Random Caustics: Natural Textures and Wave Theory Revisited

Jos Stam

INRIA, Rocquencourt. BP 105, 78153 Le Chesnay Cedex France

Summary

A technique to synthesizes caustic texture maps is presented. A wave description for the propagation of light is employed to achieve this effect.

Overview

In this sketch I present a novel approach to model caustics through textures synthesized using a wave description of the propagation of light.

Subtle variations in intensity such as caustics can either be simulated directly using optical simulations or can be faked using textures. The method that I propose in this sketch lies somewhere in between. In general it is easier to generate textures of surfaces than to generate textures of the illumination field reflected or refracted from such surfaces. Indeed, it is very difficult to fake moving caustics using standard texture synthesis tools. The basic idea behind my method is to construct a texture synthesis algorithm for the intensity field which is consistent with both the texture of the surface and the laws of optics. This idea is not new in computer graphics and can be traced back to Blinn's bump maps. Ten years later, Krueger formalized this idea using statistical theories [1]. He modelled both the surface height and the intensity fluctuations as random functions. Statistical models for surfaces are well known and are synthesized for example by convolving a white noise. In order to synthesize textures for the intensity fluctuations, Krueger proposes to derive statistical models for them. He simplified the problem considerably by assuming that the intensity correlation is related to the surface correlation by a perspective transformation. Qualitatively this means that the intensity fluctuations closely resemble those of the surface fluctuations. Caustics, however, are visually very different from the appearance of the water surface. In this sketch I propose an alternative method to synthesize textures of caustics using a wave description of light. Such a description was introduced to computer graphics fifteen years ago by Moravec, who unsuccessfully applied it to the global illumination problem [2]. His algorithm relies on the fact that the propagation of a planar light wave can be modelled by a series of convolutions. I will use precisely these filters defining the convolutions to synthesize textures of caustics.

The results presented in this sketch are partial. The method has to be improved and generalized in order to compete with the state of the art in caustics from water surfaces. However, I hope these results demonstrate that both the method proposed by Krueger and wave theory may have many more applications in computer graphics.

The Algorithm

The algorithm is given for an incident plane wave parallel to the random surface. At the surface the phase of this wave is perturbed because points on the wave front traverse different distances in the water. The phase perturbation is therefore directly proportional to the surface height. After passing through the fluctuating region, the plane freely travels in the water medium. This part of the propagation can be described as a convolution of the wave with a filter derived from physical optics. This convolution is best performed in the Fourier domain. The filter depends on both the depth of propagation and the wavelength of the wave. In practice, following Moravec, the latter is taken to be twice the grid spacing used in the simulation The algorithm is summarized as follows.

Generate random phase from a statistical description of the surface.
Transform resulting wave into Fourier domain.
Perform multiplication with the filter.
Inverse Fourier transform the result.

Animated textures are synthesized by generating a random phase which is correlated over time. If a spectral synthesis technique is used then both the pertubation and the resulting caustics are periodic over time.This is highly desirable since even a small texture can produce an ever evolving caustic map. This is a very useful way of adding visual detail to the bottom of a pool, for example.

Results

I have computed several animations of caustics resulting from a random surface varying over time. Refer to Figure 1 for the results of computations of several images with different depth values. Notice how the effects of focusing become more pronounced as the depth is increased. This effect is illustrated in the picture in the bottom center of Figure 1. It's a vertical slice of the caustic maps computed at different depths. Pictures of underwater scenes similar to the state of the art can be produced by storing caustic textures for different depths in a three dimensional table and volume rendering the result.

In Figure 2, I present some results which are similar to those accompanying Moravec's paper. The disturbing surface in this case is a smooth ''bump'' depicted on the right of Figure 2. Notice that spurious diffraction patterns appear even at small depth values. However, these effects do not show up as clearly for random surfaces. The diffraction effect is even more pronounced when a surface with a sharp discontinuity is used.

The results shown in this paper suggest that wave theory should be given a second chance in computer graphics. The main advantage of the wave method is that it does not suffer from aliasing. However, this problem is replaced by the problem of spurious diffractions (i.e., the interference patterns). To my knowledge no one has yet researched ways of resolving this problem or given reasons why they cannot be resolved. Hybrid ray−wave methods may possibly provide a solution.

References

[1] W. Krueger. "Intensity Fluctuations and Natural Texturing". Proceedings of SIGGRAPH'88, pp 213−220.

[2] H. P. Moravec. "3−D Graphics and the Wave Theory". Proceedings of SIGGRAPH'81, pp 289−296.

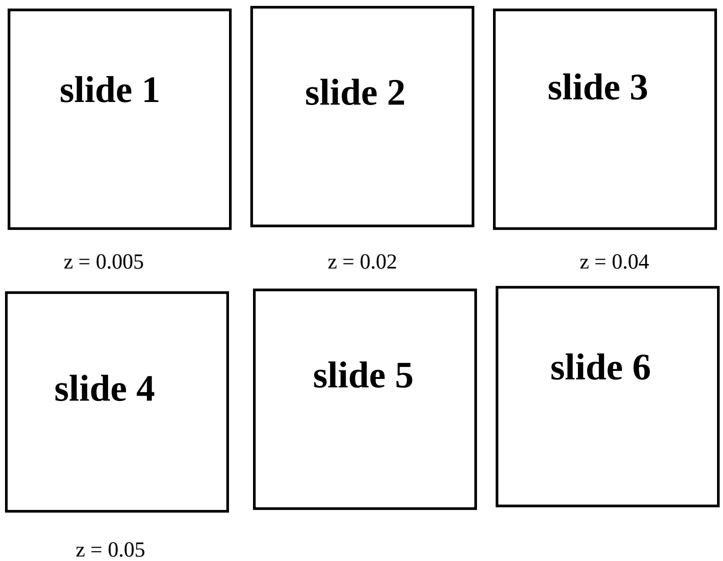

Figure 1. Simulations of caustics at different depths. The depth is given in meters below each picture. Notice how the caustic effects become more pronounced. The center bottom picture is a vertical slice demonstrating the focusing of light with depth.

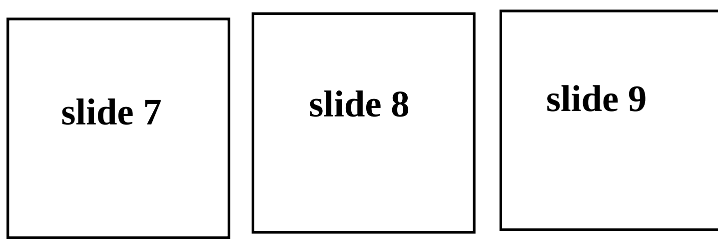

Figure 2. Caustics from a smooth "bump" depicted on the right. The two pictures on the left show these caustics at different depths.