Environment Matting
Blue screen matting

input image

alpha composite
Problem: blue foreground

source image

alpha composite
Two-screen matting

alpha composite
Problem: refractive object

alpha composite
Problem: refractive object

alpha composite

photograph
Refracted image of a single pixel
Refracted image of a single pixel
Refracted image of a single pixel
Environment matting framework
C =

composite

background
\[ C = F \]

- **C**: composite
- **F**: foreground
- **T**: background
\[ C = F + (1 - \alpha)B \]
\[ C = F + \int W T \]
\[ C = F + \int W \]
\[ C = F + \int W \, T \]
Arbitrary weighting function
Arbitrary weighting function
Hierarchical environment matting

Zongker et. al.

SIGGRAPH 1999
\[ C = F + (1 - \alpha) B + RM(T, A) \]
Acquisition setup
Hierarchical backgrounds
Hierarchical backgrounds
Searching for $\alpha$ and $A$

$$E = \sum \left| C_{\text{observed}} - C_{\text{computed}}(\alpha, A) \right|^2$$

hypothesize $\alpha$ and $A$
Separate $x$ and $y$ extent searches

$$(\alpha, l, r)$$

$$(\alpha, t, b)$$
Environment matte composite
\[ C = F + (1 - \alpha)B + R \mathcal{M}(T, A) \]
Results and comparisons

environment matte composite

alpha matte composite
Results and comparisons

environment matte composite  photograph
Results and comparisons

environment matte composite

alpha matte composite
Results and comparisons

environment matte composite

photograph
Results and comparisons

environment matte composite

alpha matte composite
Results and comparisons

environment matte composite
glassware
photograph
Results
Reflective objects
Many rays not captured
Add sidedrops to capture these rays
Capturing multiple sides
Contributions from multiple sides
Depth correction
Capturing at a single depth
Capturing a second depth
Constructing the 3D beam
Rendering at novel depths
Rendering at novel depths
Problem: glossy surface

environment matte composite  photograph
Problem: multiple mappings

environment matte composite

photograph
Problem: color dispersion

environment matte composite

photograph
Problem: many photographs needed
Environment matting

higher accuracy \quad O(\log n) \quad \text{fewer images}
Towards higher accuracy

higher accuracy $O(n)$ fewer images $O(\log n)$
Towards real-time capture

higher accuracy

$O(n)$  $O(\log n)$  1

fewer images
Real-time environment matting

Chuang et. al.

SIGGRAPH 2000
\[ C = F + (1-\alpha)B + RM(T,A) \]
\[ C = F + (1 - \alpha) B + R M(T, A) \]

3 observations
11 variables

• A, R
• \alpha
• F
\[ C = R \mathcal{M}(T, A) \]

3 observations
7 variables

• \( A, R \)
• \( \alpha \)
• \( F \)
$$C = \rho M(T, A)$$

3 observations

5 variables

• $A, R \rightarrow A, \rho$
• $\alpha$ colorless
• $F$
\[ C = \rho \ T(c_x, \ c_y) \]

3 observations
3 variables

• \(A, R \rightarrow A, \rho \rightarrow c_x, c_y, \rho\)
• \(\alpha\) colorless specularly refractive
• \(F\)
Estimate $w_x, w_y$
Stimulus function

\[ M(T, A) \approx T(c_x, c_y) \]
Ideal plane in RGB cube

$T(x, y)$
Calibrated manifold in RGB cube

$T(x, y)$

$C'$

$(c_x, c_y)$
Estimate $c_x, c_y$ and $\rho$

$$C' \rightarrow (c_x, c_y)$$

$$\rho = \frac{\|KC\|}{\|KC'\|}$$
Difference thresholding
Morphological operation
Feathering
Problem: noisy matte
Edge-preserving filtering

- isotropic filter
- anisotropic filter
Edge-preserving filtering

without filtering  with filtering
Heuristics for specular highlights

\[ \rho > 1 + \varepsilon \]

background manifold

Diagram showing \( W \), \( K \), and \( T \) with \( \rho > 1 + \varepsilon \) and \( C \).
Heuristics for specular highlights
\[ C = \rho T(c_x, c_y) \]
Heuristics for specular highlights

input - estimation = foreground (highlights)
Composite with highlights
Towards higher accuracy

higher accuracy  \( O(n) \)  \( O(\log n) \)  fewer images
Arbitrary weighting function
Multimodal oriented Gaussian
Multimodal oriented Gaussian
Multimodal oriented Gaussian

