Lecture 22: Light and shading
Announcements

• PS10 out
• 2nd-to-last lecture on low-level vision.
• Rest of course: recent vision topics.
Many interpretations of color!
The Workshop Metaphor

(a) an image

The Workshop Metaphor

(a) an image
(b) a likely explanation


Source: J. Barron
The Workshop Metaphor

(a) an image
(b) a likely explanation

(c) painter’s explanation

The Workshop Metaphor

(a) an image  (b) a likely explanation

(c) painter’s explanation  (d) sculptor’s explanation

The Workshop Metaphor

(a) an image
(b) a likely explanation
(c) painter’s explanation
(d) sculptor’s explanation
(e) gaffer’s explanation

Today

- Light and surfaces
- Shape from shading
- Photometric stereo
- Intrinsic image decomposition
Recall: interaction of light and surfaces

Spectral radiance: power in a specified direction, per unit area, per unit solid angle, per unit wavelength.

\[ BRDF = f(\theta_i, \phi_i, \theta_e, \phi_e, \lambda) = \frac{L(\theta_e, \phi_e, \lambda)}{E(\theta_i, \phi_i, \lambda)} \]

Spectral irradiance: incident power per unit area, per unit wavelength

Figure 10-7. The bidirectional reflectance distribution function is the ratio of the radiance of the surface patch as viewed from the direction \((\theta_e, \phi_e)\) to the irradiance resulting from illumination from the direction \((\theta_i, \phi_i)\).

[Horn, 1986]
For now, ignore specular reflection
And Refraction...
And Interreflections…

Source: Photometric Methods for 3D Modeling, Matsushita, Wilburn, Ben-Ezra. Changes by N. Snavely
Recall: effect of BRDF on sphere rendering

Diffuse/Lambertian reflection

https://marmoset.co/posts/physically-based-rendering-and-you-can-too/

Source: W. Freeman
Diffuse reflection

- Dull, matte surfaces like chalk or latex paint
- Microfacets scatter incoming light randomly
- Effect is that light is reflected equally in all directions

Source: S. Lazebnik and K. Bala
Directional lighting

- All rays are parallel
- Equivalent to an infinitely distant point source

Source: N. Snavely
Diffuse reflection

\[ R_e = k_d \mathbf{N} \cdot \mathbf{L} R_i \]

image intensity of \( P \)

\[ I = k_d \mathbf{N} \cdot \mathbf{L} \]

Simplifying assumptions we’ll often make:

- **I = \( R_e \):** “camera response function” is the identity
  - can always achieve this in practice by inverting it
- **\( R_i = 1 \):** light source intensity is 1
  - can achieve this by dividing each pixel in the image by \( R_i \)

Source: N. Snavely
Other BRDFs

- Ideal diffuse (Lambertian)
- Ideal specular
- Directional diffuse
Non-smooth-surfaced materials

from Steve Marschner
Shape from shading

\[ I = k_d N \cdot L \]

Assume \( k_d \) is 1 for now.

What can we measure from one image?
- \( \cos^{-1}(I) \) is the angle between \( N \) and \( L \)
- Add assumptions:
  - Constant albedo
  - A few known normals (e.g., silhouettes)
  - Smoothness of normals

In practice, SFS doesn’t work very well: assumptions are too restrictive, too much ambiguity in nontrivial scenes.

Source: N. Snavely
An ambiguity that artists exploit!

Contours provide extra shape information

Consider points on the *occluding contour*:

- $N_z$ positive
- $N_z$ negative

Projection direction ($z$)

Source: S. Lazebnik

Application: finding the direction of the light source

\[ I(x, y) = N(x, y) \cdot S(x, y) \]

Full 3D case:

\[
\begin{pmatrix}
N_x(x_1, y_1) & N_y(x_1, y_1) & N_z(x_1, y_1) \\
N_x(x_2, y_2) & N_y(x_2, y_2) & N_z(x_2, y_2) \\
\vdots & \vdots & \vdots \\
N_x(x_n, y_n) & N_y(x_n, y_n) & N_z(x_n, y_n)
\end{pmatrix}
\begin{pmatrix}
S_x \\
S_y \\
S_z
\end{pmatrix}
= 
\begin{pmatrix}
I(x_1, y_1) \\
I(x_2, y_2) \\
\vdots \\
I(x_n, y_n)
\end{pmatrix}
\]

For points on the occluding contour, \( N_z = 0 \):

\[
\begin{pmatrix}
N_x(x_1, y_1) & N_y(x_1, y_1) \\
N_x(x_2, y_2) & N_y(x_2, y_2) \\
\vdots & \vdots \\
N_x(x_n, y_n) & N_y(x_n, y_n)
\end{pmatrix}
\begin{pmatrix}
S_x \\
S_y
\end{pmatrix}
= 
\begin{pmatrix}
I(x_1, y_1) \\
I(x_2, y_2) \\
\vdots \\
I(x_n, y_n)
\end{pmatrix}
\]


Source: S. Lazebnik
Finding the direction of the light source


Source: S. Lazebnik
Application: Detecting composite photos

[Johnson and Farid, 2005]
Photometric stereo

Source: N. Snavely
Photometric stereo

Can write this as a linear system, and solve:

\[
\begin{bmatrix}
I_1 \\
I_2 \\
I_3 \\
\end{bmatrix} = k_d \begin{bmatrix}
L_1^T \\
L_2^T \\
L_3^T \\
\end{bmatrix} N
\]

Source: N. Snavely
Photometric Stereo

Input

Recovered albedo

Recovered normal field

Recovered surface model

Source: Forsyth & Ponce, S. Lazebnik
Photometric Stereo

Source: N. Snavely
Video photometric stereo

Video Normals from Colored Lights
Gabriel J. Brostow, Carlos Hernández, George Vogiatzis, Björn Stenger, Roberto Cipolla

Fig. 2. Applying the original algorithm to a face with white makeup. Top: example input frames from video of an actor smiling and grimacing. Bottom: the resulting integrated surfaces.
But what if we don’t know the BRDF?

[Johnson and Adelson, 2009]
Lights, camera, action

Sensor

Lights

Camera
Figure 7: Comparison with the high-resolution result from the original retrographic sensor. (a) Rendering of the high-resolution $20 bill example from the original retrographic sensor with a close-up view. (b) Rendering of the captured geometry using our method.
Figure 9: Example geometry measured with the bench and portable configurations. Outer image: rendering under direct lighting. Inset: macro photograph of original sample. Scale shown in upper left. Color images are shown for context and are to similar, but not exact scale.
What about paint?

\[ I = k_d \mathbf{N} \cdot \mathbf{L} \]

\( k_d \) is reflectance or albedo
Intrinsic image decomposition

Source: J. Barron
Intrinsic image decomposition

\[ I = R + S(Z, L) \]

- \( R \): log-reflectance
- \( R(Z, L) \): log-shading image of \( Z \) and \( L \)
- \( S(Z, L) \): log-reflectance
- \( L \): illumination

Source: J. Barron
Intrinsic image decomposition

Reflectance

Shading
CNN-based reflectance estimation

Bell et al., “Intrinsic images in the wild”, 2014
Applications of intrinsic image decomposition

[Barron and Malik “SIRFS”, 2012]
Application: relighting

[Barron and Malik “Scene-SIRFS”, 2013]
Application: relighting

[Barron and Malik “Scene-SIRFS”, 2013]
Next week: perceptual grouping