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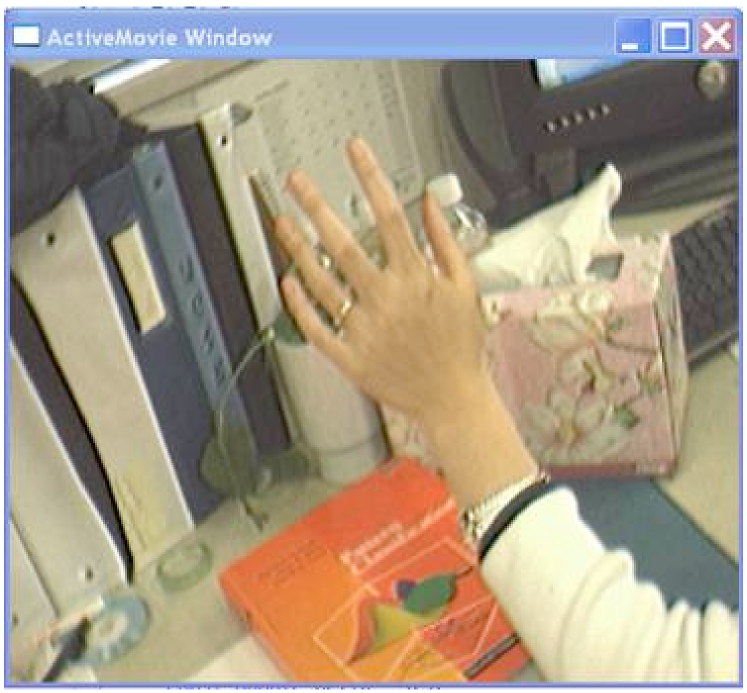
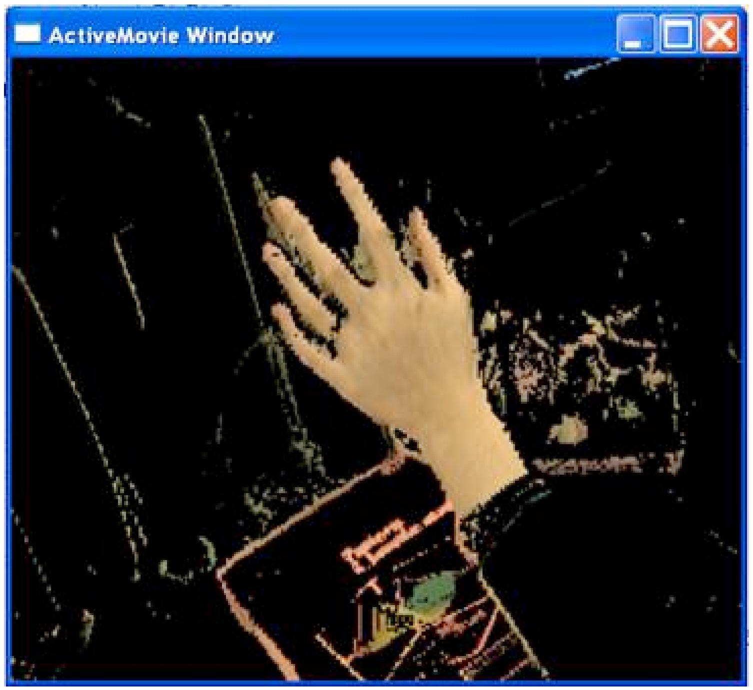
Lecture 27:

Skin Color

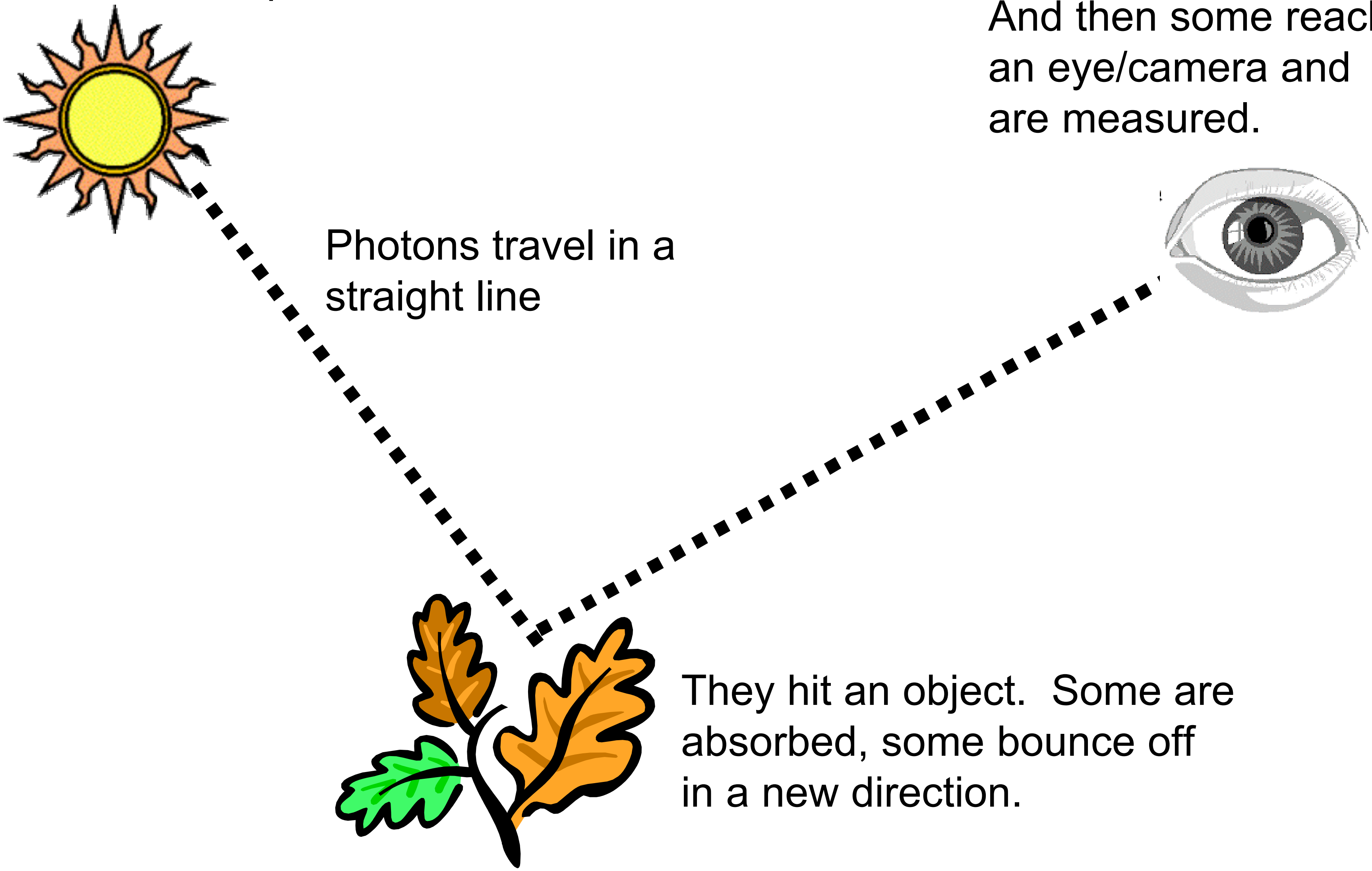




Review: Light Transport

Source emits photons

And then some reach an eye/camera and are measured.

