a leaf cell of the octree can have a large spread of normals simply

because the geometry within that cell has a large degree of curvature. This type of normal cone construction can cause a rendering engine to draw many more polygons than necessary because polygons that should be classified as invisible, e.g., back facing, are instead classified as visible since the polygons are grouped in a leaf cell with a large spread of normals indicating, erroneously, that they are visible.

Therefore, there is a need to provide a method for automatically generating detail directed visibility elements, e.g., detailed directed normal cones, that will more accurately classify geometry such as polygons according to visibility, thus avoiding unnecessary processing such as the rendering of polygons as described above.

SUMMARY OF THE INVENTION

It is an object of the present invention to generate detail directed visibility elements to enable more accurate decisions about the visibility of rendering elements such polygons and points.

The present invention provides a method for generating a detail directed hierarchical representation of orientations of a surface of a graphics model. The surface of the graphics model is partitioned into surface cells, each surface cell enclosing a portion of the surface. The surface cells are stored in a hierarchical data structure having levels, wherein the number of levels for a particular portion of the surface is determined by surface detail of the particular portion. A visibility element of the enclosed portion of the surface is determined for each surface cell, the visibility element specifying an axis and a spread defining a range of normal values of the enclosed portion of the surface. The visibility element is stored with the associated surface cell. The surface detail of the particular portion can be determined by a degree of curvature and shading parameters of the surface of the particular portion.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a flow diagram of a method for generating view dependent dynamic rendering elements according to the invention;

FIGS. **2***a*, **2***b*, **2***c*, and **2***d* show examples of visibility elements;

FIG. **3** is a flow diagram of a process for generating visibility elements used by the method of FIG. **1**;

FIG. **4** is a flow diagram of a process for maintaining active cells of an adaptively sampled distance field representing a model;

FIG. **5***a* is a dynamic model with 16984 triangles at 47 frames per second; and

FIG. **5***b* is a dynamic model with 23364 triangles at 41 frames per second.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Introduction

FIG. **1** shows a computerized dynamic modeling system and method **100** according to our invention. The modeling system and method **100**, as a basis, uses an adaptively sampled distance field (ADF) **120** to represent a digitized model that can be animated, in real-time, for use by the entertainment industry and physical simulations.

The basic data structure of an ADF is described in U.S. patent application Ser. No. 09/370,091 "*Detail-Directed Distance Fields*" filed by Frisken et al. on Aug. 6, 1999, incorporated herein in its entirety by reference.

The ADF **120** can be generated from an input model **105** by a ADF generation method **115** according to generation parameters **110**. For example, the generation parameters can specify a level-of-detail, or acceptable error measures. The method **115** adaptively samples distance values in a signed distance field of the model **105**, and stores the distance values in a spatial hierarchy of cells, for example a sparse octree of cells. Distance values with a positive sign are exterior to the object, negative distance values are interior, and zero distance values represent the surface of the object.

Methods that can operate on ADFs are described in: U.S. patent application Ser. No. 09/810,983 "*System and Method for Generating Adaptively Sampled Distance Fields with Bounded Distance Trees*" filed by Perry et al. on Mar. 16, 2001, U.S. patent application Ser. No. 09/810,839 "*Conversion of Adaptively Sampled Distance Fields to Triangles*" filed by Frisken et al. on Mar. 16, 2001, U.S. patent application Ser. No. 09/811,010 "*System and Method for Modeling Graphics Objects*" filed by Perry et. al. on Mar. 16, 2001, and U.S. patent application Ser. No. 09/809,682 "*System and Method for Converting Range Data to 3D Models*," filed by Frisken et al. on Mar. 16, 2001.

Overview of System and Method

Our method and system **100** begins with the input model **105** constructed using any known modeling technique. For example, the model **105** can be in the form of range images, a point cloud, a triangle mesh, or an implicit function. Because the model **105** can be in many forms, our method is particularly suited for animation and physical modeling where many different model forms are often used in conjunction depending on production and time requirements, cost, and available technologies.

Our method comprises two stages: a pre-processing static stage **101**, and a real-time dynamic stage **102**. The static stage **101** generates **115** the ADF **120** from the model **105**, and determines **300** visibility elements (VE) **210**, see FIG. **2**, for the ADF **120** to produce a single static ADF$_{VE}$ **140**. The static stage also initializes **130** active cells **150** and a count of the total number of rendering elements N$_{RE}$ **180** required for the dynamic stage **102**.

The dynamic stage **102** adapts and optimizes the active cells **150** and the N$_{RE}$ **180**, which can be initially view-independent, for dynamically varying view parameters **160** and frame rate requirements **165**. The dynamic stage is performed every frame, or every few frames, as required. During each adaptation of the active cells **150** and the N$_{RE}$ **180**, the ADF$_{VE}$ **140** is considered to determine when active cells **150** need to be added or removed.

