Fast Tree Ambient Occlusion Approximation

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Abstract

We present a fast ambient occlusion approximation algorithm for real-time tree rendering. The main contribution of the proposed method concerns the preprocessing stage of ambient occlusion. The proposed method is a divide-and-conquer calculation framework with limited user intervention. The proposed approach splits the plant geometry into clusters. On each plant primitive, ambient occlusion approximation is then defined from statistical inner cluster properties and a fast outer cluster occlusion. The implementation achieves flexible ambient occlusion effects with linear complexity.

Keywords: tree visualization, natural phenomena rendering, global illumination, ambient occlusion, accessibility value approximation

1. Introduction

Realistic tree rendering is a challenging task in computer graphics. A tree model with tens of thousands or even millions of organs is common in an outdoor scene.

If global illumination algorithms can generate realistic images of trees [4], [7], local illumination is mainly used in practice, especially in real-time applications, due to the geometrical complexity of such objects. Realistic and real-time trees and vegetation rendering is thus a significant research topic.

Ambient occlusion method is an efficient and effective approximation for global illumination algorithms. It is an environment lighting method that models the self-shadowing effect among geometry primitives.

The ambient occlusion operates in two steps: a preprocessing step and the (real-time) rendering step.

In the preprocessing step, an accessibility value for each point is calculated, this value encodes how much the outer world the point can see without occluded by other geometry primitives. It is always a off line procedure, heavy to implement. In the real-time rendering step, the result of lighting calculation is modulated by accessibility value to generate a self-shadowing effect.

Ambient occlusion was introduced by Zhukov et al. [9] under the name obscuration, while Landis [3] did formalize the terms of ambient occlusion and detailed the usage of ambient occlusion in movie productions.

Requested time in the preprocessing step for complex geometry object is a key point. Pharr [5] and Dustin [2] took advantage of the modern GPU’s high performance [5] to perform efficiently the preprocessing step on geometry objects. But for a complex tree model, even these methods fail since their complexity is quadratic.

We propose here a linear approach, approximating ambient occlusion. This paper summarises a previously published study [8]. The main contribution lies in the preprocessing stage, with a new accessibility value estimation algorithm. The proposed method provides several advantages: it is easy to implement; suitable for tree model with a large number of organs; with few parameters to be adjusted to achieve flexible ambient lighting effect.

2. PCA analysis on plant organs

A tree model with million of triangles is common, and the triangles can be considered as randomly distributed. We use here PCA (Principle component analysis) [6], which is a classical method in stochastic analysis.

According to PCA analysis, for a group of organs, called a cluster in this paper, we can calculate a statistical ellipsoid:

\[(x - \mu)^T S^{-1} (x - \mu) = c^2 \]  

where \(x\) is the centroid of an organ, \(\mu\) is the sample mean vector, \(S\) is the sample variance-covariance matrix, and \(c\) is a constant.

Equation 1 defines an ellipsoid that envelopes most of the organs in a cluster. The center of the ellipsoid is \(\mu\), the three
Ellipsoid fitting axes are eigenvectors $e_i (i = 1, 2, 3)$ of $S$, and the lengths of these axes are proportional to the corresponding square root of eigenvalues. The origin at $\mu$ and the three axes in the direction of $e_i$ define a local coordinate frame for each ellipsoid.

The constant $c$ is defined by the Chebyshev inequality:

$$P|x - \mu| < c \geq 1 - \frac{\sigma^2}{c^2}$$ (2)

In a cluster, more organs are enclosed in the PCA ellipsoid as $c$ becomes larger. We define now a density function standing for the distribution of organs:

$$D = \sum_{j=1}^{n} B_j$$ (3)

where $B_j$ is bounding box of organ $j$, $|S|$ is the determinant of $S$, called general variance, $4 \cdot |S|$ is proportional to the volume expansion of organs in a cluster [6].

### 3. Ambient occlusion approximation

The method in this paper assumes the following two assumptions, widely respected for many trees and plants:

- organs in a tree always appear grouping style
- each group of organs can be approximated by simple geometry

Palm trees, due to their few wide palms may not satisfy these criteria. By considering leaflets building the palms, the method is still efficient, as shown in Figure 6.

An organ is occluded by organs in the same cluster as well as organs in other clusters. We differentiate these two kinds of ambient occlusion information, named intra-cluster ambient occlusion and inter-cluster ambient occlusion.

Thus the accessibility value of a vertex is a function of two variables: intra-cluster accessibility value and inter-cluster accessibility value

$$A(P) = f(A_{inner}, A_{inter})$$ (4)

Our ambient occlusion calculation framework contains three steps: plant organ clustering, intra-cluster ambient occlusion calculation, and inter-cluster ambient occlusion calculation.

We use a simplified version of the hierarchical ellipsoidal skeleton definition [1] to cluster organs. Not that, in many cases, a direction of a clustering plane and clustering value can be set interactively by the user, thus avoiding the k-means procedure time. Figure 1 shows the PCA ellipsoid generated from the clustering result of a common ash tree model (Figure 1).

#### 3.1. Intra-cluster accessibility value

Intra-cluster accessibility value calculation defines the accessibility within a single cluster. We make the assumption from observation that the smaller the distance from a vertex to the ellipsoid center is, the higher the probability to be occluded is. Statistical distance is thus used, leading to the following definition of the intra-cluster accessibility value:

$$A_{inner}(P) = f\left(\frac{(x - \mu)\cdot S^{-1}(x - \mu)}{c^2}\right)$$ (5)

Left side of Figure 2 shows the result of this intra-cluster accessibility value.

