Efficient Methods for Fast Shading

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***Abstract*—On devices without battery consuming and specialized hardware for rendering, it is important to improve the speed and quality so that these methods are suitable for real-time rendering. Furthermore such algorithms are needed on the coming multicore architectures. We show how the methods by Gouraud and Phong, the commonly most used methods for shading, can be improved and made faster for both software rendering as well as simple low energy consuming hardware implementations. Moreover, this paper summarizes the authors' achievements in increasing shading speed and performance and a Bidirectional Reflectance Distribution Function is simplified for faster computing and hardware implementation.**

***Index Terms*—shading, fast shading, BRDF approximation**

I. INTRODUCTION

The shading methods by Gouraud [11] and Phong [12] are the most widespread methods for scanline rendering today. This is caused by their relative easiness, satisfactory quality and hardware supply ability. The trend today is to use specialized hardware for rendering. However, on small hand held devices like cell phones, where battery consumption is crucial there is still a need for fast software shading algorithms, which also can be implemented in simple and energy efficient hardware. Moreover they could be used on multicore architectures, like the CELL-BE processor by IBM [15] and the coming multicore processor from intel [16], which are processors that both can be used for shading purposes.

This paper summarizes some efficient methods by the authors that can be used for shading and that allows a considerable increase in both speed and quality.

II. THE METHODS OF THE SHADING PRODUCTIVITY INCREASING

It has theoretically been proved [1] that during the shading process according to Gouraud, the growth of the color intensities ΔI_{Γ} and ΔI_{B} correspondingly, both along scanlines and over the edges are constant values and this eliminates the necessity for re-computing them for every rasterization line. Let us describe the interconnection between growth of color intensities along the edge and the scanlines. It has been that the growth of the intensities $\Delta I_H, \Delta I_V$ and ΔI_D in horizontal, vertical and diagonal directions correspondingly are constants and are equal where I_A, I_B, I_C are the color intensities at the triangle vertexes as shown in figure 1.

$$\Delta I_{\Gamma} = \frac{(I_A - I_C)\cdot \Delta Y_{BC} - (I_B - I_C)\cdot \Delta Y_{AC}}{\Delta X_{AC}\cdot \Delta Y_{BC} - \Delta X_{BC}\cdot \Delta Y_{AC}},$$

$$\Delta I_{B} = \frac{(I_B - I_C)\cdot \Delta Y_{BC} - (I_A - I_C)\cdot \Delta Y_{AC}}{\Delta X_{AC}\cdot \Delta Y_{BC} - \Delta X_{BC}\cdot \Delta Y_{AC}},$$

$$\Delta I_{Д} = \Delta I_{\Gamma} + \Delta I_{B} \quad (1)$$

This special property makes it possible to parallelize Gouraud rendering [2] by using the first order Serpinsky triangulation. This is done by dividing the initial triangle into four parts using the centers of each edge as shown in figure 2. While considering the fact that the color intensity change is constant an approach was theoretically founded. In this way we get three identical triangles and one that is mirrored.

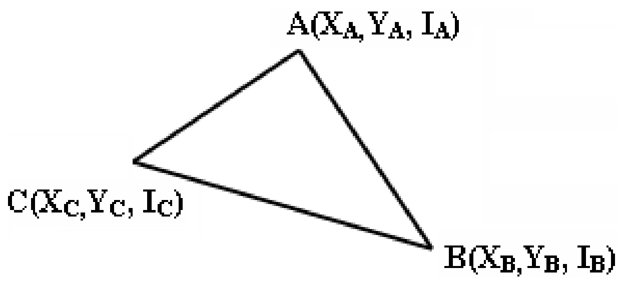

Figure 1. Color Intensities Scheme.

Considering the fact that the color intensity growth is a constant value over the entire triangle we can shade it by computing the shading of only one of the new triangles and then transform the rendering results etc to the others.

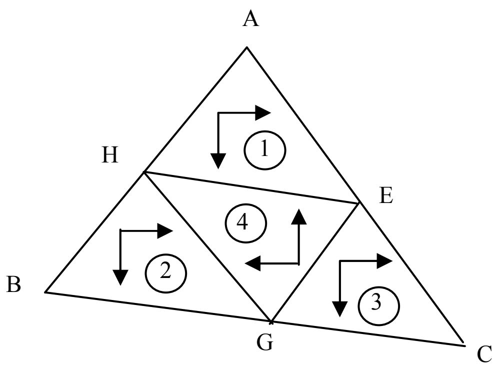

Figure 2. Shading directions of rectangular triangles.

