Interactive Image-Space Techniques for Approximating Caustics

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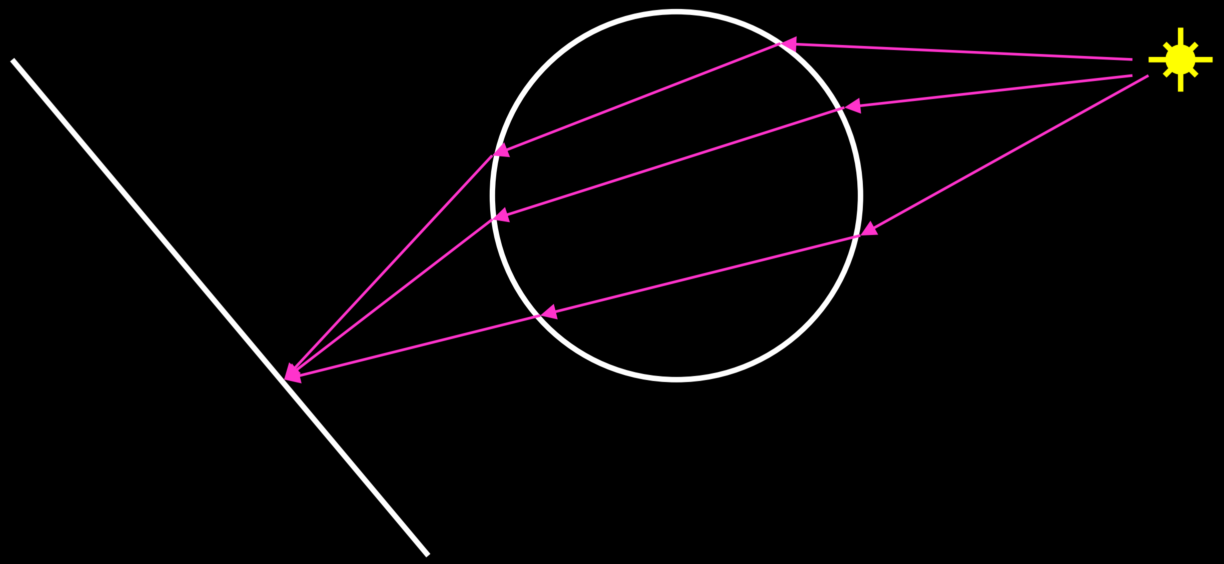
Motivation

- Realistic rendering
  - – Anytime a specular object reflects / refracts

What is a Caustic?

- Focusing of light
  - – Key idea: a point “sees” light multiple times



Challenge for Interactivity

- High frequency
  - Need lots of photons
  - Interpolation leads to blurring
- Photons *converge* & *diverge*
  - Rasterization likes coherent rays
- Complex data structures
  - E.g., kd-trees or 3D grids
  - Not GPU friendly

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Previous Work

- Particle tracing
  - Path tracing [Kajiya86]
  - Photon mapping [Jensen96]
  - Parallel CPUs for interactivity [Wald02]
  - With hardware acceleration [Purcell03,Woop05]
  - Tracing through object samples [Wand03]
- Beam tracing
  - For underwater caustics [Watt90]
  - Underwater caustic volumes with scattering [Nishita94]
  - Hardware accelerated caustic volumes [Iwasaki02]
  - Warped caustic volumes [Ernst05]

Previous Work

- Results depend on specular model
  - Planar geometry [Diefenbach97]
  - Virtual geometry [Ofek98, Schmidt03]
  - Pseudo-refraction [Oliveira00, Hurley00, Lindholm01]
  - Light field reflections [Yu05]
  - Image-space refractions [Wyman05]
- Better specular models gives better caustics
  - Reflection & refraction an important part of caustics research

Rendering Caustics

- Usually a two-pass process:
  – Shoot photons from the light
    - Record final locations
    - Store in data structure for easy access
  – Render from the eye
    - At visible surface points find “nearby” photons
    - Weight and average nearby photons
    - Add to direct lighting

Our Algorithm

- Maintains standard two-pass process
  - Splits gather into 2 passes

1. Use GPU to find photons hit locations
2. Determine photon locality
   - Three options:
     - Render “caustic triangles” onto surfaces *(see paper)*
     - Render photons into light-space buffer
     - Render photons directly in eye-space
3. Render from eye