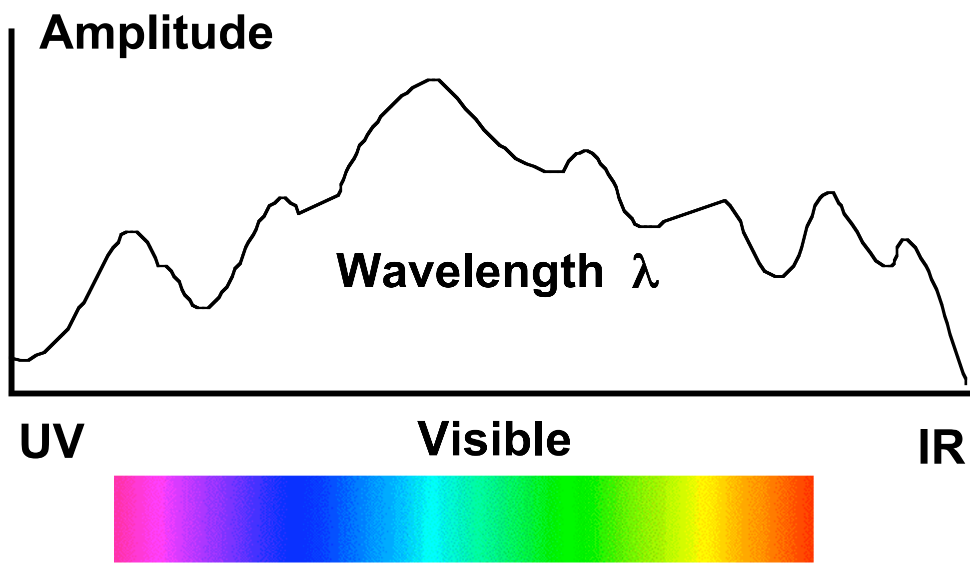


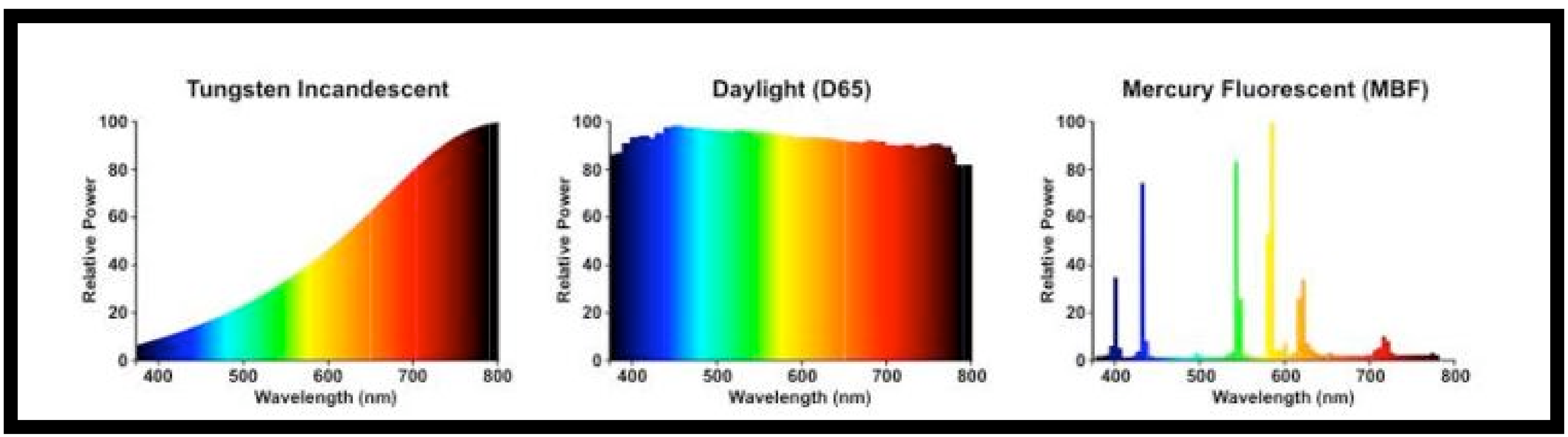
Photons travel in a straight line

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

Color of Light Source

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





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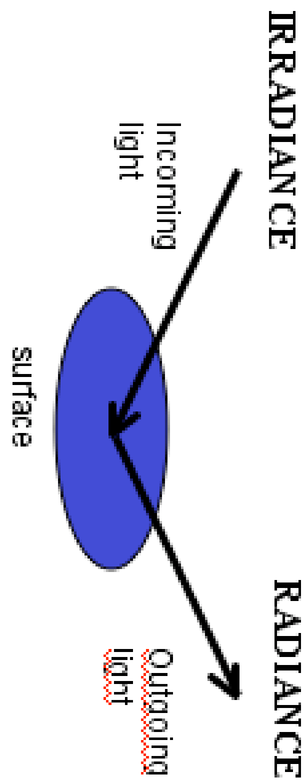
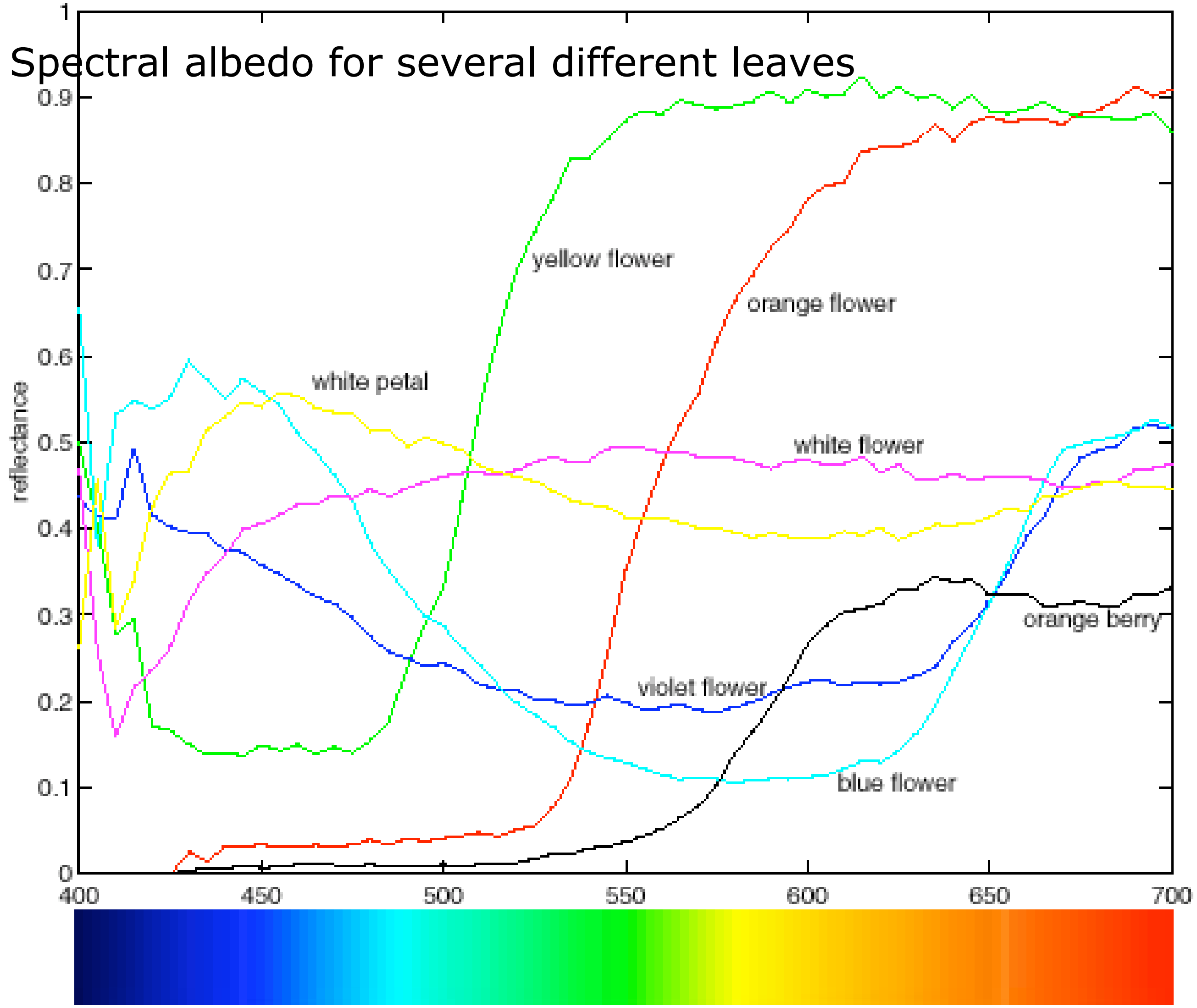
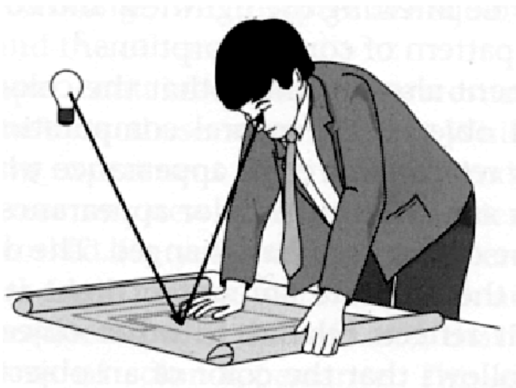
Spectral Albedo

Ratio of incoming to outgoing radiation at different wavelengths.



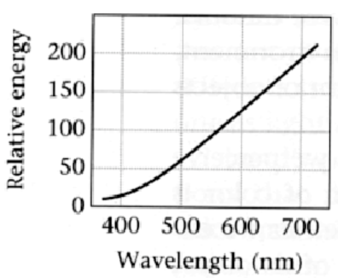


Spectral Radiance



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.

Spectral Irradiance



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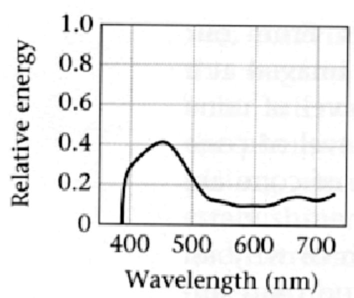
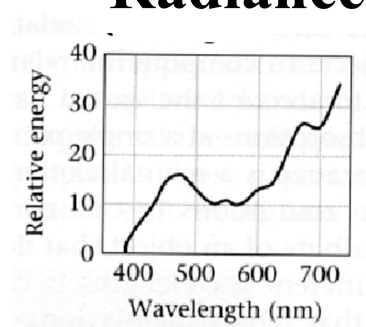
Spectral Albedo



=

Spectral Radiance



Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

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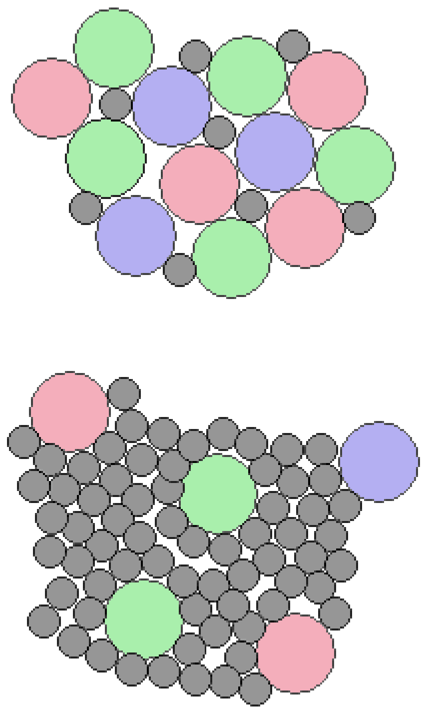
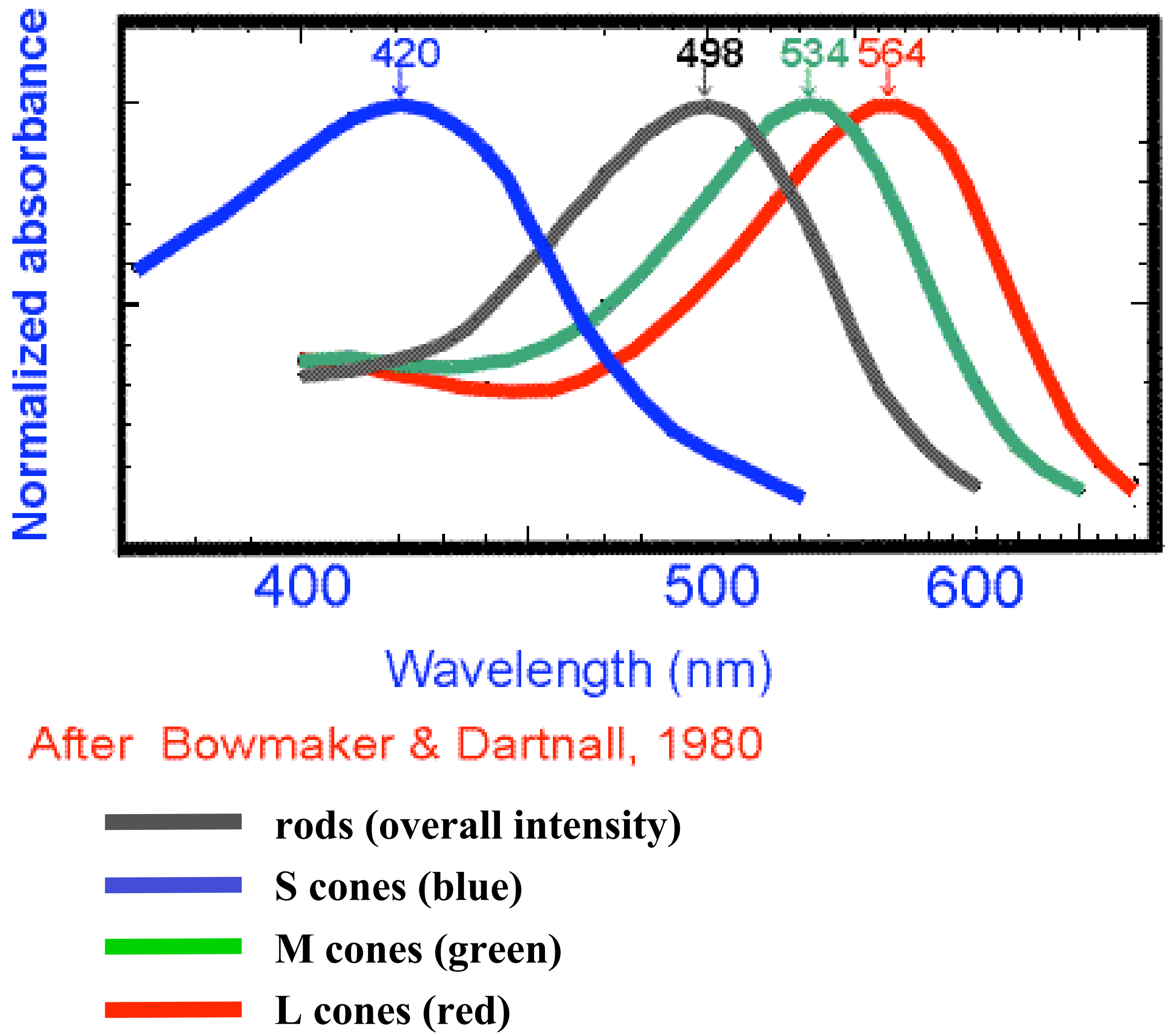
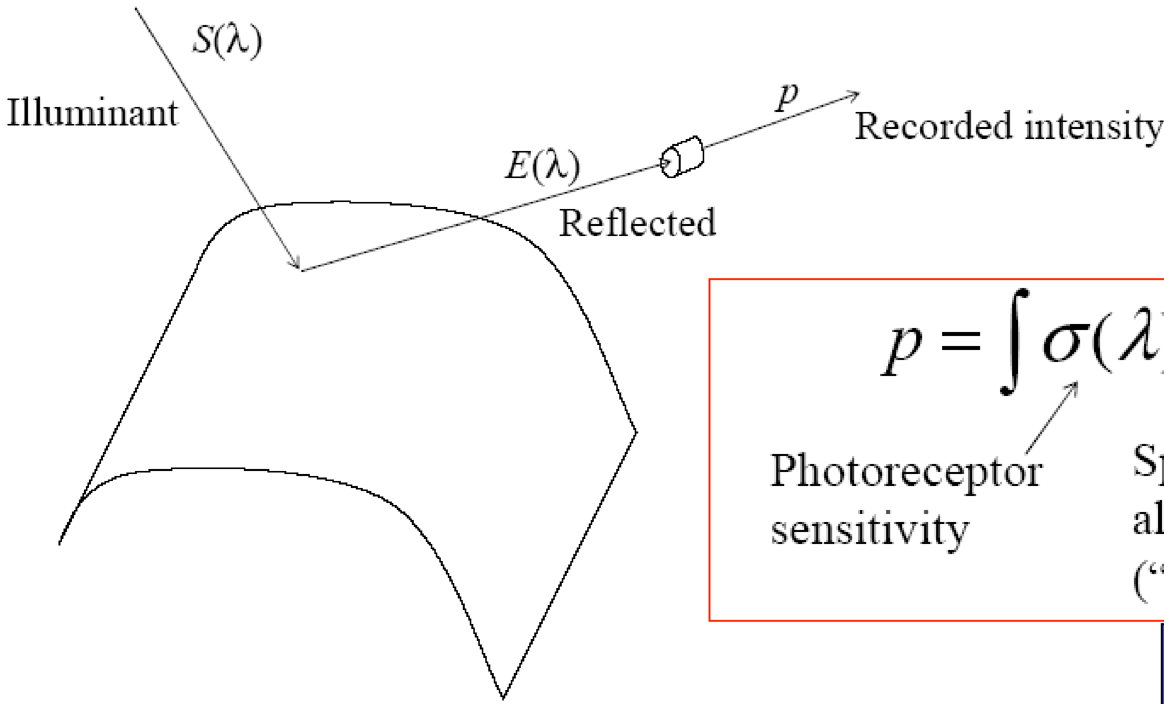
Human Eye: Rods and Cones





Putting it all Together = Color



$$p = \int \sigma(\lambda)\rho(\lambda)S(\lambda)d\lambda$$

Photoreceptor sensitivity

Spectral albedo ("object color")

