GPU-Assisted Rendering Techniques

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NVIDIA®

Shader Model 3.0 Hardware Is Here!

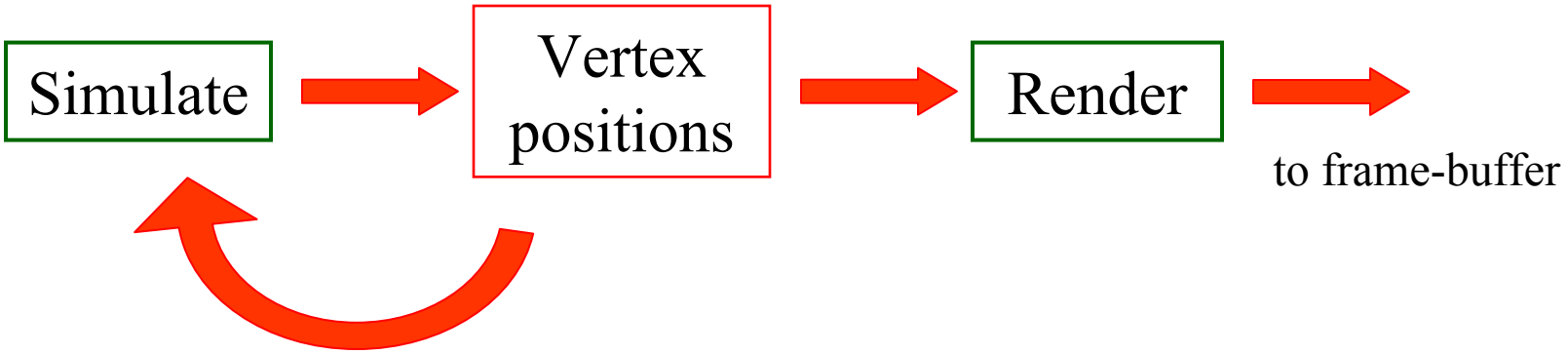
- What can I do with it?
- How can it help me with my game?
  - How can I use it to offload the CPU?
  - How can it help my image quality?

How Can It Help My Game?

- Offload work from the CPU to the GPU
  - "Render To Vertex Buffer" technique
  - Uses texture-fetch feature of VS 3.0
- Image quality
  - Per-pixel specular lighting
  - Normal-map mipmaps produce artifacts (distant objects shimmer)

