Visual Material Traits
Recognizing Per-Pixel Material Context

Gabriel Schwartz  
gbs25@drexel.edu

Ko Nishino  
kon@drexel.edu
What tells us this road is unsafe?
Material Category Recognition Methods

- Give single predictions for the entire image

Adelson [1]
Liu et al. [4]
Hu et al. [3]
Sharan et al. [6]

Images from [2].
Material Category Recognition Methods

- Give single predictions for the entire image
- Require object information
  - object mask
  - bounding box

Adelson [1]
Liu et al. [4]
Hu et al. [3]
Sharan et al. [6]

Images from [2].
Material Category Recognition Methods

- Give single predictions for the entire image
- Require object information
  - object mask
  - bounding box
- Predict categories that are really object properties

Adelson [1]
Liu et al. [4]
Hu et al. [3]
Sharan et al. [6]

Images from [2].
Material Category Recognition Methods

- Give single predictions for the entire image
- Require object information
  - object mask
  - bounding box
- Predict categories that are really object properties
- Object information not always available

Adelson [1]
Liu et al. [4]
Hu et al. [3]
Sharan et al. [6]

Images from [2].
Intra-Class Appearance Variability

Images from [7].
Visual Material Traits: Characteristic
Material Properties

Image from [5].
Visual Material Traits: Characteristic Material Properties

Material traits are locally-recognizable material properties.

Image from [5].
Visual Material Trait Appearances

- What material properties can we see locally?

Images from [7].
Visual Material Trait Appearances

- What material properties can we see locally?
- Certain properties are easy to describe

Images from [7].
What material properties can we see locally?

Certain properties are easy to describe

- Shiny

Images from [7].
Visual Material Trait Appearances

- What material properties can we see locally?
- Certain properties are easy to describe
  - Shiny
  - Smooth

Images from [7].
Visual Material Trait Appearances

- What material properties can we see locally?
- Certain properties are easy to describe
  - Shiny
  - Smooth
- Some are more challenging
Visual Material Trait Appearances

- What material properties can we see locally?
- Certain properties are easy to describe
  - Shiny
  - Smooth
- Some are more challenging
  - Fuzzy? Soft?

Images from [7].

7/22
Visual Material Trait Appearances

- What material properties can we see locally?
- Certain properties are easy to describe
  - Shiny
  - Smooth
- Some are more challenging
  - Fuzzy? Soft?

How do we represent these traits?
Learning to Represent Material Traits

- Learn features that model the appearance of material traits

- Features should be:
  - Fast to compute
  - Able to be extracted anywhere
  - Discriminative

- Convolution filters may satisfy all of these properties

- How do we learn them?
Learning to Represent Material Traits

- Learn features that model the appearance of material traits
- Features should be:

- Fast to compute
- Able to be extracted anywhere
- Discriminative

Convolution filters may satisfy all of these properties.

How do we learn them?
Learning to Represent Material Traits

- Learn features that model the appearance of material traits

- Features should be:
  - Fast to compute
Learning to Represent Material Traits

- Learn features that model the appearance of material traits
- Features should be:
  - Fast to compute
  - Able to be extracted anywhere

Convolution filters may satisfy all of these properties.
Learning to Represent Material Traits

- Learn features that model the appearance of material traits
- Features should be:
  - Fast to compute
  - Able to be extracted anywhere
  - Discriminative
Learning to Represent Material Traits

- Learn features that model the appearance of material traits

- Features should be:
  - Fast to compute
  - Able to be extracted anywhere
  - Discriminative

- Convolution filters may satisfy all of these properties
Learning to Represent Material Traits

- Learn features that model the appearance of material traits
- Features should be:
  - Fast to compute
  - Able to be extracted anywhere
  - Discriminative
- Convolution filters may satisfy all of these properties
- How do we learn them?
Learning Filters for Trait Representation

- Convolutional Autoencoder (CAE) model for feature learning
- Find optimal filters ($W$) s.t. they:

\[
\begin{align*}
\min_{W,W'} & \quad \sum_{i=1}^{N} \| I_i - R_i \|_2^2 + \alpha \| p - 1 \|_F^2 + \beta \left( \| W \|_F^2 + \| W' \|_F^2 \right)
\end{align*}
\]
Learning Filters for Trait Representation