Illuminant color

3 cones

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**

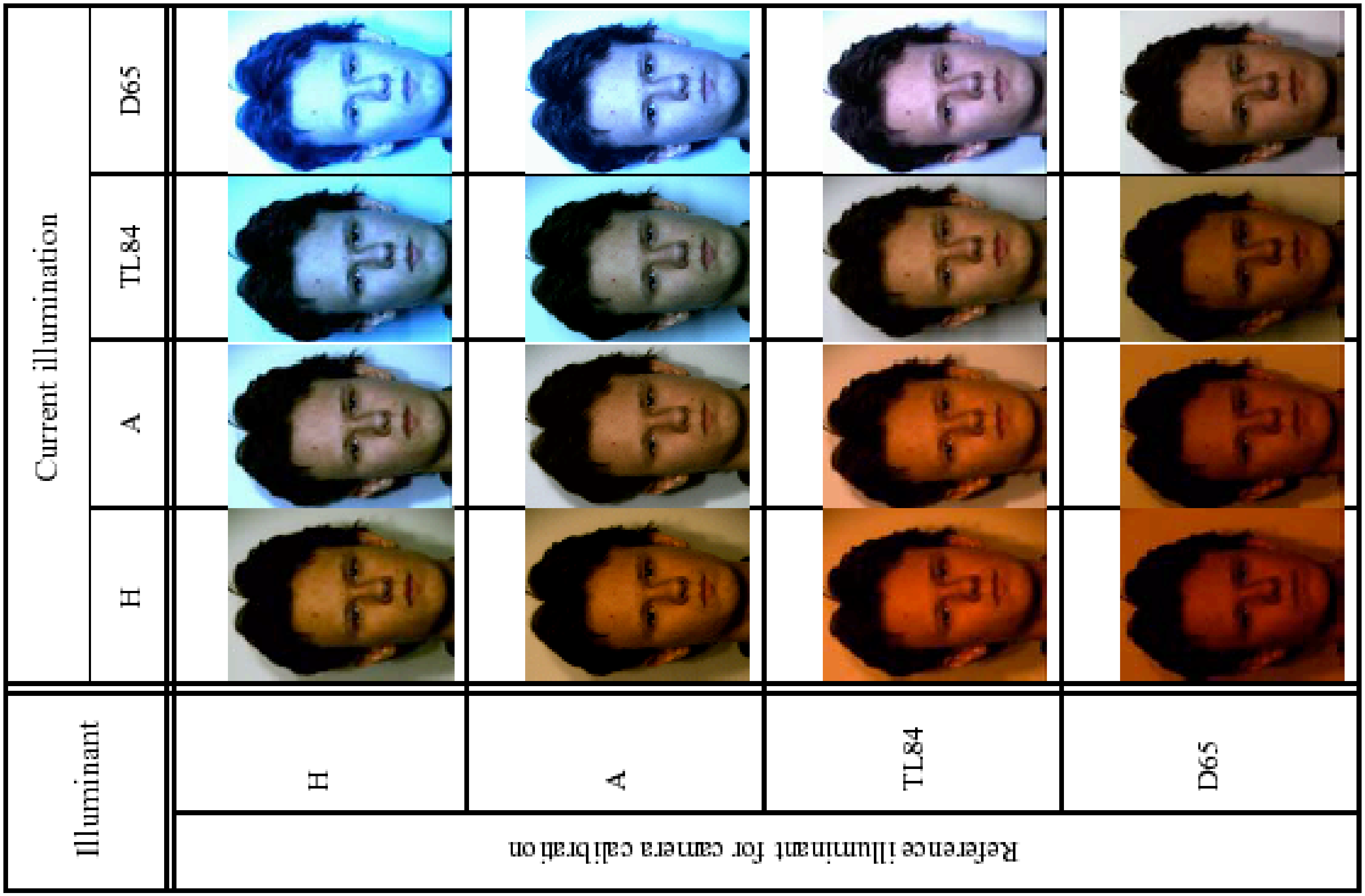
The Physics of Skin Color

Analytic derivation:
Moritz Storring, Hans Andersen and Eric Granum, "Skin Colour Detection under Changing Lighting Conditions," 7th Symposium on Intelligent Robotics Systems, Coimbra Portugal, July 1999.

Experimental measurement:
Birgitta Martinkauppi, "Face Colour Under Varying Illumination: Analysis and Applications," Ph.D. Thesis, Oulu University Press, Oulu Finland, 2002.

Problem: Color Variation

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



Sample from Oulu Physics-Based Face Database

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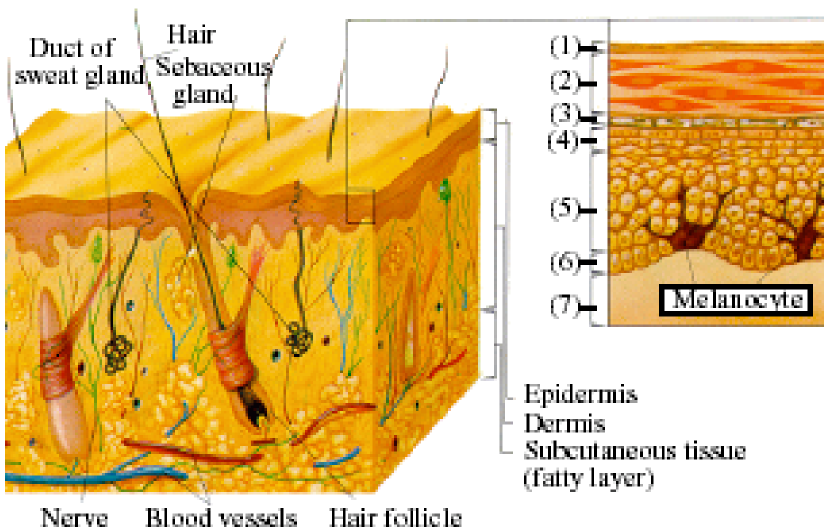
Skin Reflectance Model

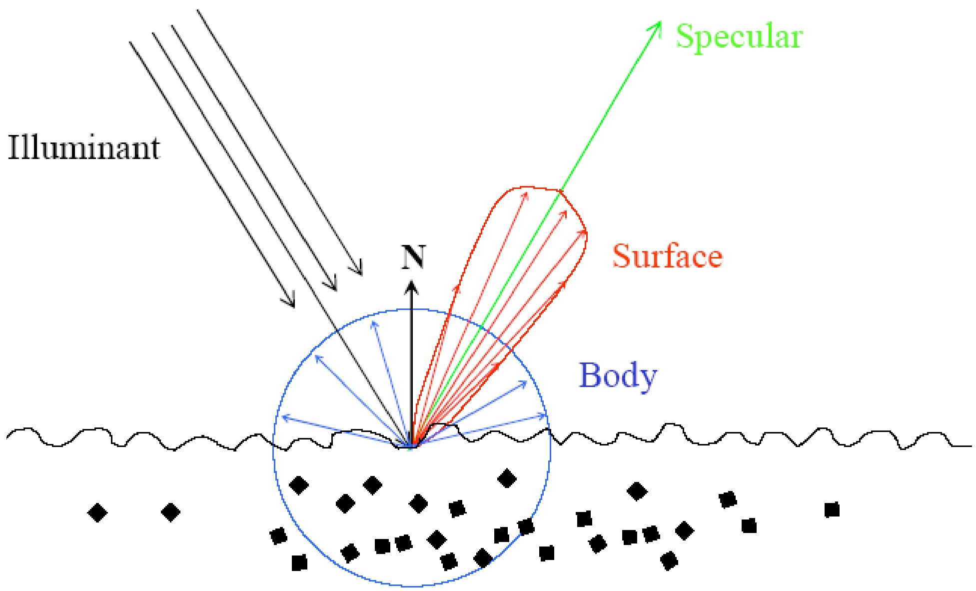
Skin is well-modeled by a dichromatic reflectance model.

transparent medium (dermis)

pigmentations (hemaglobin, melanin)

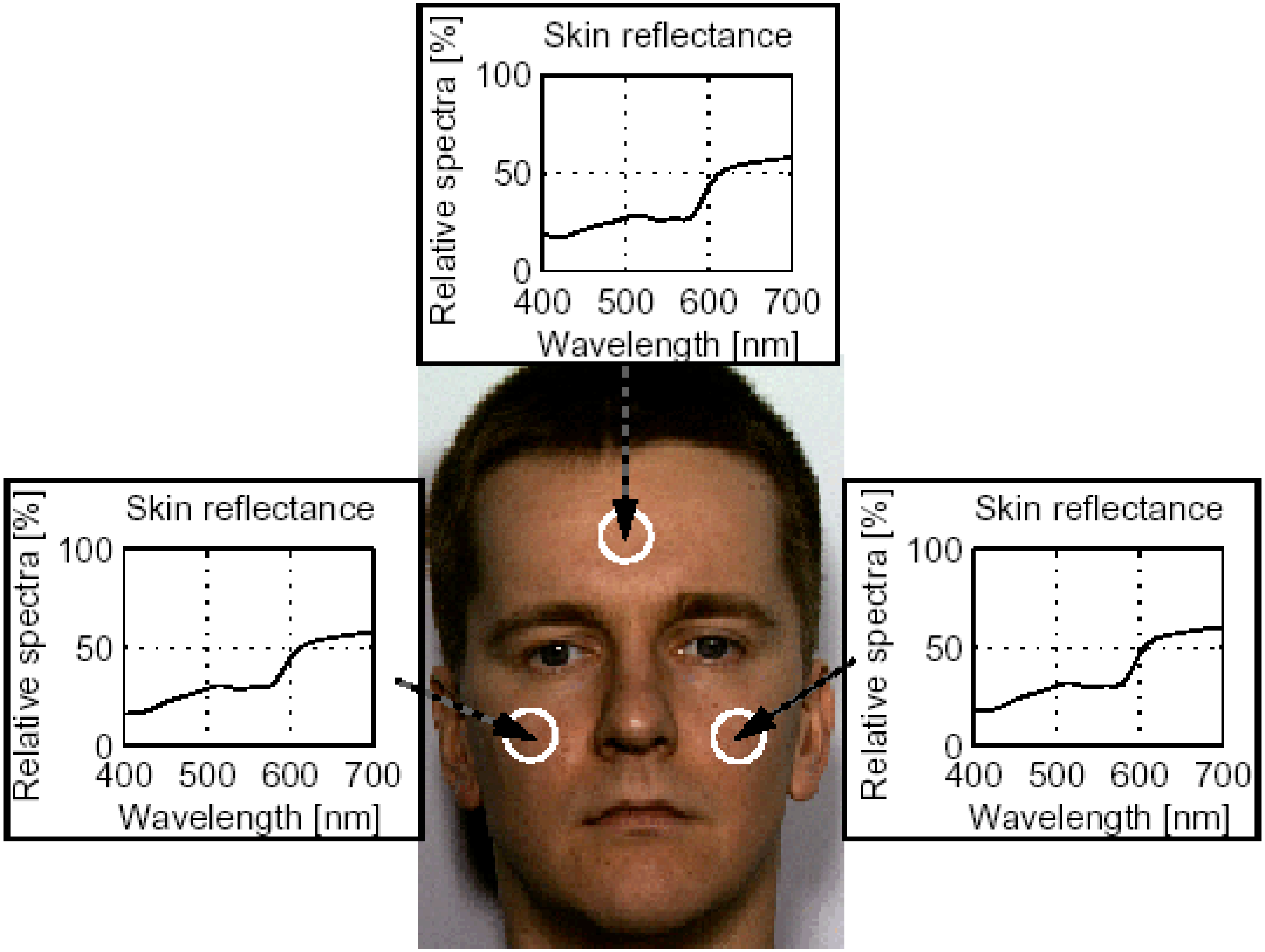
specular reflection (oil on skin)



