Complex Water Effects at Interactive Frame Rates

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Simulation
- ring waves (gravity and capillary waves)
- Kelvin ship wakes (angle of 38°)
- wind waves, etc.

Display
- geometry of water surface
- reflections of sun and sky (Fresnel)
- caustics with shadows in them
- refraction of ground and caustics
Former Work

A quarter of a century of water simulation in computer graphics:
1986: Fournier/Reeves and Peachey

Commercial Products:
- Areté RenderWorld, Psunami, ...
- Alias|Wavefront Maya 4.5 Fluid Effects
- ...

Simulation
Simulation: Propagation of Waves

Linearized PDEs: Convolution with fixed circular wave, determined from hydrodynamics

Fast convolution (512 x 512) through FFT
Simulation: Ship Waves

Sum ship waves produced between one time step and the next:

- convolve with profile of ship at last time step
- +
- convolve with profile of ship at next time step
Simulation: Tripling the Speed

Run simulation at triple speed, interpolate wave field for intermediate steps (cubic interpolation using derivative)

Simulation Steps

Display Frames
Display
Display: Vertices vs. Texels

For efficiency less geometry, more textures

- Water surface as $95 \times 95 \times 2$ triangles,

- Textures (multi-texturing, pixel shader) at $384 \times 384$ texels resolution
Display: Water Textures

- **Refraction** per vertex: influence of water height,
  **per texel:** influence of normal vector

- **Reflection** of sun (Phong) and sky (Fresnel effect) as textures calculated on the fly

refr. index = 1
Display: Caustics

Caustics on the ground as a collection of triangles

Illuminance inversely proportional to area
Display: Caustics

The graphics chip can compute the area dependence by itself: Use an appropriate MIP map texture.
Display: Caustics

Blur by emulating an accumulation buffer
Performance, Outlook
Performance

Wave Propagation (1/3 Step) 52 ms
Generate Ship Waves 6 ms
Generate Caustics; Blur 18 ms
Generate Reflection Textures 51 ms
Render Water Surface 42 ms

**total** 170 ms = 6 fps

System:
Pentium®-4 at 2,5 GHz
nVidia® GeForce® 4 Ti 4200
Outlook

Future Work:

- Accelerate texture generation and rendering
- Include more effects of non-linearity
- Include refraction and reflection of waves