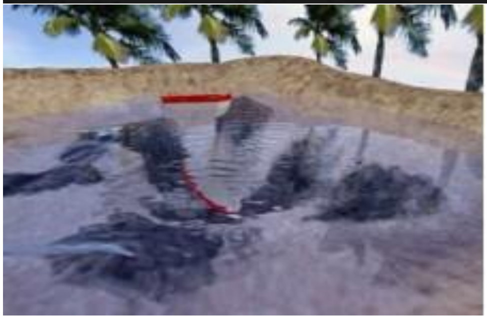
Project 3: Check Point #2
Water Surface and Rendering (GPUShader)

Introduction

Water is common seen in daily life. However, the interaction and rendering of water involve complex physical computation. In this work, we would like you to explore a few possibilities to simulate the water surface and render the surface with shader programs and CUDA programs which become more and more important in graphics.



The Basic Task

With the advance of GPU technology, GPU becomes more and more popular in computer graphics especially in game industry. It is also noticed by general computation community. Water surfaces are common in computer graphics, especially in games for creating fantastic effects. They are a critical element that can significantly improve the level of realism in a scene. But depicting them realistically is a hard problem, because of the high visual complexity present in the motion of water surfaces, as well as in the way light interacts with water. This project would give you the chance to explore techniques developed for rendering realistic depictions of the water surface. With these two things in mind, this project would like you to have the experience by implementing a shader program and a CUDA program to generate a water surface and then rendering it with reflection and refraction effects. In addition, ray-tracing is very important global illumination algorithm to generate realistic images in graphics community. Therefore, the project also asks you to implement a ray tracer for rendering the water and other scene objects.

Please print Project3-Grading.doc, let TA to check your score.

You can download Project3_CheckPoint2_Solution.zip to execute.

The Tasks

Fundamentally, to generate the perception of the water in an interactive application consists of two tasks:

1. Your program has to generate a water surface according to some physical rules which are formed for some specific phenomenon in your mind. This generated surface represents the boundary of water for a renderer to generate proper images for illustrating the water surface.
2. Your program must render the water surface to simulate the effects of refraction and reflection. Furthermore, the caustics caused by water movement on the sea floor can be added to add more reality.

In addition, realistically rendering the water surface is also important for other graphics applications, a basic ray-tracing algorithm is required to simulate the global illumination effect in the scene. The ray tracer will generate an image according to rays through the center of all pixels to interact with the scene object and then compute the lighting effects and shadow effects.

Basic requirements

Technique	Points	Suggestion
Basic system • Sine waves • Height maps waves • Sky mapping reflection / Tiles refraction	5	**(If you did not finish this, you cannot get any score.**

Advanced Features (Water surface-related techniques)

Meeting the basic requirements will get you a basic grade of 10.

These are really advanced features. It is much better to have the advanced features (that are really central to the assignment) than these frills, but frills can be fun. And we will give you points for them (**but remember, you can't get points for frills unless the more basic stuff works**)

Technique	Points
Wave equation	3
Multi-passed scenic • Reflection (5) • Refraction (5)	10
Interactive Water Surfaces	3
Hack caustics effect	3
Photorealistic simulated caustics effect	5
Buoyancy and Floating Objects	3
Foam and Spray	5
Dynamic Tessellation	3

Water surface generation with GPU

Basically, the water surface can be simply decomposed into two geometric components: high-level surface structure and low-level surface details.

1. The surface structure represents the large scales of the wave movement and can be represented with a set of 2D grid with the y direction represent the height of the grid point. A vertex shader can be used to simulate the movement at the vertices by changing the normal and the y position of the vertex.
2. The surface detail represents the small-scale perturbation in the local area and generally can be represented as a normal map. A pixel shader is created to generate a normal map for those perturbation.