#### 3.2. Inter-cluster accessibility value

Inter-cluster accessibility value calculation defines the accessibility value towards the ellipsoids the current point doesn’t belong to. For a given point, the procedure of inter-cluster accessibility value calculation estimates this value by sending a set of uniformly distributed rays (in an hemisphere around the point normal), simply counting the intersection hits with the other ellipsoids. When performing a
ray-cluster intersection test, we use the ellipsoid to represent the cluster, as defined earlier. The ray-ellipsoid intersection is calculated in ellipsoid’s local frame, making implementation easy and efficient. In our implementation, the inter-cluster accessibility value is performed by the CPU. Details and algorithm can be found in our detailed paper [8].

Right side of Figure 2 shows the result of this inter-cluster accessibility value computation on our example. When the organs in a cluster accumulated with high density, this approximation is reasonable. If not, the density function (Function 3) can be used to modulate the result.

Figure 3. Apricot tree without AO

Figure 4. Apricot tree with AO

Figure 5. Common Ash tree with AO

Figure 6. Palm Tree with AO and HAO

4. Result and discussion

We implement our ambient occlusion framework on a PC with an INTEL® Pentium® 4 2.8GHz CPU, 512M memory. GPU is not used in preprocessing stages.

With our ambient occlusion method self shadowing effect appears as shown in the comparisons of Figure 3 to Figure 4. The dense clusters are shadowed properly due to intra-cluster ambient occlusion. And the organs close to ramifications in the structure are correctly shadowed due to the inter-cluster ambient occlusion.

The method is applicable on different tree structures as shown in Figure 4 and Figure 5. The apricot tree has sparsely distributed branching structure, whereas the ash tree contains heavy distributed organs. Luck of self-shadowing on the Ash trunk is due to the very low level of primitives. On this example remeshing is necessary, since the trunk is defined by only two cylinders. Other plant examples, including the Walnut tree used in next section, can be found in [8].

We also implemented the HAO (Hardware accelerated ambient occlusion) algorithm described in [2] for comparison. Results on four plants are shown in Figure 6. The HAO image shows more detail, while the proposed method creates realistic blurred shadowing effect due to approximation. We give computational figures in Table 1 and graph in Figure 7 for comparison with HAO. Our ambient occlusion method is more efficient than [2], even without GPU acceleration.

Figure 7 shows the preprocessing time needed for the HAO method and ours. The computational complexity of the HAO method is quadratic with respect to the number of
Table 1. Comparison with the GPU based approach (HAO) [2]. In the table, we specify the number of geometrical primitives, the number of clusters, give the time spend to define the clusters, the time for inner ambient occlusion, time spend for calculation of inter-cluster ambient occlusion, and the time requested by the Hardware accelerates ambient occlusion (HAO) [2].

<table>
<thead>
<tr>
<th>Tree type</th>
<th>Vertices</th>
<th>Triangles</th>
<th>Clusters</th>
<th>C Time (s)</th>
<th>Intra AO (s)</th>
<th>Inter AO (s)</th>
<th>HAO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thread Palm</td>
<td>132775</td>
<td>69847</td>
<td>3</td>
<td>172</td>
<td>0.0183</td>
<td>1.124</td>
<td>2.26 hours</td>
</tr>
<tr>
<td>Common Ash</td>
<td>305204</td>
<td>162808</td>
<td>3</td>
<td>117</td>
<td>0.04036</td>
<td>4.4291</td>
<td>7.95 hours</td>
</tr>
<tr>
<td>Walnut</td>
<td>703692</td>
<td>402686</td>
<td>8</td>
<td>249</td>
<td>0.0954</td>
<td>19.535</td>
<td>72.66 hours</td>
</tr>
<tr>
<td>Apricot</td>
<td>818174</td>
<td>700288</td>
<td>5</td>
<td>312</td>
<td>0.1125</td>
<td>16.7260</td>
<td>100.44 hours</td>
</tr>
</tbody>
</table>

Figure 7. Time comparison

geometric primitives, while our method has a nearly linear complexity.

5. Conclusion and future work

In this paper, we introduce a fast ambient occlusion approximation for real-time tree rendering. The proposed method involves clusters related to tree organ density and evaluates an accessibility value from both intra-cluster and inter-cluster values. The approach is linear and easy to implement compared to the existing methods. The approach may suffer of accurate details, but approximates effectively the self-shadowing effect on trees showing ramified structures and accumulated organs in the crown. Nevertheless, tests hold on palm trees are satisfactory.

In the future, this work can be extended in several ways.
- In our implementation, the tree organs clustering procedure is semi-automatic, thus an automatic clustering algorithm, taking into account the hierarchical branching structure of trees could be really efficient.
- The proposed method can be generalized to calculate the ambient occlusion solution for several plants. In such a case, only the inter-accessibility value should be recalculated, and the intra-accessibility value can be reused.
- The use of GPU capabilities may increase drastically the speed of the inter-cluster accessibility value.

6. Acknowledgement

This work is supported by China 863 National Program (2006AA01Z301), NSFC (No 60073007, 60473110), LIAMA GreenLab project, and French National Research Agency NATSIM project (ANR-05-MMSA-45). All the plant models are from AMAP-Genesis™.

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