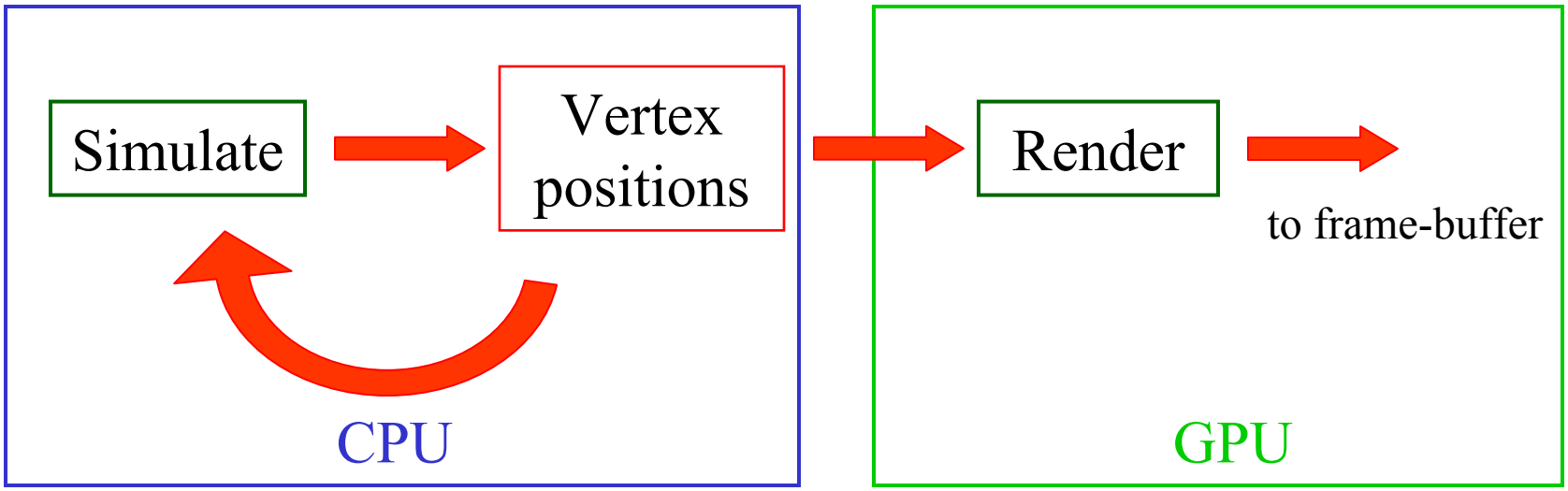
Offloading the CPU

Typical Workflow



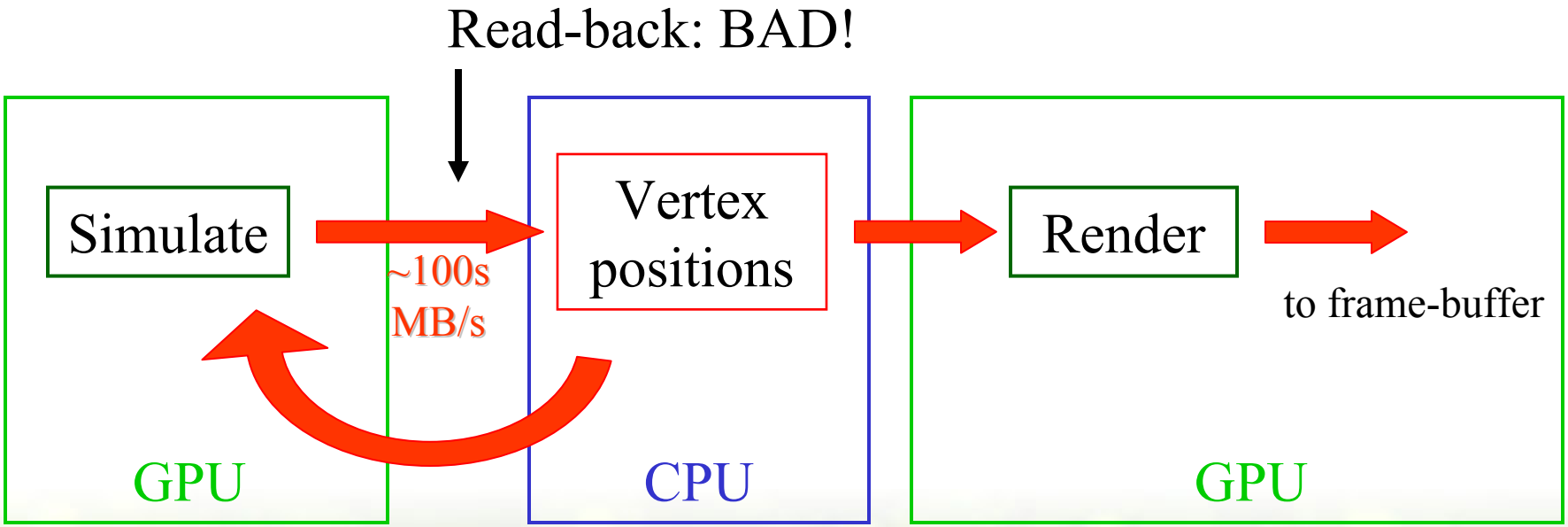
Offloading the CPU

Typical Workflow



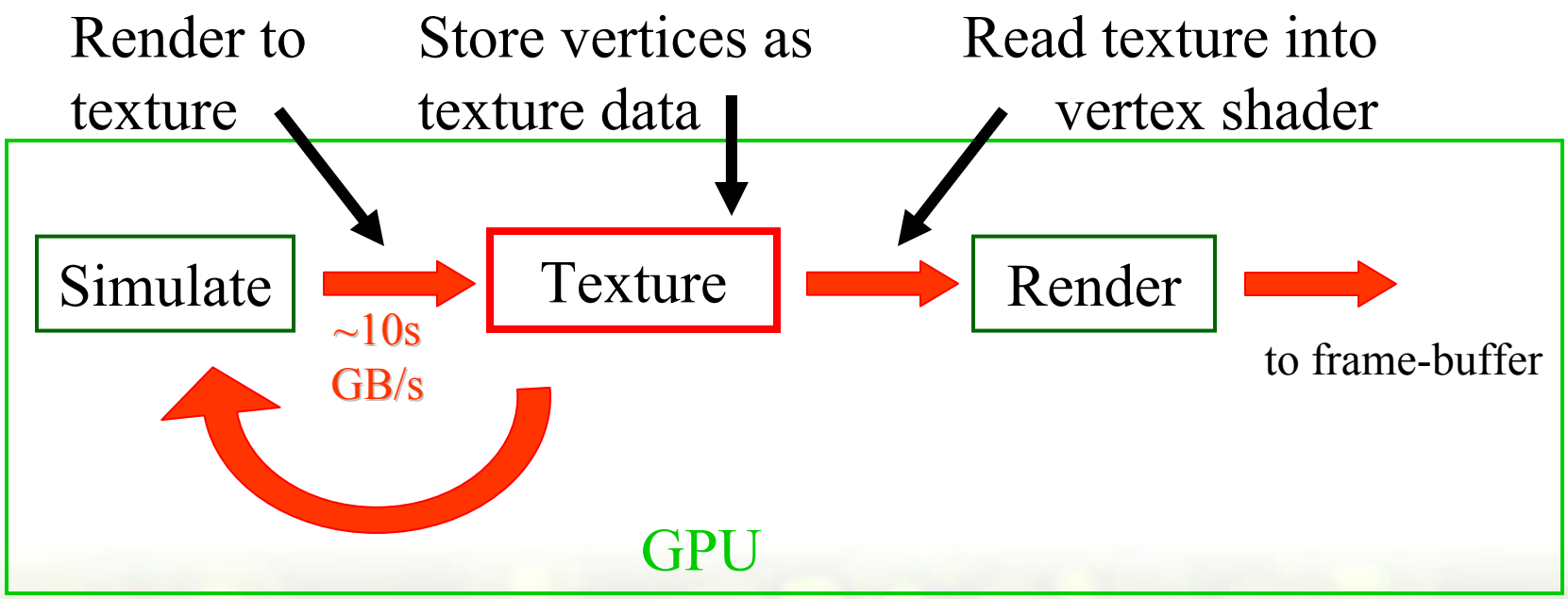
Simulating On the GPU?

- Use them programmable shaders!



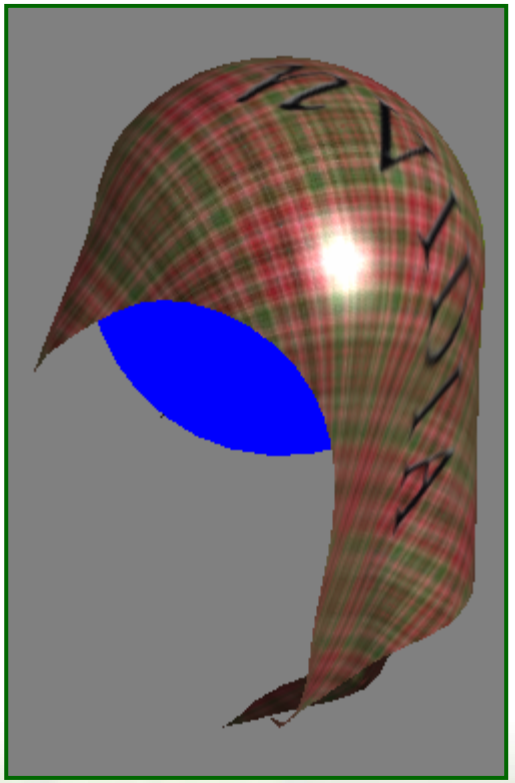
“Render To Vertex Buffer”

