Fast Separation of Direct and Global Images Using High Frequency Illumination

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Related Works

- **Inverse Light Transport (Seitz et. al. ICCV 05)**
  - Estimates interreflections contribution given the number of reflections
  - Based on Lambertian assumption and large amounts of data need

- **Dual Photography (Sen et. al. Siggraph 05)**
  - Estimates the transport matrix between camera and projector
  - Still requires a lot of images
  - Don’t need full transport matrix
Direct and Global Components

• Direct Components
  • The radiance of a scene point due to illumination from the source directly

• Global Components
  • Radiance of a scene point due to illumination from other points in the scene
  • Interreflections
  • Subsurface scattering
  • Volumetric scattering
  • Translucency
Direct and Global Components

\[ L[c, i] = L_d[c, i] + L_g[c, i] \]

Radiance = Direct Component + Global Component

\[ L_g[c, i] = \sum_P A[i, j] L[i, j] \]

The sum of all interreflections from all patches

\[ A[i, j] \]

BRDF and Geometry

\[ L[i, j] \]

Radiance of patch \( j \) in the direction of patch \( i \)

\[ L_g[c, i] = L_{gd}[c, i] + L_{gg}[c, i] \]

\[ L_{gd}[c, i] = \sum_P A[i, j] L_d[i, j] \]

2nd order of the form as above

\[ L_{gg}[c, i] = \sum_P A[i, j] L_g[i, j] \]
Interreflections

\[ L[c, i] = L_d[c, i] + L_g[c, i] \quad L_g[c, i] = \sum_{P} A[i, j] L[i, j] \]
High Frequency Illumination Pattern

Source

Camera

Surface
Direct and Global Components

\[ L_g[c, i] = L_{gd}[c, i] + L_{gg}[c, i] \]

\[ L^+_{gd}[c, i] = \sum_Q A[i, j] L_d[i, j] \quad L^+_{gg}[c, i] = \sum_P A[i, j] L_g[i, j] \]

If \( A \) is smoothing and we sample at high enough frequency

\[ L^+_{gd}[c, i] = \alpha L_{gd}[i, j] \]

\[ L^+_{gg}[c, i] = \alpha L_{gg}[i, j] \quad \alpha = \text{Fraction of the patches lit} \]

\[ L^+[c, i] = L_d[c, i] + \alpha L_g[c, i] \]
High Frequency Illumination Pattern

\[ L^+[c,i] = L_d[c,i] + \alpha L_g[c,i] \]
\[ L^-[c,i] = (1-\alpha)L_g[c,i] \]

\[ L^+[c,i] = L_d[c,i] + \alpha L_g[c,i] + b(1-\alpha)L_g[c,i] \]
\[ L^-[c,i] = bL_d[c,i] + (1-\alpha)L_g[c,i] + \alpha bL_g[c,i] \]
Subsurface Scattering

Source

Camera

Translucent Surface
Volumetric Scattering

Source

Camera

Translucent Surface
Experiment System

• Using a scene with variety of physical phenomena
• Scene is lit with a 1024x768 Projector
• Images were captured with a same size (1024x768) camera
  • Due to the Bayer filter and the noise it incurs
  • 32 takes of the same scene was averaged per image

A: Diffuse Interreflection (Board)
B: Specular Interreflection (Nut)
C: Subsurface Scattering (Marble)
D: Subsurface Scattering (Wax)
E: Translucency (Frosted Glass)
F: Volumetric Scattering (Dil. Milk)
G: Shadow (Fruit on Board)
Experiments

- **Experiment 1**
  - Vary the size of the illumination patch used to construct the high frequency pattern
  - From 3 to 11

- **Experiment 2**
  - Lit the scene with 100 different illumination patterns
  - Kept points of interests unlit @ 6x6 patch

- **Experiment 3**
  - Vary alpha

- **Experiment 4**
  - Vary the frequency of the checkerboard patterns
Experiment 1: Unlit Surrounding Patch

- A: Diffuse Interreflection (Board)
- B: Specular Interreflection (Nut)
- C: Subsurface Scattering (Marble)
- D: Subsurface Scattering (Wax)
- E: Translucency (Frosted Glass)
- F: Volumetric Scattering (Dil. Milk)
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### Experiment 2: Randomized Lighting

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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<td>35.1</td>
<td>43.8</td>
<td>67.4</td>
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<td>5.5</td>
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<td>7.1</td>
<td>0.9</td>
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</tbody>
</table>

- A: Diffuse Interreflection (Board)
- B: Specular Interreflection (Nut)
- C: Subsurface Scattering (Marble)
- D: Subsurface Scattering (Wax)
- E: Translucency (Frosted Glass)
- F: Volumetric Scattering (Dil. Milk)
- G: Shadow (Fruit on Board)
Experiment 3: Alpha Variation

A: Diffuse Interreflection (Board)
B: Specular Interreflection (Nut)
C: Subsurface Scattering (Marble)
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Experiment 4: Vary Checkerboard Frequency
Checkboard Illumination Shifts

Due to some light-leakage and defocusing from the projector, more than two images were taken to minimize error.

A 8x8 pixel checkboard pattern (alpha = 0.5) was advanced by 3 pixels 5 times in each direction, for a total of 25 images. The min and max ($L_{\text{min}}$, $L_{\text{max}}$) were found per pixel, in turned used for computing direct and global illumination ($L_d$, $L_g$).
Results

Scene

Direct

Global
Results

Scene

Direct

Global
Results

Scene

Direct

Global
Novel Image
Results

Scene

Direct

Global
Variants of Separation Method

- Coded Structured Light
- Shifted Sinusoids

Rather than using a projector, utilize a natural light source and occlude.

- Shadow of Line Occluder
- Shadow of Mesh Occluders
Results
Results

Scene

Direct

Global
Photometric Stereo using Direct Images

Source 1  Source 2  Source 3

Bowl

Global

Direct

Shape

Nayar et al., 1991
Single Image Separation

Utilize an $n \times m$ window around pixels.

Save the value if it is the min or max in its window.

Interpolate to generate full resolution image.

Reduce resolution by a factor of $k$ through averaging.
Failure Case

Direct

Global

Scene
Score: 2 (accept)

Pros:

Simple Concept
Lots of results
Photometric Stereo confirmation

Cons:

Mainly qualitative approach for proving effectiveness
Appendix could be clarified
No details on how source occluders were removed from images
Additional Results
Results
Results

Scene

Direct

Global