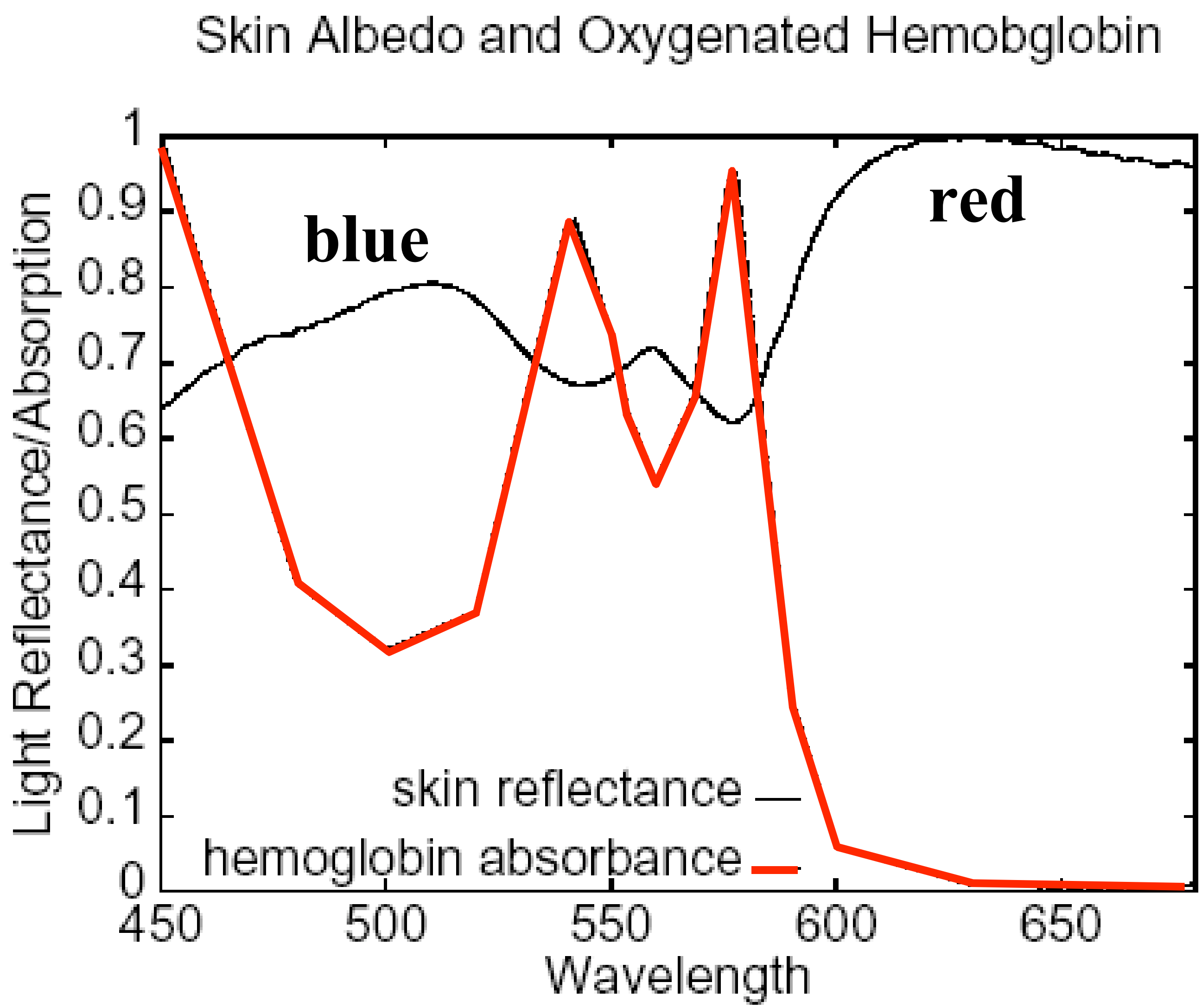


Dichromatic reflectance model

Measuring Spectral Albedo of Skin

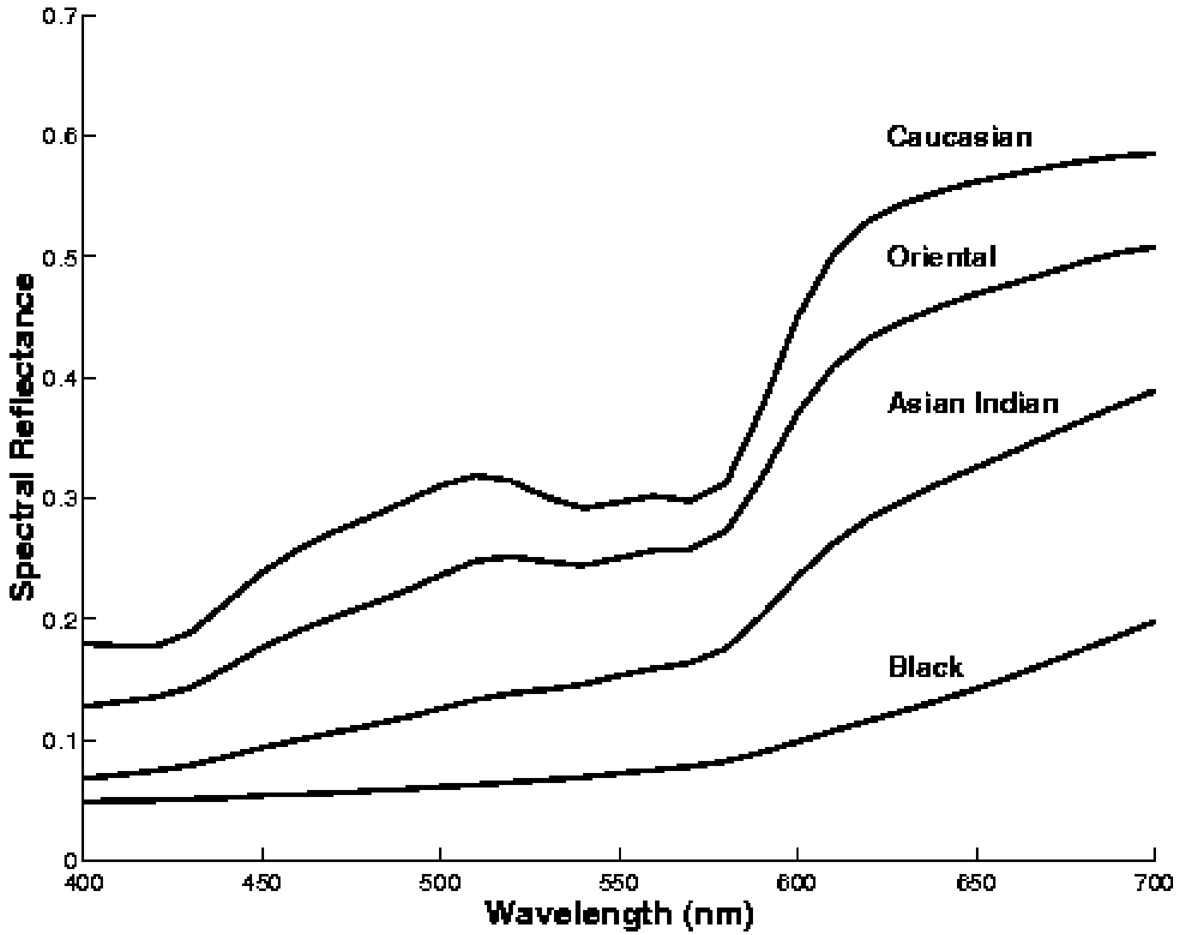


Understanding Skin Albedo



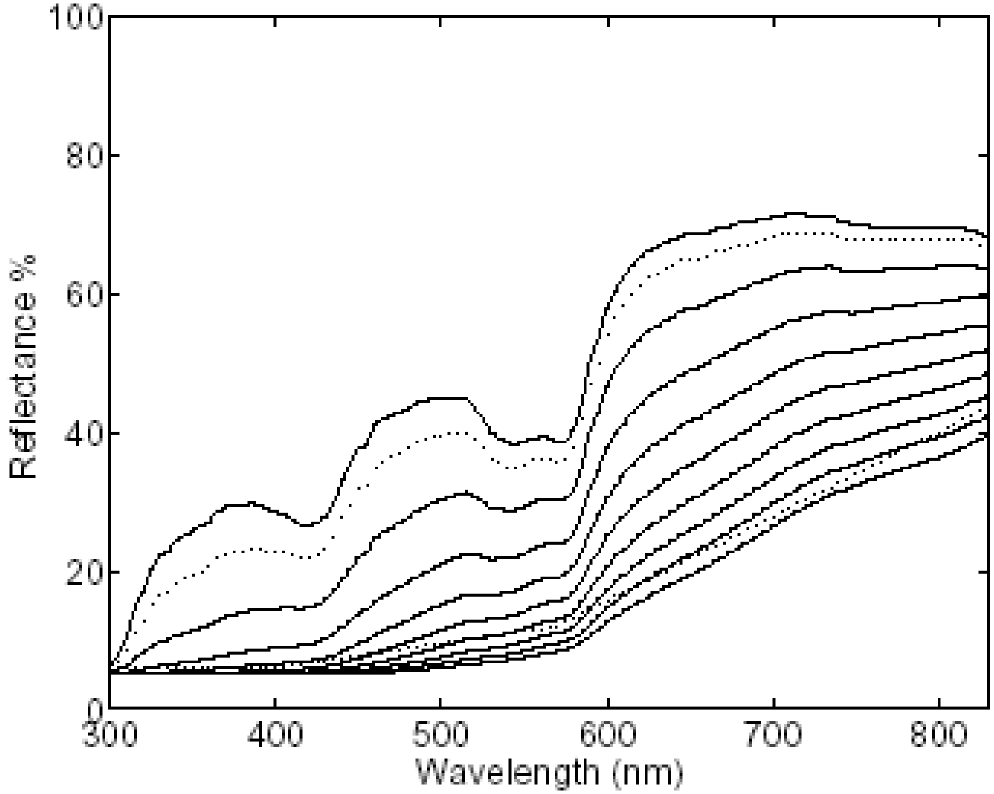
Understanding Skin Albedo

Increase in melanin yields darker skin, masking the absorbtion band pattern of the hemaglobin.



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 absorbtion)



Simpler approximation: $I_1(\lambda) \sim s\, I_2(\lambda)$; λ = wavelength

s = scale factor

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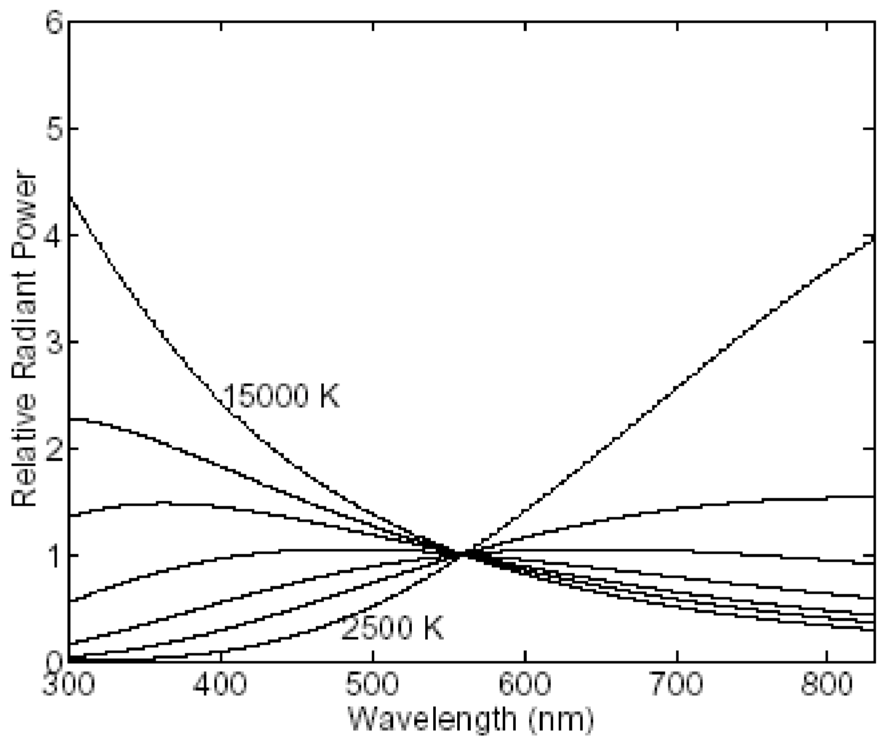
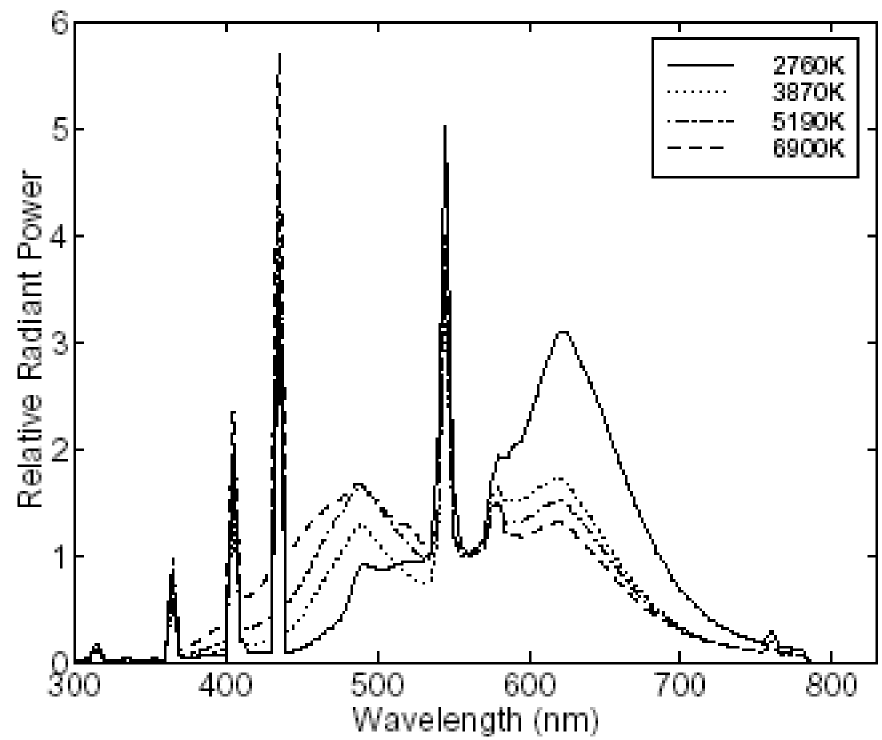
Illuminant SPD

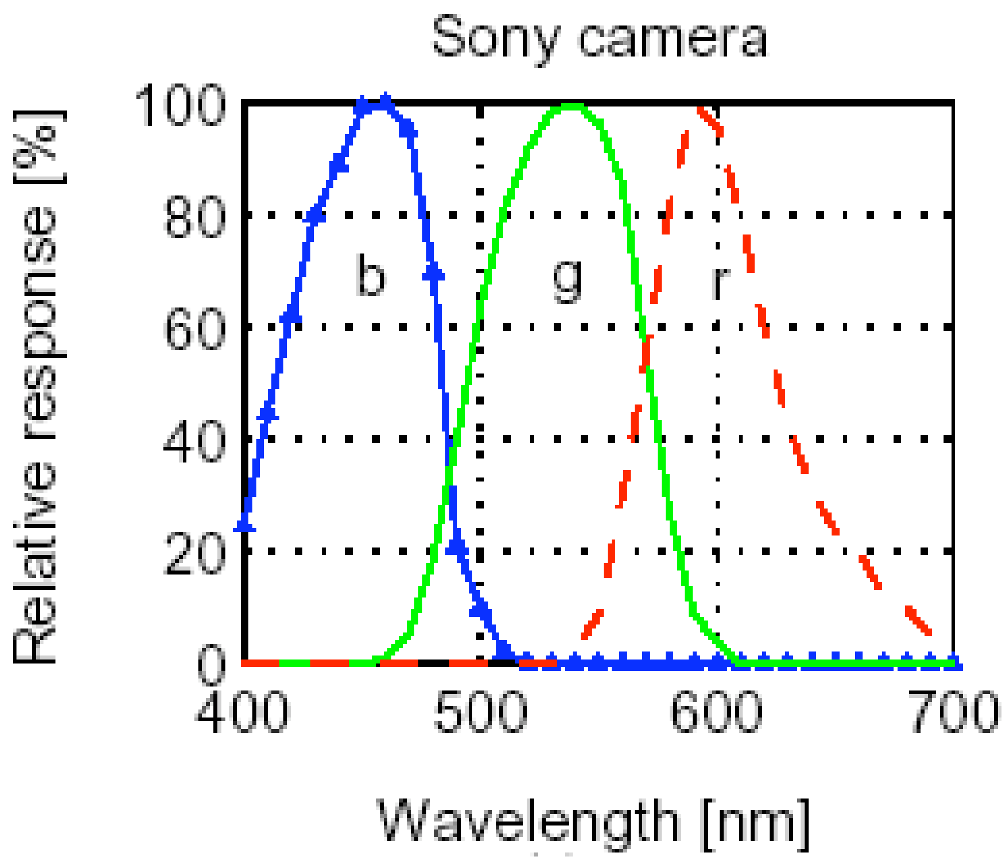




Blackbody sources
(for theoretical calculations)

Artificial light sources

Camera Spectral Response



SONY DXC-755P 3CCD
(manufacturer can supply this)