- Removes read-back from GPU to CPU



Examples

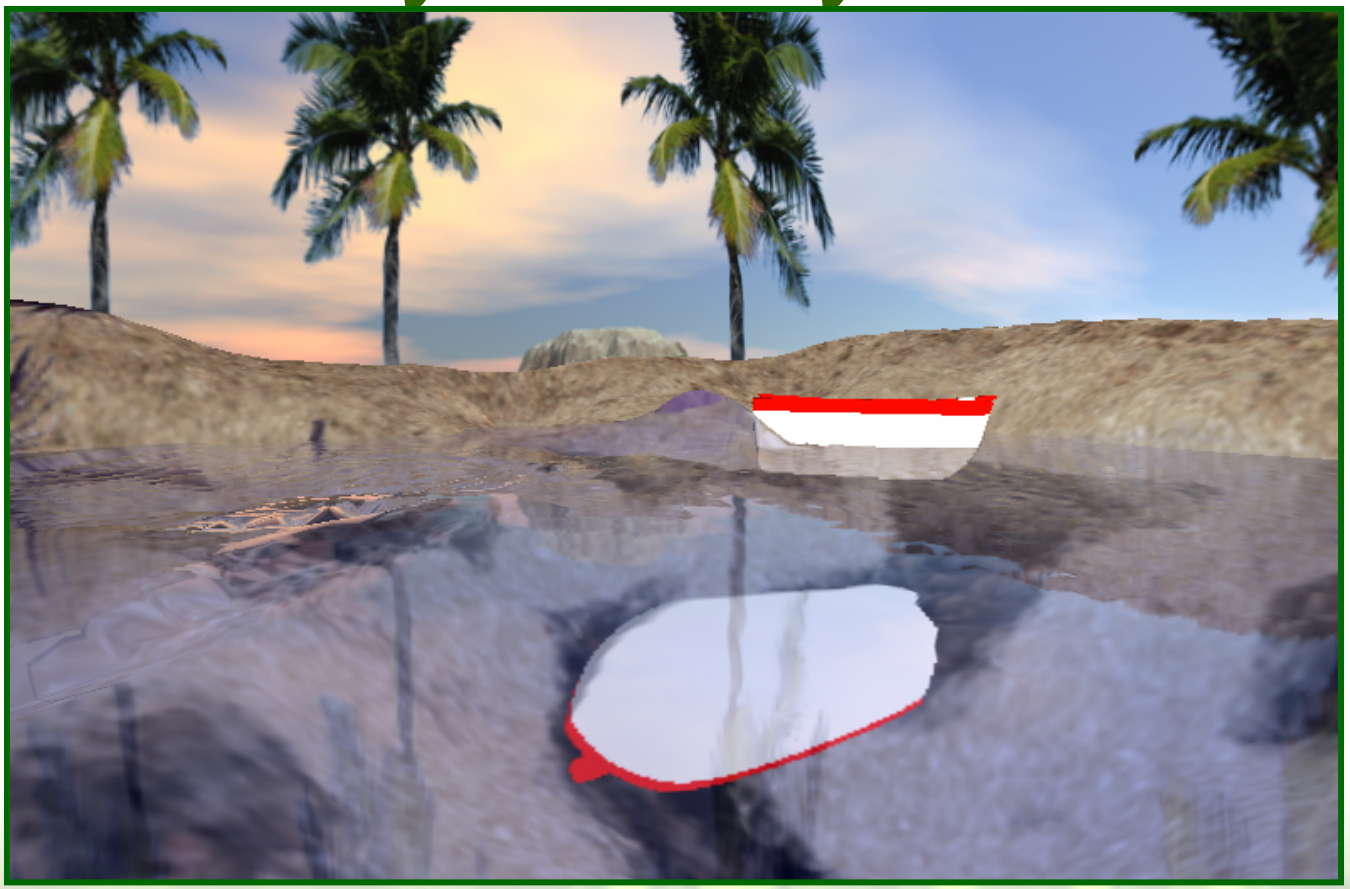
- Cloth
  - Collide cloth against scene
  - Run cloth physics: damped springs
- Displacement Mapping
  - Displace vertices



More Examples

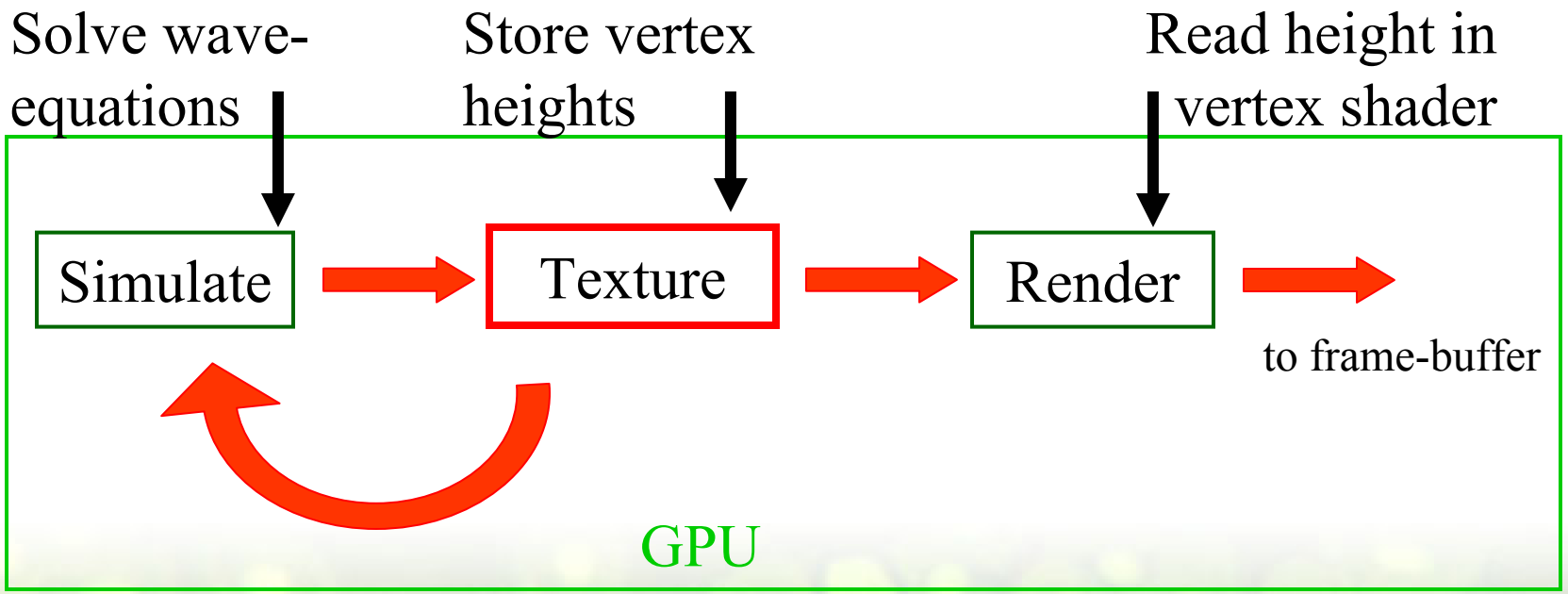
- Snow/Sand accumulation
  - Simulate friction/sliding
- Wind (simulation) bending grass
- Particle Systems
- Water waves/wakes

