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Shapes and Textures for Rendering Coral

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Abstract

A growth algorithm has been developed to build coral shapes out of a tree of spheres. A volume density defined by the spheres is contoured to give a "soft object". The resulting contour surfaces are rendered by ray tracing, using a generalized volume texture to produce shading and "bump mapped" normal perturbations.

1 Introduction

We constructed the coral as a soft object (Wyvill et. al., [1]) inside the Katachi system (Kunii & Wyvill [2]) and ray traced it (Wyvill & Trotman [3]). We built the coral by a parametrized growth algorithm, similar to those which have been used to build trees (Bloomenthal [4], Aono & Kunii [5], De Reffye et. al. [6], Viennot et. al. [7], and Prusinkiewicz & Lindenmayer [8]). Kawaguchi [9] has also animated undersea creatures, defined by metaballs (Nishimura et. al. [10]), the Japanese equivalent of soft objects.

The surface of a soft object is the contour of a volume density, defined as the sum of spherically or elliptically symmetric densities centred at various points. In this work, we used only spherical densities, and each was specified by a centre and an outer radius at which the density function becomes zero. Section 2 explains the growth algorithm which governed the placement of these spheres.

We wanted to change the surface colour and perturb the surface normal vector (Blinn [11]) at each point on the coral, in order to render a realistic texture. The standard methods of texture and "bump" mapping look up values in a 2-D colour or bump height table. However such mappings are difficult to apply to a general contour surface, because there is no simple method to assign the co-ordinate functions into the 2-D texture tables. Therefore volume textures (Peachey [12], Perlin [13], Wyvill et. al. [14]) are the preferred method for contour surfaces. These are defined directly as functions of the 3D

co-ordinates of a surface point, often by analytic computation rather than table look-up. To generate our coral texture, we have generalized this idea, and compute the colour and normal perturbations as functions of both the 3D surface point and the normal to the contour surface. Section 3 describes this generalized volume texture. Section 4 gives our results.

2 Coral Structure

The coral structures are “soft objects” contoured from the sum of spherically symmetric density functions, so the structure is determined by the centres of the spheres, and the outer radii at which the density functions become zero. The structures were made by randomly adding one layer or “generation” at a time to a growing collection of spheres, starting from a single core sphere, and building up a tree graph.

All the spheres in a given layer n have the same radius $r(n)$. The distance $bond_r(n)$ between the centre of a new sphere and its parent in the previous layer is a fixed multiple of the sum of their radii. The direction from a parent to a new child sphere is chosen randomly on a truncated unit sphere. The truncation removes those directions with z component below $zlow$, in order to cause an upward tendency in the growth.

The maximum number of spheres in a layer n is a predefined constant $max_sphere(n)$. Parents and directions are chosen randomly, and the resulting new sphere is tested for collision and shape criteria, as described below, and rejected if it fails. The trials continue until $max_sphere(n)$ new spheres have been accepted, or the number of trials exceeds $maxtrials = tryfac * max_sphere(n)$, for a chosen factor $tryfac$.

The square of the distance between each trial sphere and every accepted sphere is tested against one of two collision criteria. The choice between them is determined by a generation count g . If the trial sphere and the test sphere have a common ancestor back at most g generations (e.g., a common grandparent), then a smaller, more lenient collision factor “*adjacent*” is multiplied by the sum of their radii to determine the distance of closest approach. This factor may be chosen so that the contour surface connects the two spheres into one blob. If there is no close enough common ancestor, then a larger factor “*nonadjacent*” is used, which makes the two spheres of non-zero density disjoint, and causes the blobs to separate.

At each level there are two other shape constraints for the sphere centres; a minimum distance from the central root node, and a minimum z value. These can be used to force the coral to grow outward and/or upward.

In the current system, the minimum distance and minimum z limits are incremented at each level n by fixed multiples of $bond_r(n)$, so only the multipliers need be specified. In turn, $bond_r(n)$ depends on the sphere radius $r(n)$, which is taken to be of the form $a * b^n$, so only a few constants need be specified to generate a coral shape. These are listed in Table 1.

- 1 The total number of levels in the tree
- 2 The initial radius, a , for the root sphere
- 3 The radius decrease per level, b , with $b < 1$, so that $r(n) = b * r(n - 1)$
- 4 The *bondfactor*, so that $bond_r(n) = bondfactor * (r(n) + r(n - 1))$
- 5 The number g of generations back for which a common ancestor allows a lenient approach distance.
- 6 The factor "*adjacent*" which multiplies $r(n) + r(i)$ to give the lenient distance for closest approach of two spheres at levels i and n with a common ancestor at level $max(0, n - g, i - g)$.
- 7 The corresponding factor "*nonadjacent*" for more distantly related spheres.
- 8 The multiple of $bond_r(n)$ used to increment the minimum distance from the root node.
- 9 The multiple of $bond_r(n)$ used to increment the minimum z value.
- 10 The truncation level $zlow$ for the unit sphere of directions between parent and child.
- 11 The base d in the formula $max_sphere(n) = floor(c * d^n)$. (c is always 2)
- 12 The factor *tryfac* in the formula $max_sphere(n) = tryfac * max_sphere(n)$ for the number of random spheres to try at level n before giving up.
- 13 An initial seed for the random number generator, used to vary the shape even when the above 12 constants are the same.