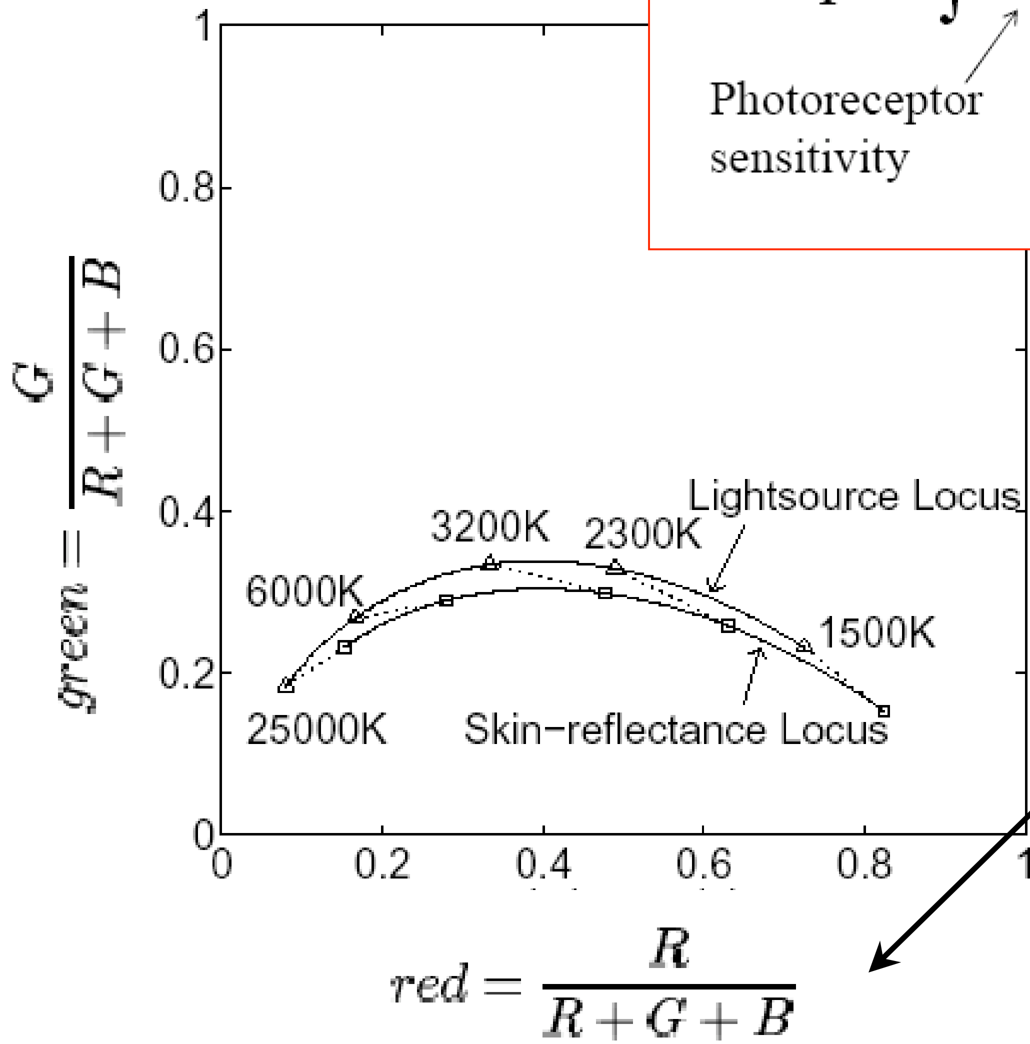
Skin Color Locus : Analytic Computation

$$p = \int \sigma(\lambda)\rho(\lambda)S(\lambda)d\lambda$$

Photoreceptor sensitivity

Spectral albedo ("object color")

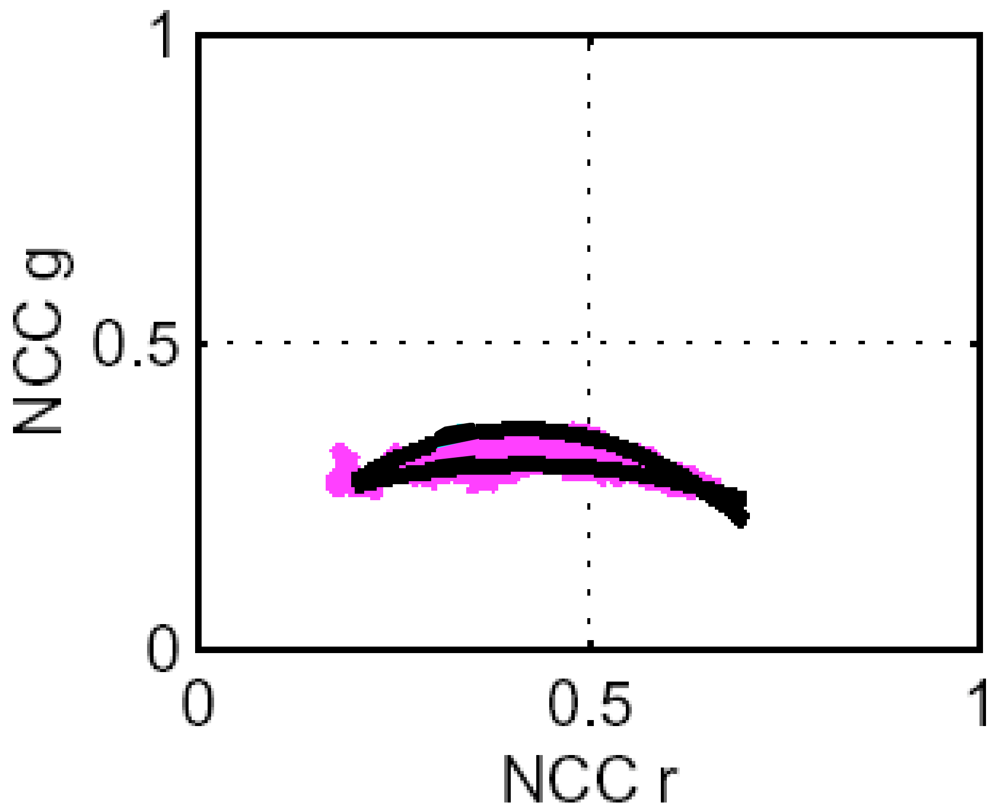
Illuminant color



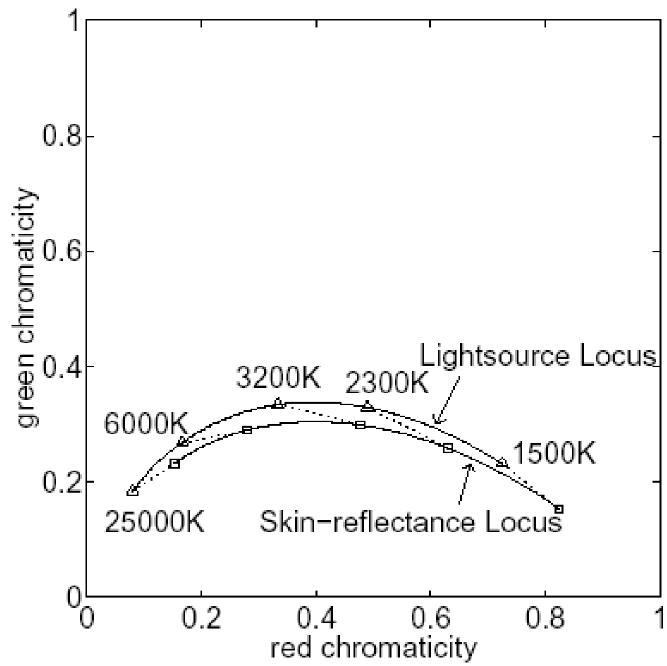
"Normalized Color"

recall simple scaling of SPD curves

Skin Color Locus : Experimental Measure

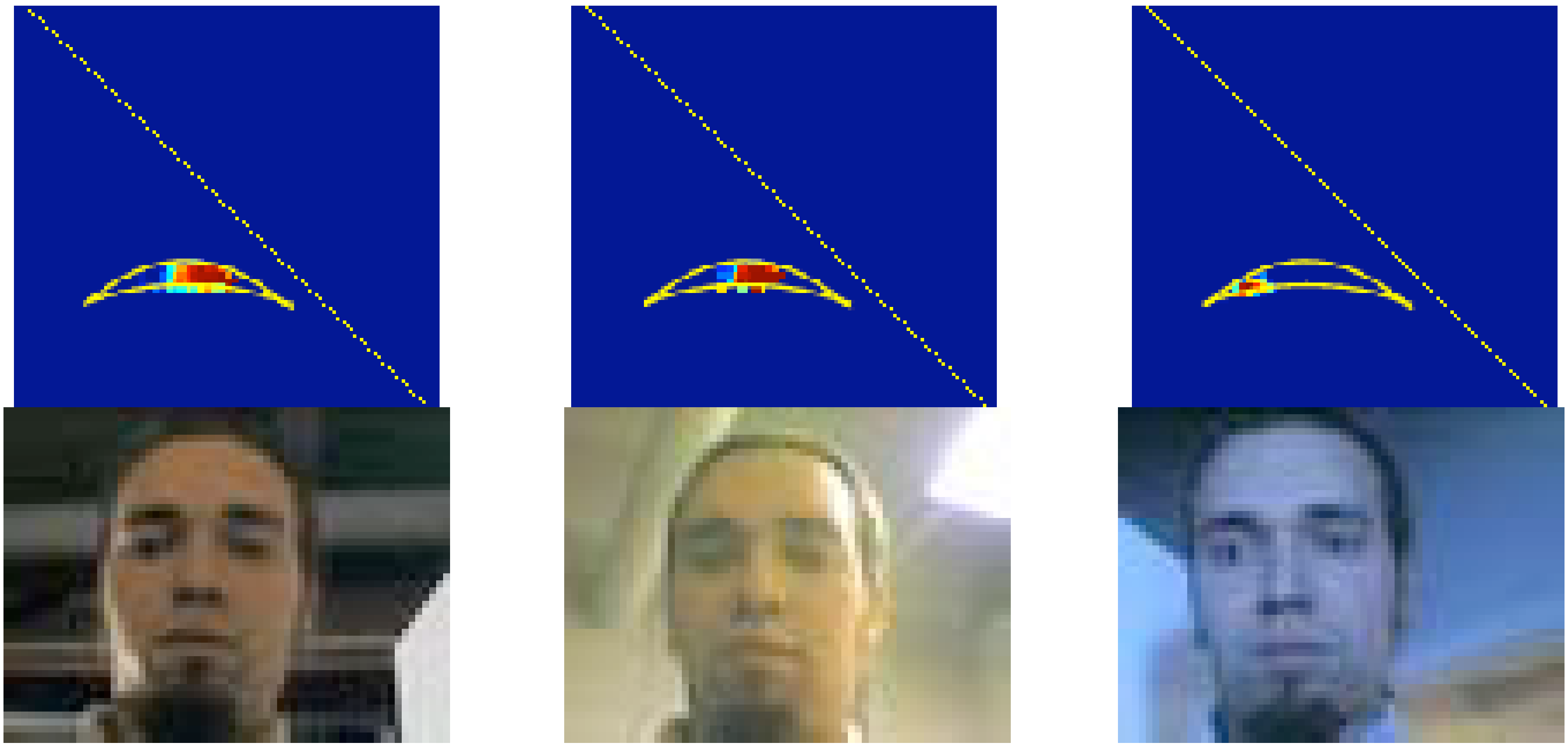


Fairly good agreement!



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.

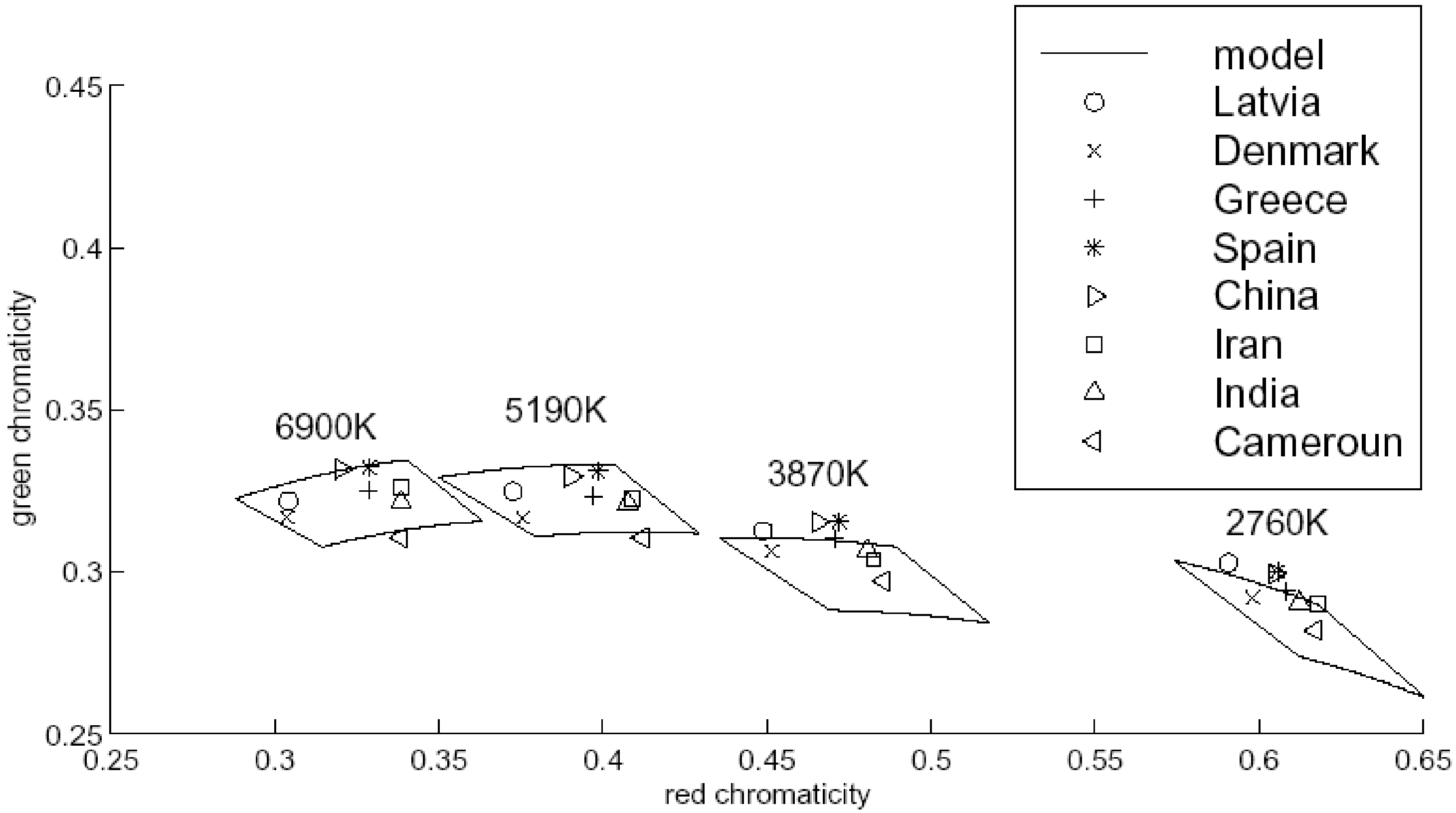
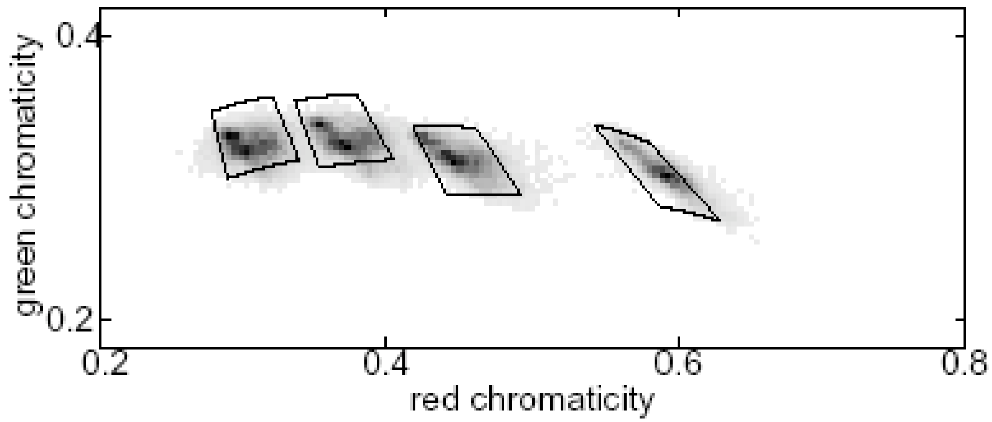


