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Rugged Texture Generation by Stochastic Models

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Most objects in nature have irregularities or rugged surfaces. However, Most studies in computer graphics have been directed to smoothly shaded images. Blinn's wrinkled surfaces method is known as the rendering technique for rugged surfaces. However, his texture pattern generation is restricted to the regular texture or the hand drawn texture. In this paper, we propose rugged texture generation algorithms using stochastic fractals. This method can make realistic rugged surfaces for broken rock, unglazed china and metallic casting, and artistic surfaces. Several samples of images made with this technique are included.

INTRODUCTION

Most objects in nature have irregularities or rugged surface. When we desire to use computer graphics for designing the interior or exterior of the house, we required the realistic image. The more real display images become , the wider range of application graphics techniques acquire and the more accurate judgement for selecting the parts becomes. For example, if trees, grass, stones or clay could be displayed realistic, the gardening computer aided design (CAD) would make a great progress and it could be easy to select a material that customer want.

In computer graphics, fractal models (Mandelbrot:1982) have been used as modeling techniques for complex surfaces. Mountains, planets and trees have been realistically portrayed by the use of fractal functions(Forinier et al:1982, Aono & Kunii:1984). The advantages of this model are (1) generating complex images from very small database, and (2) describing stochastically the surface irregularities of natural objects or phenomenon. The former is very interesting on image generation. That is, the approach have no need of measuring the surface in 3-D, and don't require a large amount of storage.

We applied stochastic fractal model to the rugged texture generation. The resulting new algorithms generate the surfaces of broken rock,unglazed china and metallic casting. The differences between them are the fractal functions and the intensity of pixels.

In addition we tried to generate the artistic surface objects whose surface subregions are made by stochastic model. Each subregion are surrounded by perpendicular bisector between two neighbor region center point and have each texture function.

INTENSITY OF SURFACE

In this chapter, we illustrate the mesh data structure and intensity of the pixel on the surface.

THe mesh data structure means three dimensional(3D) object representation that the heights in lattice points are difined on two dimensional array, as shown in Fig.1(a). Surface of a object is represented by the patches which are constructed by the each lattice points. This structure is very simple for computer graphics. In the opaque object, the reflected light is composed of diffuse reflection, specular reflection and ambient light reflection.

Diffuse reflection is observed on a dull, mat surface, scattering light equally in all directions, so that it's independent on viewing angles. Lambert's cosine law relates the amount of reflected light to the cosine of the angle between the point light source direction L and the surface normal N , shown in Fig.1(b).

The specular reflection is observed on shiny surfaces, causing the highlight. It reflects light unequally in different directions.Intensity of the specular reflection reaches the maximum when the surface normal agrees with the H direction (Whitted :1980). H is a bisector vector between the light source L and the viewer V.

Ambient light is a light of uniform brightness caused by the reflection from the many surfaces present in environments. It is reflection equally in all direction.

Therefore, the intensity of a sample point on the image plane R is

$$R = Id + Is + Ia \tag{1}$$

$$Id = \begin{cases} N \cdot L = \cos\theta & \text{for } N \cdot L \geq 0 \\ 0 & \text{for } N \cdot L < 0 \end{cases} \tag{2}$$

$$Is = \begin{cases} (H \cdot N)^n = \cos^n\beta & \text{for } H \cdot N \geq 0 \\ 0 & \text{for } H \cdot N < 0 \end{cases} \tag{3}$$

$$Ia = Ca \quad \text{(Constant)} \tag{4}$$

where;

Id : the intensity of the diffuse reflection
Is : the intensity of the specular reflection
Ia : the intensity of ambient light
N : Unit surface normal vector
L : Unit light source vector
H : bisector vector between L and viewer V
Unit mirror-direction vector based on reflected ray

