Current state of intro students graphic's ability

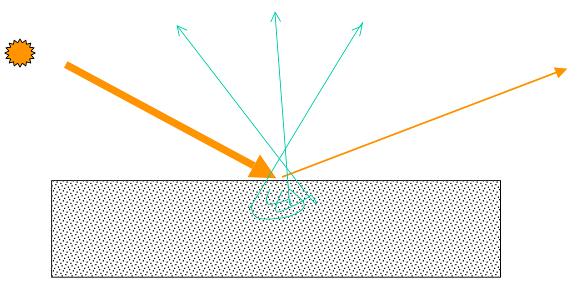
Know how to draw polygons
Know about cameras
Know how to map 3D polygons onto the screen
Know how to draw the bits closest to the cameras

Issues
Should we live in a polygonal world?
How do you get polygons for complex objects?
What color should each pixel be?

Light interacting with the world

- The signal reaching your eye from a surface is the result of the surface interacting with the light following on it.
- Many effects when light strikes a surface. It could be:
  - absorbed
  - transmitted
  - reflected
  - scattered (in a variety of directions!)

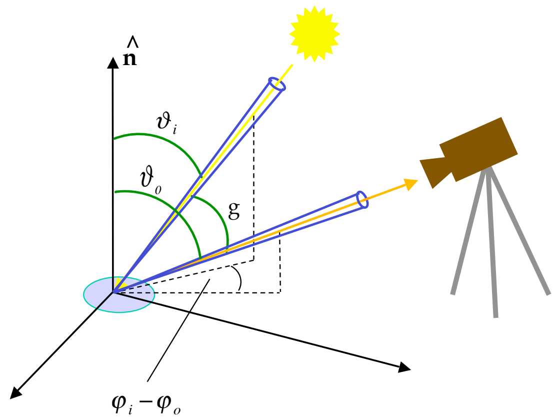
This shows some possibilities that can happen to the line from **one** direction.



Bidirectional Reflectance Distribution Function (BRDF)

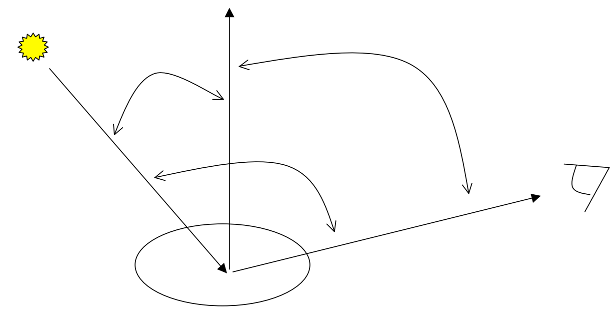
- The BRDF is a technical way of specifying how light from sources interacts with the matter in the world
- Understanding images requires understanding that this varies as a function of materials. The following "look" different
  - mirrors
  - white styrofoam
  - colored construction paper
  - colored plastic
  - gold
- The BRDF is the **ratio** of what comes out to what came in
- What comes out <--> "radiance"
- What goes in <--> "irradiance"
- Details on the BRDF available as supplementary material

This shows angular effects. There are also spectral (color effects).



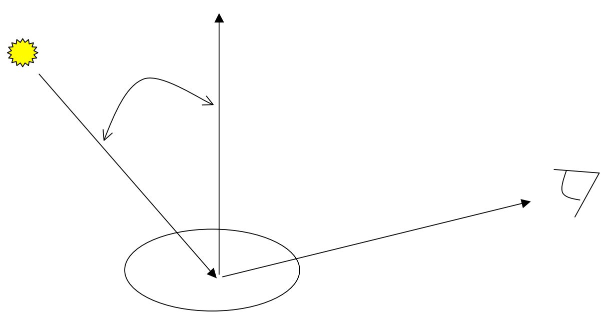
Isotropic surfaces

The BRDF for many surfaces can be well approximated as a function of 3 variables (angles), not 4. In this case, turning the surface around the normal has no effect. The surface is said to be *isotropic*.



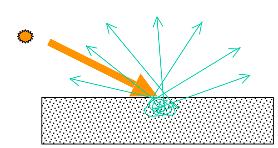
Lambertian surfaces

- Even simpler case--the BRDF does not depend on the viewing (output) direction (e.g., Lambertian).



Lambertian surfaces

- Simple special case of reflectance: ideal diffuse or matte surface--e.g. cotton cloth, matte paper.
- Surface appearance is independent of viewing angle.
- Typically such a surface is the result of lots of scattering---the light “forgets” where it came from, and it could end up going in any random direction.



- What counts is how much light power reaches the surface

Lambertian surfaces and albedo

- We will refer later to "radiosity" as a unit to describe light leaving the surface taken as whole
  - Technically, it is the total power leaving a point on the surface, per unit area on the surface (Wm^{-2})
- Recall that for a Lambertian surface, the direction that light leaves is not an issue.
- Percentage of light leaving the surface compared with that falling onto it, is often called diffuse reflectance, or *albedo* for a Lambertian surface.

