GPU-based Accelerated Spectral Caustic Rendering of Homogeneous Caustic Objects

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What is Caustics?

Refractor/reflecter (Caustic Object)

Light source from bottom plate

Caustics
Spectral Caustics

- Refraction index varies across the visible wavelength
- Typical implementation: compute three times, each for R, G, and B channels and may suffer from ‘broken’ caustics
- Correct approach: redo all caustic computation for each visible wavelength
Related Work

- Various rainbow-like effect, such as Light interference on a thin layer (Sun et al. 1999) and Diffraction (Imura et al. 2003)
- Spectral information compression, such as a set of linear basis functions (Marimont and Wandell 1992)
- Photon mapping with spectral rendering, i.e. store the photons in RGB representation (hence conversion spectral <-> RGB representations is necessity) : Lai and Christensen 2007, Hachisuka 2007
Our Work (1/2)

• Accelerate the full spectrum caustic computation while maintaining the quality
• Render using Stochastic Progressive Photon Mapping
• Two-step acceleration scheme:
  – Cluster the wavelength based on refraction similarity: to reduce the number of intersection tests
  – Determine the number of iterations based on our defined importance level
Our Work (2/2)

• Combine both steps
  – Refine each cluster (from 1\textsuperscript{st} acceleration scheme) with the amount of refinement computed from the 2\textsuperscript{nd} acceleration scheme
• Is implemented using OptiX, a CUDA-based ray-tracer engine
• The work has been published at:
  http://link.springer.com/article/10.1007/s00371-014-1037-z
Acceleration Scheme 1

- Basic idea: If the index of refraction for a range of wavelength is almost similar, then the rays of those wavelength will be refracted to almost the same direction. Hence, cluster the rays in this range of wavelength into a ray.
- To reduce the number of intersection tests.
- Cluster based on the change of the refraction angle with respect to the change of wavelength.
Acceleration Scheme 2 (1/2)

- Each wavelength should be refined with different amount depending on its importance level:

\[ u(\lambda) = l(\lambda) y(\lambda) \sum_i m_i(\lambda) L_i \hat{g}_i \]

Lightness

![Diagram showing CIE D65, Light Power, Luminosity Function, and Surface Reflectance graphs.](image-url)
Acceleration Scheme 2 (2/2)

- We also take into account the geometrical distribution of the surface material:
  \[ u(\lambda) = l(\lambda)y(\lambda) \sum_i m_i(\lambda)L_i \hat{g}_i \]
- Materials whose surfaces received more caustics should be given more weight/priority
- Use spherical uniform sampling

We sample the material types of the surrounding surfaces from the bounding box (blue box) corners and the center of the caustic object. The numbers denote the material type. As shown in the figure, sampling of material #3 is higher as the smaller box enclosing the caustic object has material #3. Some parts of material #0 and #2 are sampled, and none of material #1 is sampled.
GPU Implementation

- Precomputation
- Camera Pass
- Photon Shooting
- Photon Gathering

SPPM Iteration

Wavelength Cluster Pass
Precomputation

• Done in CPU

• All the necessary startup process
  – Compute the clustering
  – Compute the amount of iteration for each cluster
Camera Pass

- To compute direct illumination and visible points
- Output the accumulated direct lighting: light power * reflectance * eye response function for the wavelengths in the current cluster pass
- Also output geometrical information: intersection point coordinate and normal
Photon Shooting Pass

• First pass of indirect illumination computation
• Each photon carries power of the wavelengths in the current cluster pass
• Power of each photon is stored in a ‘flattened’ 2D buffer (to 1D)
  – Row = one photon
  – Column = one wavelength
Photon Gathering Pass (1/2)

- Second pass of indirect illumination computation
- A temporary flux buffer to store gathered photon flux
  - For each gathered photon, accumulate their flux (multiplied by surface reflectance) for each wavelength in the current cluster pass
  - Row = One visible pixel
  - Column = One wavelength
Photon Gathering Pass (2/2)