SIMULATION OF MATERIAL SURFACE

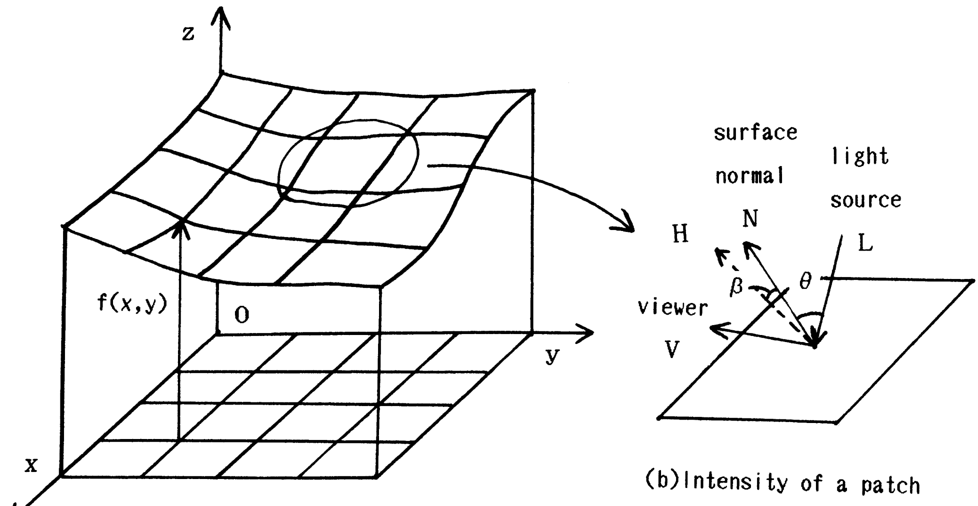

Fig.1 Mesh data structure and intensity of a patch

TEXTURE

The surfaces of computer generated shaded images tend to look artificial due to their extreme smoothness. It is needed to simulate the surface irregularities that are on real surfaces. The surface irregularities are observed on natural shapes such as terrains and planets, and material surfaces such as rock that was divided by hammer, unglazed china, and casting. Almost all physical surfaces can be decomposed into their macroscopic elements (such as sphere, cube, cylinder and so on) and have a microscopics structure called "texture"(Fig.2).

Texture provides a great deal of information about the material surface. Texture generation is very important study for computer graphics and image understanding.

Texture have a shine, color and roughness. Strictly speaking, each component of a surface varies with the location. However, this model is very complex, so that.a shine and color are assumed to be uniform in this chapter. Our discussion will concentrate upon a problem of roughness.

Roughness are caused by the microscopic structure of surface form. The following two methods were considered for the representation of texture.

The first one is a method making sampling pitch fine. The finer sampling pitch, the more accurate the form on object surfaces. However, as sampling pitch become fine, the memory space increase fast and it becomes difficult to measure the real heights of the surface. This method can be applied only to limited problems.

The second one is a method describing the microscopic feature of the surface using some parameter and reconstructing the surface form when the image are displayed. The method can't reconstruct the real original surface, but reconstruct the image approximately. In texture surface, the representation of qualitative feature is important, and it isn't important whether the generated image coincides with original surface or not. This is a good method for "Computer Graphics", because of saving memory space. The following section describes the second method in detail.

TEXTURE GENERATION BY FRACTAL MODELS

We apply fractal models for the representation of material surfaces. The color and roughness depends on the quality of the material. This section addresses the roughness on a plane. For a curved surface, Blinn's(1978) wrinkled function mapping method can be used.

His methods treat the digitized image, so that we discuss the texture generation by fractal models on the lattice point in the following.

When the rugged texture function are given in two dimensional array f(u,v)(Fig.3), the normal vectors are composed of the function and the original object surface.The procedure below uses fractal model to generate the rugged texture.

[Procedure 1]

(1) Heights for four corner points on a patch are given arbitrarily.

(2) A standard height of midpoint between two corner points is calculated by liner interpolation.

(3) The height of the midpoint is added to the fractal displacement. That is, a height of midpoint f_M is defined by the Eq.5(Fig.4).

$$f_M = \frac{f_R + f_L}{2} + g \times S^{(n)} \qquad (5)$$

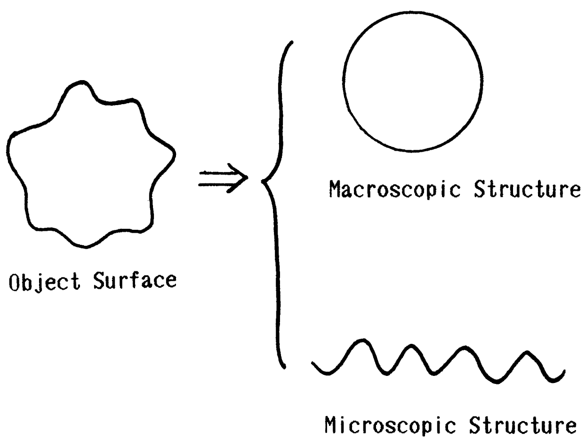

Fig.2 Object surface

$$S^{(n)}=S^{(n-1)} \times \left(\frac{1}{2}\right)^{h} \quad , \quad S^{(0)}=1.0 \qquad (6)$$

where f_M: height of midpoint
f_L: height of left end-point
f_R: height of right end-point
g: uniformly random numbers $(-0.5 \leq g \leq 0.5)$
n: recursive level
h: self-similarity parameter

(4) The height of the center point on a square is calculated by adding four corner point mean heights to the fractal displacement($g \times S^{(n)}$).

(5) The above process is repeated until the edge of a square becomes one pixel length.

For example, the heights of the points 1,2,3,4 shown in Fig.3 are calculated at first stage, so that the height of point 5 is calculated. At next stage, the heights of points 6,7,8,9,10 are calculated, and the same procedure process in other square, so that the heights of all the point shown in Fig.3 are calculated.

