SIGGRAPH 2012

USC Institute for Creative Technologies

Graphics Lab

Estimating Diffusion Parameters From Polarized Spherical Gradient Illumination

USC Institute for Creative Technologies

Introduction

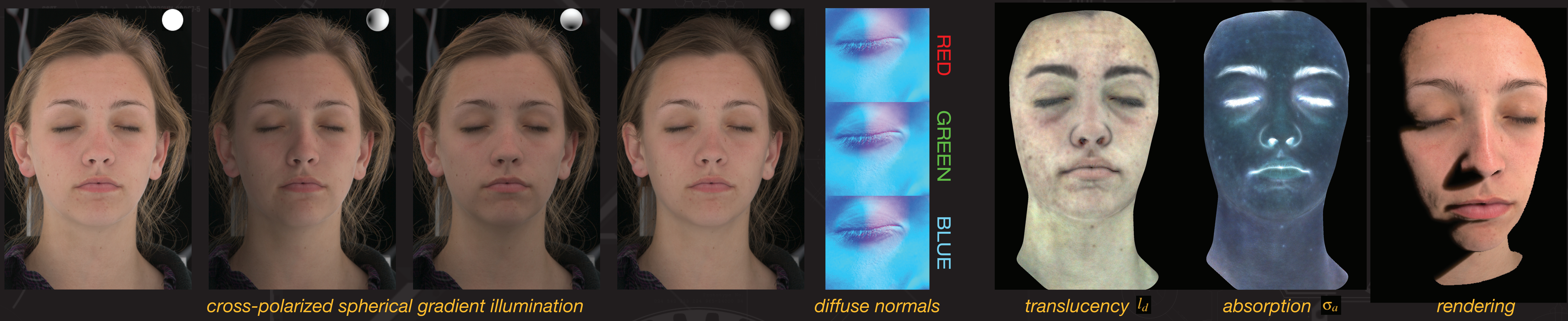

Figure 1: Per-surface point diffusion parameters estimated from just four observations under cross-polarized 0^{th} and 1^{st} order spherical gradient illumination conditions.

The appearance of many common materials is the result of subsurface light transport that gives rise to the characteristic "soft" appearance and the unique coloring of such materials. Jensen et al. [2001] introduced the dipole-diffusion approximation to efficiently model isotropic subsurface light transport. The scattering parameters needed to drive the dipole-diffusion approximation are typically estimated by illuminating a homogeneous surface patch with a collimated beam of light, or in the case of spatially varying translucent materials with a dense set of structured light patterns. A disadvantage of most existing techniques is that acquisition time is traded off with spatial density of the scattering parameters.

Recently, Ma et al. [2007] proposed a technique to obtain high quality estimates of diffuse and specular albedo and photometric normal maps from just eight photograph under four different polarized spherical gradient lighting conditions. In addition, Ma et al. also proposed a hybrid normal rendering technique that approximates the soft appearance of subsurface scattering with local shading using measured RGB diffuse normals. This suggest a connection between spherical gradient illumination and subsurface scattering. In this work, we aim to formalize this apparent connection based on radiative transfer theory. In particular, we show that *dense per-surface-point* scattering parameters can be *directly* obtained from observations under spherical gradient illumination (Fig.1), *without* resorting to any explicit fitting of observed scattering profiles.

Background

Light transport in highly scattering translucent materials can be well approximated by diffusion theory [Jensen et al. 2001]. According to radiative transfer theory, diffusion can be accurately approximated by a two-term spherical harmonic expansion of radiance:

$$L(x,\omega) = \frac{1}{4\pi}\phi(x) + \frac{3}{4\pi}\omega \cdot \vec{E}(x) \qquad (1)$$

where $\phi(x) = \int_{4\pi} L(x,\omega)d\omega$ is the scalar fluence and $\vec{E}(x) = \int_{4\pi} L(x,\omega)\omega d\omega$ is the vector irradiance.

Substituiting Equation 1 in the radiative transfer equation and assuming semi-infinite material, leads to the well-known diffuse BSSRF [Jensen et al. 2001]:

$$R_d(r) = -D\frac{(\vec{n}\cdot\nabla\phi(x_o))}{d\Phi_i(x_i)} \qquad (2)$$

where $r = ||x_o - x_i||$, and $D = 1/3\sigma_t'$ is the diffusion constant.

Relating Equations (1) and (2) yields a mechanism for estimating scattering parameters of dipole diffusion from observations of the 1^{st} -order spherical gradients. Specifically, Equation 2 relates the observed diffuse albedo R_d (cross-polarized 0^{th} order spherical statistics) to the normal aligned spherical gradient (crosspolarized 1^{st} order spherical statistics [Ma et al. 2007]) via the diffusion constant D. Assuming that the surface normal is along the +Z direction, this leads to the following compact relation between the diffusion constant and polarized spherical gradients:

$$D \propto \frac{R_d}{G_Z} \qquad (3)$$

where G_Z refers to the spherical gradient along the surface normal direction. Given the the spherical gradients form a rotational basis, we can create a linear gradient in any arbitrary direction using a linear combination of the three principal gradients G_X, G_Y, and G_Z.

