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Project report

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Overview

The paper I have chosen to implement is “Real-time Realistic Ocean Lighting using Seamless Transitions from Geometry to BRDF ”by Eric Bruneton, Fabrice Neyret, and Nicolas Holzschuch at EUROGRAPHICS 2010 Volume 29 (2010). This paper presents a new algorithm for modelling, animation, illumination and rendering of the ocean, in real-time, at all scales and for all viewing distances. Their algorithm is based on a hierarchical representation, combining geometry, normals and BRDF(Bidirectional reflectance distribution function).
An overview of the paper will be given followed by a detailed description of the implementation of the paper.

Overview of the paper

Ocean wave Model

The ocean wave model relies on the work of Pierson- Moskowitz to simulate a train of trochoids based on Gerstner swell models. This model has to regularly mesh the ocean surface region because it solves the direction of propagation and phases of wave trains on the surface In addition, the surface of the ocean has Gaussian statistic properties, at almost all scales. This is the starting hypothesis of many BRDF models.
The core of the algorithm is a hierarchical representation of the ocean, combining geometry, normals and BRDF. At each viewing distance, we evaluate the required level of detail for the geometry representation, then encode the missing detail into the normal and the BRDF. The normal represents details that are too distant to make a visible contribution to the silhouette of the waves, but still close enough to make a contribution to their aspect. The BRDF encodes details that are so small (with respect to the viewing distance) that we can apply a micro-facet BRDF model.
The geometric model is a finite sum of wave trains of all wavelengths; the transition from geometry to normal to BRDF depends on the wavelength, for each wave train. The algorithm only works for deep water waves, and does not work for coasts and shores.

Mesh formation

The way mesh is formed is crucial to the look and feel of the ocean waves. A height field is generated using a geometric formula for simulation of ocean wave amplitudes.

In Damien Hinsinger paper, an adaptive mesh has been formed which is a significant improvement in the way mesh looks. Here the mesh is generated for the ocean surface such that every element covers at least the same area on the screen. The screen has been subdivided into the quads grid which is again back projected on the plane modeling the ocean surface at rest. The resulting mesh provides the particle locations at which the procedural animation is carried out. This adaptive mesh forms the basis for the implementation of a back projected grid in Eric Bruneton 2008.

Surface Wave optics

The ocean wave surface optics has been studied very well and it is a near perfect reflector. There are situations when the suface does not appear to be specular reflector. This happens when the direct sunlight reflected from waves at a large distance from the camera appear to spread out and diffuse. The waves collection that are smaller than camera can resolve at large distances. This process is very similar to the underlying relflection mechanisms in solid surfaces that lead to Bidirectance Reflectance Distribution functions.

Water has many components to its subjective appearance that must be accounted for in any realistic rendering. The waters reflectivity will vary between five and one hundred percent, depending on angle.

For angles where the reflectivity is high, the sky will be reflected with little loss of intensity. Where waters orientation reflects the disk of the sun, extremely bright highlights are present. The spatial pattern of such highlights are very familiar. Where the reflectivity of the water surface is low, any light coming from below should be visible to the viewer.

This light can be reflected light from the water bottom, or scattered light from the water volume itself. The impurities in the water determine the proportion of scattered by the volume, as well as its color. Thus the familiar brown of muddy water and the deep blue of many tropical waters. To capture the appearance of water, this scattering must be approximated to enough accuracy to recreate these familiar opacities and colors.

Fresnel Reflectivity and Transmissivity:

Accompanying the process of reflection and transmission through the interface is a pair of coefficients that describe their efficiency. The reflectivity R and transmissivity T are related by the constraint that no light is lost at the interface. This leads to the relationship R + T = 1 . The derivation of the expressions for R and T is based on the electromagnetic theory of dielectrics.

The variation of the reflectivity across an image is an important source of the texture or feel of water. Notice that reflectivity is a function of the angle of incidence relative to the wave normal, which in turn is directly related to the slope of the surface. So we can expect that a strong contributor to the texture of water surface is the pattern of slope, while variation of the wave height serves primarily as a wave hiding mechanism.This is the quantitative explanation of why the surface slope more closely resembles rendered water than the wave height does.
When the incident ray comes from below the water surface, there are important differences in the reflectivity and transmissivity. At incidence angles below 41 degrees, the reflectivity is one and so there is no transmission of light through the interface.

