Lighting and Shadows

Thanks to Langer-Zucker, Henrik Wann Jensen, Ravi Ramamoorthi, Hanrahan, Preetham
Appearance of An Outdoor Scene

- Reflectance (BRDF, BTF)
- Illumination Spectrum
- Medium (Atmosphere)
- Sensor Model
- Scene Structure (Depth, Surface Normal)
- View Geometry
- Illumination Geometry
- Time

Appearance
Illumination Direction

February 18th 2002, 10 AM
Clear and Sunny

February 18th 2002, 11 AM
Clear and Sunny

February 18th 2002, 12 Noon
Clear and Sunny

February 18th 2002, 2 PM
Clear and Sunny

February 18th 2002, 3 PM
Clear and Sunny

February 18th 2002, 4 PM
Clear and Sunny
Illumination Spectra

May 4th 2002, 6 AM
Clear Day, Sun Rise

May 4th 2002, 12 Noon
Clear Day, Noon

May 4th 2002, 6 PM
Clear Day, Sun Set

May 4th 2002, 9 PM
Clear Night
Cloud Cover

March 22nd 2002, 7 AM
Sunny, No Clouds

March 4th 2002, 7 AM
Partly Sunny, Partly Cloudy

March 13th 2002, 7 AM
Overcast
Weather Conditions

April 16th 2002, 3 PM
Sunny, Mild Haze

April 12th 2002, 3 PM
Overcast, Light Rain

April 19th 2002, 3 PM
Overcast, Dense Fog

April 28th 2002, 3 PM
Overcast, Dense Mist
April 28th 2002, 6 AM
Rain & Mist, Visibility 2.5 miles
0.1 inches Precipitation last hour

April 28th 2002, 9 AM
Rain & Mist, Visibility 1.5 miles
0.23 inches Precipitation last hour

April 28th 2002, 12 Noon
Light Rain & Mist, Visibility 1.25 miles
0.08 inches Precipitation last hour

April 28th 2002, 3 PM
Dense Mist, Visibility 0.75 miles
0.02 inches Precipitation last hour
Four Seasons (New York)

Winter, January 4th 2002, 9 AM
Clear and Sunny

Fall, September 9th 2001, 9 AM
Clear and Sunny

Spring, March 14th 2001, 9 AM
Clear and Sunny

Summer, May 15th 2002, 9 AM
Clear and Sunny
Lighting Design

• From Frank Gehry Architecture, Ragheb ed. 2001
Lighting Design

• From Frank Gehry Architecture, Ragheb ed. 2001
Nomenclature for Lighting

Size: point line area volume

Directionality: collimated divergent convergent

Distance: infinity near-field

Temporal: static time-varying

Natural sun sky firefly moon

Artificial halogen fluorescent flash projector laser
Isotropic Point Light Source

We see an inverse distance squared fall off in intensity. Here light does not weaken, but only spreads in a sphere.
How to quantify light?

Need to consider light propagation in a cone.
Solid Angle

\[ d\omega = \frac{dA'}{R^2} = \frac{dA \cos \theta_i}{R^2} \]  (steradian)

What is the solid angle subtended by a hemisphere?
Radiant Intensity of Source:

Light Flux (power) emitted per unit solid angle

\[ I = \frac{d\Phi}{d\omega} \]  

(watts / steradian)
Surface Irradiance

Surface Irradiance:

\[ E = \frac{d\Phi}{dA} \quad \text{(watts/m}^2\text{)} \]

Light Flux (power) incident per unit surface area.

Does not depend on where the light is coming from!
Surface Radiance (tricky!)

\[ L = \frac{d^2 \Phi}{(dA \cos \theta_r) \ d\omega} \]  
(watts / m\(^2\) steradian)

- Flux emitted per unit foreshortened area per unit solid angle.
- \(L\) depends on direction \(\theta_r\).
- Surface can radiate into whole hemisphere.
- \(L\) depends on reflectance properties of surface.
Isotropic Point Source

\[ \Phi = \int_{S^2} I \, d\omega \]

\[ = 4\pi I \]

\[ I = \frac{\Phi}{4\pi} \]
How much light falls on a surface?

Lambert's Cosine Law
Illumination: Isotropic Point Source

\[ I(\omega) = \frac{\Phi}{4\pi} \]

\[ d\Phi = I\, d\omega = E\, dA \]

\[ I\, d\omega = \frac{\Phi \cos \theta}{4\pi \, r^2} \, dA = E\, dA \]

\[ E = \frac{\Phi \cos \theta}{4\pi \, r^2} \]

\[ \frac{\Phi \cos \theta}{4\pi \, r^2} \Rightarrow \frac{\Phi \cos^3 \theta}{4\pi \, h^2} \]
Infinite Line Source

Line source shows cylindrical symmetry.