- Convolutional Autoencoder (CAE) model for feature learning
- Find optimal filters ($W$) s.t. they:
  - Model trait patches

\[
\begin{align*}
E_i & = h(W \ast I_i + b_e) \\
R_i & = W' \ast E_i + b_r \\
\min_{w,w'} & \frac{1}{N} \sum_{i=1}^{N} \|I_i - R_i\|_F^2
\end{align*}
\]
Convolutional Autoencoder (CAE) model for feature learning

Find optimal filters \((W)\) s.t. they:
- Model trait patches
- Form a sparse encoding

\[
\begin{align*}
E_i &= h(W \ast I_i + b_e) \\
R_i &= W' \ast E_i + b_r
\end{align*}
\]

\[
h(x) = \begin{cases} 
1 & \text{if } x \geq 0 \\
0 & \text{otherwise}
\end{cases}
\]

\[
\min_{W, W'} \frac{1}{N} \sum_{i=1}^{N} \|I_i - R_i\|_F^2 + \alpha \left\| p - \frac{1}{N} \sum_{i=1}^{N} E_i \right\|_F^2
\]
Learning Filters for Trait Representation

- Convolutional Autoencoder (CAE) model for feature learning
- Find optimal filters ($W$) s.t. they:
  - Model trait patches
  - Form a sparse encoding
  - Have constrained magnitude

\[
E_i = h(W \ast I_i + b_e)
\]
\[
R_i = W' \ast E_i + b_r
\]

\[
h(x) = \begin{cases} 
  1 & \text{if } x \geq 0 \\
  0 & \text{if } x < 0
\end{cases}
\]

\[
\min_{W, W'} \frac{1}{N} \sum_{i=1}^{N} \| I_i - R_i \|_F^2 + \alpha \left\| \rho - \frac{1}{N} \sum_{i=1}^{N} E_i \right\|_F^2 + \beta \left( \| W \|_F^2 + \| W' \|_F^2 \right)
\]
Learning Filters for Trait Representation

- Convolutional Autoencoder (CAE) model for feature learning
- Find optimal filters \( (W) \) s.t. they:
  - Model trait patches
  - Form a sparse encoding
  - Have constrained magnitude

\[
E_i = h(W \ast I_i + b_e)
\]
\[
R_i = W' \ast E_i + b_r
\]

\[
h(x) = \begin{cases} 
1 & \text{if } x > 0 \\
0 & \text{if } x \leq 0 
\end{cases}
\]

\[
\min_{W, W'} \frac{1}{N} \sum_{i=1}^{N} \|I_i - R_i\|^2_F + \alpha \left\| \rho - \frac{1}{N} \sum_{i=1}^{N} E_i \right\|^2_F + \beta \left( \|W\|^2_F + \|W'\|^2_F \right)
\]
Learned Filters

Filter Responses

Convolution Filters

Input Images

Describe appearances CAE cannot:
- Color Histograms
- HOG
- LBP
Learned Filters + Supplemental Nonlinear Features

Filter Responses

Convolution Filters

Input Images

- Describe appearances CAE cannot:
Learned Filters + Supplemental Nonlinear Features

- Filter Responses
- Convolution Filters
- Describe appearances CAE cannot:
  - Color Histograms
Learned Filters + Supplemental Nonlinear Features

- Filter Responses
- Convolution Filters
- Input Images

- Describe appearances CAE cannot:
  - Color Histograms
  - HOG
Learned Filters + Supplemental Nonlinear Features

- Describe appearances CAE cannot:
  - Color Histograms
  - HOG
  - LBP
Material Trait Recognition Process

- Training data: Flickr Materials Database (FMD) [7] images with trait annotations
Material Trait Recognition Process

- Training data: Flickr Materials Database (FMD) [7] images with trait annotations

