A Spectral Shading Model for Human Skin

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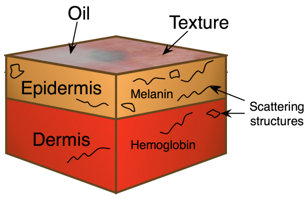
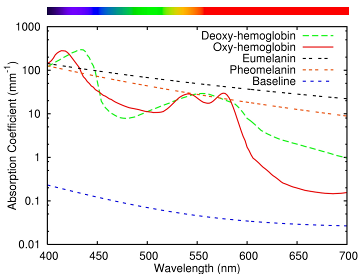
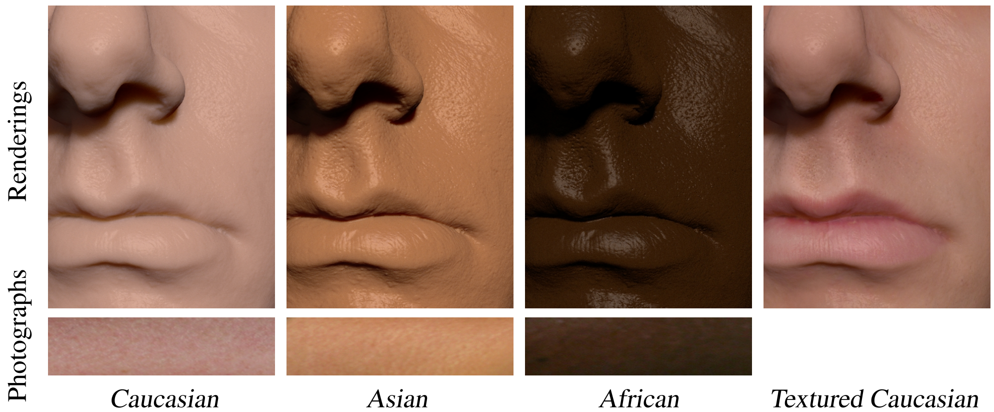


Two layer skin model



Spectral absorption coefficients



Different skin types simulated with our model (top) compared to actual photographs of real skin samples (bottom). For Caucasian skin, $C_m = 0.5\%$, $\beta_m = 0.7$, $C_h = 0.5\%$, and $\rho_s = 0.3$. For Asian skin, $C_m = 15\%$, $\beta_m = 0$, $C_h = 1\%$, and $\rho_s = 0.3$. For African skin, $C_m = 50\%$, $\beta_m = 0.7$, $C_h = 5\%$, and $\rho_s = 0.3$. The far right image applies an albedo texture to the Caucasian skin.

We have developed an analytical spectral shading model for human skin. Our model accounts for both subsurface and surface scattering. To simulate the interaction of light with human skin, we have narrowed the number of necessary parameters down to just four, controlling the amount of oil, melanin, and hemoglobin, which makes it possible to match specific skin types. Using these physically-based parameters we generate custom spectral diffusion profiles for a two-layer skin model (shown in the top left figure) that account for subsurface scattering within the skin. We use the diffusion profiles in combination with a Torrance-Sparrow model for surface scattering to simulate the reflectance of the specific skin type. The images above show examples of simulated Caucasian, Asian and African skin types compared with photographs of real skin.

We generate the spectral diffusion profiles by modeling the skin as a two layer translucent material using the multipole diffusion model [Donner and Jensen 2005]. Each homogenous layer has spectral absorption and scattering coefficients depending on its chemical and physical structure. The top layer, the epidermis, absorbs light depending on the amount and type of melanin in the skin. Its spectral absorption coefficient σ_a^{epi} is defined as

$$\sigma_a^{epi}(\lambda)=C_m(\beta_m\sigma_a^{em}(\lambda)+(1-\beta_m)\sigma_a^{pm}(\lambda))+(1-C_m)\sigma_a^{\text{baseline}}, \quad (1)$$

where C_m is the total volume fraction of melanin in the epidermis, σ_a^{em} is the absorption of eumelanin, σ_a^{pm} is the absorption of pheomelanin, and β_m linearly interpolates between the two melanin types. These two melanin types are the basic building blocks of real melanin in skin. $\sigma_a^{\text{baseline}}$ is the baseline absorption of skin due to mesostructures and other small concentrations of chemicals. The baseline absorption spectra of skin and of melanins are broad and fairly featureless, and are described well by power laws