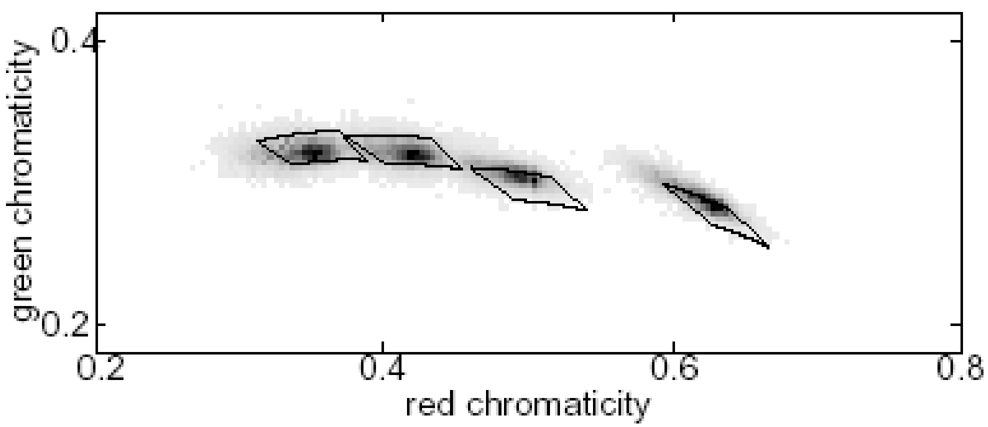
Fig. 6.: Chromaticity plane with modelled skin colour areas and mean values of the measured skin colour distribution under the four different CCT as described in section 3.

Example

Same individual under different lighting conditions.



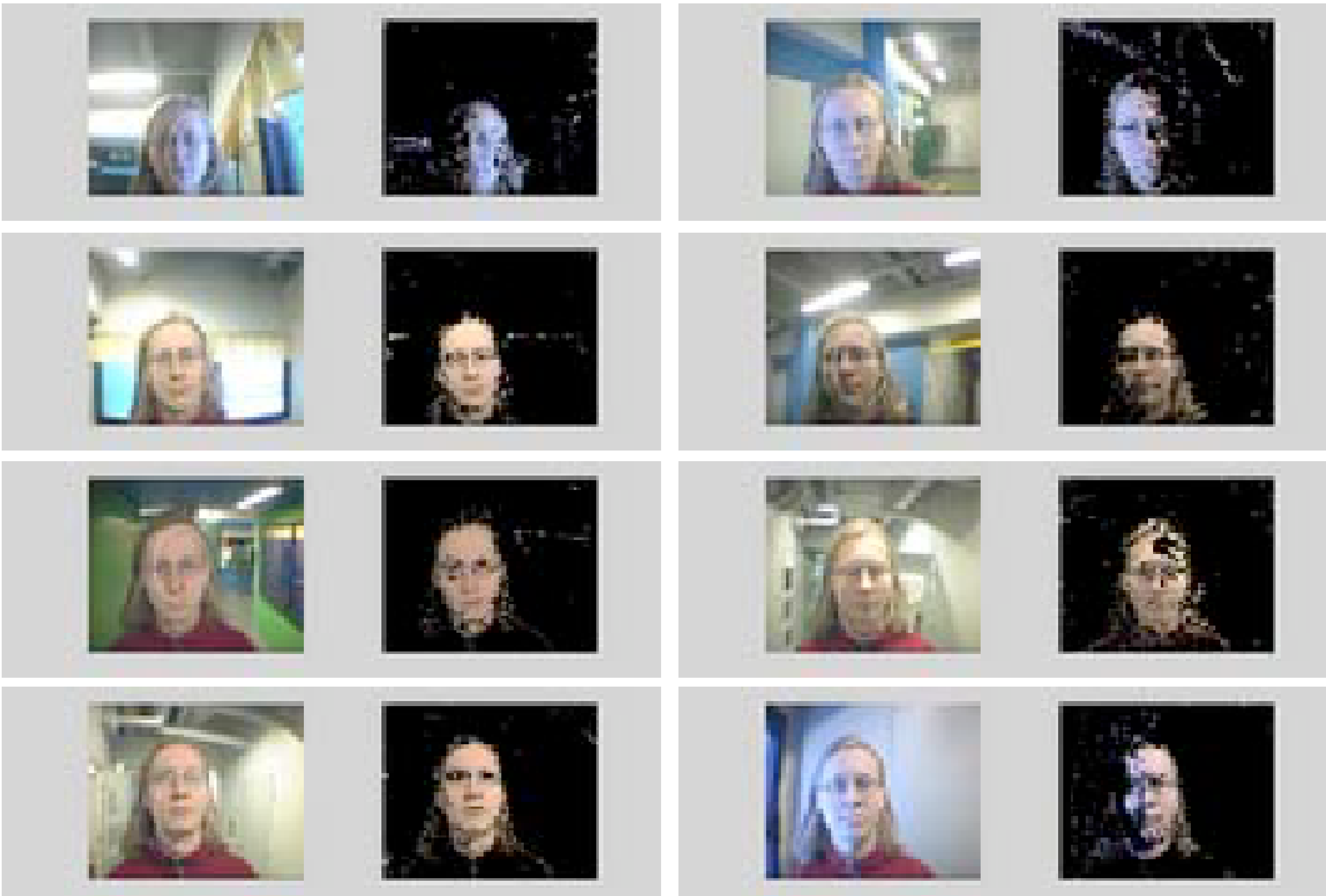
Subject 1: Caucasian



Subject 2: Asian Indian

Sample Application

Face tracking under varying illumination conditions



Jones and Rehg, 2002

"Statistical Color Models with Application to Skin Detection", M. J. Jones and J. M. Rehg, *Int. J. of Computer Vision*, 46(1):81-96, Jan 2002

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**

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Learning from Examples

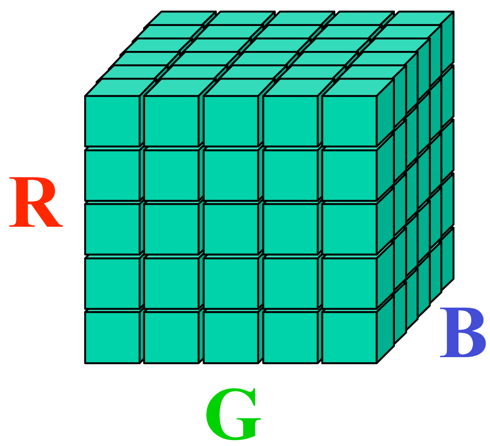
First, have some poor grad student hand label thousands of images

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

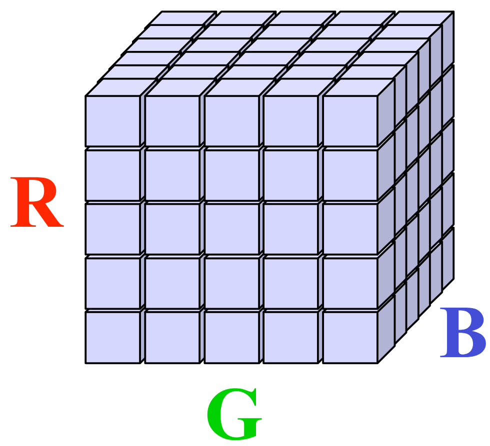
$$P(\text{rgb} \mid \text{not skin}) = \frac{\text{number of times rgb seen for a non-skin pixel}}{\text{total number of non-skin pixels seen}}$$

These statistics stored in two 32x32x32 RGB histograms

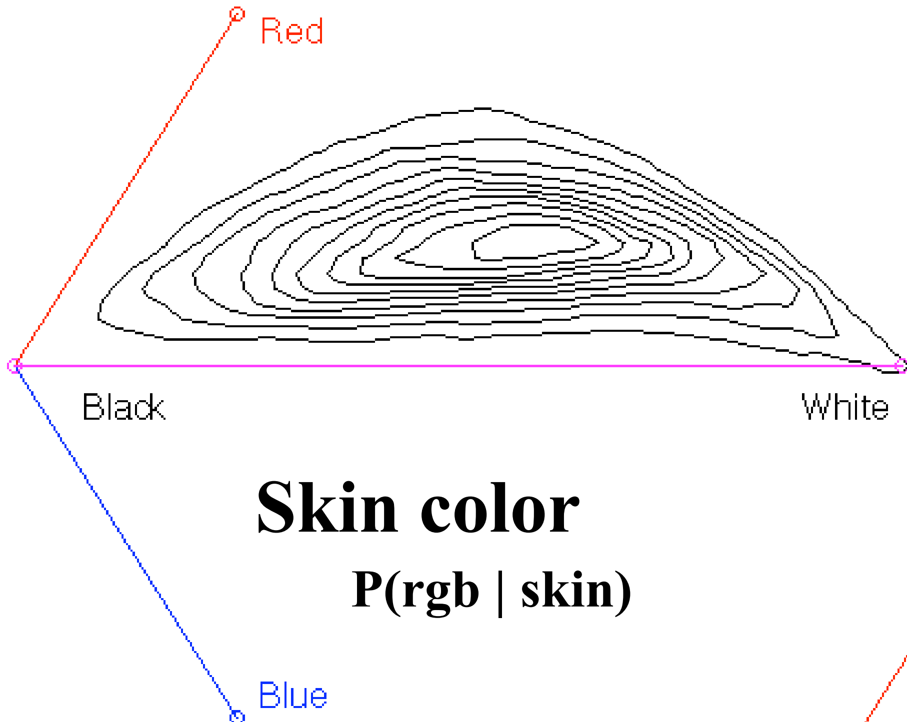
Skin histogram



Non-Skin histogram

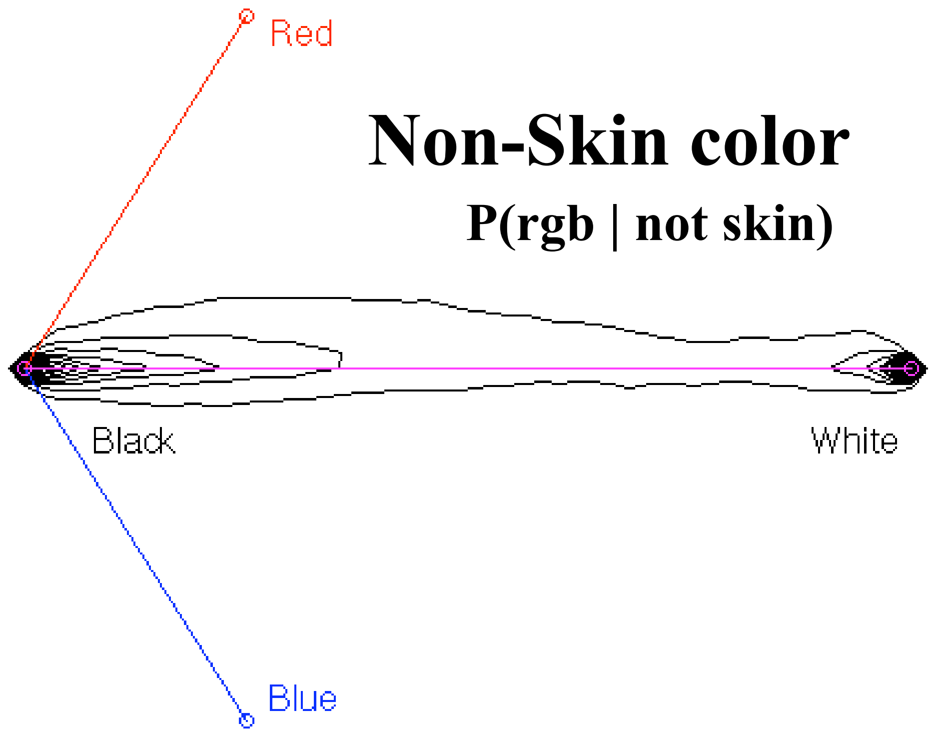


Learned Distributions



Skin color

P(rgb | skin)