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Implementation

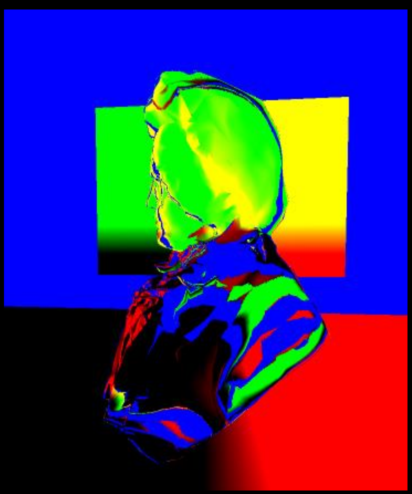
1. Render photons from light view
   - Store photon positions and depth map
   - (Optional) store photon direction, attenuation, surface normal
2. Render photons (as points)
   - Splat photons or perform image-space Gaussian blur
   - Draw into light-space map or directly in eye-space
3. Render from eye
   - Project light-space map like a shadow map

Photon Shooting

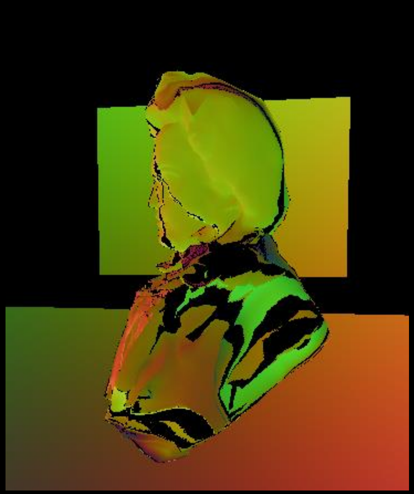
- Render from light
  - Use any existing reflection or refraction technique
  - Similar to shadow mapping

Standard Rendering From Light's View

Depth Map



Final Photon Locations



Incident Photon Direction

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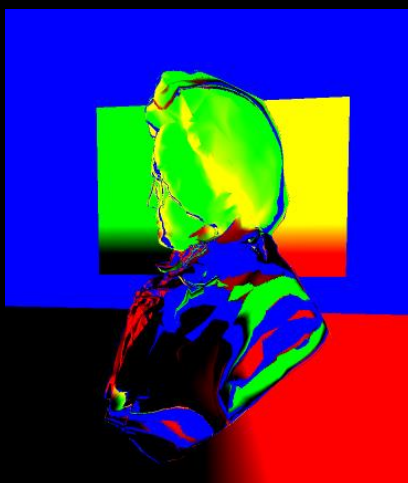
Photon Gathering



Use photon data in vertex shader, render points at photon locations

Light Space

Eye Space

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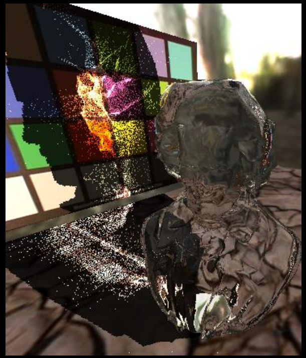
Photon Gathering

- Directly visualizing photons is noisy
  - Cannot feasibly shoot enough
  - Photons are ideal points
    - Want to find irradiance (over area of a visible pixel)
  - Average over "nearby" photons



- Without complex data structure:
  - Find nearby photons in image space!
    - [Gunther04] proposed for distributed ray traced caustics

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Photon Gathering

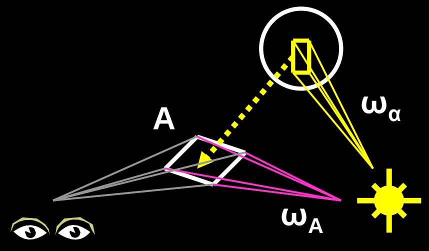
- For real-world distance ε to search:
  - Some NxN region contains all photons within ε
  - Region also contains extra photons
  - Used stored position to ignore extra photons
  - We used a fixed 7x7 region
    - Equivalent to a fixed-size nearest neighbor query

- Or splat photons into image-space
  - Use alpha-blending
  - Not discussed in paper… But faster!

Intensity Determination

- Gather radiance over small area
  - Assumes all units physically based
  - OpenGL / DirectX apps usually use arbitrary units
- Idea: Caustics see the light multiple times
  - Count how many times photons hit a point
  - Use the *ratio* at each pixel:
    - (# photons w/caustics) / (# photons w/o caustics)
  - Be aware: Not all photons are equal!

Intensity Determination



- Each photon has energy:

$$E_\alpha = (\omega_\alpha / 4\pi)\, E_L$$

  – Based on solid angle (ω_α) photon covers

- Each eye-view pixel corresponds to region A
  – This region subtends some solid angle (ω_A) seen from the light
  – Without caustics, A would receive energy:

$$E_A = (\omega_A / 4\pi)\, E_L$$

- Total energy can then be computed (a ratio):

$$E_{total} = \sum_{\alpha_i \text{ in } A} (E_{\alpha_i} / E_A)$$

(See paper for computing ω_A)

