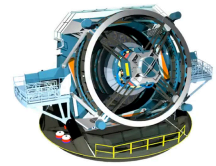
Reflectance, Lights

Computer Vision I
CSE 252A
Lecture 7

What I learned about this week



- Large Synoptic Survey Telescope
- 3.2Gigapixel camera
- 189 CCD’s, each with 16 megapixels
- Pixels are 10µm
- Filter wheel
- 6200 lbs
- https://www.lsst.org/about/camera

What I learned about this week

Portrait mode on the Pixel 2 and Pixel 2 XL smartphones

Tuesday, October 17, 2017

Posted by Marc Levoy, Principal Engineer and Yael Pritch, Software Engineer

Portrait mode, a major feature of the new Pixel 2 and Pixel 2 XL smartphones, allows anyone to take professional-looking shallow depth-of-field images. This feature helped both devices earn DxO's highest mobile camera ranking, and works with both the rear-facing and front-facing cameras, even though neither is dual-camera (normally required to obtain this effect). Today we discuss the machine learning and computational photography techniques behind this feature.

HDR+ picture without (left) and with (right) portrait mode. Note how portrait mode’s synthetic shallow depth of field helps

https://research.googleblog.com/2017/10/portrait-mode-on-pixel-2-and-pixel-2-xl.html

Announcements

- HW1 due Friday
- Some point around HW1

Projective Transformation
(Homography)

- 3 x 3 linear transformation of homogenous coordinates
- Points map to points,
- lines map to lines

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{21} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

Special cases
- –Affine transformation: $[a_{31}\ \ a_{32}\ \ a_{33}] = [0\ 0\ 1]$
- –Rigid: Affine and upper-left 2x2 submatrix is orthogonal

HW1: Warping by Homography

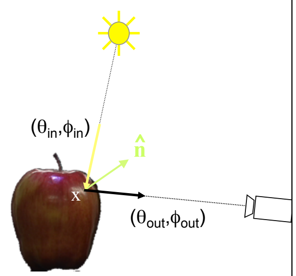
t = Hs

s: source image coordinates
t: arget image coordinates

BRDF

With assumptions in previous slide

- **Bi-directional Reflectance Distribution Function**
  $\rho(\theta_{in}, \phi_{in} ; \theta_{out}, \phi_{out})$
- **Ratio of emitted radiance to incident irradiance (units: sr^{-1})**
- **In local coordinate system at x**
  - **Incoming light direction:** θ_{in}, ϕ_{in}
  - **Outgoing light direction:** θ_{out}, ϕ_{out}

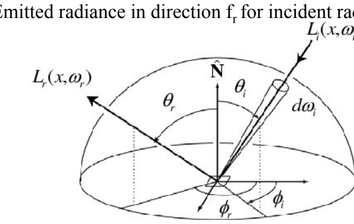


$$\rho(x;\theta_{in},\phi_{in};\theta_{out},\phi_{out}) = \frac{L_o(x;\theta_{out},\phi_{out})}{L_i(x;\theta_{in},\phi_{in})\cos\theta_{in} d\omega}$$

Where ρ is sometimes denoted f_r.

The Reflection Equation

Emitted radiance in direction f_r for incident radiance L_i.



$$L_r(x,\omega_r) = \int_{H^2} f_r(x,\omega_i \to \omega_r) L_i(x,\omega_i)\cos\theta_i \, d\omega_i$$

where $\omega_i = (\theta_i, \phi_i)$

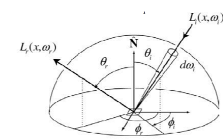
Properties of BRDFs

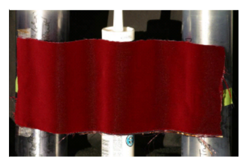
1. Non-negative: $\rho(\theta_{in}, \phi_{in} ; \theta_{out}, \phi_{out}) \geq 0$
2. Helmholtz Reciprocity Principle:
   $\rho(\theta_{in}, \phi_{in} ; \theta_{out}, \phi_{out}) = \rho(\theta_{out}, \phi_{out} ; \theta_{in}, \phi_{in})$
3. Total energy leaving a surface must be less than total energy arriving at the surface