Non-Skin color

P(rgb | not skin)

Likelihood Ratio

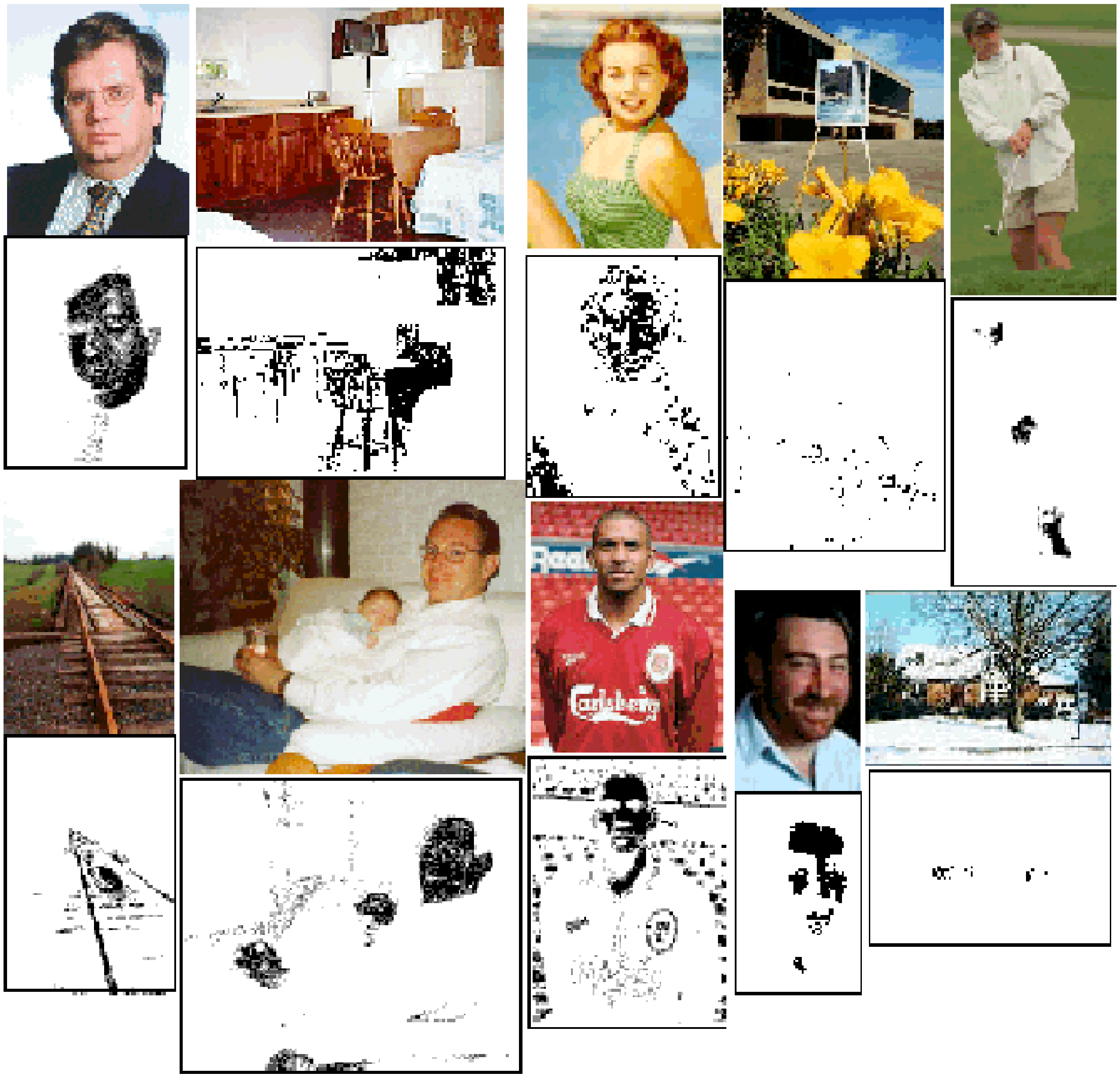
Label a pixel skin if $\dfrac{P(\text{rgb} \mid \text{skin})}{P(\text{rgb} \mid \text{not skin})} > \Theta$

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

$$0 <= \Theta <= 1$$

Sample Pixel Classifications

$\Theta = .4$



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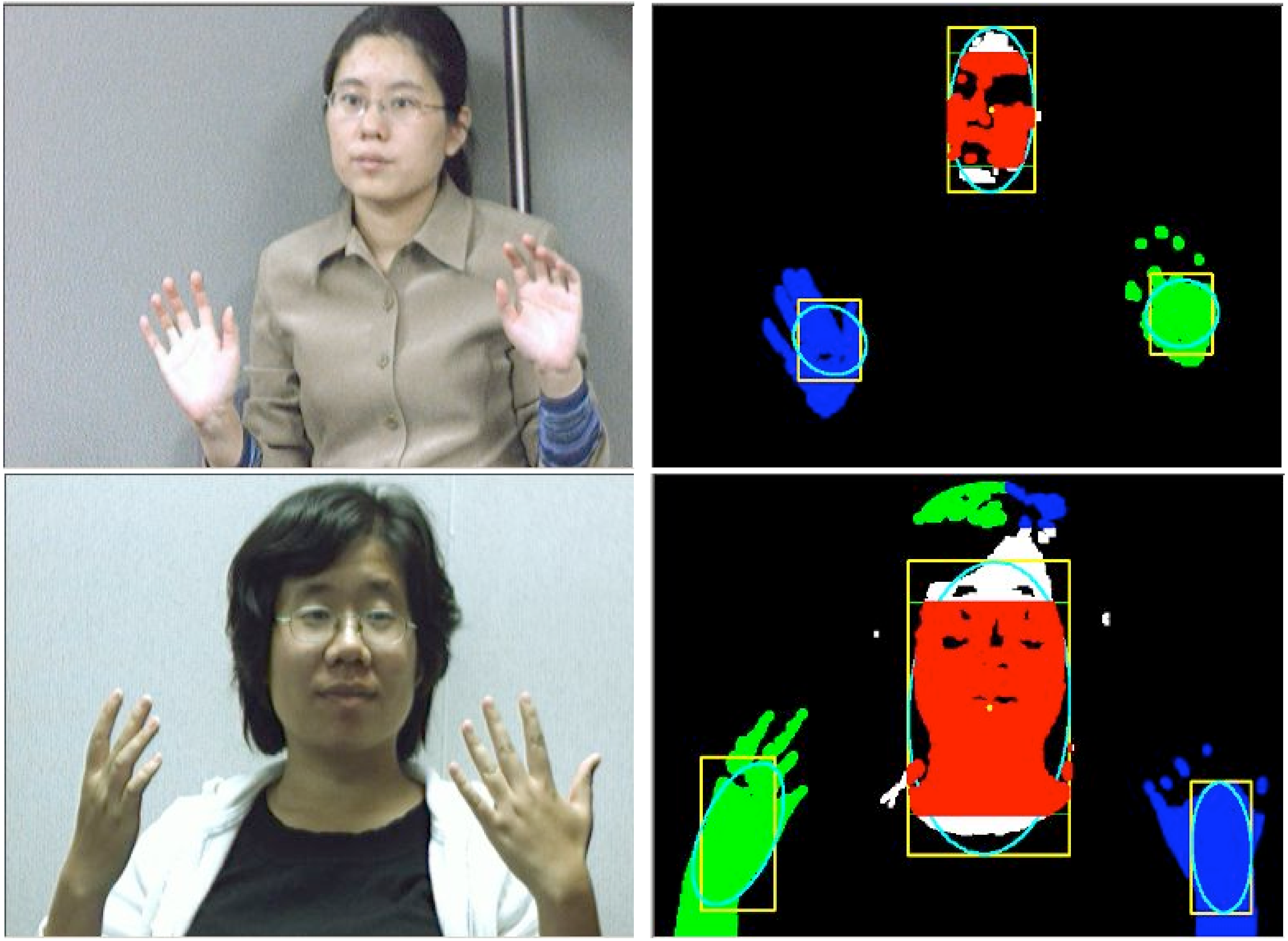
Sample Application: HCI

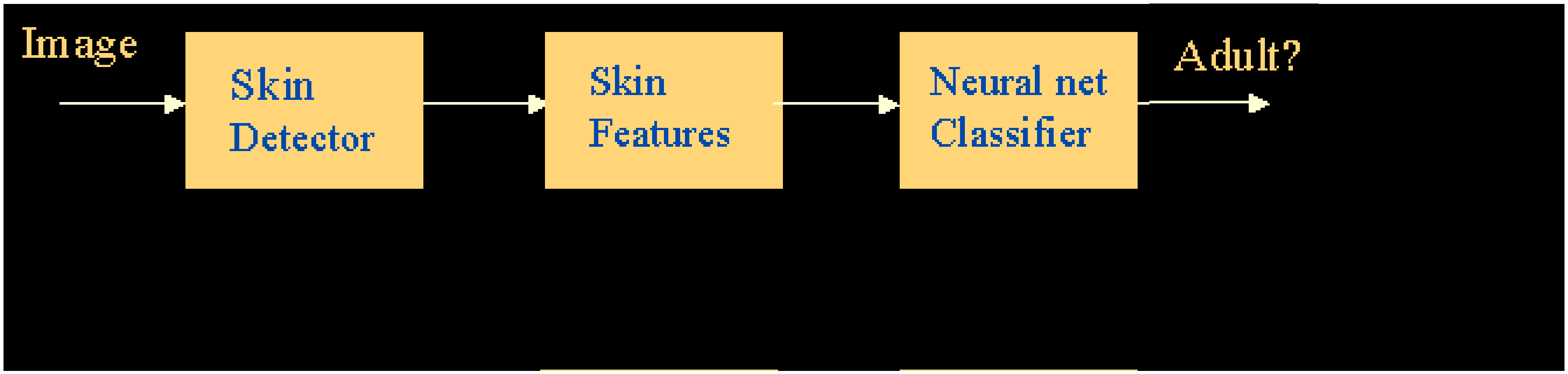
Haiying Guan, Matthew Turk, UCSB

Sample Application: HCI

Haiying Guan, Matthew Turk, UCSB



Sample Use: Adult Image Classification

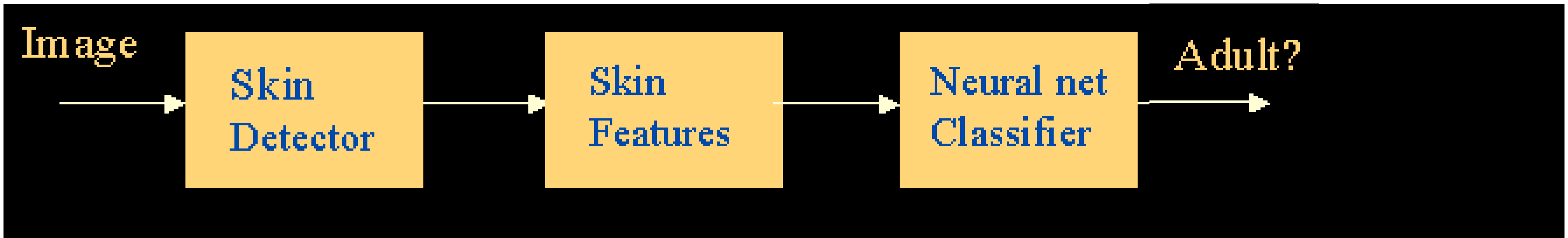


Based on Five Features:

- 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

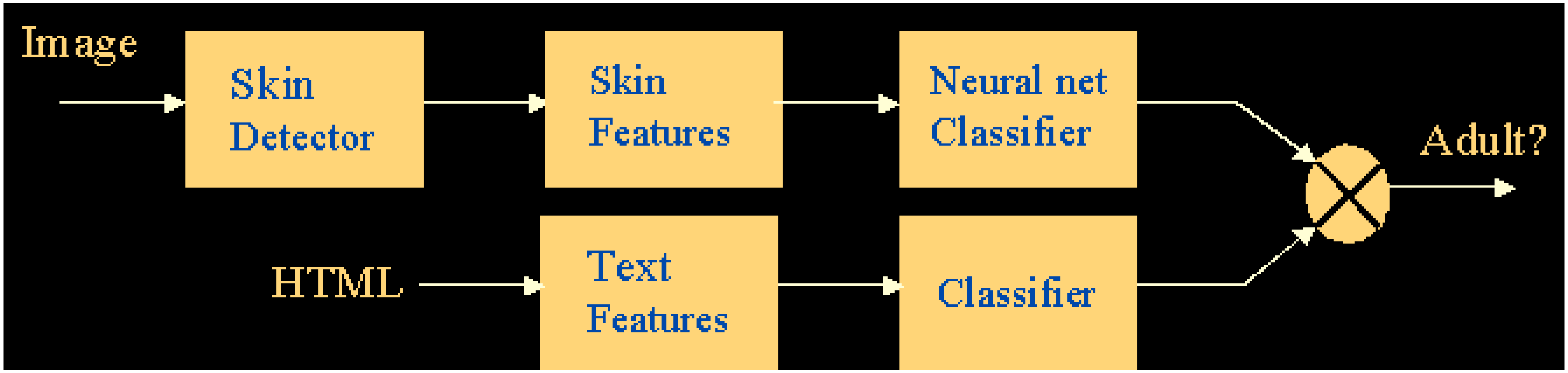
Adult Image Classification



(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



	% correctly detected adult images	*% false alarms*
Color-based Detector	85.8%	7.5%
Text-based Detector	84.9%	1.1%
Combined Detector	93.9%	8.0%