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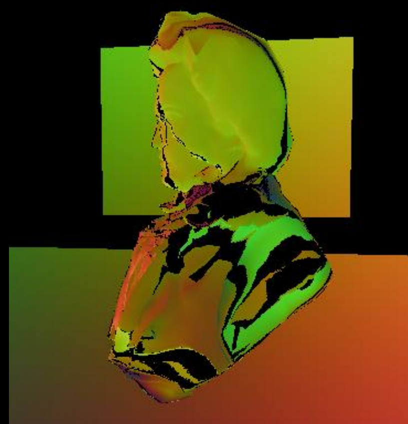
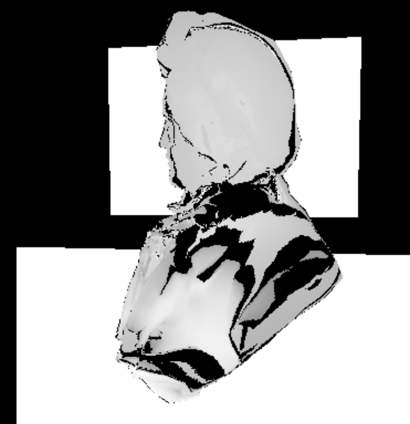
Non-Diffuse Receivers

- Irradiance not always enough!
  - Specular surfaces get different contribution from each photon
  - When splatting or gathering photons, account for direction



Incident photon direction



Photon attenuation
(Fresnel or volumetric)

- Also consider photon attenuation

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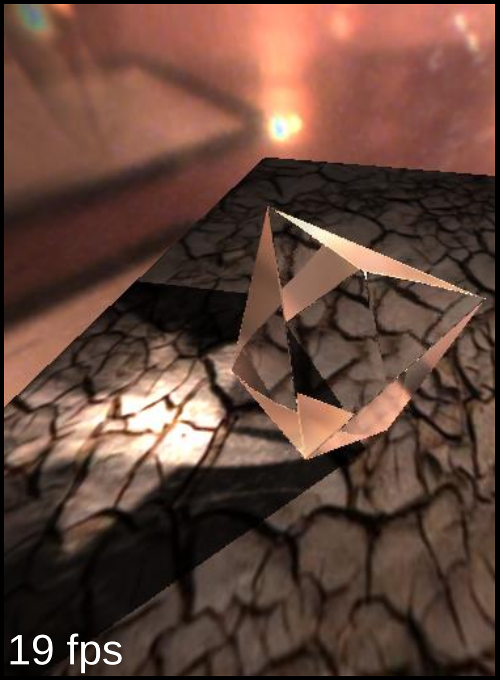
Results



Rendering speed dominated by photon count, as each photon is rendered as a vertex.

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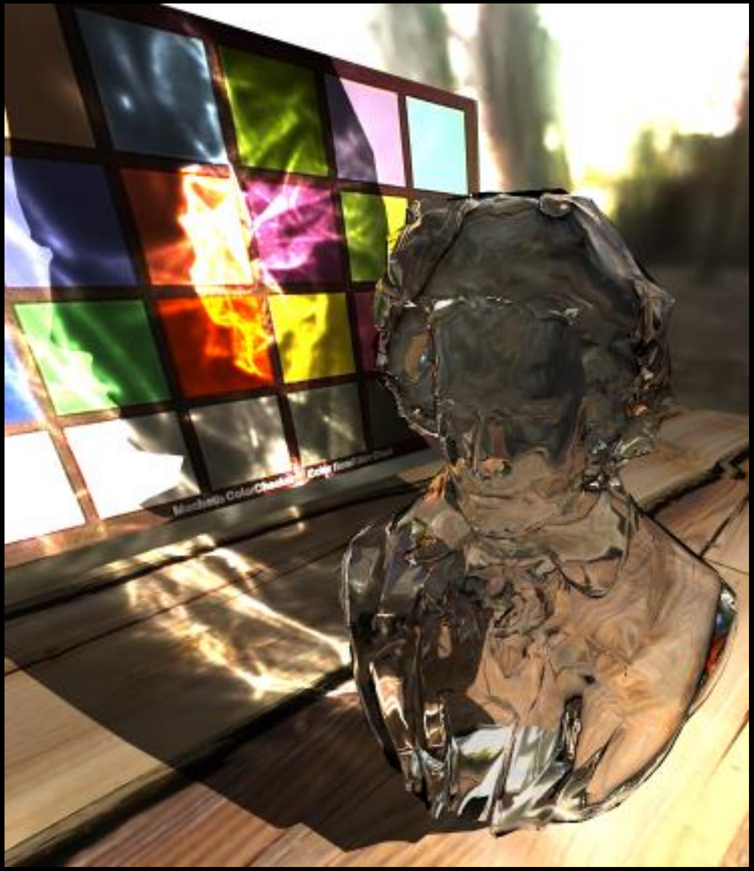
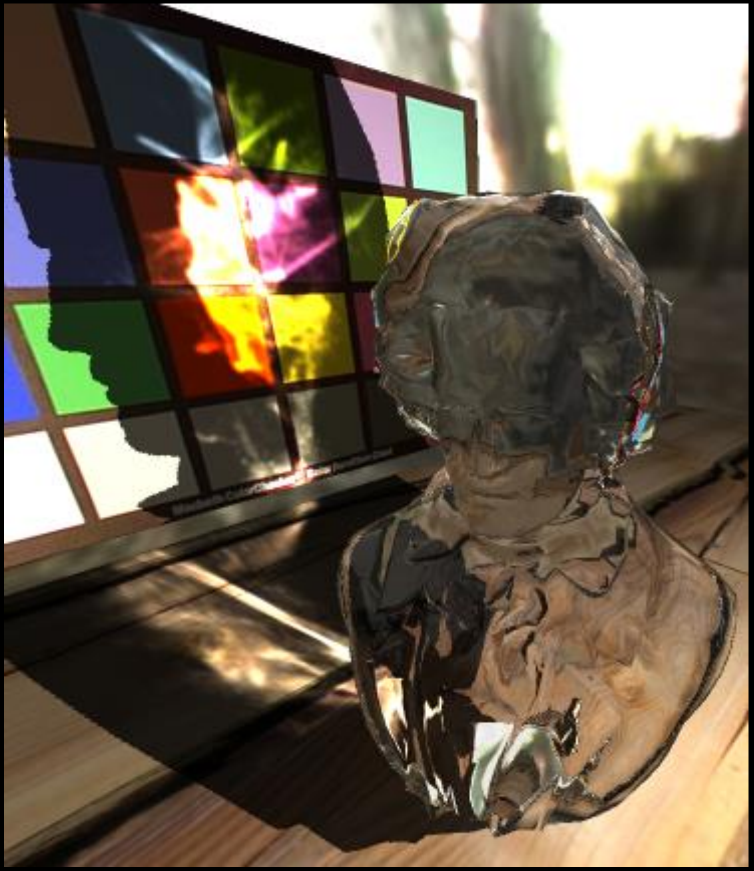
Results