Demo by Jeremy Zelsnack



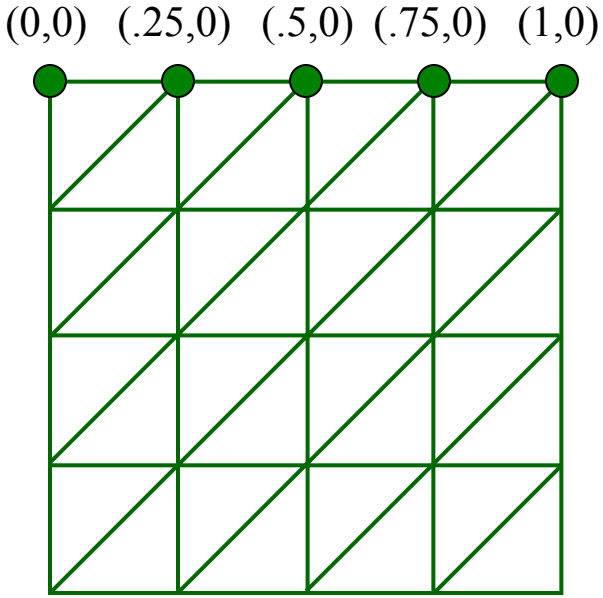
Rendering Water

- Tessellated, flat plane for water



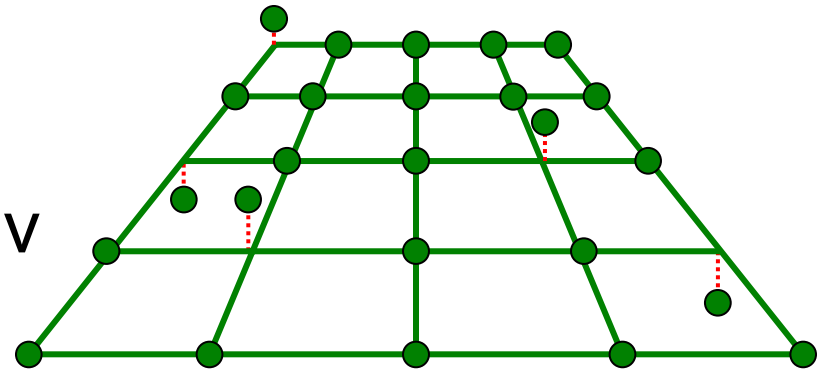
How Does It Work?

- Create a vertex-mesh for water surface
  - Say, 128 by 128 vertices
  - Encode vertex's mesh-position as uv-coordinates



Vertex Shader Work

- Read ‘height-map’
  - Floating-point texture
  - Read texture at vertex’s uv
- Add result to vertex’s y
- Transform/Project vertex

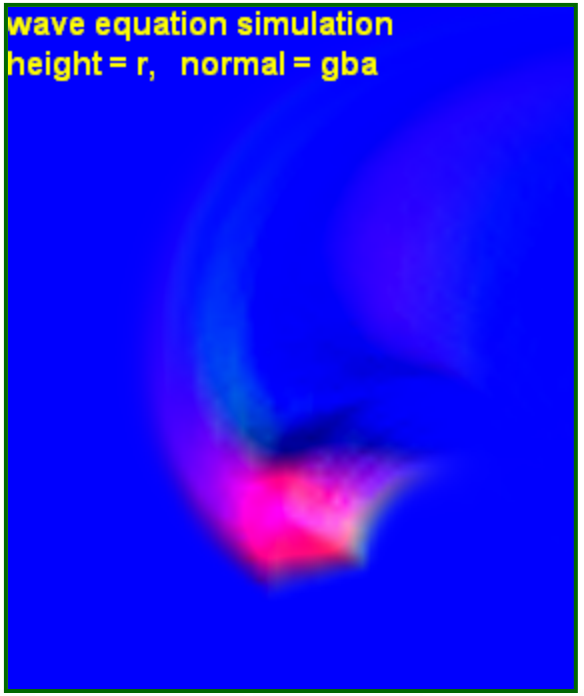


vertex.y += tex(u, v)

Out.pos = WorldViewProj * vertex

Height-Map Is Dynamic

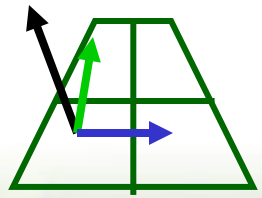
- Update every frame
  - With GPU via render-to-texture
- Simulate water movement with Verlet integration



Verlet Integration

- $A = \sum (\text{neighbors}) - 4\ H_{n-1}$
  $H_n = (H_{n-1} - H_{n-2}) + A$
  - Operates on positions only
  - No need to store velocity or acceleration

- Compute normal from positions:
  $N = \text{Normalize}(S \times T)$

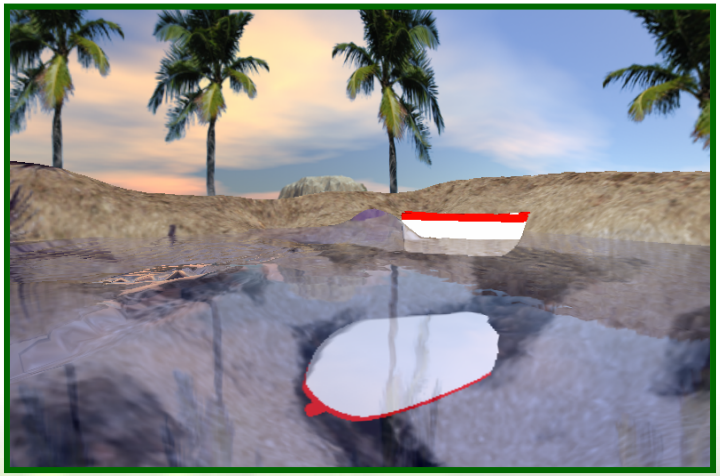


Add Disturbances to Height Map

- Blend displacements into the water
  - For example: the boat, rocks, shore
- Verlet-integration integrates it next frame
- Yes, floating-point render-target blending