This phenomenon is total internal reflection, and can be seen just by swimming around in a pool. The angle at which total internal reflection begins is called Brewsters angle.

BRDF

Numerous empirical and theoretical models for the local reflection of light from surfaces have been introduced over the past 20 years. Empirical and theoretical models have the same goal of reproducing real reflectance functions, but the respective approaches are very different.

An empirical model is simply a formula with adjustable parameters designed to fit a certain class of reflectance functions. Little attention is paid to the physical derivation of the model, or the physical significance of its parameters.

The interaction of light with a surface can be expressed as a single function, called the bidirectional reflectance distnbution function, or BRDF. This is a function of four angles, two incident and two reflested, as well as the wavelength and polarization of the incident radiation.

In the context of ocean optics, Ross et al have recently found a very accurate BRDF model for anisotropic rough surfaces whose slopes and heights follow Gaussian distributions, with uncorrelated heights and slopes (which is the case when summing enough trochoids).

They derived their BRDF by computing the probability to see a microfacet of slopes , which is visible from both the viewer v and the source l, using Smith shadowing factors. Their major contribution was to analytically integrate the resulting expression to get a normalized visibility probability distribution

BRDF Model:

In Ross's paper, the specular component has been described extensively for the BRDF. It can be modeled in many ways, each having advantages and drawbacks. The method that is usually considered to be the most accurate uses a Monte Carlo approach to create many random three-dimensional (3D) instances of the sea surface.

Hundreds, or even thousands of rays are then traced from a source to a detector for each instance of the surface. The results obtained are then averaged into an overall reflectance, and ultimately into radiance. High accuracy can be obtained as shadows, hiding of waves by other waves, and multiple scattering are all naturally taken into account, making a limited amount of simplifications and assumptions. The drawback of this detailed calculation is long computational time, undesirable for most applications other than academic research.
A much faster and popular method of calculating the BRDF basically involves the convolution of Fresnel reflectances with the probabilities of a source actually being reflected toward the receiver. Although quicker, this basic approach has many physical limitations since the effects manifested by a true 3D surface are overlooked. These shortcomings become clear when trying to reproduce actual observations.It is possible to account for some of these effects by altering the slope probability-density functions using shadowing and hiding functions. However, adding these corrections slows down computation significantly since it often involves solving a number of embedded numerical integrals.
In order to maintain the desired level of physical correctness while obtaining reasonable computation times, many different approximations can be used. Zeisse found an analytical expression for calculating sea reflectance including some amount of hiding and weighting, but the nature of his approximations limits the use of the expression to grazing angles only. Mermelstein et al developed a method using a number of small angle and small slope approximations along with parametric fits to many of the physical quantities to calculate radiances quickly. Again, some of the approximations yield inaccurate results in some reflection geometries.

The need for rapid computation of accurate sea radiance demands a better solution.Hence Ross proposed a solution to the BRDF equations that eliminates the need for any numerical integration while including as much physical correctness as practical. The result is a significant reduction in sea radiance computation time, with no intrinsic limitations on reflection geometries. The model is then applied and simulations are shown to be in very good agreement with measurements.

Optical effects:

Optical properties can be decomposed into a reflection component and a refraction component, modulated by a Fresnel function as follows:

$$C_{result} = F(\theta) * C_{reflect} + (1 - F(\theta)) * C_{refract}$$

where C_{result} is the resulting color of the water surface, $C_{reflect}$ is the color coming from above-water environment along the reflection vector, $C_{refract}$ is the color coming from the underwater scene along the refraction vector,$F(\theta)$ is the Fresnel term, and θ the angle of the viewer to the water surface.

Reflection:
The reflection color caused by the environment can be further divided into three parts: sky reflection, sun light and local reflection.

$$C_{result} = C_{skylight} + C_{sunlight} + C_{localreflect}$$

Refraction :

The refraction color is decided by the scattering object color inside the water and the color of water which is influenced by scattering and absorption effects of water molecules and suspensions.

Implementation

Details

I implemented the model using vertex and fragment shaders. The vertex shader projects the screen space regular grid, displaces it , and projects it back.The fragment shader computes the per pixel normals using and then the Sun, sky and refracted light as described in the paper. The wave parameters are generated on CPU and stored in a texture. We generate them either with the Hasselmann spectrum .

