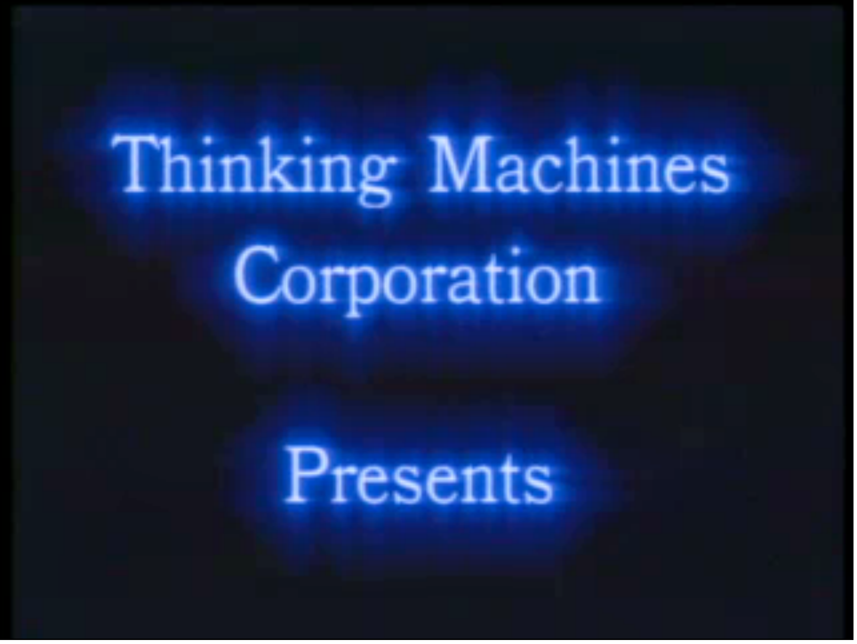


CS-184: Computer Graphics

Lecture 3: Shading

Maneesh Agrawala
University of California, Berkeley

Slides based on those of James O'Brien and Adrien Treuille

Announcements

Account sheets available after class

Sign up for Google Group

Maneesh's office hours:

- MW 12-12:30pm and T 5-6pm
- 635 Soda Hall

~~Assignment 1: due Sat Sep 4 by 11pm~~

Assignment 2: due Fri Sep 10 by 11pm

Assignment 3: due Fri Sep 17 by 11pm

Today

Local Illumination & Shading

- The BRDF
- Simple diffuse and specular approximations
- Shading interpolation: flat, Gouraud, Phong
- Some miscellaneous tricks

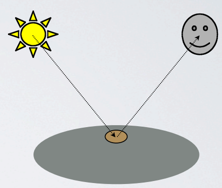
Local Shading

Local: consider in isolation

- 1 light
- 1 surface
- The viewer

Recall: lighting is linear

- Almost always...
  (some materials reflect light nonlinearly)



Counter example: photochromatic materials

Local Shading

Examples of non-local phenomena

- Shadows
- Reflections
- Refraction
- Indirect lighting

The BRDF

The **B**i-directional **R**eflectance **D**istribution **F**unction

Specifies how light reflects off surface

- Incoming light direction
- Direction of viewer
- Orientation of surface
- Returns fraction of light that reaches the viewer

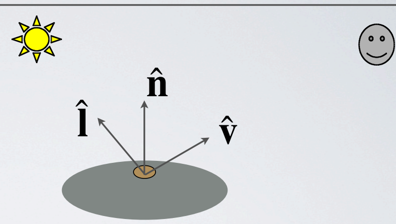
$$\rho = \rho(\theta_V, \theta_L)$$
$$= \rho(\mathbf{v}, \mathbf{l}, \mathbf{n})$$

Represents reflective aspects of surface material at a point

We'll worry about physical units later...