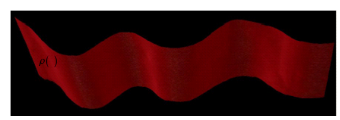
$$\int_{\Omega_i} L_i(\mathbf{x},\theta_i,\phi_i)\cos\theta_i \, d\omega_i \geq \int_{\Omega_o}\left[\int_{\Omega_i} \rho(\theta_i,\phi_i;\theta_0,\phi_o) L_i(\mathbf{x},\theta_i,\phi_i)\cos\theta_i \, d\omega_i\right]\cos\theta_o d\omega_o$$

Important class of BRDFs: Isotropic BRDF

$$\rho(\theta_i,\phi_i;\theta_o,\phi_o) = \rho_r(\theta_i,\theta_o,\phi_i - \phi_o)$$



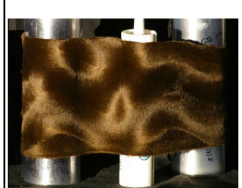




Isotropic BRDF's are symmetric about the surface normal. If the surface is rotated about the normal for the same incident and emitting directions, the value of the BRDF is the same.

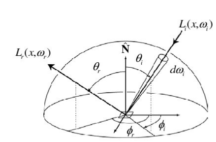
Anisotropic BRDF

$\rho(\theta_i,\phi_i;\theta_o,\phi_o)$ is an arbitrary function



Lambertian (Diffuse) Surface

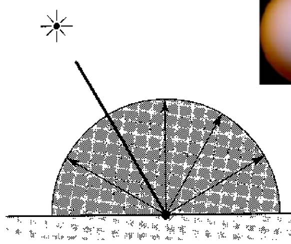
- BRDF is a constant called the albedo. $\rho(x;\theta_{in},\phi_{in};\theta_{out},\phi_{out}) = K$
- Emitted radiance is NOT a function of outgoing direction – i.e. constant in all directions.
- For lighting coming in single direction ω_i, emitted radiance is proportional to cosine of the angle between normal and light direction



$$L_r(x,\omega_r) = \int_{H^2} f_r(x,\omega_i \to \omega_r) L_i(x,\omega_i)\cos\theta_i \, d\omega_i$$

$$L_r = K\hat{N}\cdot\omega_i$$

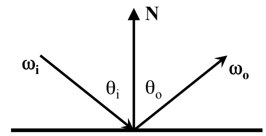
Lambertian reflection



- Lambertian
- Matte
- Diffuse

Light emitted equally in all directions.

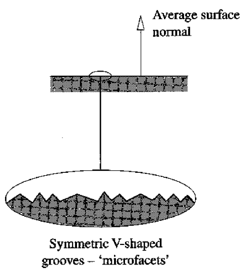
Specular Reflection: Smooth Surface

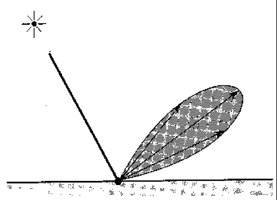


- N, ω_i, ω_o are coplanar
- $\theta_i = \theta_o$

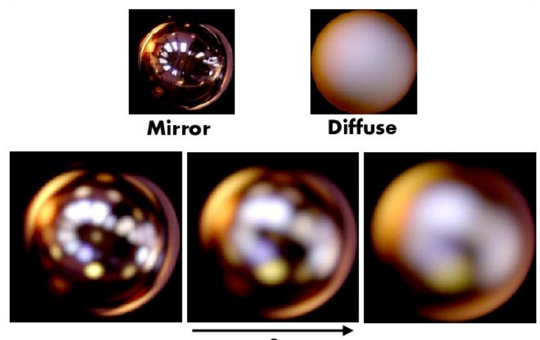
Speculum – Latin for "Mirror"