Add Usual Eye Candy

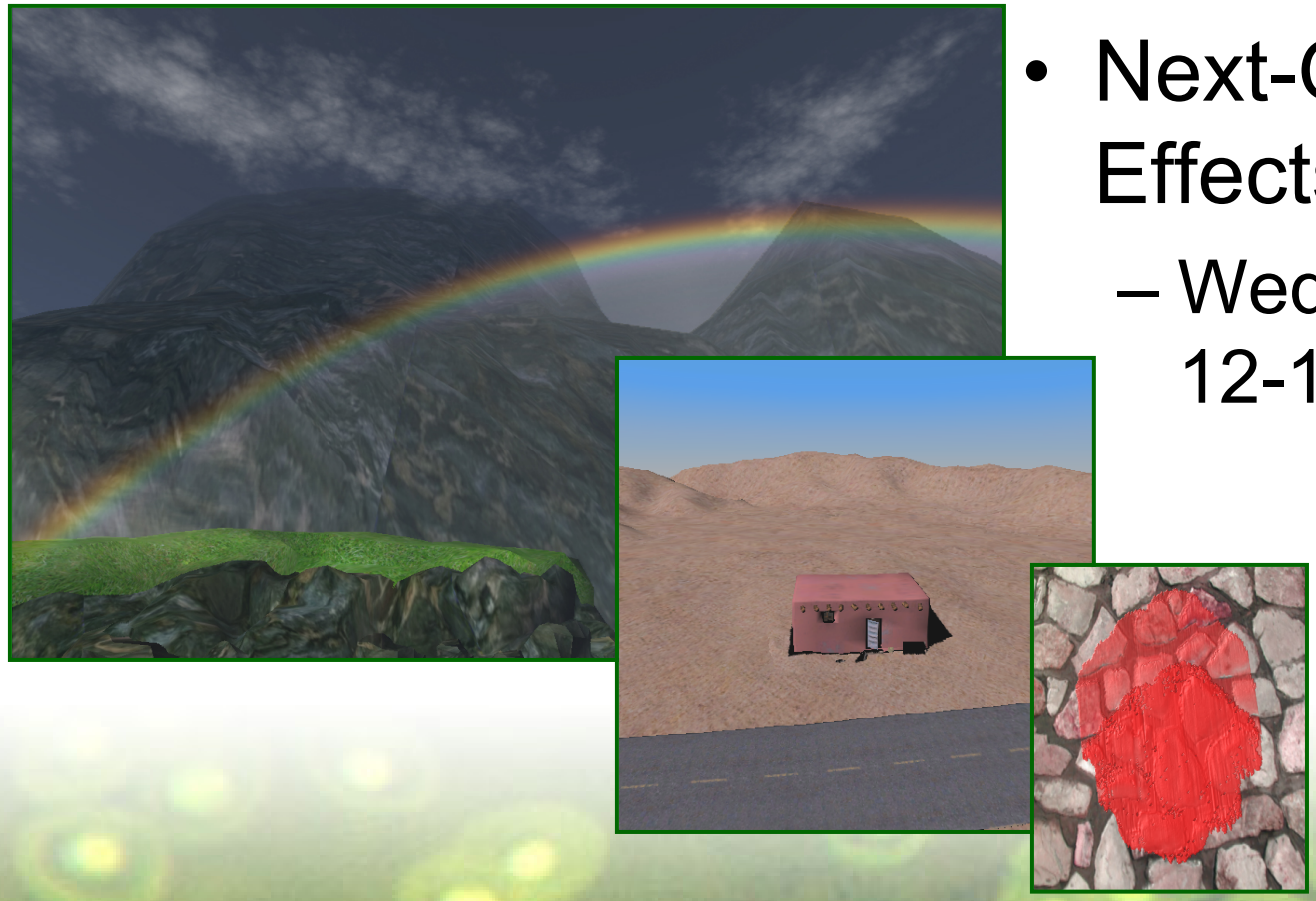
- Caustics
  - Bilinear filtering of the normals crucial: low-res (128x128) texture
- Reflection/Refraction
- Fresnel



Advantages

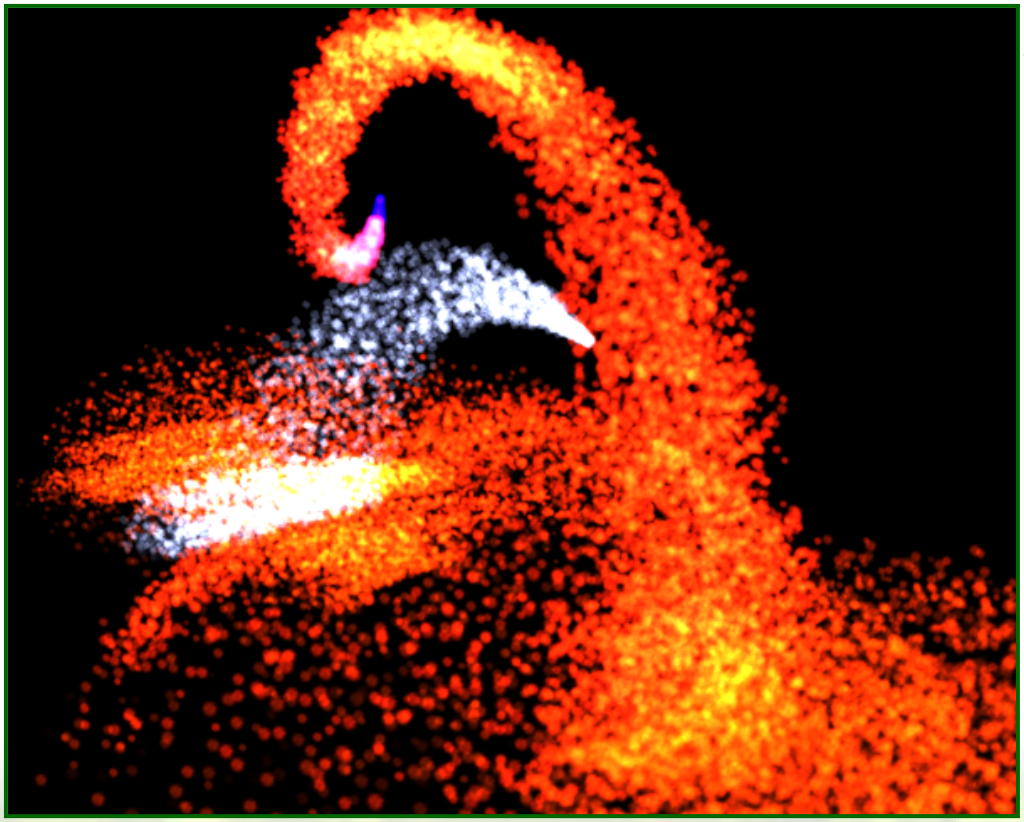
- Fast!
  - Simulation happens on 128x128 texture
  - Small by GPU standards
  - Frame-rate unaffected by simulation
- Reasonable geometric complexity
  - 128x128 is 16k vertices

