Lecture 27:
Skin Color
Review: Light Transport

*Source* emits photons

Photons travel in a straight line

They hit an object. Some are absorbed, some bounce off in a new direction.

And then some reach an eye/camera and are measured.
Color of Light Source

Spectral Power Distribution: Relative amount of light energy at each wavelength

![Graph showing spectral power distribution across UV, Visible, and IR wavelengths]

- **UV**
- **Visible**
- **IR**

Wavelength $\lambda$
Spectral Albedo

Ratio of incoming to outgoing radiation at different wavelengths.
Spectral Radiance

Often are more interested in relative spectral composition than in overall intensity, so the spectral BRDF computation simplifies to a wavelength-by-wavelength multiplication of relative energies.

\[ \text{Spectral Irradiance} \times \text{Spectral Albedo} = \text{Spectral Radiance} \]

Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995
Human Eye: Rods and Cones

After Bowmaker & Dartnall, 1980

- rods (overall intensity)
- S cones (blue)
- M cones (green)
- L cones (red)
Putting it all Together = Color

\[ p = \int \sigma(\lambda) \rho(\lambda) S(\lambda) d\lambda \]

- Photoreceptor sensitivity
- Spectral albedo
- Illuminant color

\[ p_s = \int \sigma_s(\lambda) E(\lambda) d\lambda \]
\[ p_m = \int \sigma_m(\lambda) E(\lambda) d\lambda \]
\[ p_l = \int \sigma_l(\lambda) E(\lambda) d\lambda \]
Describing Color

Today we consider a sample material, human skin, and look at two approaches to describe the color of skin in order to find it in images.

1) physics-based approach
2) learning-based approach
Goal: Label Skin Pixels in an Image

Applications:
Person finding/tracking
Gesture recognition
The Physics of Skin Color

Analytic derivation:

Experimental measurement:
**Problem: Color Variation**

Apparent color varies due to lighting color and camera spectral response.

<table>
<thead>
<tr>
<th>Current illumination</th>
<th>D65</th>
<th>TL84</th>
</tr>
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<td>A</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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<td>H</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
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<table>
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<tr>
<th>Illuminant</th>
<th>H</th>
<th>A</th>
<th>TL84</th>
<th>D65</th>
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<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
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<tr>
<td>A</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
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</tbody>
</table>

Sample from Oulu Physics-Based Face Database
Skin Reflectance Model

Skin is well-modeled by a dichromatic reflectance model. Transparent medium (dermis), pigmentations (hemoglobin, melanin), specular reflection (oil on skin).
Measuring Spectral Albedo of Skin
Understanding Skin Albedo

Skin Albedo and Oxygenated Hemoglobin

- **blue**
- **red**

![Graph showing skin reflectance and hemoglobin absorbance](image)
Understanding Skin Albedo

Increase in melanin yields darker skin, masking the absorption band pattern of the hemoglobin.
Analytic Model

Generate different skin albedos by using observed curve for caucasian, and calculate the reduction in reflectance due to an increase in melanin (a substance that has a known absorption).

\[ I_1(\lambda) \sim s I_2(\lambda) \; ; \; \lambda = \text{wavelength} \]

Simpler approximation: \( I_1(\lambda) \sim s I_2(\lambda) \; ; \; \lambda = \text{wavelength} \)

\( s = \text{scale factor} \)
Illuminant SPD

Blackbody sources
(for theoretical calculations)

Artificial light sources
Camera Spectral Response

SONY DXC-755P 3CCD
(manufacturer can supply this)
Skin Color Locus: Analytic Computation

\[ p = \int \sigma(\lambda) \rho(\lambda) S(\lambda) d\lambda \]

Photoreceptor sensitivity \hspace{1cm} Spectral albedo \hspace{1cm} Illuminant color

(“object color”)

“Normalized Color”

recall simple scaling of SPD curves
Skin Color Locus: Experimental Measure

Fairly good agreement!
Skin Locus Examples

Histograms of skin color for different lighting conditions. Red: high values, blue: low values.
Tighter Bounds

If you know the camera and light source, you can derive much tighter analytic bounds on skin color.

Fig. 6.: Chromaticity plane with modelled skin colour areas and mean values of the measured skin colour distribution under the four different CCT as described in section 3.
Example

Same individual under different lighting conditions.