We have emperically derived a relation that approximates the diffusion constant *D* using observations under spherical gradient illumination. This involves converting Equation 2, which expresses a *spatial* gradient, into an *angular* gradient by including an estimate of the local curvature K in Equation 3. In our work, we estimate the local curvature from photometric normals estimated using sperical gradient illumination.

Results

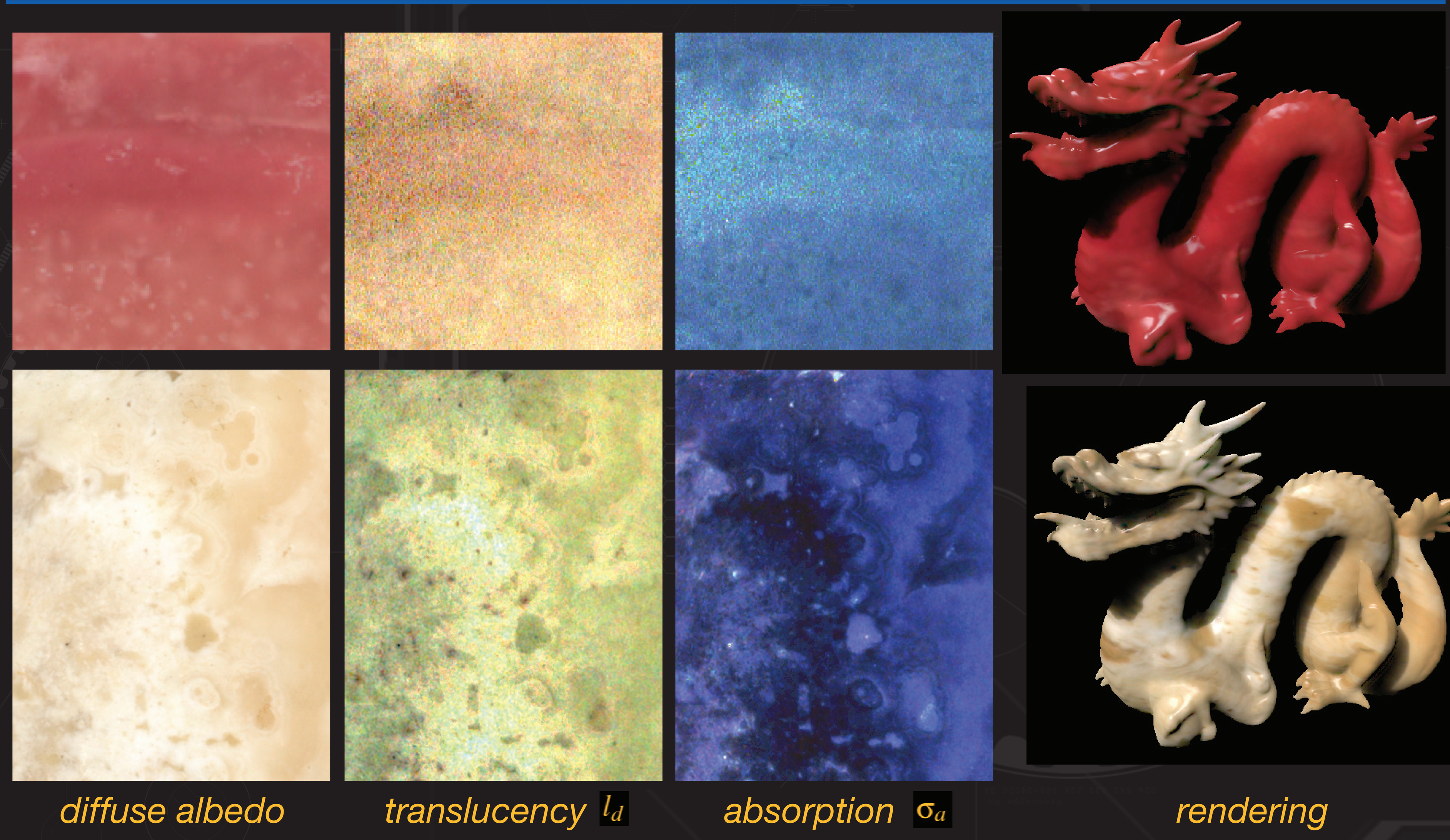

Figure 2: Per-surface point diffusion parameters estimated for a red wax sample (top row) and a sandstone sample (bottom row)

REFERENCES

JENSEN, H. W., MARSCHNER, S. R., LEVOY, M., AND HANRHAN, P. 2001. A practical model for subsurface light transport. In Proceedings of ACM SIGGRAPH 2001, 511–518.

MA, W.-C., HAWKINS, T., PEERS, P., CHABERT, C.-F., WEISS, M., AND DEBEVEC, P. 2007. Rapid acquisition of specular and diffuse normal maps from polarized spherical gradient illumination. In Rendering Techniques, 183–194.

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