More Details on This Sample (and Others)



- Next-Gen Special Effects Showcase
  - Wednesday, 12-1pm

Particles via Render-to-VB

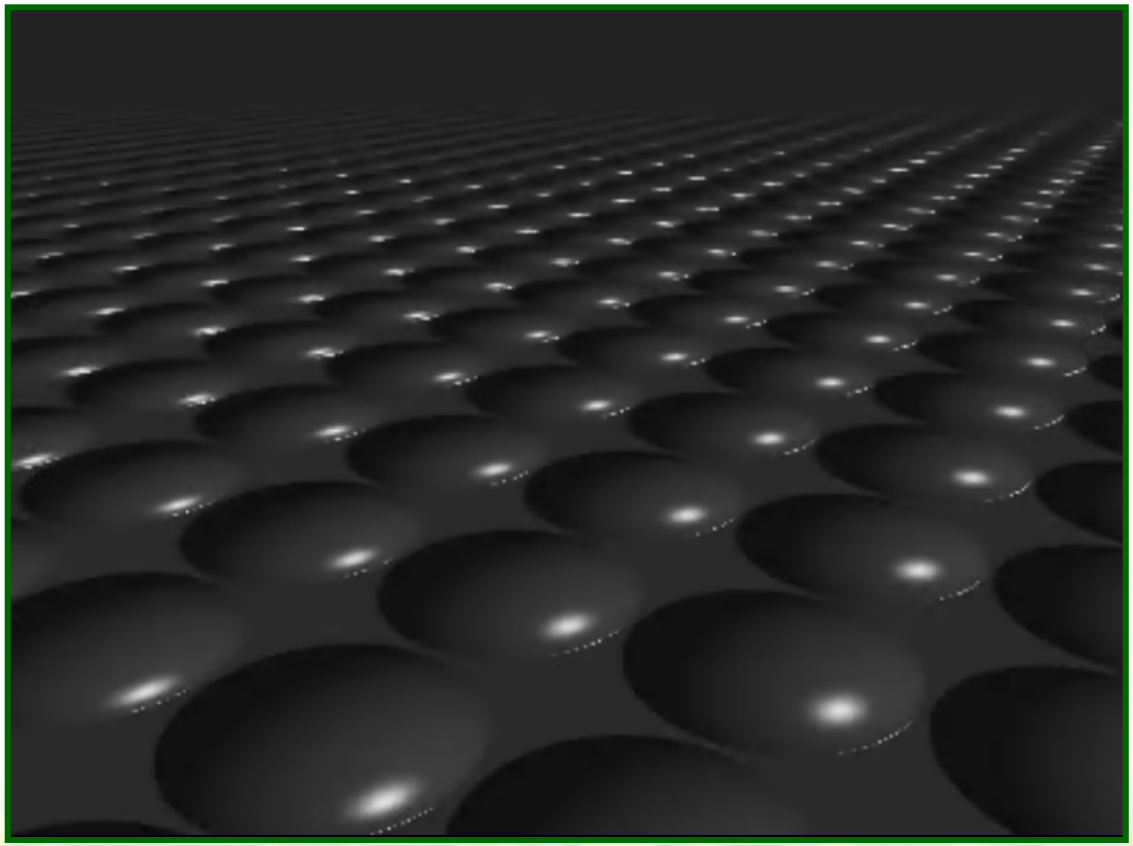


- Building a Million Particle System
  - Lutz Latta
  - Wednesday, 12-1pm

Image Quality

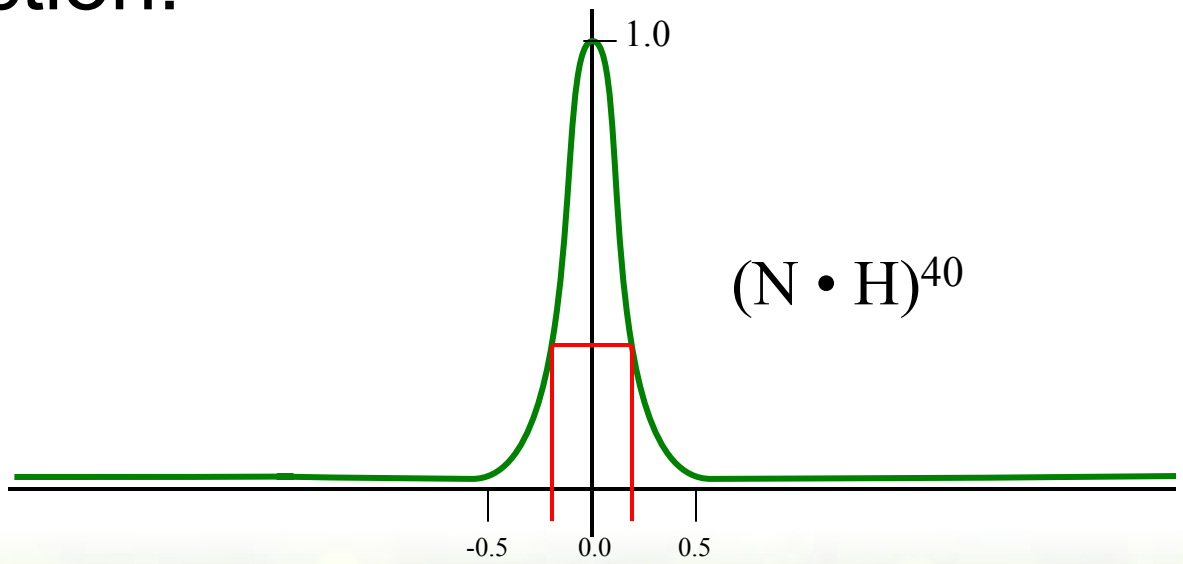
- Per-pixel specular lighting
  - Normal-map mipmaps produce artifacts (shimmer on distance objects)
  - Uses floating-point texture filter and blend

Normal-Map Mipmap Artifacts



What Is the Problem?