The BRDF

$$\rho(\mathbf{v}, \mathbf{l}, \mathbf{n})$$



Could also capture spatial variation $\rho(x, \mathbf{v}, \mathbf{l}, \mathbf{n})$

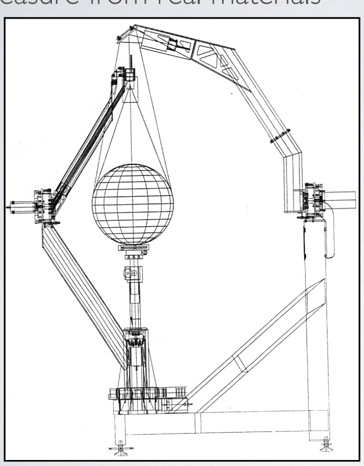
Frequency dependent

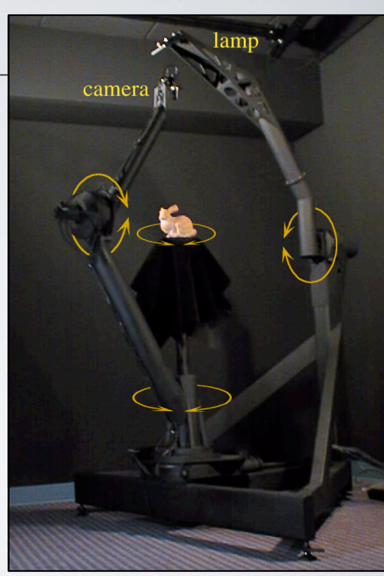
- Typically use independent functions for R, G and B
- Does not work perfectly
- Better:

$$\rho = \rho(\theta_V, \theta_L, \lambda_{\text{in}}, \lambda_{\text{out}})$$

Obtaining BRDFs

Measure from real materials





Images from Marc Levoy

Obtaining BRDFs

Measure from real materials

Computer simulation

- Simple model + complex geometry

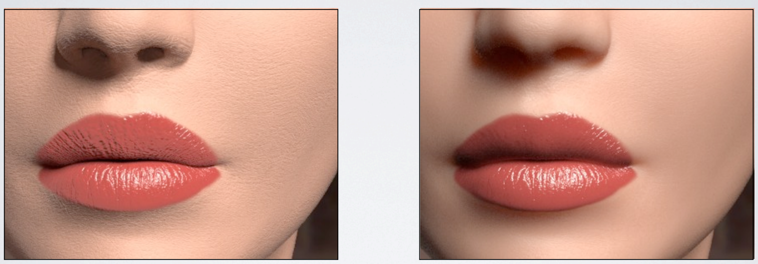
Derive model by analysis

Make something up

Beyond BRDFs

The BRDF model does not capture everything

- *e.g.* Subsurface scattering (BSSRDF)



Images from Jensen *et. al, SIGGRAPH 2001*

Beyond BRDFs

The BRDF model does not capture everything

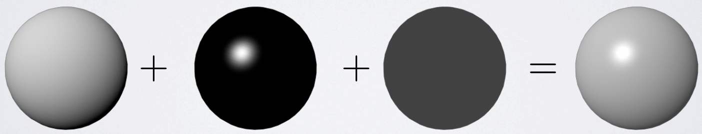
- *e.g.* Inter-frequency interactions

$\rho = \rho(\theta_V, \theta_L, \lambda_{\text{in}}, \lambda_{\text{out}})$ This version would work....

A Simple Model

Approximate BRDF as sum of

- A diffuse component
- A specular component
- A "ambient" term

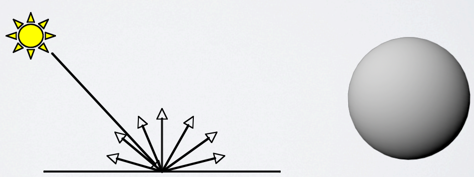


Diffuse Component

Lambert's Law

- Intensity of reflected light proportional to cosine of angle between surface and incoming light direction
- Applies to "diffuse," "Lambertian," or "matte" surfaces
- Independent of viewing angle

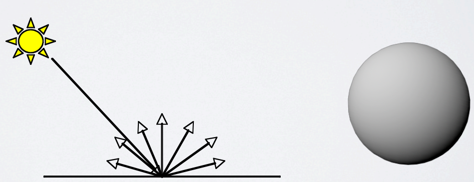
Use as a component of non-Lambertian surfaces



Diffuse Component

$$k_d I(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})$$

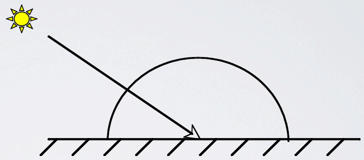
$$\max(k_d I(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}), 0)$$



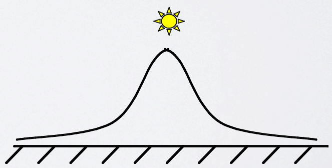
Comment about two-side lighting in text is wrong...