Table 1

There are two other features which can be turned on or off. The first interpolates an extra sphere between a parent A and child B , in order to keep the density high when the distance between parent and child spheres is large. We placed this sphere to make the branches curve smoothly. The second feature attempts to continue the curve of this branch from child B to grandchild C , in the case that B has no other children. The position of C is originally generated in the random search, and this random position is only revised if the smooth continuation does not violate the collision constraints.

By changing the 13 constants in Table 1 and deciding whether to enable the above two features, a large variety of coral shapes can be generated. Initially these shapes were examined in hidden line sketches of the spheres, and only the pleasing ones were used to generate soft contour surfaces. The sketches were generated using a fraction of the outer radii for the spheres, chosen to approximate the eventual soft contour surface.

3 Enhanced Volume Textures

We tried to generate shapes and textures for the coral to approximate those in the photographs in Wood [15] and Kaplan [16]. According to Wood [15] (page 18) the coral polyps lay down a skeleton with a cylindrical wall (*theca*) surrounding the *chalice* which contains the digestive system of the polyp. Radial walls called *septa* divide the chalice, and extend outward beyond the theca towards neighbouring polyps.

We wanted to show the chalices as a round depressions, uniformly distributed on surface of the coral. A straightforward method to give the locations for these depressions is to intersect the contour surface with a collection of spheres. We chose a cubic close packing of spheres for its uniform density and because it was easy to determine the closest sphere centre to a given 3-D point. This packing is based on a regular cubic lattice, with a sphere at the midpoint of each cube edge, and also one at the centre of each cube. Each sphere is surrounded by 12 other equidistant spheres.

Figure 1 shows the result of intersecting an ellipsoid with a close packed collection of spheres. Note that the approximate circles in which the ellipsoid intersects the sphere have differing radii.

We wanted all the chalices to have about the same radius. In order to achieve this, we used an "enhanced volume texture" which is a function of both the 3-D coordinate on the contour surface, and the surface normal at that point.

Figure 2 shows a contour surface S passing near two sphere centres C_1 and C_2 . Points $P_i, i = 1, 2$ are the closest points on S to C_i , so that the normals N_i lie along the lines C_iP_i . Then right circular cylinders of radii r and axes C_iP_i intersect the surface in approximate circles of radius r , so using these cylinders will make the circles have equal radii.

For any point P in the surface S , we could find the nearest centre C_i of the cubic close packing, find the distance s to the corresponding axis C_iP_i (C_2P_2 in

Figure 2), and calculate the texture as a function of s . However, finding the points P_i would involve a lot of iterative calculation, and also storage unless the calculation is repeated for each texture evaluation. Instead we draw a line $C_i D_i$ through C_i parallel to the unit normal N at P , and take q as the distance from P to this line. If the principle radii of curvature of the surface S are large compared to the distance between the centres C_i , q is a good approximation to s . Thus, we find the centre C_i of the close packing which is nearest to P , and compute

$$q = \left| (P - C_i) - ((P - C_i) \cdot N) N \right|$$

The texture is then a function of q . Figure 3 shows the approximate circles coloured white whenever $q < r$. Note that the circles have approximately the same radius, but that occasionally two circles intersect at the plane of transition between two different closest centres P_i and P_j . (This intersection can be interpreted in our application as polyp budding (see [15]).)

Figure 4 shows an ellipsoid with a bump mapped coral texture. The surface normal to the ellipsoid was perturbed radially as a function of q , to indicate the raised wall (theca) of the chalice and the depression it surrounds. In addition, the normal was perturbed tangentially to represent the septa which divide the chalice into sections, and also extend between them. This tangential perturbation was computed as a function of the direction of the vector TP in Figure 2. The areas where the septa cross the theca were made whiter to indicate the tentacles, by changing the surface shade.

4 Results

Figure 5 shows a single coral, rendered with bump mapped texture as described above. The first twelve shape parameters listed in table 1 were set respectively as 8, 2., .9, 1.6, 2, .2, 1.12, .67, .55, -1., 1.34, and 16., and the sphere and smooth continuation features were used. Figure 6 shows two corals with the same texture, positioned in a sandy bottom, and rendered with shadows. The orange coral on the left is the same as the one in Figure 5. The blue-green coral on the right had shape parameters 11, 2., .85, .7, 4, .2, .7, .47, .45, 0., 1.34, and 30., and did not use the two features.

Figure 7 shows two more corals without shadows. The red one on the left had parameters 11, 1.6, .85, 1.67, 2, .35, 1.16, .6, .67, .22, 1.26, and 26., and used the two features. The volume texture scale was set large enough to be visible,

which made the polyp distribution at the tips of the thin branches unreasonably sparse. The green coral on the right had parameters of 8, 2.6, .92, .52, 5, .1, .35, .37, .22, -.2, 1.34 and 30., and did not use the two features. For positioning the raised wall of the theca in the texture, we did not use a function of q , as described in section 3. We instead used a function of the ratio of the distances of a surface point to the two nearest cubic close packing sphere centres. This caused the walls to butt against each other. Figure 8 is an enlargement of the centre of Figure 7, showing the textures more clearly.

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Figure 1

Figure 2

Figure 3

Figure 4

Fig. 1

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