Generally, there are several ways to implement the wave on the surface of water:

1. Sine waves (Ref. 1): The sum of the sine waves are chosen to represent the complex water surface movement. The equation can be expressed as

$$W_i(x, y, t) = A_i \times \sin(D_i \cdot (x, y) \times w_i + t \times \varphi_i)$$
$$\mathrm{H}(\mathrm{x}, \mathrm{y}, \mathrm{t}) = \sum (A_i \times \sin(D_i \cdot (x, y) \times w_i + t \times \varphi_i))$$

- Wavelength (L): the crest-to-crest distance between waves in world space. Wavelength L relates to frequency w as w = 2π/L.
- Amplitude (A): the height from the water plane to the wave crest.
- Speed (S): the distance the crest moves forward per second. It is convenient to express speed as phase-constant, , where φ = S x 2π/L.
- Direction (D): the horizontal vector perpendicular to the wave front along which the crest travels. Please refer to Ref. 1 for more direction details.

2. Height maps (Ref. 3): similar to sine wave method, height map method decomposes the wave on the water surfaces into a set of different level of detail represented as a heightmap (the shape of single component and generated by artists) The following shows an example of the height map.

The combination of the heightmap can be expressed as the following equation.

$$H(x, y, t) = \sum_{i=0}^{N} b(A_i^x x + B_i^x, A_i^y y + B_i^y, A_i^t t + B_i^t)$$

Please refer to Ref. 3 for more heightmap details.

3. Wave equation (Ref. 4): Generally, the movement of the wave can be expressed as a wave equation as listed in the following:

$$\frac{\partial^2 y}{\partial t^2} = c^2 (\frac{\partial^2 y}{\partial x^2} + \frac{\partial^2 y}{\partial z^2})$$

Then by modeling the water surface as cubic B-spline surfaces, the right-hand side of the equation can be expressed by the following:

$$c^2 \left(\frac{\partial^2 y}{\partial x^2} + \frac{\partial^2 y}{\partial z^2}\right) = c^2 \left(\left[y_{-1,0} + y_{1,0} - 2 \cdot y_{0,0}\right] + \left[y_{0,-1} + y_{0,1} - 2 \cdot y_{0,0}\right]\right)$$

$$c^2 \left(\frac{\partial^2 y}{\partial x^2} + \frac{\partial^2 y}{\partial z^2}\right) = c^2 (y_{-1,0} + y_{1,0} + y_{0,-1} + y_{0,1} - 4 \cdot y_{0,0})$$

And then the integration can be computed with one of the following integration methods

$$p(t_2) = 2 \cdot p(t_1) - p(t_0) + \frac{1}{2} \cdot a(t_1) \cdot h^2$$

$$p(t_2) = 2 \cdot p(t_1) - p(t_0) + a(t_1) \cdot h^2$$

$$p(t_2) = (1 + \alpha) \cdot p(t_1) + \alpha \cdot p(t_0) + \frac{1}{2} \cdot a(t_1) \cdot h^2$$

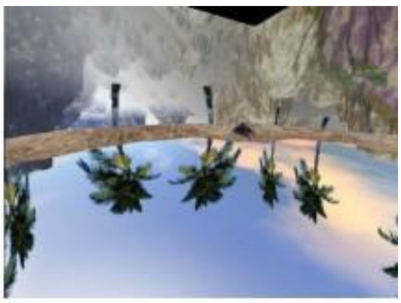
Then the equation is solved at each vertex of the 2D mesh to generate the water surface. Please refer to Ref. 4 for details.

Water surface rendering with GPU

Two important effects for the water surface rendering: reflection and refraction. We assume that we are looking outside the water. The reflection and refraction can be generated with the following different methods

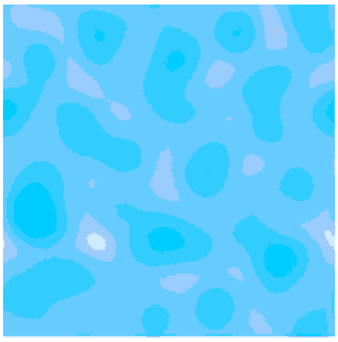
1. Combination of refraction and reflection with an environment map for the sky and a set of texture map for the box. (Ref. 1)
2. Using the refraction map and reflection map to simulate the possible viewing condition from above
3. The water to simulate the refraction and reflection effects. (Ref. 4). The following shows an example of refraction and reflection map