Lambertian surfaces

The Lambertian assumption leads to very simple rule to shade an object. Specifically, we attenuate brightness by

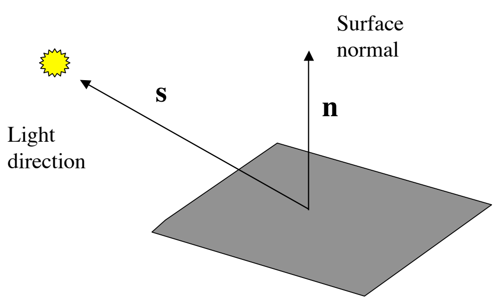
$$\mathbf{n} \bullet \mathbf{s}$$

Surface normal

Light source direction

Must know this

Lambertian Reflection



Brightness is proportional to **n•s**

Comments on light source direction

The direction to a nearby light changes as you move around in the scene.

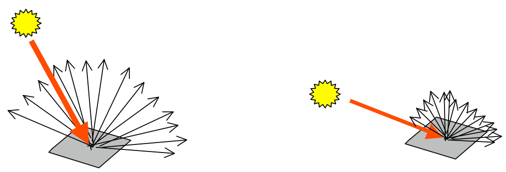
If we say a light source is "at infinity", we mean that it is so far away that only the direction is important.

Example: On the scale of a city, the sun is at infinity.

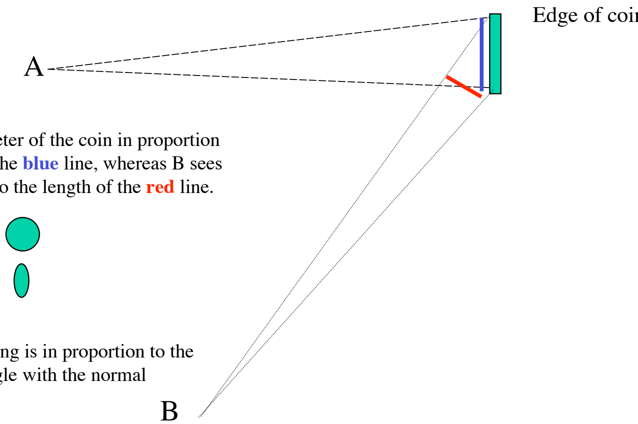
Lambertian Reflection

Why is brightness proportional to **n•s** ?

Intuitive argument: The surface scatters light in all directions equally, but as the angle of the light becomes oblique, the amount of light per unit area is reduced (foreshortening) by a factor of the cosine of the angle.



Foreshortening illustrated



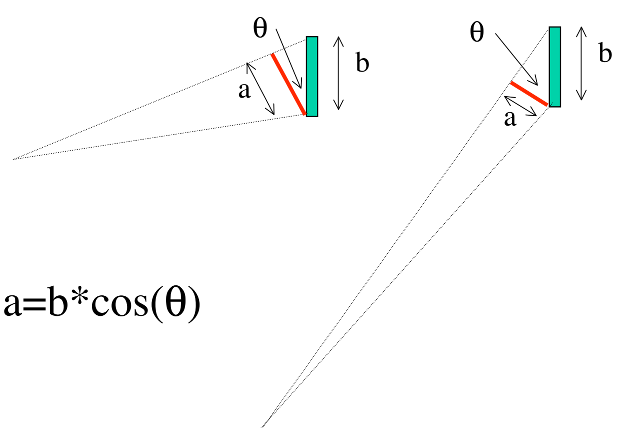
A sees the diameter of the coin in proportion to the length of the **blue** line, whereas B sees it in proportion to the length of the **red** line.

Further, A sees

But B sees

The foreshortening is in proportion to the cosine of the angle with the normal (next slide)

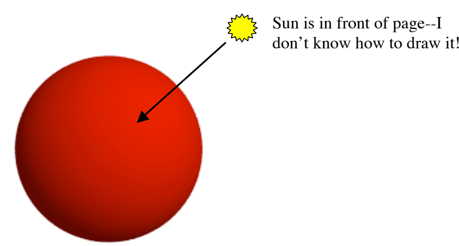
Foreshortening illustrated



$$a=b*\cos(\theta)$$

Lambertian surfaces

- Surface brightness is only a function of the foreshortening of the incident light (the more oblique it is, the less bright the surface).



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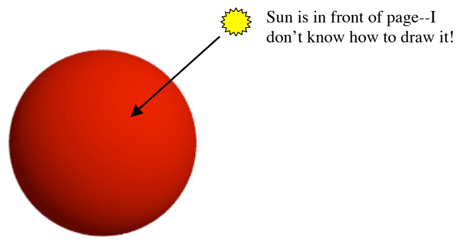


- Question: Is the moon a Lambertian reflector?