Processing Details

FIGS. **2***a–d* show example visibility elements, for example, a visibility cone, disk, and patch, and a cone positioned on a surface in 3D space. As described in further detail below, a detail directed visibility element (VE) **210** is determined **300** for each surface cell in the ADF **120**, producing an annotated ADF$_{VE}$ **140**.

The visibility element **210** minimally includes an axis **213** and a means **214**, such as an angle, for defining the range, or spread, of normals of the surface associated with the visibility element. The visibility element **210** may also include a reference point **215**, which anchors the visibility element in a coordinate system, and a data structure **216**, such as a sphere, cube, and ADF cell, for describing the bounding volume of the surface associated with the visibility element **210**.

The spread of normals **214** of the visibility element **210** essentially corresponds to the detail, e.g., the degree of curvature, of the portion of the surface associated with the visibility element **210**.

The visibility element **210** associated with each surface cell in the ADF **120** indicates whether the associated surface cell could be potentially visible in a rendered image. The surface cell is potentially visible if any direction within the spread of normals **214** about the axis **213** of the visibility element **210** intersects an infinite sized image plane, i.e., the viewing plane. When a surface cell is visible, it is said to be "front-facing," otherwise it is "back-facing." Whether or not the surface cell is actually visible for a selected viewing frustum depends on specific viewing parameters **160**.

A data structure **216** of the visibility element **210** can be used to determine whether the surface associated with the visibility element **210** is within the selected viewing frustum. If the data structure **216** indicates that the surface is outside of the selected viewing frustum, then the surface is invisible under the specific viewing parameters **160** of FIG. **1**.

Because the visibility elements **210** associated with every surface cell of the ADF$_{VE}$ **140**, they can be used to determine potential visibility of the surface cells for any viewing parameters **160**. Therefore, the ADF$_{VE}$ **140** is said to be view independent and static.

Using parameters **135**, the process **130** determines an initial set of active cells **150** that can be view independent. The parameters **135** can include the position and size of an initial view frustum. Each active cell of the set **150** corresponds to a selected one of the surface cells in the static ADF$_{VE}$ **140**. The process **130** also determines initial rendering elements for each active cell of the set **150**, and computes the initial total number of rendering elements N$_{RE}$ **180** for all the active cells of the set **150**. Frisken et al. in "*Conversion of Adaptively Sampled Distance Fields to Triangles*", see above, describe a method for converting the active cells of the set **150** to triangular rendering elements.

A process **400** dynamically modifies the set of active cells **150** depending on the dynamic viewing parameters **160**. The process **400** also minimizes the number of rendering elements N$_{RE}$ **180** that are produced in order to satisfy the frame rate requirements **165**. In addition, the process **400** optimizes the visual quality of the images produced by using a higher level of detail in visually important regions, for example, the silhouette of a graphics object, or portions of the graphics object that are closer to the viewer.

A process **155** extracts the rendering elements **170** from the active cells **150**. The rendering elements **170** can be in the form of points, non-uniform rational B-splines (NURBS), triangles, or other graphics primitives. A standard hardware or software rendering engine **175** can then further process the rendering elements to produce a sequence of image frames for various applications such as games, physical simulations, and movie production.

The dynamic process **400** increases the number of rendering elements N$_{RE}$ **180** when a particular active cell of the set **150** results in too few elements, and decreases the number of rendering elements N$_{RE}$ **180** when a particular active cell of the set **150** results in too many elements. Thus, the number of rendering elements N$_{RE}$ **180**, at any one time, is kept at an optimal minimum that ensures quality images and meets desired frame rates. See below for the specific method steps which add and delete the rendering elements **170** associated with the active cells **150**.

Detailed Directed Visibility Elements

FIG. **3** shows the process **300** for determining visibility elements **210** in greater detail. In step **320**, the distance values at a plurality of locations associated with, e.g., within and near, each leaf surface, i.e., boundary, cell of the ADF **120** are determined. That is, the root cell, intermediate cells, and interior and exterior cells are excluded from this process.

The distance values at the plurality of locations can be used **322** to analytically determine the visibility element axis **213** and spread **214** of the surface contained in the cell. The distance values at the plurality of locations can also be used **321** to derive the surface normals at a second plurality of locations. The surface normals at the second plurality of locations are then combined to determine the visibility element axis **213** and spread **214** of the surface contained in the cell. When step **320** finishes, every surface leaf cell of the ADF **120** is annotated with the visibility element **210**, producing ADF_{VE_LEAF} **323**.