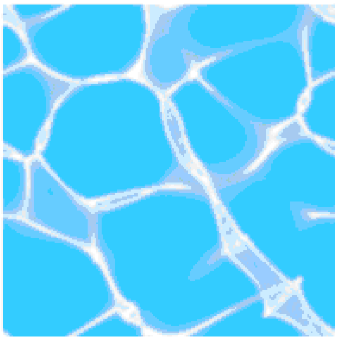
Refraction Map



Reflection Map

4. In addition to the refraction and reflection, the caustics on the floor due to concentration of refraction and reflection is also visually important. Therefore, simulate the caustics effect on the floor is also important for the rendering.



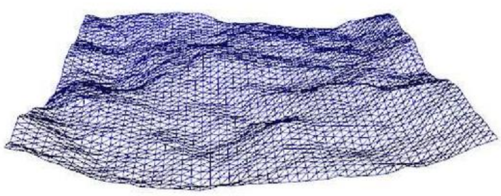


Other items:

1. Buoyancy and Floating Objects:
   - Object Interaction: In simulations, objects interact with fluids based on their density, volume, and shape. Objects will float if the buoyant force is equal to or greater than their weight, and they will sink if the buoyant force is less than their weight.
   - Some suggested objects for interaction are spheres, driftwood, boats, etc.
2. Foam and Spray:

   Below are some suggested methods and steps for simulating the generation of foam and spray:
   - Conditions for Foam Generation:
     - Speed: Foam may be generated when the flow speed of the water exceeds a certain threshold.
     - Turbulence: In turbulent areas of the water flow, the probability of foam generation is higher.
     - Collision: Foam may also be generated when water collides with other objects, such as rocks or ships.
   - Particle System:
     - Foam and spray can be simulated using a particle system, where each particle represents a part of the foam or spray.
   - Lifecycle:
     - Particles of foam and spray have a lifecycle. They begin from generation and gradually disappear over time.
   - Texture:
     - Specific textures are used to represent the appearance of foam and spray. These textures can be semi-transparent, and alpha blending can be used to simulate the transparency of the foam.
   - Foam Aggregation:
     - In some cases, foam may aggregate together, forming larger clumps of foam. This can be simulated using attractions between particles or other methods.
   - Color and Lighting:
     - The color of foam and spray may be affected by ambient light, shadows, and other lighting effects.
3. Dynamic Tessellation:

   This technique dynamically increases or decreases mesh density based on the viewpoint and the movement of the water surface. This allows for more geometric detail where detailed simulation is needed, while less geometric detail is used in distant or less important areas. You need to provide a test button to turn on/off the display of the connectivity on the Mesh (Ref. 3).



View-Dependent Tessellation of Ocean Surfaces

What to hand in?

As usual, you must hand in everything needed to build and run your program, including all texture files and other resources.

In your readme, please make sure to have the following (you can break it into separate files if youprefer):

1. Instructions on how to use your program (in case we want to use it when you're not around)
2. Descriptions of what your program does to meet all of the minimum requirements.

You should make a subdirectory of the project directory called "Gallery." In this directory, please put a few JPG pictures of the best scenes in your town. Please name the pictures login-X.jpg (where X is a number). Put a text file in the directory with captions for the pictures. (note: to make pictures, use thescreen print and then use some program to convert them to JPG).

Reference

1. GPU Gems Chapter 1: Effective Water Simulation from Physical Models
2. GPU Gems Chapter 2: Rendering Water Caustics
3. GPU Gems II Chapter 18: Using Vertex Texture Displacement for Realistic Water Rendering
4. Vertex Texture Fetch Water:
5. Source Code from NVidia
6. User guide from NVidia