I used a geometric progression for the wavelengths , which allows us to optimize the evaluation of waves. It is minimal for distant views where no details can be seen.

The model has been implemented and tested on my Lenovo laptop which uses Intel i7 Processor.

Results

The results for lighting at various angles of Sun radiance has been tested and presented below. The below figures include both stormy sea (Figure 1 and Figure 2) and calm sea (Figure 3 and Figure 4) cases.

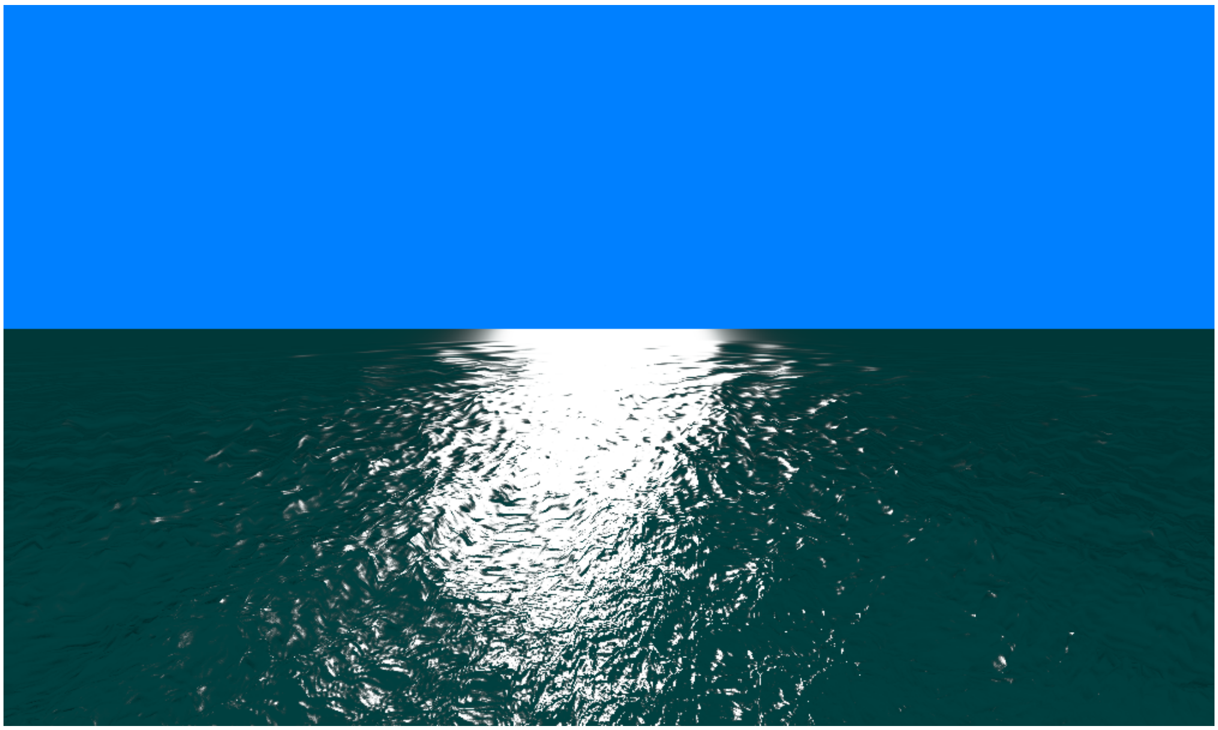

Figure 1: Stormy sea

Conclusion

I implemented the ocean wave lighting using projected grid, height field generation and BRDF lighting model as in Eric Bruneton's paper. Shaders are also used for this purpose and the final results of lighting are presented in this report.