Rough Specular Surface





Phong Model



CS348B Lecture 10 Pat Hanrahan, Spring 2002

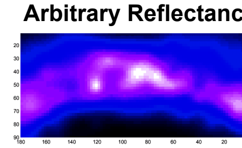
Non-Lambertian reflectance

Lots of BRDF Models

Common Models

- Lambertian
- Phong
- Physics-based
  - Specular [Blinn 1977], [Cook-Torrance 1982], [Ward 1992]
  - Diffuse [Hanrahan, Kreuger 1993]
  - Generalized Lambertian [Oren, Nayar 1995]
  - Thoroughly Pitted Surfaces [Koenderink et al 1999]
- Phenomenological
  - [Koenderink, Van Doorn 1996]

Arbitrary Reflectance



- Non-parametric model
- Anisotropic
- Non-uniform over surface
- BRDF Measurement *[Dana et al, 1999], [Marschner]*

Specialized

- Hair, skin, threads, paper [Jensen et al]

General BRDF: e.g. Velvet

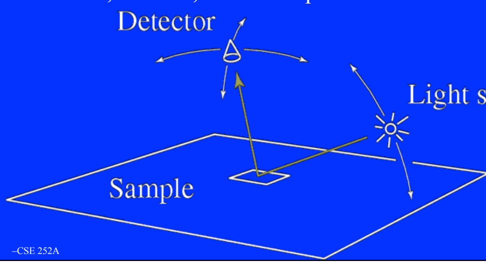
Portrait of Sir Thomas Morre, Hans Holbein the Younger, 1527

[After Koenderink et al, 1998]

Ways to measure BRDFs

Gonioreflectometers

- Three degrees of freedom spread among light source, detector, and/or sample



Gonioreflectometers

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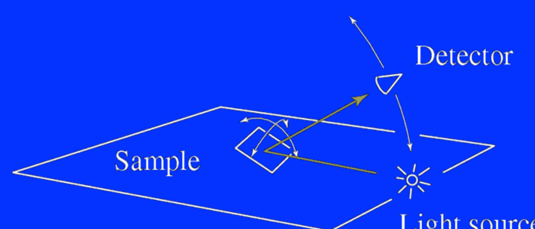
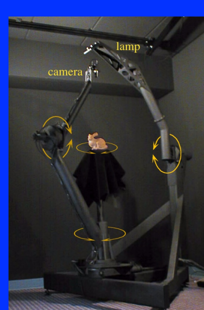


Gonioreflectometers

- Can add fourth degree of freedom to measure anisotropic BRDFs



4 degree-of-freedom gantry

BRDF Not Always Appropriate

BRDF

BSSRDF

http://graphics.stanford.edu/papers/bssrdf/

(Jensen, Marschner, Levoy, Hanrahan)

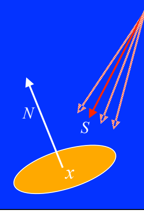
Light sources and shading

- A light source is a power source that emits light (instead of reflecting it)
- Laser – a single ray
- Point source – like a light bulb
- Line source – fluorescent light bulb
- Area source

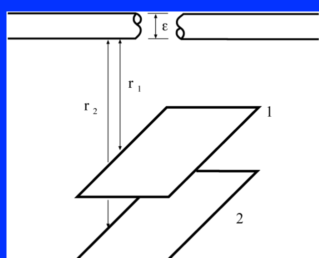
Nearby point source model

$$L=\rho_d(x)\left(\frac{\hat{N}(x)\bullet S(x)}{r(x)^2}\right)$$

- N is the surface normal
- ρ_d is diffuse (Lambertian) albedo
- S is source vector - a vector from x to the source, whose length is the intensity term



Nearby Line Source



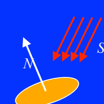
Intensity due to line source varies with inverse distance, if the source is long enough

Distant Point Source Model

- Assume that all points in the model are close to each other with respect to the distance to the source. Then the source vector doesn't vary much, and the distance doesn't vary much either, and we can roll the constants together to get:

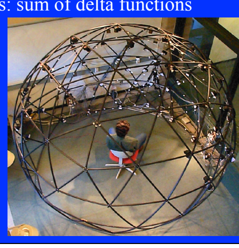
$$L=\rho_d(x)N(x)\bullet S(x)$$

- N is the surface normal
- ρ_d is diffuse (Lambertian) albedo
- S is source vector - a vector in source direction, whose length is the intensity term