Diffuse Component

Plot light leaving in a given direction:



Plot light leaving from each point on surface



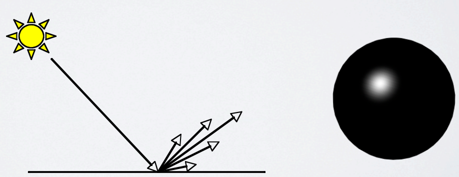
Specular Component

Specular component is a mirror-like reflection

Phong Illumination Model

- A reasonable approximation for some surfaces
- Fairly cheap to compute

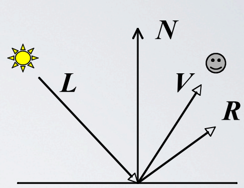
Depends on view direction

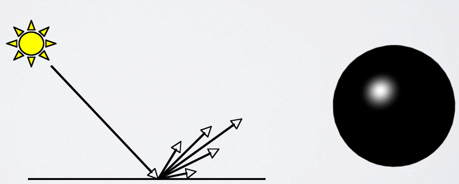


Specular Component

$$k_s I(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}})^p$$

$$k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$

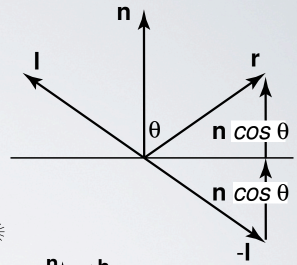




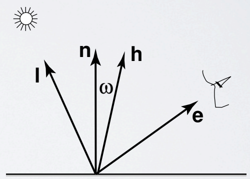
Specular Component

Computing the reflected direction

$$\hat{\mathbf{r}} = -\hat{\mathbf{l}} + 2(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})\hat{\mathbf{n}}$$



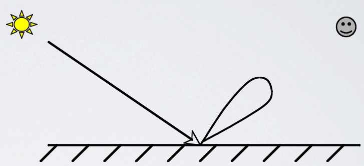
$$\hat{\mathbf{h}} = \frac{\hat{\mathbf{l}} + \hat{\mathbf{v}}}{||\hat{\mathbf{l}} + \hat{\mathbf{v}}||}$$



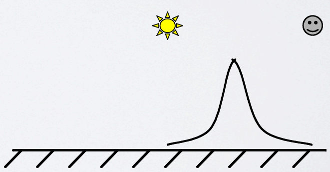
different specular term $k_s I(\hat{\mathbf{h}} \cdot \hat{\mathbf{n}})^p$

Specular Component

Plot light leaving in a given direction:

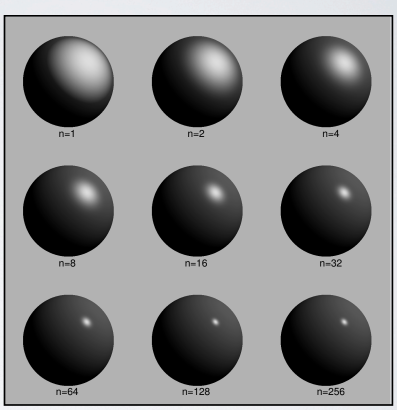


Plot light leaving from each point on surface



Specular Component

Specular exponent sometimes called "roughness"

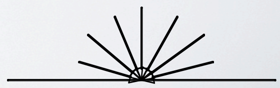


Ambient Term

Really, its a cheap hack

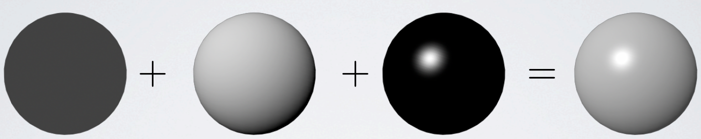
Accounts for "ambient, omnidirectional light"