- Better BRDF approximation
- Multiple mappings
- Wavelength-coupled variation
Unimodal axis-aligned Gaussian composite background
Unimodal axis-aligned Gaussian
Unimodal axis-aligned Gaussian
Unimodal axis-aligned Gaussian
Unimodal axis-aligned Gaussian

\[ \sigma_s \]

composite

\[ \sqrt{\sigma_u^2 + \sigma_s^2} \]

background
Unimodal axis-aligned Gaussian
Unimodal axis-aligned Gaussian
Unimodal axis-aligned Gaussian
Unimodal oriented Gaussian
Multimodal oriented Gaussian
Multimodal oriented Gaussian
Multimodal oriented Gaussian
Glossy surface

SIGGRAPH 99 photograph
Glossy surface

higher accuracy algorithm

photograph
Oriented Gaussian

without orientation  photograph
Oriented Gaussian

with orientation

photograph
Multiple mappings

SIGGRAPH 99  photograph
Multiple mappings

higher accuracy algorithm

photograph
Color dispersion

SIGGRAPH 99

photograph
Color dispersion

higher accuracy algorithm

photograph
Frequency-based environment matting

Zhu et. al.

Pacific Graphics 2004
Frequency-based environment matting

$B(x_1, t)$
$B(x_2, t)$

$x_1$
x_2

$C(t)$

spectrum of $C$
Results: refraction

frequency-based environment matting

photograph
Results: color dispersion

frequency-based environment matting

photograph
Results: oriented

frequency-based environment matting

photograph
Results: oriented

frequency-based environment matting  photograph
Wavelet environment matting

Peers et. al.

EGSR 2003
Wavelet environment matting

\[ B = \sum a_i B_i \]

\[ C = \sum a_j C_j \]
Results: number of basis images

reference image

1200 basis images
Results: number of basis images

reference image

1200 basis images
Results: wavelet patterns

- Reference image
- 1000 Haar patterns
- 1000 Daubechies (9,7) patterns
Results: wavelet patterns

Reference image

1000 Haar patterns

1000 Daubechies (9,7) patterns
Results: wavelet patterns

reference image

1000 Haar patterns

1000 Daubechies (9,7) patterns
Results: diffuse materials
Image-based environment matting

Wexler et. al.

EWSR 2002
Image-based environment matting
Image-based environment matting
Image-based environment matting
Results
Results
## Comparisons

<table>
<thead>
<tr>
<th>category</th>
<th>method</th>
<th>asymptotic # of images</th>
<th>typical # of images</th>
<th>weighting function</th>
<th>materials</th>
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<tbody>
<tr>
<td>active</td>
<td>RTEM</td>
<td>$1$</td>
<td>$1$</td>
<td>warping function</td>
<td>colorless, speculally refractive</td>
</tr>
<tr>
<td></td>
<td>HEM</td>
<td>$O(\log k)$</td>
<td>$20$</td>
<td>box filter</td>
<td>refraction, translucency, highly specular, color transparency</td>
</tr>
<tr>
<td></td>
<td>GEM</td>
<td>$O(k)$</td>
<td>$600$</td>
<td>sum of Gaussians</td>
<td>+color dispersion, multiple mappings and glossy reflection</td>
</tr>
<tr>
<td></td>
<td>FBEM</td>
<td>$O(k)$</td>
<td>$1,200$</td>
<td>product of two 1D functions</td>
<td>-multiple mappings</td>
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<tr>
<td></td>
<td>WEM</td>
<td>$O(k^2)$</td>
<td>$1,200$</td>
<td>object images</td>
<td>+diffuse reflection</td>
</tr>
<tr>
<td>passive</td>
<td>IBEM</td>
<td>N/A</td>
<td>$40$</td>
<td>probability map</td>
<td>colorless, speculally refractive</td>
</tr>
<tr>
<td></td>
<td>ROEM</td>
<td>N/A</td>
<td>$200$</td>
<td>warping function</td>
<td>colorless, speculally refractive</td>
</tr>
</tbody>
</table>
Reference