<table>
<thead>
<tr>
<th>Trait</th>
<th>CAE</th>
<th>Oriented</th>
<th>HOG</th>
<th>LBP</th>
<th>Color Histograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shiny</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Fuzzy</td>
<td></td>
<td>●</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Transparent</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Uses</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

... (13 Material Traits)
Material Trait Recognition Process

- Training data: Flickr Materials Database (FMD) [7] images with trait annotations

Learn Filters | Select Features | Train Per-Trait Classifiers

<table>
<thead>
<tr>
<th>Trait</th>
<th>CAE</th>
<th>Oriented</th>
<th>HOG</th>
<th>LBP</th>
<th>Color Histograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shiny</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Fuzzy</td>
<td></td>
<td>●</td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Transparent</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>⋮ (13 Material Traits)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Uses</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>
Material Trait Recognition Process

- Training data: Flickr Materials Database (FMD) [7] images with trait annotations

<table>
<thead>
<tr>
<th>Trait</th>
<th>CAE</th>
<th>Oriented</th>
<th>HOG</th>
<th>LBP</th>
<th>Color Histograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shiny</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Fuzzy</td>
<td></td>
<td>●</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Transparent</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Total Uses</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

(13 Material Traits)
Material Trait Recognition Process

- Training data: Flickr Materials Database (FMD) [7] images with trait annotations

Learn Filters

Select Features

Train Per-Trait Classifiers

Extract Features

Recognize Traits

<table>
<thead>
<tr>
<th>Trait</th>
<th>CAE</th>
<th>Oriented</th>
<th>HOG</th>
<th>LBP</th>
<th>Color Histograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shiny</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Fuzzy</td>
<td></td>
<td>●</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Transparent</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Uses</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

(13 Material Traits)
Patch Recognition Results

Shiny  Fuzzy  Metallic  Soft  Smooth Liquid  Rough  Woven

True Positives

False Positives

Shiny  Fuzzy  Metallic  Soft  Smooth Liquid  Rough  Woven
Per-Pixel Material Trait Maps

Image from [5].
Per-Pixel Material Trait Maps

Image from [5].
Per-Pixel Material Trait Maps

Image from [7].
Per-Pixel Material Trait Maps

Image from [7].
What can we do with these material traits?
Material Recognition via Trait Distributions

$p (\text{trait}_i | \text{category}_j)$
Material Recognition Accuracy: Flickr

Average: 49.2%
[Liu et al.] (w/o obj): 42.6%  (w/obj): 57.1%

Images from [7].
Material Recognition Accuracy: ImageNet

Average: 60.5%

Images from [2].
Segmentation with Material Traits

Images from [5].

Baseline NCuts

With Traits
Summary

- Material traits:
  - may be recognized locally and accurately

Future work:
- Discover new traits
- Improve applications
Summary

► Material traits:
  ▶ may be recognized locally and accurately
  ▶ have distributions that encode material categories
Summary

- **Material traits:**
  - may be recognized locally and accurately
  - have distributions that encode material categories
  - segment images into intuitively separate regions

Future work:
- Discover new traits
- Improve applications
Summary

- Material traits:
  - may be recognized locally and accurately
  - have distributions that encode material categories
  - segment images into intuitively separate regions

- Future work:
  - Discover new traits
  - Improve applications
E. H. Adelson.  
On Seeing Stuff: The Perception of Materials by Humans and Machines.  

J. Deng, W. Dong, R. Socher, L.-J. Li, K. Li, and L. Fei-Fei.  
ImageNet: A Large-Scale Hierarchical Image Database.  
In *CVPR*, 2009.

D. Hu, L. Bo, and X. Ren.  
Toward Robust Material Recognition for Everyday Objects.  

Exploring Features in a Bayesian Framework for Material Recognition.  

D. Martin, C. Fowlkes, D. Tal, and J. Malik.  
A Database of Human Segmented Natural Images and its Application to Evaluating Segmentation Algorithms and Measuring Ecological Statistics.  

Recognizing Materials Using Perceptually Inspired Features.  

L. Sharan, R. Rosenholtz, and E. Adelson.  
Material Perception: What Can You See in a Brief Glance?  