Without it everything looks like it's in space



Summing the Parts

$$R = k_a I + k_d I \max(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}, 0) + k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$

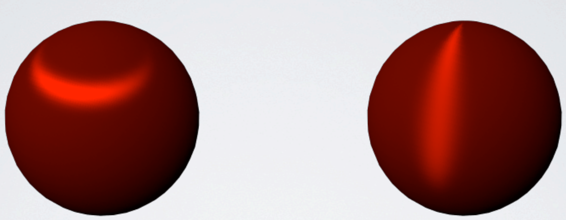


Recall that the $k_?$ are by wavelength

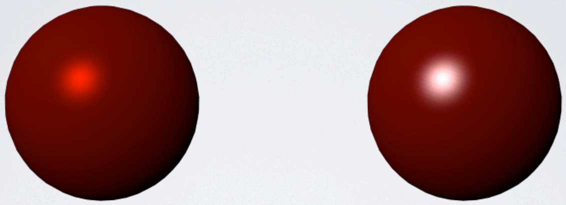
- RGB in practice

Sum over all lights

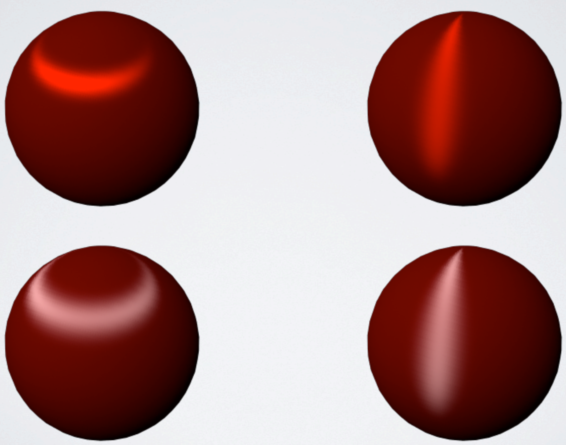
Anisotropy



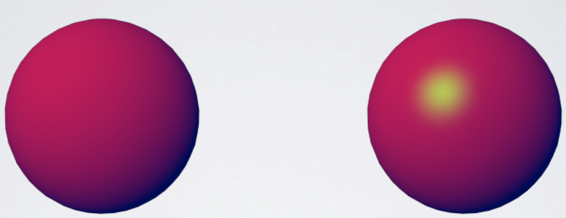
Metal -vs- Plastic



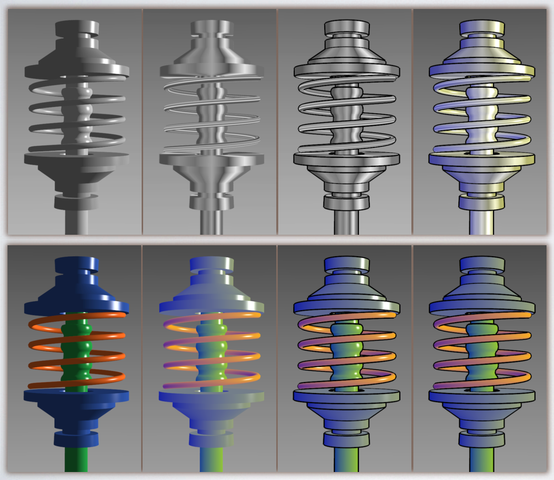
Metal -vs- Plastic

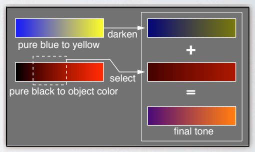


Other Color Effects



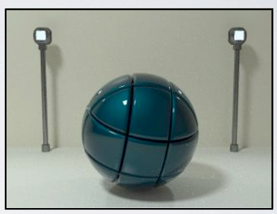
Other Color Effects





Images from Gooch *et. al, 1998*

Measured BRDFs



BRDFs for automotive paint

Images from Cornell University Program of Computer Graphics

Measured BRDFs

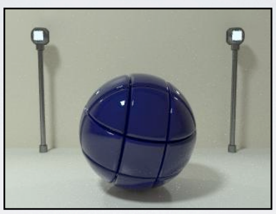
BRDFs for aerosol spray paint

Images from Cornell University Program of Computer Graphics

Measured BRDFs

BRDFs for house paint

Measured BRDFs



BRDFs for lucite sheet

Details Beget Realism

The "computer generated" look is often due to a lack of fine/ subtle details... a lack of richness.