- Specular term $(N \bullet H)^s$ is high-frequency function:

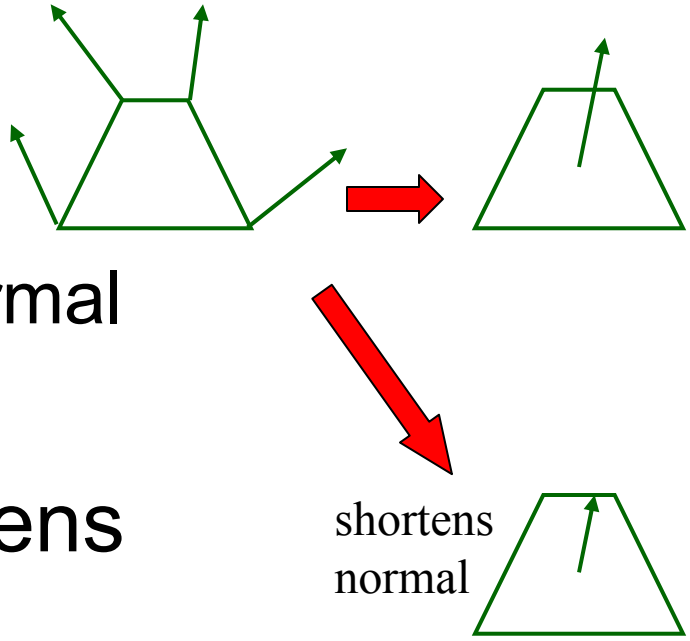


Sampling Frequencies

- Magnification case:
  accesses top-level mipmap
  - Sufficient sampling
- Minification case: lower mip-levels
  - Without mipmaps: sparkle city
  - With mipmaps: better, but not much

What Is a Normal-Map Mipmap?

- Averaging
  - Replace 4 normals with 1 completely different normal



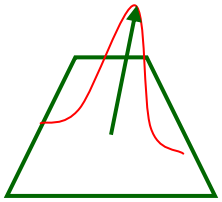
- Not re-normalizing shortens that normal
  - Scales down dot-product

What We Really Want

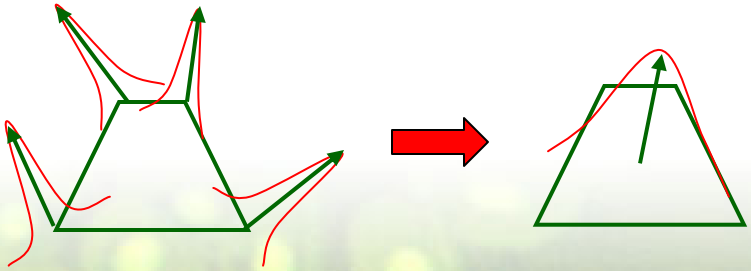
- N • H is a hack
  - N represents all normals in texel
- Integrate over all normals in texel
  - Integral is N • H only if all N in texel are the same
  - Not true for mipmaps

How To Integrate

- Approximate dot-product via Gaussian:
  $(N \bullet H)^s = \cos^s \alpha \approx e^{-\frac{1}{2} s \alpha^2}$



- Gaussians with standard deviation
  - Sum of them is another Gaussian with standard deviation



After A Lot Of Math…

- Dot-product with Gaussian is:
  $N_a = \sum_i N_i$
  $f_t = 1/(1 + s\,(1/|N_a| - 1))$ (Toksvig factor)

  specular term = $f_t\,((N_a \bullet H) / |N_a|)^{f_t\,s}$

Corner Cases

- Dot-product with Gaussian is:
  $N_a = N$
  $f_t = 1/(1 + s\,(1/|N_a| - 1))$ (Toksvig factor)

  specular term = $f_t\,((N_a \bullet H) / |N_a|)^{f_t\,s}$

Corner Cases

- Dot-product with Gaussian is:
  $N_a = N$
  $f_t = 1/(1 + s\,(1/|N| - 1)) = 1$

  specular term $= 1\,(\,(N \bullet H) / |N|)^{1\,s}$
  $= (N \bullet H)$

Another Corner Case

- Dot-product with Gaussian is:
  $N_a = \sum_i N_i = 0$
  $f_t = 1/(1 + s\,(1/0 - 1)) = 0$

  specular term = $0\,(\,(0 \bullet H) / 0)^{0\ s}$

Effect

- Length of normal expresses distribution
- Constant normal across texel
  - Computes sharp high-lights
- Widely varying normals across texel
  - High-light faints and widens

Messy Formula To Compute?

- Function $f_t((N_a \bullet H) / |N_a|)^{f_t s}$ depends on
  - s (constant)
  - $N_a \bullet H$
  - $N_a \bullet N_a$
- 2D texture look-up: $tex(N_a \bullet H, N_a \bullet N_a)$
  - Different 2D textures for different s