In a bottom up fashion, step **325** determines visibility elements **210** for each non-leaf surface cell by combining the visibility elements **210** of the cell's children **323** until the root cell is reached and thus all surface cells have an associated visibility element **210**. The resulting visibility elements **210** reflect the adaptive detail directed nature of the ADF **120**. That is, the resulting visibility elements **210** are detail directed.

The ADF **120** is then annotated **325** with the determined visibility elements **210** to produce the ADF_{VE} **140**.

The process **300** can also be used for generating detail directed visibility elements **210** for any arbitrary input model **105**. First, an ADF **120** is generated **115** from the input model **105** using generation parameters **110**. Second, the ADF_{VE} **140** is produced as described above.

Step **330** then associates rendering elements, e.g., triangles, with the cells of the ADF_{VE} **140** that contain the rendering elements, producing ADF_{VE_ELEMS} **331**. Step **340** generates a visibility element spatial data structure input model_{VE} **341** that comprises the visibility elements **210** and their associated rendering elements. The input model_{VE} **341** can be used to perform visibility testing without requiring access to the ADF **120** and the ADF_{VE} **140**.

Dynamic Modification of Active Cells

FIG. **4** shows the process **400** for dynamically modifying active cells. Input to the process includes the viewing parameters **160**, the active cells **150**, the frame rate requirements **165**, the ADF_{VE} **140**, the N_{RE} **180**, and a weighting function **401**.

Step **410** assigns a cell weight, e.g., $0 \leqq \text{cell weight} \leqq 1$, to each active cell, and determines a total weight W **411**, initially zero. A cell is assigned a high weight, e.g., one, if the cell is on the object's silhouette, and zero weight if the cell is back-facing or outside the view frustum. Cells that are oblique to the view direction can be assigned intermediate weights, e.g., 0.5.

During weighting, other parameters, such as the projected screen size of the cell and specular highlighting, an exemplary shading parameter, can be considered. In addition, our method can use the cell's error measure as an indicator of surface roughness or curvature. The error measure can be factored into the weight.

Step **420** determines whether a cell has too few or too many rendering elements (RE's). This determination uses the following formulation:

$$D = (\text{cell weight})/W - (\text{cell's number of RE's})/N_{RE}.$$

If $D < t_1$, then the cell has too many rendering elements, where t_1 is a first threshold. In this case, the cell is added to a first list **421** for ascending the ADF_{VE} **140**. If $D > t_2$, then the cell has too few rendering elements, and the cell is added to a second list **422** for descending the ADF_{VE} **140**.

In step **430**, a determination is made to add or deleted cells depending on the lists **421–422**. For each cell that has too many rendering elements, its parent cell is added to a first queue **431** used to add active cells, and the parent cell's boundary children cells are added to a second queue **432** used to delete active cells.

For each cell with too few rendering elements, the cell's boundary children cells are added to the first queue **431**, and the cell is added to second queue **432**.

Queues for Adding and Deleting Active Cells

To ensure that the frame rate requirements **165** are met, add operations are stored in the add queue **431**, and delete operations are stored in the delete queue **432**. The delete operations are processed after every adaptation to keep the number of rendering elements at a minimum. The add operations in the add queue **431** can be ordered according to the ratio D defined above. Add operations can be processed when frame time is available using a feedback system **166**. It is also possible to geomorph, i.e., interpolate, between new rendering elements and existing rendering elements to avoid jerky motion and "popping" artifacts.

Step **440** adds and deletes active cells **150**, and updates the total number of rendering elements N_{RE} **180** accordingly. For each new active cell, its rendering elements are determined **440** and the number of new rendering elements is added to the total number of rendering elements N_{RE} **180**. By appropriately setting the thresholds t_1 and t_2, the number of rendering elements N_{RE} **180** to be processed by a particular rendering engine **175** can be adjusted to meet frame rate and quality requirements.

As shown in FIGS. **5***a* and **5***b*, the method and system according to our invention produces detail-directed rendering elements, such as triangle meshes, that have a high visual quality. Note the silhouette quality of the bunny model in FIG. **5***a*. In addition, the invention minimizes the number of rendering elements in non-visible portions of the model. Note how areas outside the view frustum **510** are culled in FIG. **5***b*. Real-time frame rates, e.g., 30 frames per second or higher, can be sustained even as changes in the point of view cause significant differences in the visible portion of the model.