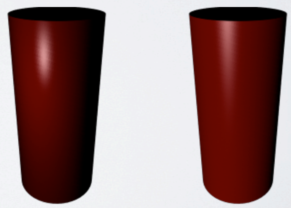
From bustledress.com

Direction -vs- Point Lights

For a point light, the light direction changes over the surface

For "distant" light, the direction is constant

Similar for orthographic/perspective viewer



Falloff

Physically correct: $1/r^2$ light intensify falloff

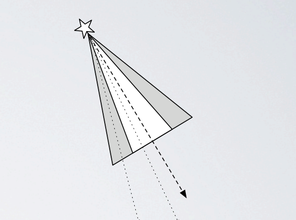
- Tends to look bad (why?)
- Not used in practice

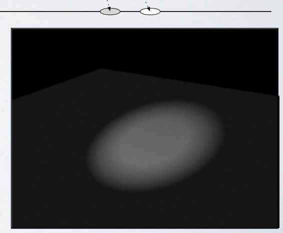
Sometimes compromise of $1/r$ used

Spot and Other Lights

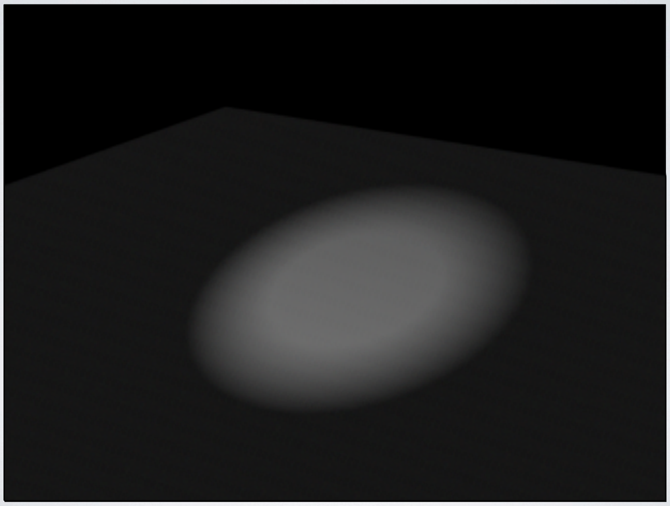
Other calculations for useful effects

- Spot light
- Only light certain objects
- Negative lights
- *etc.*

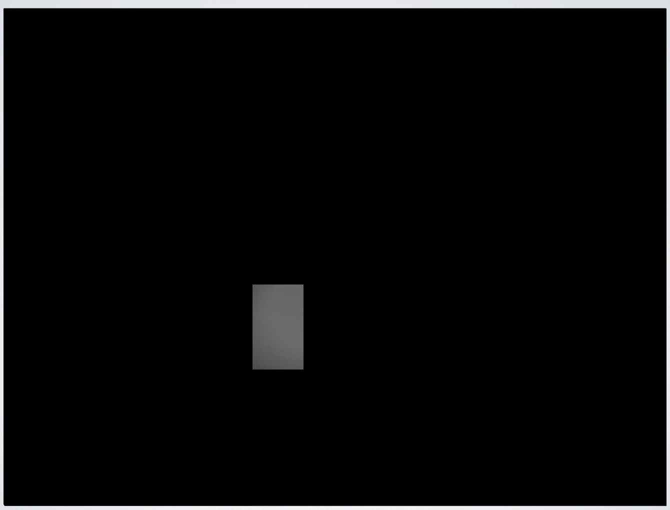




Ugly....