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It is necessary to compute the shading rasterization of only the top triangle 1 and then the elementary step change is repeated for all the other interior triangles, considering that triangles 1, 2 and 3 have identical shading directions and triangle 4 is shaded in the oncoming direction (figure 2). Before rasterization all coordinates of the triangle vertices must be defined.

Analogously, the code for interpolation of color intensities of internal points belonging to the top left triangle can be duplicated for all the other triangles, however it is performed according to their vertexes.

Inasmuch as initial triangle triangulation is performed by the bisection of its edges and change of initial triangle sides are not always even numbers so the task of dividing the triangle without non-rasterized points appears. Different divisions' variants were examined and optimal ones were defined.

The second method for increasing Gouraud shading performance is based on the independent forming of even and odd points in the scan line. In the preparation cycle color intensities I_1, I_2 are to be found according to the first and next points in the scanline. The intensities $I_{PБ}$ of the first points in the scanlines are to be defined by means of interpolation of color intensities along the basic edges, and

I_2 - with help of expression: $I_2 = I_{PБ} + \Delta I_{Г}$.

$$I_4 = I_2 + 2\Delta I_P,\ I_6 = I_4 + 2\Delta I_P, ...,$$
$$I_{2w} = I_{2w-2} + 2\Delta I_P, ...;$$
$$I_3 = I_1 + 2\Delta I_P,\ I_5 = I_3 + 2\Delta I_P,\ I_7 = I_5 + 2\Delta I_P ,...,$$
$$I_{2w+1} = I_{2w-1} + 2\Delta I_P ,... . \quad (2)$$

Another possible approach for improving the Gouraud rendering lies in the detection of highlights on triangle borders and their further forming [3].

Let us assume that normal vectors $\vec{N}_0, \vec{N}_1, \vec{N}_2$ are given in the triangle edges $(x_0, y_0), (x_1, y_1), (x_2, y_2)$. In computer graphics it is often assumed that both the light source and observer are situated in the infinity [2], i.e vector $\vec{L}$ has identical direction for all the triangle points. It was proved [4, 8], that in this case the maximal values of color intensity are at the edge points that fits equations

$$t_1 = \frac{\cos\gamma\cos\varphi - \cos\beta}{(\cos\varphi - 1)(\cos\beta + \cos\gamma)},$$
$$t_2 = \frac{\cos\gamma\cos\phi - \cos\lambda}{(\cos\phi - 1)(\cos\lambda + \cos\gamma)},$$
$$t_3 = \frac{\cos\beta\cos\vartheta - \cos\lambda}{(\cos\vartheta - 1)(\cos\lambda + \cos\beta)} . \quad (3)$$

The conformity of angles between normal vectors is represented in the figure 3.

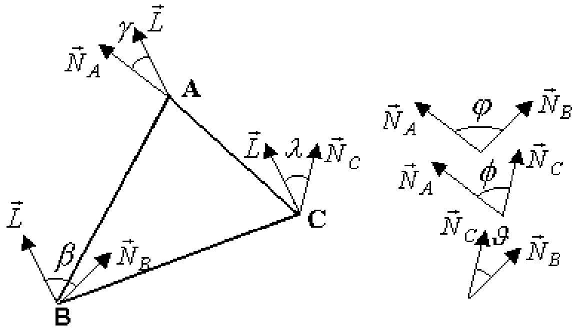

Figure 3. Normal vectors of triangle ABC.

Variables t_1, t_2, t_3 are parametric ones and varies in the interval from 0 to 1. An initial triangle can be divided into several depending on the result of the threshold values comparing with color intensities in the points t_1, t_2, t_3 .The triangles received are furthermore shaded with the Gouraud method. Such approach increases the Gouraud rendering quality due to finding out whether if highlights intersects one or several triangle edges. In the classic Gouraud shading method this detection is absent and highlights are being eliminated, yielding essential artifacts.