This invention is described using specific terms and examples. It is to be understood that various other adaptations and modifications may be made within the spirit and scope of the invention. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

We claim:

1. A method for generating a detail directed hierarchical representation of orientations of a surface of a graphics model, comprising the steps of:

partitioning the surface of the graphics model into a plurality of surface cells, each surface cell enclosing a portion of the surface, wherein the surface cells include a root surface cell, intermediate surface cells, and leaf surface cells;

storing the surface cells in a hierarchical data structure having a plurality of levels, wherein the number of levels for a particular portion of the surface is determined by surface detail of the particular portion;

determining, for each surface cell, a visibility element of the enclosed portion of the surface, the visibility element specifying an axis and a spread defining a range of normal values of the enclosed portion of the surface, wherein the determining further comprises;

determining the axis and the spread of the visibility element for each leaf surface cell by sampling a plurality of locations associated with the cell; and

determining the visibility elements for the intermediate and root surface cells from the visibility elements of the leaf surface cells; and storing the visibility element with the associated surface cell.

2. The method of claim **1** wherein the surface detail of the particular portion is determined by a degree of curvature of the surface of the particular portion.

3. The method of claim **1** wherein the surface detail of the particular portion is determined by shading parameters of the surface of the particular portion.

4. The method of claim **1** wherein the axis and the spread defining a range of normal values of the enclosed portion of the surface is determined by the surface detail of the particular portion.

5. The method of claim **1** wherein the locations are within the cell.

6. The method of claim **1** wherein the locations are near the cell.

7. The method of claim **1** wherein the locations are on the enclosed portion of the surface of the cell.

8. The method of claim **1** wherein the graphics model is a polygon mesh, the polygon mesh representing the surface of the graphics model, each polygon having one normal value.

9. The method of claim **1** wherein the graphics model is determined by evaluating an implicit function.

10. The method of claim **1** wherein the graphics model is a distance field.

11. The method of claim **10** wherein the surface cells include a root surface cell, intermediate surface cells, and leaf surface cells, each surface cell storing distance values, and further comprising:

determining distance values of each leaf surface cell at a plurality of locations;

determining the axis and the spread of the visibility element for each leaf surface cell from the plurality of distance values by analytic means; and

determining the visibility elements for the intermediate and root surface cells from the visibility elements of the leaf surface cells.

12. The method of claim **10** wherein the surface cells include a root surface cell, intermediate surface cells, and leaf surface cells, each surface cell storing distance values, and further comprising:

determining distance values of each leaf surface cell at a first plurality of locations;

deriving surface normals at a second plurality of locations from the distance values at the first plurality of locations;

combining the surface normals of each leaf surface cell to determine the axis and the spread of the visibility element for each leaf surface cell; and

determining the visibility elements for the intermediate and root surface cells from the visibility elements of the leaf surface cells.

13. The method of claim **10** wherein the distance field is adaptively sampled.

14. The method of claim **13** wherein the adaptive sampling is based on the range of normal values of the surface of the particular portion.

15. The method of claim **1** wherein the cells are N-dimensional.

16. The method of claim **1** wherein the cells are cubes.

17. The method of claim **1** wherein the cells are polyhedrons.

18. The method of claim **1** wherein the cells are spheres.

19. The method of claim **1** wherein the cells are rectangular solids.

20. The method of claim **1** wherein the cells are rectangles.

21. The method of claim **1** wherein the hierarchical data structure is a octree.

22. The method of claim **1** further comprising:

sampling orientations of the portion of the surface to determine the range of normal values.

23. The method of claim **1** further comprising:

evaluating a function specifying orientations of the portion of the surface.

24. The method of claim **1** where the graphics model includes a plurality of rendering elements representing the surface, and further comprising:

associating a set of rendering elements with each cell, the set of rendering elements representing the portion of the surface enclosed by the cell.

25. The method of claim **24** further comprising:

dynamically modifying the set of rendering elements associated with each cell according to the visibility element of the cell and viewing parameters.

26. The method of claim **25** wherein the step of dynamically modifying adds rendering elements to the cell.

27. The method of claim **25** wherein the step of dynamically modifying deletes rendering elements from the cell.

28. A method for generating a detail directed hierarchical representation of orientations of a surface of a graphics model, comprising the steps of:

partitioning the surface of the graphics model into a plurality of surface cells, each surface cell enclosing a portion of the surface, wherein the surface cells include a root surface cell, intermediate surface cells, and leaf surface cells;

storing the surface cells in a hierarchical data structure having a plurality of levels, wherein the number of levels for a particular portion of the surface is determined by surface detail of the particular portion;

determining, for each surface cell, a visibility element of the enclosed portion of the surface, the visibility element specifying an axis and a spread defining a range of normal values of the enclosed portion of the surface, wherein the determining further comprises;

determining the axis and the spread of the visibility element for each leaf surface cell by analytic means;

determining the visibility elements for the intermediate and root surface cells from the visibility elements of the leaf surface cells; and

storing the visibility element with the associated surface cell.

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