$$\sigma_a^{em}(\lambda)=6.6\times10^{1}0\times\lambda^{-3.33} \quad mm^{-1} \quad (2)$$

$$\sigma_a^{pm}(\lambda)=2.9\times10^{1}4\times\lambda^{-4.75} \quad mm^{-1} \quad (3)$$

$$\sigma_a^{baseline}(\lambda)=0.0244+8.53e^{-(\lambda-154)/66.2} \quad mm^{-1} \quad (4)$$

Absorption in the lower layer, the dermis, is dominated by hemoglobin. Hemoglobin appears in the dermis in both oxygenated and deoxygenated form, each has a slightly different spectrum as shown above[1]. The total absorption in the dermis including baseline absorption is

$$\sigma_a^{derm}(\lambda)=C_h\left(\gamma\,\sigma_a^{oxy}(\lambda)+(1-\gamma)\,\sigma_a^{deoxy}(\lambda)\right)+(1-C_h)\sigma_a^{\text{baseline}}, \quad (5)$$

where C_h is the volume fraction of hemoglobin in the dermis, and the oxygenation ratio γ is ≈ 0.7.

[1]Hemoglobin data courtesy Scott Prahl: omlc.ogi.edu/spectra/hemoglobin/

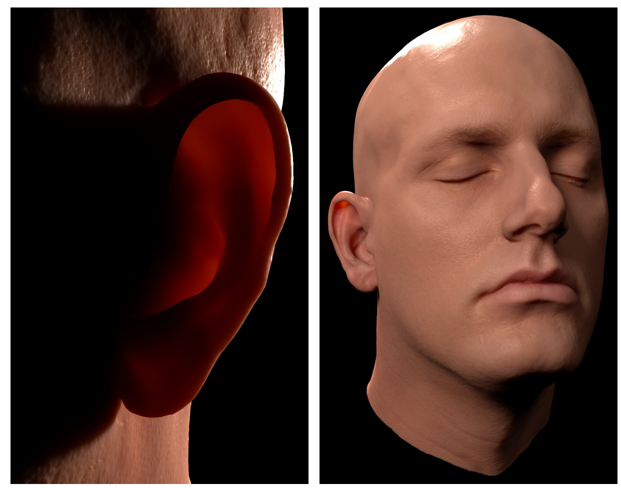


Figure 1: *The left images shows how our model captures the scattering of light through thin areas such as the ear, while the right shows the skin illuminated from several directions. For both images, the parameters are $C_m = 0.2\%$, $\beta_m = 0.5$, $C_h = 1\%$, and $\rho_s = 0.25$. Rendering took under 5 minutes on a modern workstation.*

Scattering in skin is due to high frequency changes in index of refraction between different tissues, and is modeled well by a combination of Rayleigh and Mie theory

$$\sigma_s'(\lambda)=14.74\lambda^{-0.22}+2.2\times10^{11}\times\lambda^{-4}. \quad (6)$$

When rendering images of skin, the user chooses the three parameters C_m, C_h, β_m to generate spectral data for the multipole, which computes the subsurface scattering component of skin. In our model, epidermal thickness is fixed at 0.25mm, with a semi-infinite dermis. This subsurface component is modulated by an albedo texture as described in [Donner and Jensen 2005].

To account for surface scattering from an oily layer, we model light reflected at the surface with the Torrance-Sparrow BRDF $f_{r,TS}$ [Torrance and Sparrow 1967]. We have found that a roughness value of ≈ 0.3 is sufficient. The oiliness of the skin is controlled by a linear scale factor ρ_s.

Figure 1 provides examples of our method in different lighting conditions.

References

DONNER, C., AND JENSEN, H. W. 2005. Light diffusion in multi-layered translucent materials. *ACM Trans. Graphic. 24*, 3, 1032–1039.

TORRANCE, K., AND SPARROW, E. 1967. Theory for off-specular reflection from roughened surfaces. *J. Opt. Soc. Am. 57*, 1104–1114.