Papers referenced for this report

1)Real-time water rendering: Introducing the projected grid concept, Claes Johanson, Master Thesis, 2004

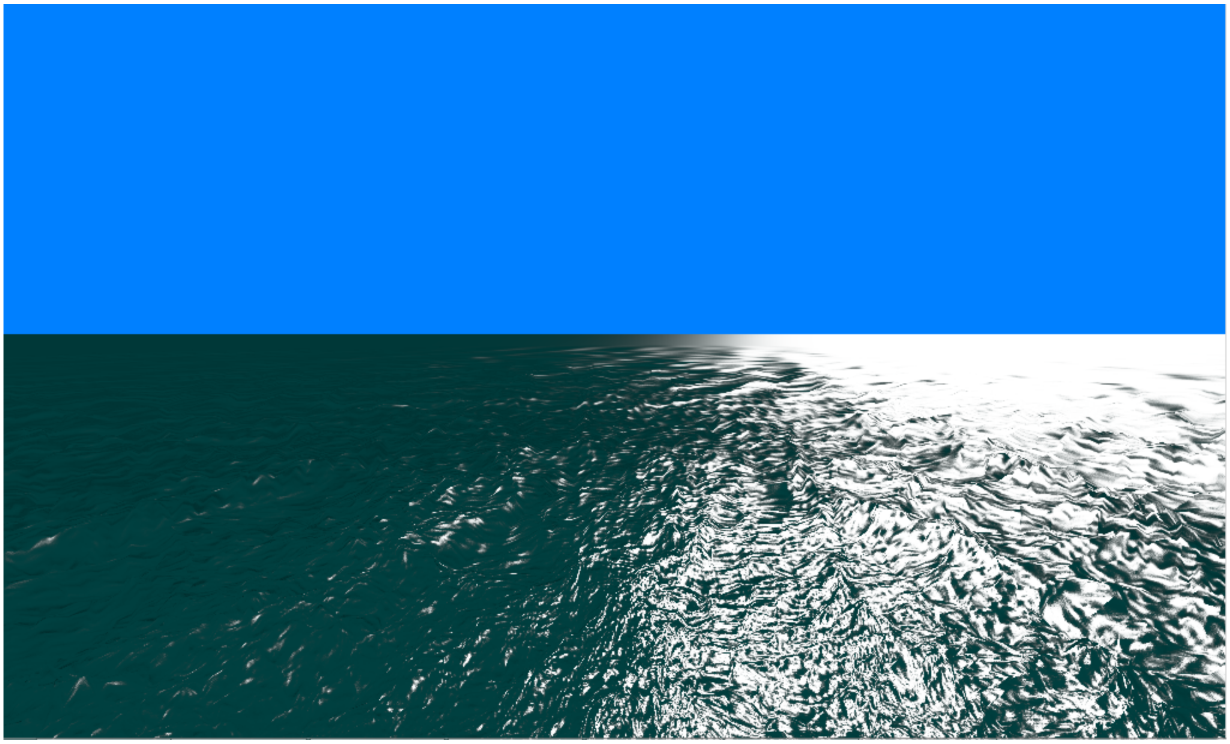

Figure 2: Stormy sea at different angle of sun radiance

2) Tessendorf, Jerry. Simulating Ocean Water. In SIGGRAPH 2002 Course Notes (Simulating Nature: Realistic and Interactive Techniques), ACM Press