Photon Map



Our Approach
(Note: Only refracted photons traced)

Demo

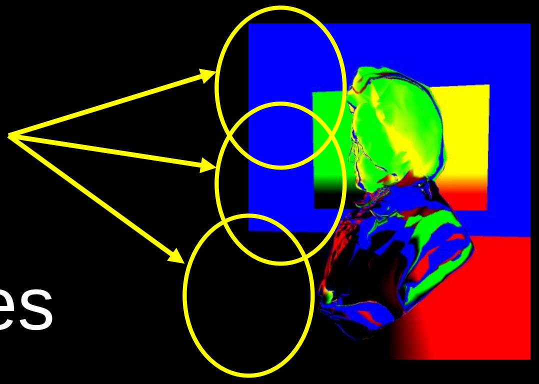
- 1.83 GHz Intel Core Duo
- nVidia GeForce Go 7800, 256 MB

- Framerates:
  - 10 – 30 fps
  - 512^2 photons (about 1/3 hit refractors)
  - 512^2 image resolution
  - Models 1,000 – 100,000 triangles

- Gathering photons over multiple frames reduces noise

Limitations

- Noise
  - Under sampling
  - Cannot gather from dynamically sized nearby regions
  - Coherency between frames difficult for dynamic scenes
- Inherited problems from specular techniques
  - Ray - b/g object intersection speed a factor for us
- "Wasted" photons
  - Not all photon buffer pixels useful
  - Expensive waste
- Limited to point light sources



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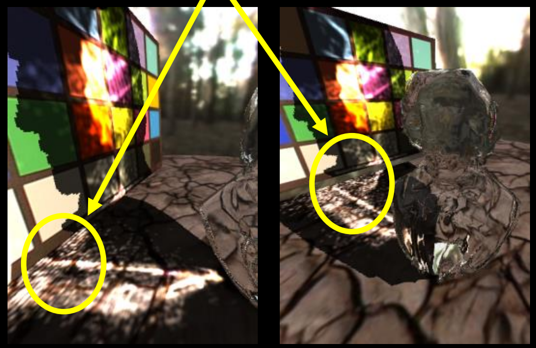
Conclusions

- Adapts photon mapping for GPUs
  - Image-space gather instead of a search
- Physically based
  - Approximation errors come from refraction technique
- Can gather in either eye- or light-space
  - Tradeoff: blur ↔ noise
  - Tradeoff: aliasing ↔ varying gather with viewpoint

Suggest: gather in light-space



Future Work

- Reducing noise
  - Adaptive photon buffer?
  - Perspective photon buffer?
  - Dynamically sized nearby neighbor search?
    - Maintain crisp caustics while reducing noise
    - Use fewer photons without temporal coherency issues
    - Good preliminary results
- Importance sampling
  - Eliminate “wasted” photons

Questions?