Texture function is stored in two dimensional array. Realistic image is made by mapping the function on the three dimensional object, such as sphere, cube and cylinder, which the user wants to display. Intensity of a pixel is calculated by Eq.1. Normal vector is composed of object normal vector and texture normal vector.

Displaying mountains in computer graphics uses Gaussian random numbers(Fournier:1982), and thus the resulting surface is smooth. But the surface of broken rock is rougher than the mountain, so that we use uniformly random numbers whose probability density is uniform within the domain of definition (from -0.5 to 0.5).

[EXAMPLES 1]

The pictures shown in Plate 1 are computer generated objects like a broken rock by hammer. The image was generated with

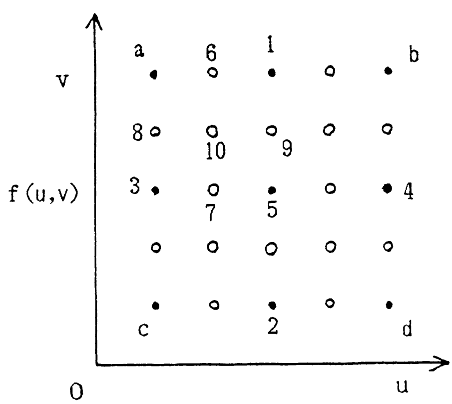

Fig.3 Procedure of texture function

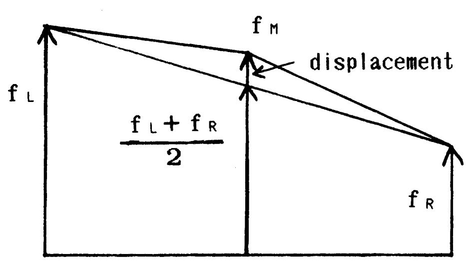

Fig.4 A height of midpoint

ambient and diffuse and specular reflection, because the actual surface of rock is composed of powderlike and crystal particles . Rugged texture was generated by stochastic fractal model given by [Procedure 1]. Self-similarity parameter h in Plate 1(a) is smaller than that in Plate 1(b).The image generation times are about five minutes per frame using 16 bit minicomputer.The radius of the sphere is 100 pixel with 15 bit per pixel.

[EXAMPLES 2]

The images of Plate 2 show objects like a unglazed china. The image was generated with ambient and diffuse reflection and without any specular reflections, because the actual surface of unglazed china is covered with clayish particles. THe self-similarity parameters h's in Plate 2(a) and (b) are different. Haruyama(1984) proposed a similar texture generation algorithms using perturbing normal vectors by two-dimensional Gaussian random variable. His method can generate the surface of moon or orange. Their impression is different from our method.

THE SURFACE OF CASTING

The surface of casting is generated with the similar algorithms to [Procedure 1] except for calculating a height of midpoint. A height of midpoint f_M is defined by the Eq.7(Fig.5).

$$f_M = \frac{f_R + f_L}{2} + |f_R - f_L| \times g \times S^{(n)} \qquad (7)$$

In Eq.7, the range of g is from -0.5 to 0.5, so that f_M is between f_L and f_R, even if $S^{(n)}$ is unit (Fig.5). Once f_M is determined, the allowable ranges of next f_M (f_{MR}, f_{ML}) have variety. For example in Fig.5, the allowable range of f_{ML} is narrow, but the allowable range of f_{MR} is wide. So that, flat square are wider than the surface using Eq.5.

[EXAMPLES 3]

The images shown in Plate 3 show objects like aluminum casting. The image was generated with ambient and specular reflection and without diffuse reflection, because the actual surface of aluminum casting is shiny. The random curve like a coast line is visible on a surface.

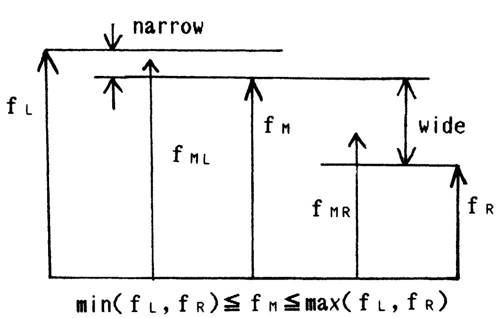

Fig.5 Restriction on midpoint

REGION DIVISION BY STOCHASTIC MODELS

Many actual object surface is an aggregation of small tile, such as turtle shell, a soccer ball and human skin. Surface like this is more interesting than uniformed surface. In this chapter, we present the texture generation technique on filling the surface with small tiles, and computer generated images made with this technique are illustrated.

[Procedure 2]

(1) We generate the subregion center points which have the same probability on the plane. That is, x-cordinate of a point is determined by uniformly random numbers, and y-cordinate of the point also is determined by uniformly random numbers, independently of x-cordinate. The arrangement of points are called Poisson's arrangement.