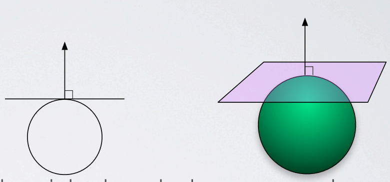


Ugly....

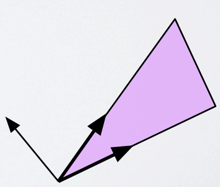


Surface Normals

The normal vector at a point on a surface is perpendicular to all surface tangent vectors



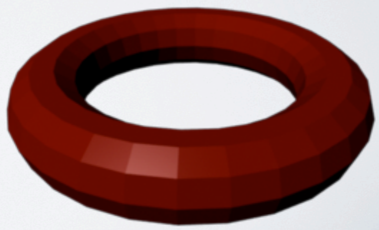
For triangles normal given by right-handed cross product



Flat Shading

Use constant normal for each triangle (polygon)

- Polygon objects don't look smooth
- Faceted appearance very noticeable, especially at specular highlights
- Recall mach bands...



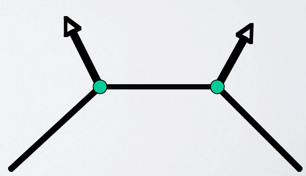
Smooth Shading

Compute "average" normal at vertices

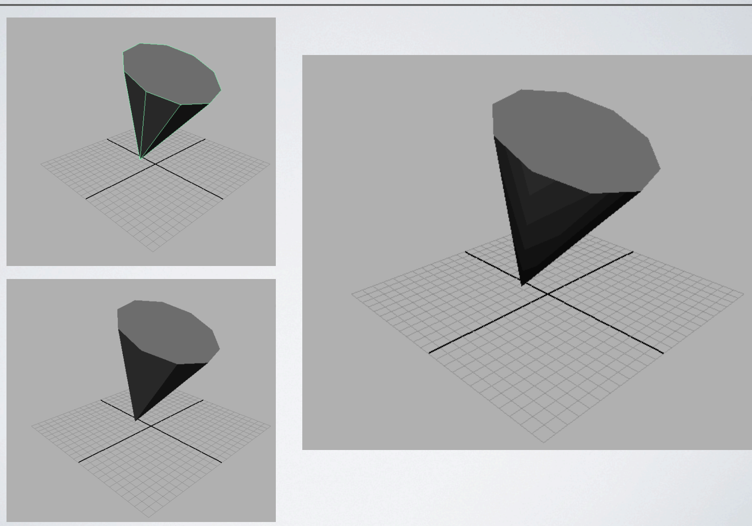
Interpolate across polygons

Use threshold for "sharp" edges

- Vertex may have different normals for each face



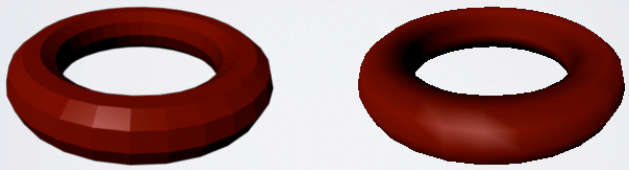
Smooth Shading



Gouraud Shading

Compute shading at each vertex

- Interpolate colors from vertices
- Pros: fast and easy, looks smooth
- Cons: terrible for specular reflections



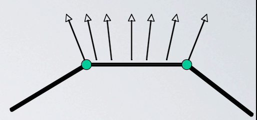
Flat　　　　　　　Gouraud

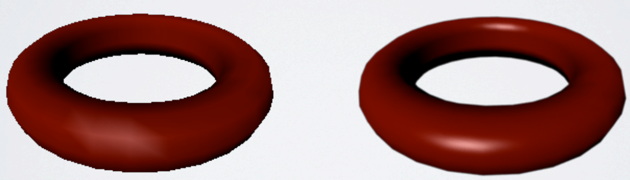
Note: Gouraud was hardware rendered...

Phong Shading

Compute shading at each pixel

- Interpolate ***normals*** from vertices
- Pros: looks smooth, better speculars
- Cons: expensive





Gouraud　　　　　　　Phong

Note: Gouraud was hardware rendered...