Adult Image Classification

Other related work:

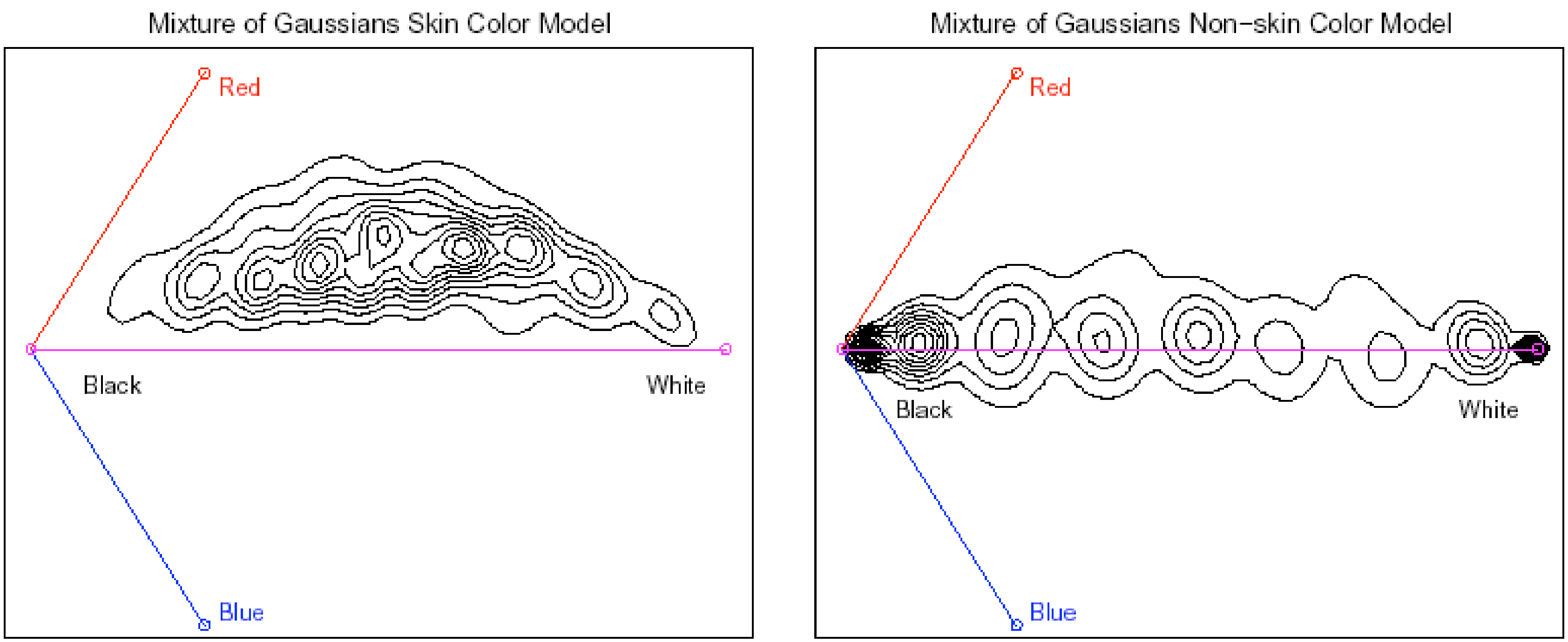
M.M. Fleck, D.A. Forsyth and C. Bregler, “Finding Naked People,” *Proc. European Conf. on Computer Vision*, Springer-Verlag, 1996. p. 593-602

James Wang, Jia Li, Gio Wiederhold and Oscar Firschein, “System for Screen Objectionable Images” Computer Communications, Vol 21(15), pp.1355-1369, Elsevier, 1998.

Back to Jones and Rehg Model

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

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



(a) Contour plot for skin model.

(b) Contour plot for non-skin model.

Jones and Rehg Mixture Model

Mixture of Gaussian Skin Color Model

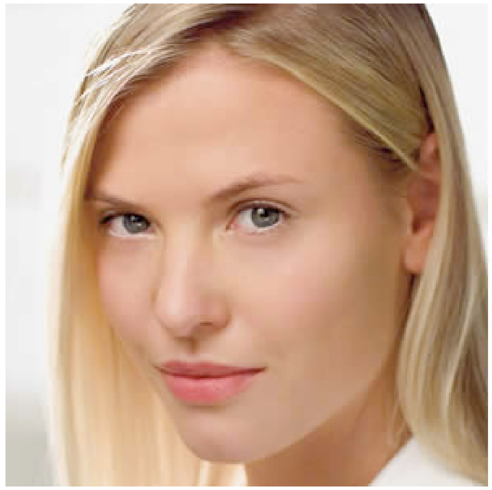
Kernel	*Mean*	*Covariance*	*Weight*
1	(73.53, 29.94, 17.76)	(765.40, 121.44, 112.80)	0.0294
2	(249.71, 233.94, 217.49)	(39.94, 154.44, 396.05)	0.0331
3	(161.68, 116.25, 96.95)	(291.03, 60.48, 162.85)	0.0654
4	(186.07, 136.62, 114.40)	(274.95, 64.60, 198.27)	0.0756
5	(189.26, 98.37, 51.18)	(633.18, 222.40, 250.69)	0.0554
6	(247.00, 152.20, 90.84)	(65.23, 691.53, 609.92)	0.0314
7	(150.10, 72.66, 37.76)	(408.63, 200.77, 257.57)	0.0454
8	(206.85, 171.09, 156.34)	(530.08, 155.08, 572.79)	0.0469
9	(212.78, 152.82, 120.04)	(160.57, 84.52, 243.90)	0.0956
10	(234.87, 175.43, 138.94)	(163.80, 121.57, 279.22)	0.0763
11	(151.19, 97.74, 74.59)	(425.40, 73.56, 175.11)	0.1100
12	(120.52, 77.55, 59.82)	(330.45, 70.34, 151.82)	0.0676
13	(192.20, 119.62, 82.32)	(152.76, 92.14, 259.15)	0.0755
14	(214.29, 136.08, 87.24)	(204.90, 140.17, 270.19)	0.0500
15	(99.57, 54.33, 38.06)	(448.13, 90.18, 151.29)	0.0667
16	(238.88, 203.08, 176.91)	(178.38, 156.27, 404.99)	0.0749

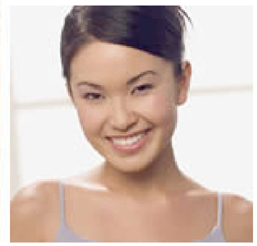
Jones and Rehg Mixture Model

Mixture of Gaussian Non-skin Color Model

Kernel	*Mean*	*Covariance*	*Weight*
1	(254.37, 254.41, 253.82)	(2.77, 2.81, 5.46)	0.0637
2	(9.39, 8.09, 8.52)	(46.84, 33.59, 32.48)	0.0516
3	(96.57, 96.95, 91.53)	(280.69, 156.79, 436.58)	0.0864
4	(160.44, 162.49, 159.06)	(355.98, 115.89, 591.24)	0.0636
5	(74.98, 63.23, 46.33)	(414.84, 245.95, 361.27)	0.0747
6	(121.83, 60.88, 18.31)	(2502.24, 1383.53, 237.18)	0.0365
7	(202.18, 154.88, 91.04)	(957.42, 1766.94, 1582.52)	0.0349
8	(193.06, 201.93, 206.55)	(562.88, 190.23, 447.28)	0.0649
9	(51.88, 57.14, 61.55)	(344.11, 191.77, 433.40)	0.0656
10	(30.88, 26.84, 25.32)	(222.07, 118.65, 182.41)	0.1189
11	(44.97, 85.96, 131.95)	(651.32, 840.52, 963.67)	0.0362
12	(236.02, 236.27, 230.70)	(225.03, 117.29, 331.95)	0.0849
13	(207.86, 191.20, 164.12)	(494.04, 237.69, 533.52)	0.0368
14	(99.83, 148.11, 188.17)	(955.88, 654.95, 916.70)	0.0389
15	(135.06, 131.92, 123.10)	(350.35, 130.30, 388.43)	0.0943
16	(135.96, 103.89, 66.88)	(806.44, 642.20, 350.36)	0.0477

Homework: Due Friday Dec 7



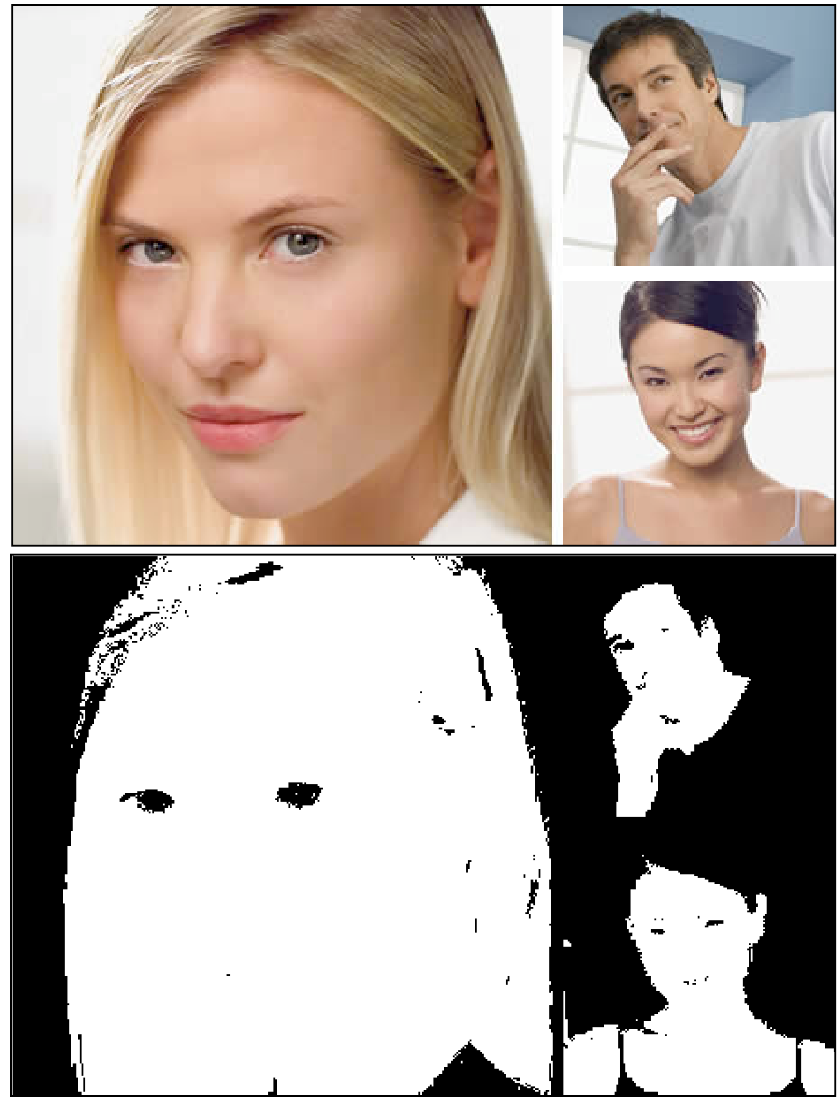

- Download jrmogskin.m from the course web site
- Try it on your own images!

What to Hand In

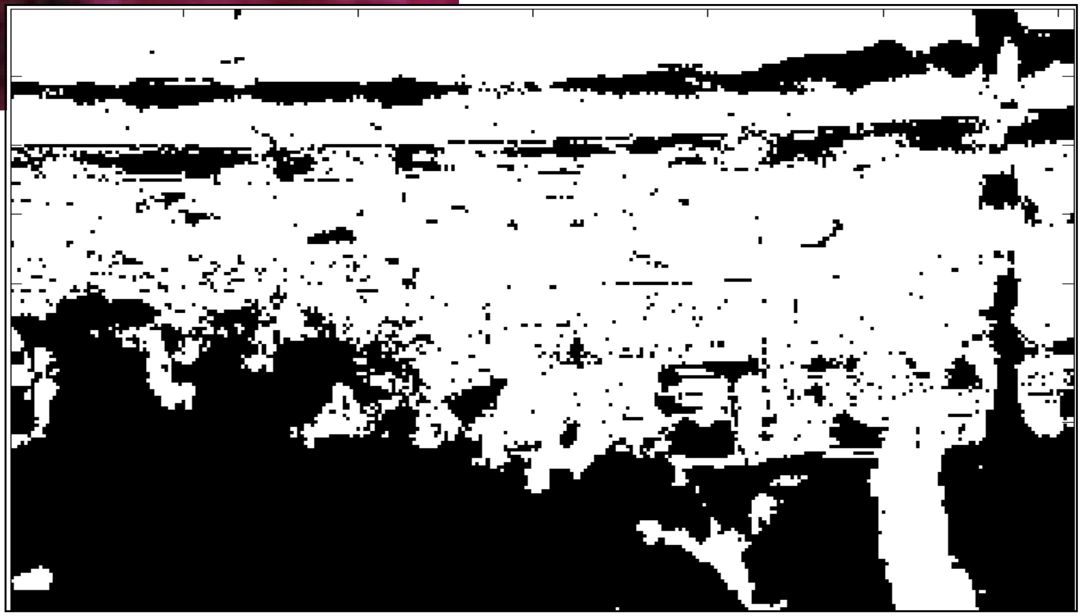
A short report, in Angel:

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



Examples

Example of
False Negatives

Explanation:
paint on skin
changes the
spectral albedo

Important Constraint

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