(2) Generate a half sphere which is centered at each center point.

(3) Convexed surface is composed of the highest value in the spheres at a position(Fig.6). Boundaries of a subregion are the perpendicular bisectors between the neighboring center points, and the boundaries become "Voronoi diagram". On the other hand, convexed surface is composed of the lowest value in the spheres. The boundaries also become Voronoi diagram.

Boundary is located at the same distance from two neighboring center points. The Voronoi diagram finds wide application in various fields such as theoretical biology (model of cells, animal's range).

[EXAMPLES 4]

Computer generated spheres mapping on a texture which were made by [Procedure 2] are shown in Plate 4. Plate 4 shows some sample results that can be achieved with this technique. The rugged textures are mapped onto the sphere. They are used only in intensity calculation, and don't alter the smooth silhouette edges of the objects.

Plate 5 shows some sample results that are mapped by the two

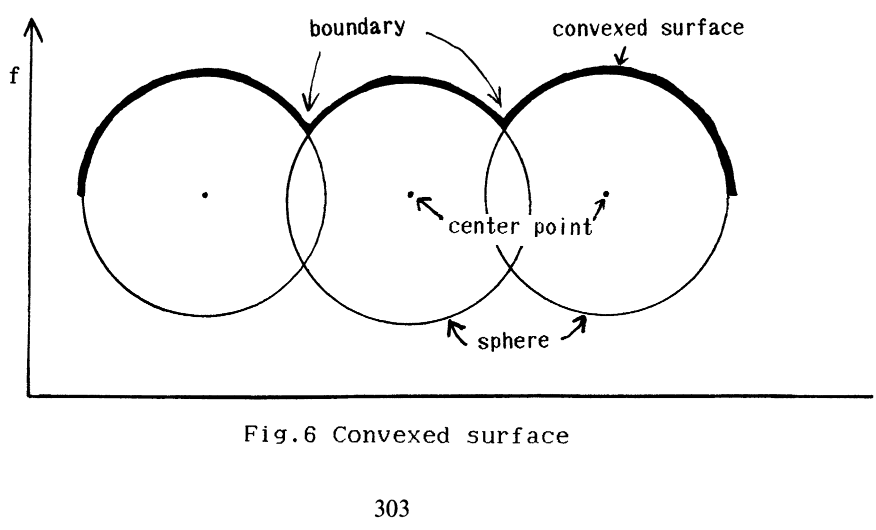

Fig.6 Convexed surface

dimensional polar cordinate sinusoidal wave function, and results by modefied sinusoidal wave function are shown in Plate 6. The sphere in Plate 7 shows result that color subregion are determined independently of roughness region. These images are interesting artistically.

SUMMARY

We present procedures which generate rugged surface textures by stochastic model, to simulate the real material surface in computer graphics. We illustrate approximate rugged surfaces such as broken rock, unglazed china and metallic casting, and present the region dividing procedure that generates artistically interesting images, where the boundaries of the subregions forms Voronoi diagram.

These procedures can generate various rugged surfaces of the materials by altering the parameters. They are suitable for the computer aided design (CAD).

REFERENCE

Aono, M.,Kunii, T.L.(1984): Botanical Tree Image Generation, IEEE CG&A, Vol.4, No.5, pp.10-34.

Blinn, J.F. (1977): Models of light reflection for computer synthesized pictures. Computer Graphics, Vol.11, No.3, pp192-198.

Blinn, J. F. (1978): Simulation of wrinkled surfaces. Computer Graphics, Vol.12, No.3, pp286-292.

Cook, R.L., Torrance, K.E. (1981): A reflectance model for computer graphics, Computer Graphics Vol.15, No.3, pp.307-316.

Fournier,A.,Fussel,D.,Carpenter,L.,(1982): Computer rendering of stochastic models, Comm.ACM, Vol.25, No.6,pp.371-384.

Haruyama. S.,Barsky, B.A.(1984): Using stochastic modeling for texture generation, IEEE CG&A, Vol.4, No.3.

Mandelbrot, B.B.(1982): The Fractal Geometry of Nature, W.H.Freeman and Company.

Phong,B.T.(1975): Illumination for Computer Generated Picture, Comm.ACM. Vol.18, No.6, pp311-317.

Whitted.T.(1980): An Improved Illumination Model for Shaded Display, Comm.ACM, Vol.23, No.6, pp.343-349.

Plate 1 Broken rock
Plate 2 Unglazed china
Plate 3 Aluminumlike casting
PLate 4 Convexed and concaved surface
Plate 5 Sinusoidal surface
PLate 6 Modefied sinusoidal surface
Plate 7 Colored subregion

(These plates are printed on Plates IV and V at the opening of this volume)