Reflectance and Natural Illumination from a Single Image

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Reflectance and Illumination Estimation
Past Work on Reflectance and Illumination Recovery

**Reflectance Only**
- Klinker et al. ‘88
- Kay and Caelli ‘94
- Lu and Little ‘95
- Sato et al. ‘97
- Boivin and Gagalowicz ‘01
- Romeiro et al. ‘08
- Romeiro and Zickler ‘10
- Chandraker and Ramamoorthi ‘11
- Lombardi and Nishino ‘12
- Oxholm and Nishino ‘12

**Joint Recovery**
- Land and McCann ‘71
- Barrow and Tenenbaum ‘78
- Sinha and Adelson ‘93
- Tappen et al. ‘02
- Ramamoorthi and Hanrahan ‘04
- Hara et al. ’05, ’08
- Sunkavalli et al. ’08
- Hara and Nishino ’09, ’11

**Illumination Only**
- Sato et al. ’03
- Stumpfel et al. ’04
- Finlayson et al. ’04
- Kim and Hong ’05
- Basri et al. ’07
- Lalonde et al. ’09, ’11
- Mei et al. ’11
Past Work on Reflectance and Illumination Recovery

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**Simple Reflectance Model**
- [Kay and Caelli ‘94]
- [Lu and Little ‘95]
- [Sato et al. ‘97]
- [Boivin and Gagalowicz ‘01]
- [Romeiro et al. ‘08]
- [Romeiro and Zickler ‘10]
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- [Oxholm and Nishino ‘12]

**Simple Illumination Conditions**
- [Land and McCann ‘71]
- [Barrow and Tenenbaum ‘78]
- [Sato et al. ‘03]
- [Stumpfel et al. ‘04]
- [Finlayson et al. ‘04]
- [Sinha and Adelson ‘93]
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- [Hara and Nishino ‘09, ‘11]
- [Lalonde et al. ‘09, ‘11]
- [Mei et al. ‘11]

**Many input images**
Frequency Ambiguity
Color Ambiguity

Illumination

Reflectance

Observed Image
Constraining Reflectance and Illumination

\[ p(R, L | I) \propto p(I | R, L) p(R) p(L) \]

\[ p(I | R, L) = \prod_x \mathcal{N}(I_x | E_x(R, L), \sigma^2) \]
We can leverage natural image statistics!
Constraining Illumination: Natural Image Statistics

\[ p_s(L) \propto \prod_i \exp \left[ - \left| \frac{\partial}{\partial x} L_i \right|^\alpha - \left| \frac{\partial}{\partial y} L_i \right|^\alpha \right] \]

Log histogram of the derivatives of \( L \)

x derivative

y derivative
Constraining Illumination:
Entropy Increase Due to Reflectance

- Mirror
- Nickel
- Pink Jasper
- Silver Metallic Paint
- Green Latex

Entropy Increases
Blur Increases
Entropy Increases
Enforcing a Low-Entropy Illumination Estimate

• A prior that encourages low entropy

\[-\ln p_e(L) = H(L)\]

• Continuous entropy

\[H(L) = -\int p(x) \log p(x) \, dx\]

• Kernel density estimation (Gaussian kernel)

\[p(x) = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left[ -\frac{(x - L_i)^2}{2\sigma^2} \right]\]
Constraining Reflectance: A Statistical Approach

- Directional Statistics BRDF \[f_\lambda(\omega_i, \omega_o) = \sum_j \exp \left[ \kappa(j, \lambda)(\theta_d) \cos \gamma(j, \lambda)(\theta_d)(\theta_h) \right] - 1\]

- Simple but powerful prior \[p(R) \sim \mathcal{N}(0, \Sigma_R)\]
Color Ambiguity

• Perform estimation two times:
  – First constraining illumination to be greyscale
  – Next allowing illumination to be full color
How many lights are there?

We can’t know
Results: Synthetic

Input

Estimated Illumination

Ground Truth Illumination

Reflectance

Ground truth ‘alum-bronze’
Predicting the Appearance of Materials with Recovered Illumination

Input

<table>
<thead>
<tr>
<th>Material</th>
<th>Ground Truth</th>
<th>Relighting with estimated illumination</th>
</tr>
</thead>
<tbody>
<tr>
<td>alum-bronze under ‘Eucalyptus Grove’ lighting environment</td>
<td><img src="image1" alt="Ground Truth" /></td>
<td><img src="image2" alt="Relighting" /></td>
</tr>
<tr>
<td>violet-acrylic under ‘Uffizi Gallery’ lighting environment</td>
<td><img src="image3" alt="Ground Truth" /></td>
<td><img src="image4" alt="Relighting" /></td>
</tr>
</tbody>
</table>
Predicting Object Appearance from Different Views

Ground Truth

Input

Relighting with recovered reflectance and illumination

0°  90°  180°  270°

Ground Truth

Input

Relighting with recovered reflectance and illumination
Results:
Real-world
Results:
Real-world
Successful Estimation through the Right Priors

- Joint recovery requires tight constraints on reflectance and illumination
  - Novel entropy prior
  - Natural image statistic prior
  - DSBRDF reflectance prior
- Despite the inherit limits, we recover important illumination features to allow object appearance prediction

Entropy Increases

Natural Image Statistics

Constrain Reflectance

\[ f_{\lambda}(\omega_i, \omega_o) \]
Data set includes 6 objects in 5 natural illumination environments with calibrated ground-truth geometry

Source Code

available soon!

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Data

available soon!

cs.drexel.edu/~kon/natgeom