The intensity fall-off is inversely proportional to distance from the line source. Why?

\[ d\Phi = I \, d\omega = E \, dA \]
Infinite Planar Area Source

• Assume every point on the plane is an isotropic point light source.

• We saw inverse squared fall off, inverse fall off...so, this must be...

• Intensity CONSTANT with respect to distance! WHY?

As distance increases, \[ d\Phi = I \, d\omega = E \, dA \]

Intensity from one point source decreases

But we add intensities from all point sources on the plane.
Distant and Collimated Lighting

Distant Lighting:

Essentially source at infinity

All surface points receive light from the same direction

Intensity fall must not be ignored!

Most vision and graphics algorithms assume this.

Collimated:

Parallel rays of light on the surface

Lasers (no fall off) - need not be at infinity

Lighting at infinity - (inverse squared fall off)
Divergent and Near-field Lighting

• Every scene point can receive light from a different direction.

• Much harder to model.

• Examples: near by point sources, spot lights

• Assume distant lighting when size of scene is 10% of the distance to the source.
Overcast Sky versus Clear Sky

Which is the brightest region in an overcast sky?
Which is the darkest?

Which is the brightest region in a sunny sky (apart from the sun)?
Which is the darkest?

The luminance of the sky varies. The luminance in this zone = $L_\theta$
Overcast Sky versus Clear Sky

Notice reversal of brightness in the two skies.
Fluorescent versus Incandescent Lighting

Fluorescent:

Less heat generated.

More efficient lighting for the same brightness.

Flickers continuously.

Shows sparse, spikes in spectrum.

Incandescent:

Lots of heat generated.

Less efficient lighting for the same brightness.

No flickers.

Shows continuous spectrum.
Is there a unified representation for light sources?

How do we compare the light from a street lamp to that from an overcast sky?

It is important to unify source representation so that algorithms may be developed for all sources instead of one per type of source.

Consider the SPACE of LIGHT RAYS!
4D Hypercube of Rays

- Assumes vacuum (no absorption or scattering)
- No fluorescence, phosphorescence

\[ \mathcal{M}_{src} \equiv \{ (x, y, p, q) : x \in \left[ -\frac{h_x}{2}, \frac{h_x}{2} \right], \]
\[ y \in \left[ -\frac{h_y}{2}, \frac{h_y}{2} \right], p \in \left[ -\frac{h_p}{2}, \frac{h_p}{2} \right], q \in \left[ -\frac{h_q}{2}, \frac{h_q}{2} \right] \}. \]

Langer and Zucker, CVPR 97
Representation of Sources

Langer and Zucker, CVPR 97

(x,y)-plane  (p,q)-plane  (x,y)-plane  (p,q)-plane  (x,y)-plane  (p,q)-plane

Laser beam – 0D  Point source – 2D  Distant Source (Sun) – 2D

Area source (Sky) with a crack in the door – 3D  Area source (Sky) with door completely open – 4D
Examples of sources

$(x,y)$-plane

$(p,q)$-plane
What is a Light Source?

Is sky a source? If so, why not a white piece of paper?

Is a translucent object a source?

How to differentiate between source rays and non-source rays?

Define a minimum set of absorbants at the ends of rays so that the whole ray space is dark.
Illuminating Objects using Measurements of Real Light

Environment assigned “glow” material property in Greg Larson’s RADIANCE system.

http://radsite.lbl.gov/radiance/

See also: Larson and Shakespeare, “Rendering with Radiance”, 1998
Light Probe Images

Eucalyptus Grove
UC Berkeley

Uffizi Gallery
Florence

St. Peter’s Basilica
Rome

Grace Cathedral
San Francisco

Light Probe Image Gallery:
www.debevec.org/Probes
Types of Omnidirectional Images

Latitude/Longitude

Cube Map
Shadows
Attached and Cast Shadows

Attached shadow

Cast shadow
Very hard shadows

Sloan, Kautz, Snyder 2002

Very soft shadows

Sen, Cammarano, Hanrahan, 2003
All-Frequency Lighting and Shadows

Teapot in Grace Cathedral
Sharper and Softer parts of Shadows

Point source model not good for rendering scenes.