Subject 1: Caucasian

Subject 2: Asian Indian
Sample Application

Face tracking under varying illumination conditions
General Idea:

• Drop the physics. Learn from examples instead.
• Learn distributions of skin and nonskin color
• Nonparametric distributions: color histograms
• Bayesian classification of skin pixels
Learning from Examples

First, have some poor grad student hand label thousands of images

\[
P(\text{rgb} \mid \text{skin}) = \frac{\text{number of times rgb seen for a skin pixel}}{\text{total number of skin pixels seen}}
\]

\[
P(\text{rgb} \mid \text{not skin}) = \frac{\text{number of times rgb seen for a non-skin pixel}}{\text{total number of non-skin pixels seen}}
\]

These statistics stored in two 32x32x32 RGB histograms
Learned Distributions

Skin color
\( P(\text{rgb} \mid \text{skin}) \)

Non-Skin color
\( P(\text{rgb} \mid \text{not skin}) \)
Likelihood Ratio

Label a pixel skin if \[
\frac{P(\text{rgb} \mid \text{skin})}{P(\text{rgb} \mid \text{not skin})} > \Theta
\]

\[
\Theta = \frac{(\text{cost of false positive}) \cdot P(\text{seeing not skin})}{(\text{cost of false negative}) \cdot P(\text{seeing skin})}
\]

\[0 \leq \Theta \leq 1\]
Sample Pixel Classifications

$\Theta = .4$
Sample Application: HCI

Haiying Guan, Matthew Turk, UCSB
Sample Application: HCI
Haiying Guan, Matthew Turk, UCSB
Sample Use: Adult Image Classification

Based on Five Features:

- Percentage of pixels detected as skin.
- Average probability of the skin pixels.
- Size in pixels of the largest connected component of skin.
- Number of connected components of skin.
- Percentage of colors with no entries in the skin and non-skin histograms

Jones and Rehg
Adult Image Classification

(a) Examples of images correctly classified by our detector. Both images were classified as adult images.

(b) Example of an image misclassified as adult by our detector.
Combining Color and Text

<table>
<thead>
<tr>
<th>Detector Type</th>
<th>% Correctly Detected Adult Images</th>
<th>% False Alarms</th>
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<tbody>
<tr>
<td>Color-based Detector</td>
<td>85.8%</td>
<td>7.5%</td>
</tr>
<tr>
<td>Text-based Detector</td>
<td>84.9%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Combined Detector</td>
<td>93.9%</td>
<td>8.0%</td>
</tr>
</tbody>
</table>
Adult Image Classification

Other related work:


Back to Jones and Rehg Model

A compact description is provided by converting the histogram-based model into a Gaussian Mixture model.

\[ P(x) = \sum_{i=1}^{N} w_i \frac{1}{(2\pi)^{\frac{3}{2}} |\Sigma_i|^{\frac{1}{2}}} e^{-\frac{1}{2}(x-\mu_i)^T \Sigma_i^{-1} (x-\mu_i)}, \]

(a) Contour plot for skin model.  
(b) Contour plot for non-skin model.
# Jones and Rehg Mixture Model

## Mixture of Gaussian Skin Color Model

<table>
<thead>
<tr>
<th>Kernel</th>
<th>Mean</th>
<th>Covariance</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(73.53, 29.94, 17.76)</td>
<td>(765.40, 121.44, 112.80)</td>
<td>0.0294</td>
</tr>
<tr>
<td>2</td>
<td>(249.71, 233.94, 217.49)</td>
<td>(39.94, 154.44, 396.05)</td>
<td>0.0331</td>
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<tr>
<td>3</td>
<td>(161.68, 116.25, 96.95)</td>
<td>(291.03, 60.48, 162.85)</td>
<td>0.0654</td>
</tr>
<tr>
<td>4</td>
<td>(186.07, 136.62, 114.40)</td>
<td>(274.95, 64.60, 198.27)</td>
<td>0.0756</td>
</tr>
<tr>
<td>5</td>
<td>(189.26, 98.37, 51.18)</td>
<td>(633.18, 222.40, 250.69)</td>
<td>0.0554</td>
</tr>
<tr>
<td>6</td>
<td>(247.00, 152.20, 90.84)</td>
<td>(65.23, 691.53, 609.92)</td>
<td>0.0314</td>
</tr>
<tr>
<td>7</td>
<td>(150.10, 72.66, 37.76)</td>
<td>(408.63, 200.77, 257.57)</td>
<td>0.0454</td>
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<tr>
<td>8</td>
<td>(206.85, 171.09, 156.34)</td>
<td>(530.08, 155.08, 572.79)</td>
<td>0.0469</td>
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<tr>
<td>9</td>
<td>(212.78, 152.82, 120.04)</td>
<td>(160.57, 84.52, 243.90)</td>
<td>0.0956</td>
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<tr>
<td>10</td>
<td>(234.87, 175.43, 138.94)</td>
<td>(163.80, 121.57, 279.22)</td>
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<tr>
<td>11</td>
<td>(151.19, 97.74, 74.59)</td>
<td>(425.40, 73.56, 175.11)</td>
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<tr>
<td>12</td>
<td>(120.52, 77.55, 59.82)</td>
<td>(330.45, 70.34, 151.82)</td>
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<tr>
<td>13</td>
<td>(192.20, 119.62, 82.32)</td>
<td>(152.76, 92.14, 259.15)</td>
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<tr>
<td>14</td>
<td>(214.29, 136.08, 87.24)</td>
<td>(204.90, 140.17, 270.19)</td>
<td>0.0500</td>
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<tr>
<td>15</td>
<td>(99.57, 54.33, 38.06)</td>
<td>(448.13, 90.18, 151.29)</td>
<td>0.0667</td>
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<tr>
<td>16</td>
<td>(238.88, 203.08, 176.91)</td>
<td>(178.38, 156.27, 404.99)</td>
<td>0.0749</td>
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</table>
## Jones and Rehg Mixture Model