In computer graphics the Blinn illumination model [13] is widespread and the specular intensity is computed with following formula:

$$I_s = I\, k_s \cos^n \gamma , \quad (4)$$

where I - intensity of external light source; k_s - coefficient of specular reflection; γ - angle between normal vector $\vec{N}$ and surface normal vector $\vec{H}$, that is received by the adding of light direction vector $\vec{L}$ and observing vector $\vec{V}$; n - exponent is surface specularity.

The major computational part of specular color takes place for BRDF computing the $\cos^n \gamma$, $n = 1 - 1000$. A new BRDF was proposed that has considerably lower power in comparison with such BRDF like $\cos^n \gamma$. It's expressed with the formula $\cos^k(\sqrt{n/k} \cdot \gamma)$, where k – is a coefficient, that is detected depending on the surface specularity coefficient n ($k << n$).

The usage of various powers k for different values of n was proposed for guaranteeing the necessary approximation accuracy. For instance in approximation of $\cos^n \gamma$ by function $\cos^k(\sqrt{n/k} \cdot \gamma)$ with relative error 3% it's enough to take only to values of k: 1, 3.

An modification of well known Schlick BRDF [14, 9] was proposed. It lies in using different values of powers depending on the specular exponent. This is the following formula [5]

$$\cos^{\left\lfloor 2^{\log_2 n-2}\right\rfloor}\gamma/\left(n-n\cos\gamma+\cos\gamma\right) \quad (5)$$

A problem of BRDF approximation with functions of 2nd [6] and 3rd [7] degree and its hardware realization was examined.

With the purpose of increasing the shading performance it is possible to use a combination of methods both Gouraud and Phong [5]. Therefore, for example, it is possible to divide the scanline into segments with length divisible by a power of two [10]. The values of color intensities according to the Phong method are determined in end points of each segment, and intermediate pixels – according to the Gouraud method. The length of the segments can be adaptively changed and is determined by the curvature of a surface and the direction of the vector **H**.

During the computation both specular and diffuse color intensity for points on a 3D surface, it is required that normalization of normal vectors is performed. This is explained by the fact that cosines of angles that are used in the shading function can easily be found by the inner product of unit length vectors. Taking into consideration that normalization is performed for the observer's vector, light source's vector and the normal vector, the challenging problem of decreasing the computational effort for this resource-intensive procedure is urgent. Therefore a method for adaptive normal vector normalization is proposed [5]. The normalization is performed only in cases of considerable change in colour intensity.

In figure 4 is provided an example of determination of intermediate normal vectors between vectors $\vec{N}_a$ and $\vec{N}_b$, that are situated at the scanline endpoints. It is shown that

$$\frac{d_{(1/2^i)}}{d_{(1/2^{i+1})}} \approx 4 .$$

The following correlation is received for error detection $d_{(1/2^i)}$:

$$d_{(1/2^{i+1})} = 1 - \frac{\sqrt{2+z_{(1/2)^i}}}{2} .$$

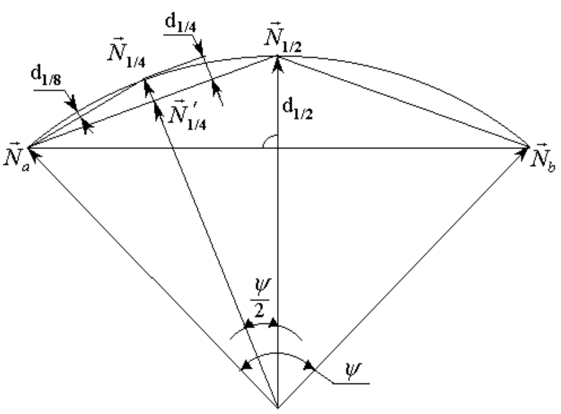

Figure 4. Determination of intermediate vectors of normal.

It is proposed that when the error $d_{(1/2^i)}$ value is lower than a certain threshold value, then it is possible to use linear interpolation between normal vectors.