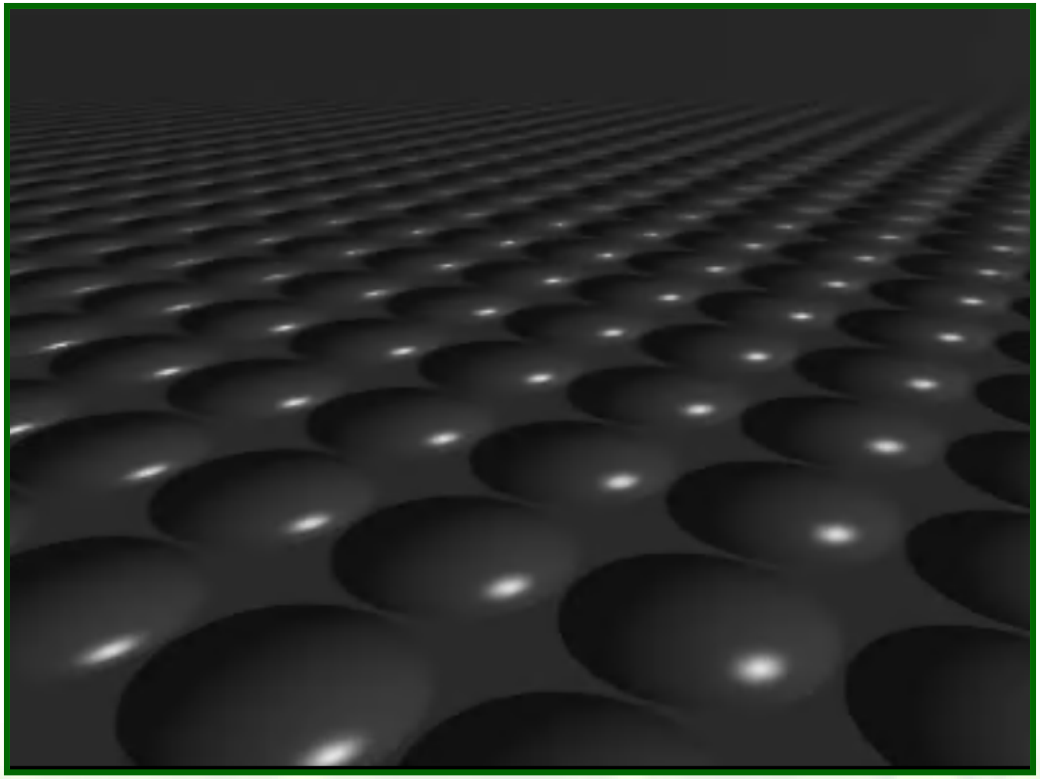
Implementation

- Generate mipmaps via averaging
  - Leave vectors un-normalized!
- Fetch N_a
  - Fp16 to minimize precision errors
  - Anisotropic filtering for best results

Implementation Continued

- Compute $N_a \bullet H$ and $N_a \bullet N_a$
- Fetch specular using those coordinates
  - Since it is a function look-up:
  - Bilinear only
  - No mipmaps
  - 128x128 works ok

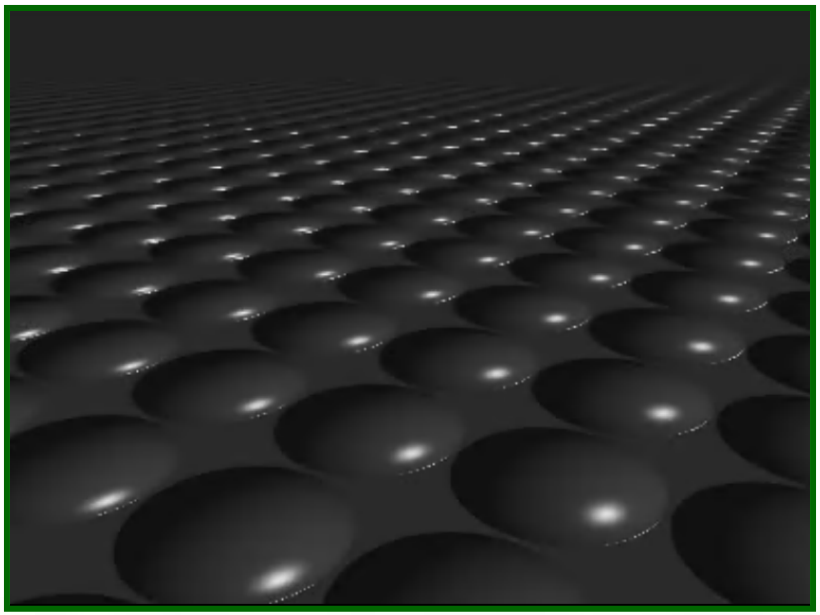
Result and Observations



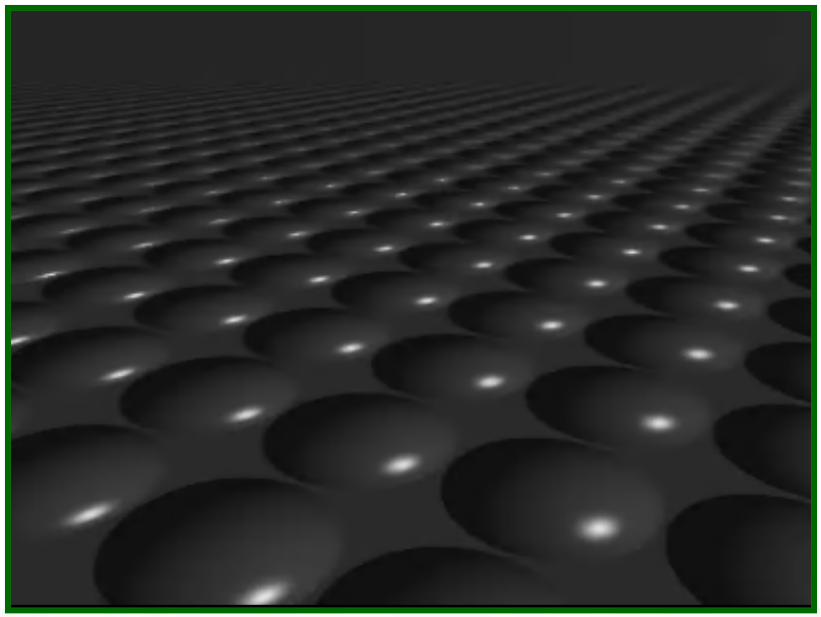
- Short normals in base-level: reduced specularity
- Specialize normal mipmap generation
- Applies to interp. vertex normals
- Applies to reflection-map lookups (LOD them)

Before/After Comparison

Before



After



Questions, Comments, Feedback?

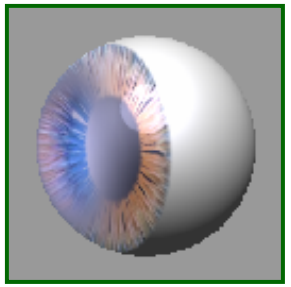
- mwloka@nvidia.com
- **http://developer.nvidia.com**
  The Source for GPU Programming
- Slides available online

More Rendering Techniques: NVIDIA's SDK 7.0

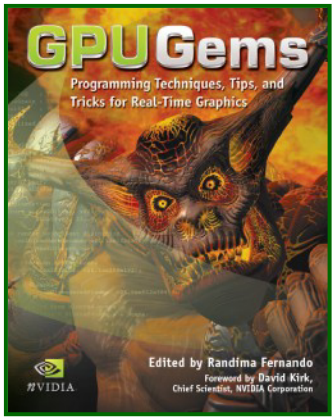
- 200+ rendering techniques
- CD available @ NVIDIA's booth
- Free

Other Rendering Technique Talks

- Cinematic Effects II: The Revenge
  - Wed, 9-10am



- *GPU Gems* Showcase
  - Wed, 5:30-6:30pm



- Real-Time Translucent Animated Objects
  - Fri, 2:30-3:30pm