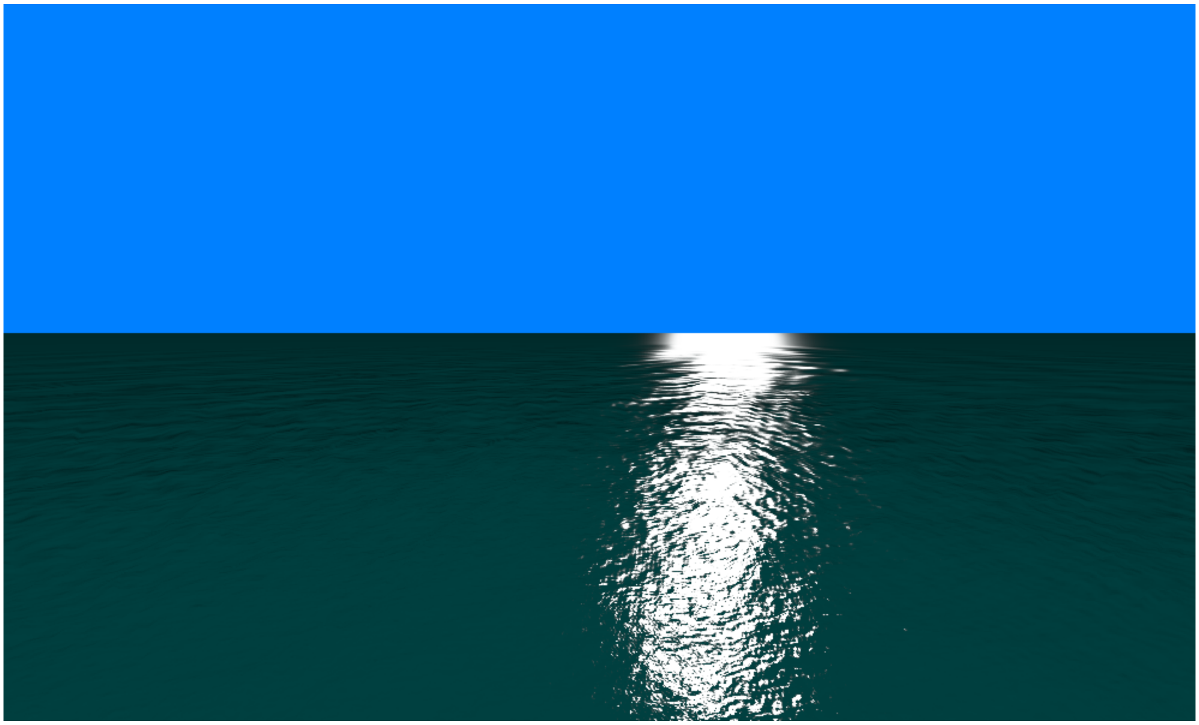

Figure 3: Calm sea

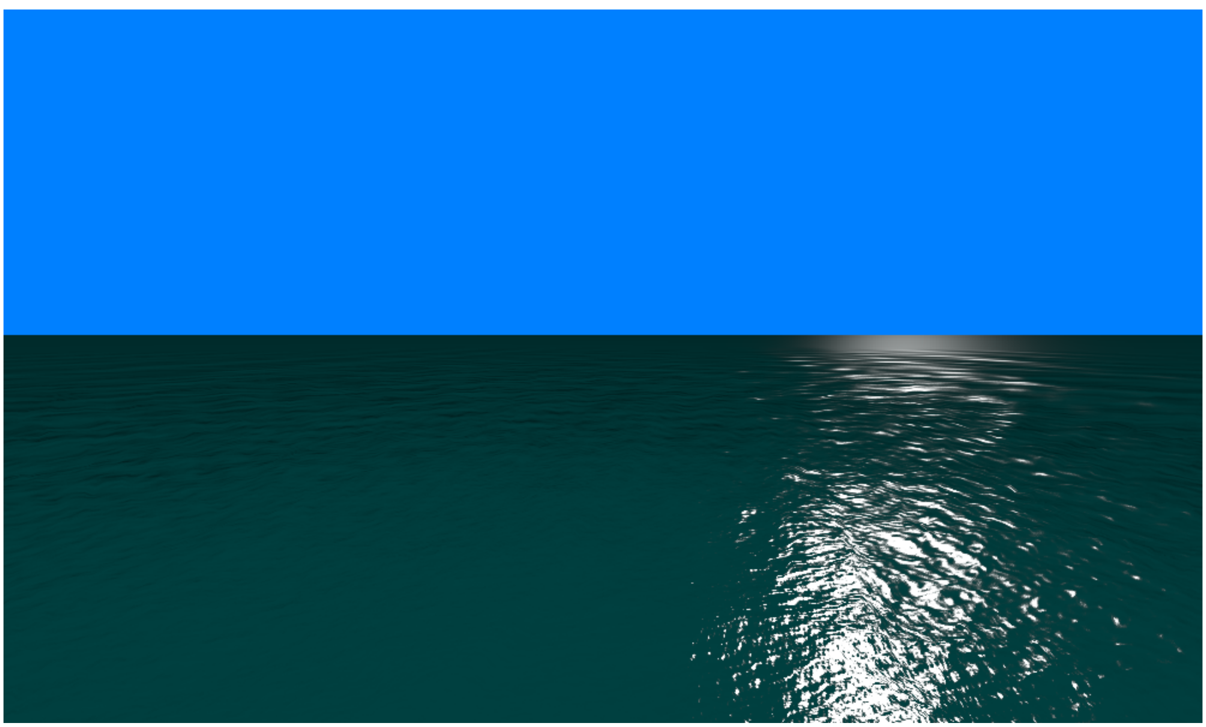

Figure 4: Calm sea at different angle