The normal vectors are received by the bisection of the angle between given vectors. Hence, for example,

$$\vec{N}_{(1/2)} = \frac{\vec{N}_a + \vec{N}_b}{\sqrt{2(1+\cos\psi)}} = \frac{\vec{N}_a + \vec{N}_b}{z_{(1/2)}} ,$$

where

$$z_{(1/2)} = \sqrt{2(1+\cos\psi)} . \quad (6)$$

For the further division the following formulas are proposed

$$\vec{N}_{(1/2^{n+1})} = \frac{\vec{N}_a + \vec{N}_{(1/2^n)}}{\sqrt{2+z_{(1/2^n)}}} , \qquad z_{(1/2^{n+1})} = \sqrt{2+z_{(1/2^n)}} .$$

The problem of spherical angular interpolation [17] for Phong rendering is examined. Recursive correlations are found, according to which the normal vector for the current pixel could be computed with help of normal vectors for two previous pixels, i.e.

$$\vec{N}(t+1) = 2\vec{N}(t)\cos\varphi - \vec{N}(t-1) ,$$

where φ is the angle between the start and final vectors on the scanline. Analogous expression takes place for the determination of the diffuse color

$$I(t+1)_d = 2I(t)_d \cos\varphi - I(t-1)_d \quad (7)$$

When using this recursive relation it is possible to compute diffuse color and thus the inner product using two multiplication operations: two subtraction operations and two swap operations that allows an increase in performance up to 40%.

III. ALTERNATIVE BRDF MODEL

Let us examine BRDF approximation with $W(\gamma,n) = \left(\frac{A}{B}(\cos\gamma - 1) + 1\right)^2$ in conditions that $0 \le \gamma \le \pi/2$.

This function is chosen, because of the following:

a) cosine – is a basic function for both functions;

b) at $\gamma = 0$ $\cos^n\gamma = \left(\frac{A}{B}(\cos\gamma - 1) + 1\right)^2 = 1$, that fits boundary conditions;

c) both functions in the interval $0 \le \gamma \le \pi/2$ are positive;

d) the $\left(\frac{A}{B}(\cos\gamma - 1) + 1\right)^2$ function reaches zero value – this ensures smooth fading;

e) the A and B coefficients give a possibility to change highlight.

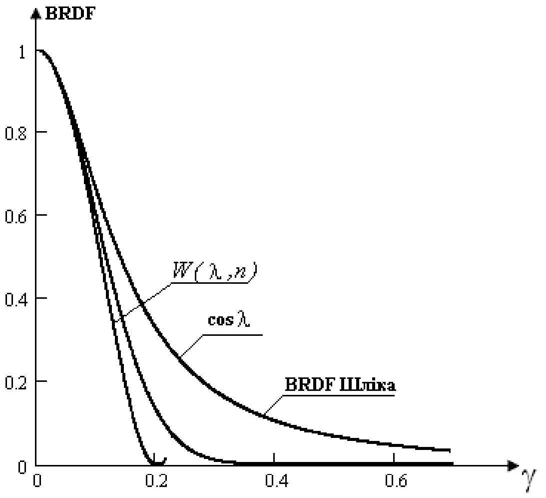

Figure 5. BRDF Models.

In figure 5 the following functions are represented in the graph: Schlick function, $\cos^n\gamma$, $\left(\frac{n}{2}(\cos\gamma - 1) + 1\right)^2$.

The graph shows an extremely accurate approximation of the center part of the highlight – and smooth fading after.

IV. CONCLUSIONS

The new approach for accelerated diffuse color computation according to the Phong method is proposed for shading 3D objects. The peculiarity of this approach lies in the synchronous hardware determination of two points at the scanline. For this approach the new approximation formula is used for normalization of normal vectors.

The adaptive method for shading is efficient, in which two different illumination models are used depending on availability of highlight within the triangle. The increase of performance is possible when determining whether there are highlights within the triangle and then using the illumination model that considers specular color, and in all the other cases using the simple model, which is considerably faster. The method for detecting an actual intersection of the edge by the highlight or its detection within a triangle is proposed.

Considering, that highlight on the surface of graphic objects occupies a tiny area the adaptive approach allows an essential increase of performance for shading.

Not only problems dealt with adaptive usage of illumination models are highlighted but also the methods for shading. At the same time surface curvature is considered and level of specular and diffuse light.

The methods being proposed allows a considerable increase in shading performance, and can be used for designing software and hardware for computer graphics.

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