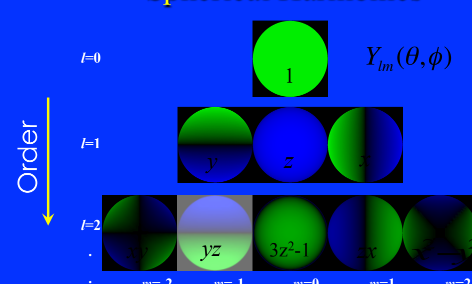


Lighting at infinity

- Direction is a three vector **s**, with $|\mathbf{s}| = 1$.
- Described as function on a sphere: radiance as a function of direction r(**s**)
- Single point source is a delta function at some direction
- Multiple point sources: sum of delta functions



Diffuse lighting at infinity: Spherical Harmonics

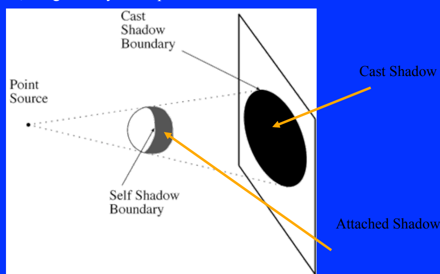


(Borrowed from: Ramamoorthi, Hanrahan, SIGGRAPH'01)

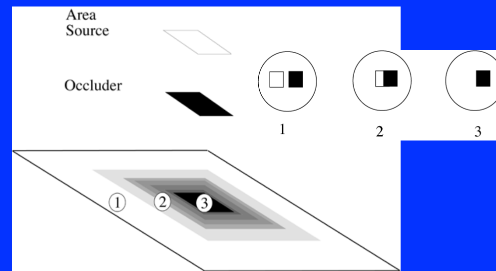
Green: Positive
Blue: Negative

Shadows cast by a point source

- A point that can't see the source is in shadow
- For point sources, the geometry is simple



Area Source Shadows



1. Fully illuminated
2. Penumbra
3. Umbra (shadow)

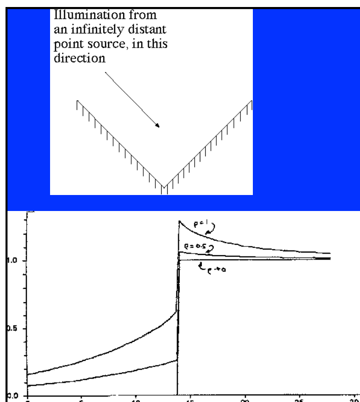
Shading models

Local shading model

- Surface has incident radiance due only to sources visible at each point
- Advantages:
  - often easy to manipulate, expressions easy
  - supports quite simple theories of how shape information can be extracted from shading
- Used in vision & real time graphics

Global shading model

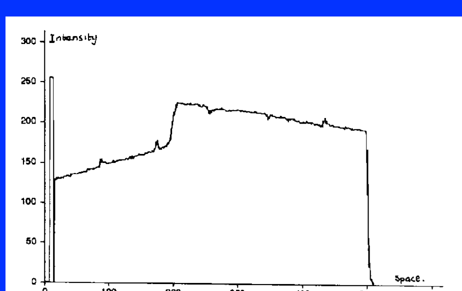
- surface radiosity is due to radiance reflected from other surfaces as well as from surfaces
- Advantages:
  - usually very accurate
- Disadvantage:
  - extremely difficult to infer anything from shading values
- Rarely used in vision, often in photorealistic graphics



At the top, geometry of a gutter with triangular cross-section; below, predicted radiosity solutions, scaled to lie on top of each other, for different albedos of the geometry. When albedo is close to zero, shading follows a local model; when it is close to one, there are substantial reflexes.

Figure from "Mutual Illumination," by D.A. Forsyth and A.P. Zisserman, Proc. CVPR, 1989, copyright 1989 IEEE

Irradiance observed in an image of this geometry for a real white gutter.



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