• Update the shared accumulated flux (based on the temporary flux of current iteration and shared accumulated flux) for each wavelength in the current cluster pass

• To visualize, multiply and accumulate the shared accumulated flux with eyes response function for each wavelength and combine with the direct illumination result
Experiments

- CPU: Intel I7-3820 3.60 GHz and GPU: GTX 690 4 GB
- Was implemented in OptiX
  - GPU-based ray tracing engine, was built over CUDA
- Maximum iterations for each nm: 2000
- Minimum nm step: 1 nm
- Threshold: 0.1 degree
Results (1/4)

<table>
<thead>
<tr>
<th>Method</th>
<th>Time</th>
<th>Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brute Force</td>
<td>38.62 hours</td>
<td>802000</td>
</tr>
<tr>
<td>Ours</td>
<td>0.28 hours</td>
<td>5088</td>
</tr>
<tr>
<td>Radziszewski et al.</td>
<td>2.31 hours</td>
<td>47341</td>
</tr>
<tr>
<td>IOR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) 38.62 hours, 802000 iterations (b) 0.28 hours (speed up 137.93 times), 5088 iterations (c) 2.31 hours (speed up 16.72 times), 47341 iterations

Natural, N-SF66
Results (2/4)

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<thead>
<tr>
<th>Method</th>
<th>Time (hours)</th>
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</thead>
<tbody>
<tr>
<td>Brute Force</td>
<td>37.95</td>
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<tr>
<td>Ours</td>
<td>2.99</td>
<td>60301</td>
</tr>
<tr>
<td>Radziszewski et al.</td>
<td>11.10</td>
<td>233106</td>
</tr>
<tr>
<td>IOR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(e) 2.99 hours (speed up 12.69 times), 60301 iterations
(f) 11.10 hours (speed up 3.42 times), 233106 iterations
Results (3/4)

Brute Force

Ours

Radziszewski et al.

IOR

(g) 33.57 hours, 802000 iterations (h) 3.46 hours (speed up 9.70 times), 78714 iterations (i) 9.90 hours (speed up 3.39 times), 231239 iterations

Artificial
Results (4/4)

Brute Force
(j) 33.96 hours, 802000 iterations

Ours
(k) 1.94 hours (speed up 17.51 times), 37699 iterations

Radziszewski et al.
(l) 2.12 hours (speed up 16.02 times), 41572 iterations

IOR

Natural, Rose Bengal 10% Solution
Application

• Caustic object design and visualization
• Design the caustic object (e.g. a gemstone, crystal vase, glass bracelet, etc.) and use our method to render it to observe the refraction and caustic effects
• The rendering can be implemented in a renderfarm system, similar to our GPU renderfarm system presented in GTC 2014 (Season S4356)
Conclusion (1/2)

- Main strength of our method:
  - Quality of our rendering result is close to Brute Force rendering result
  - Also, we achieve rendering speed acceleration with the acceleration magnitude from tens to thousands
  - Compared to Radziszewski et al.’s, we also achieve higher acceleration
Conclusion (2/2)

- Limitations:
  - Consider only single type of caustic object IOR
  - Not optimized for dynamic scene
Future Work

- Handle scene that has multiple caustic objects, each with different index of refraction
- Sample the surrounding caustic objects by using real-time approximate caustic renderer
- Apply our acceleration scheme to other rendering algorithms
Acknowledgements

• Singapore National Research Foundation under its IDM Futures Funding Initiative and administered by the Interactive & Digital Media Programme Office, Media Development Authority

• Ministry of Education Singapore for the Tier-2 research funding support

• Fraunhofer IDM@NTU, which is funded by the National Research Foundation (NRF) and managed through the multiagency Interactive & Digital Media Programme Office (IDMPO) hosted by the Media Development Authority of Singapore (MDA).
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