### Mixture of Gaussian Non-skin Color Model

<table>
<thead>
<tr>
<th>Kernel</th>
<th>Mean</th>
<th>Covariance</th>
<th>Weight</th>
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<tbody>
<tr>
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<td>(254.37, 254.41, 253.82)</td>
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<td>2</td>
<td>(9.39, 8.09, 8.52)</td>
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<td>3</td>
<td>(96.57, 96.95, 91.53)</td>
<td>(280.69, 156.79, 436.58)</td>
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<td>4</td>
<td>(160.44, 162.49, 159.06)</td>
<td>(355.98, 115.89, 591.24)</td>
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<tr>
<td>5</td>
<td>(74.98, 63.23, 46.33)</td>
<td>(414.84, 245.95, 361.27)</td>
<td>0.0747</td>
</tr>
<tr>
<td>6</td>
<td>(121.83, 60.88, 18.31)</td>
<td>(2502.24, 1383.53, 237.18)</td>
<td>0.0365</td>
</tr>
<tr>
<td>7</td>
<td>(202.18, 154.88, 91.04)</td>
<td>(957.42, 1766.94, 1582.52)</td>
<td>0.0349</td>
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<tr>
<td>8</td>
<td>(193.06, 201.93, 206.55)</td>
<td>(562.88, 190.23, 447.28)</td>
<td>0.0649</td>
</tr>
<tr>
<td>9</td>
<td>(51.88, 57.14, 61.55)</td>
<td>(344.11, 191.77, 433.40)</td>
<td>0.0656</td>
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<tr>
<td>10</td>
<td>(30.88, 26.84, 25.32)</td>
<td>(222.07, 118.65, 182.41)</td>
<td>0.1189</td>
</tr>
<tr>
<td>11</td>
<td>(44.97, 85.96, 131.95)</td>
<td>(651.32, 840.52, 963.67)</td>
<td>0.0362</td>
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<tr>
<td>12</td>
<td>(236.02, 236.27, 230.70)</td>
<td>(225.03, 117.29, 331.95)</td>
<td>0.0849</td>
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<tr>
<td>13</td>
<td>(207.86, 191.20, 164.12)</td>
<td>(494.04, 237.69, 533.52)</td>
<td>0.0368</td>
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<tr>
<td>14</td>
<td>(99.83, 148.11, 188.17)</td>
<td>(955.88, 654.95, 916.70)</td>
<td>0.0389</td>
</tr>
<tr>
<td>15</td>
<td>(135.06, 131.92, 123.10)</td>
<td>(350.35, 130.30, 388.43)</td>
<td>0.0943</td>
</tr>
<tr>
<td>16</td>
<td>(135.96, 103.89, 66.88)</td>
<td>(806.44, 642.20, 350.36)</td>
<td>0.0477</td>
</tr>
</tbody>
</table>
Homework: Due Friday Dec 7

• Download jrmogskin.m from the course web site
• Try it on your own images!
What to Hand In

A short report, in Angel:
  1) one example where it works wonderfully well
  2) one example showing false positives (things that are not skin, but that are labeled as skin).
  3) one example showing false negatives (a patch of skin that is not labeled), along with an educated guess about why it was missed.
Examples Working Well
Example of False Positives
Example of False Negatives

Explanation: paint on skin changes the spectral albedo
Important Constraint

No X-rated images!!!! Keep it clean for the report.