Lambertian Reflection

Most the world is not Lambertian

Lambertian assumption failures

Lambertian Reflection

Most the world is not Lambertian

Lambertian assumption failures

Rough surfaces--important example--the moon is not Lambertian

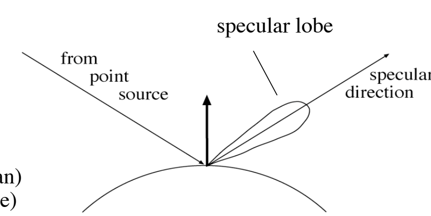
Dielectrics (plastics, many paints)

Metallic surfaces

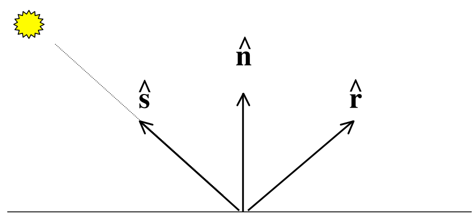
Skin

Specular surfaces

- Another important class of surfaces is specular (mirror-like).
  - specular surfaces reflect a significant amount of energy in the specular (mirror) direction
  - produces "highlights"
- Two related cases
  - a perfect mirror
  - a fuzzy mirror
- Typically there is a diffuse (Lambertian) component as well (effects are additive)



Computing reflection (specular) direction



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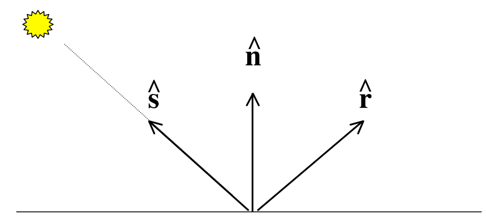


$$\hat{\mathbf{s}} + \hat{\mathbf{r}} = k\hat{\mathbf{n}} \qquad \text{and} \qquad \hat{\mathbf{n}} \bullet \hat{\mathbf{s}} = \hat{\mathbf{n}} \bullet \hat{\mathbf{r}}$$

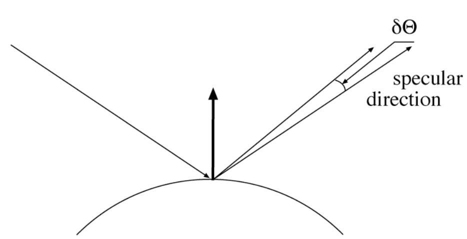
$$\hat{\mathbf{n}} \bullet \hat{\mathbf{s}} + \hat{\mathbf{n}} \bullet \hat{\mathbf{r}} = k \;\Rightarrow\; k = \mathbf{2}\hat{\mathbf{n}} \bullet \hat{\mathbf{s}}$$

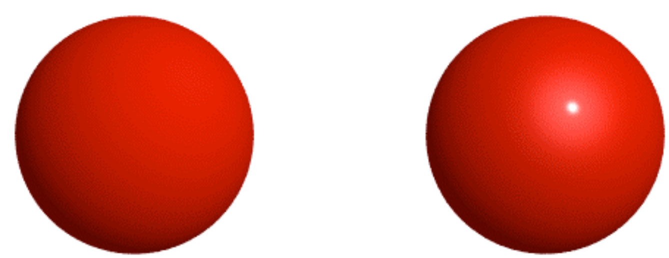
$$So \quad \hat{\mathbf{r}} = \mathbf{2}(\hat{\mathbf{n}} \bullet \hat{\mathbf{s}})\hat{\mathbf{n}} - \hat{\mathbf{s}}$$

Phong’s model of specularities

- There are very few cases where the exact shape of the specular lobe matters.
- Typically:
  - very, very small --- mirror
  - small -- blurry mirror
  - bigger -- see only light sources as “specularities”
  - very big -- faint specularities
- Phong’s model
  - reflected energy falls off with

$$\cos^n(\delta\vartheta)$$





Diffuse Lighting   Plus Specular Highlight

from
http://www.geocities.com/SiliconValley/Horizon/6933/shading.html

More about sources

- Exitance of a source is
  - the internally generated power radiated per unit area on the radiating surface
- A source will have both
  - radiosity, because it reflects
  - exitance, because it emits

Radiosity leaving = Exitance + Radiosity due to incoming light

More about sources

What about multiple lights?

What about real, nearby, point sources?

What about extended sources?

More about sources

What about multiple lights?

The effect of lighting is additive. The effect of multiple lights is the sum of the effects over the individual lights.

What about real, nearby, point sources?

The effect of lighting falls off as $1/r^2$.

What about extended sources?

The effect of light is additive. We can approximate an extended source as a collection of small point sources.

Standard nearby point source model (Lambertian reflection)

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

- N is the illuminated surface normal
- rho is diffuse albedo
- S is source vector - a vector from x to the source, whose length is the intensity term
  - this works because a dot-product is basically a cosine
- r(x) is distance from surface point to source --- term occurs because source “looks smaller” as we move away--or, alternatively, its energy is spread out over a larger surface.

Standard distant point source model

- If the source is far away, this formula reduces to the same as the Lambertian formula from before:

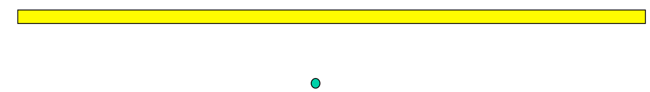
then $r(x) \cong R$

and $S(x) \cong S$

if we let $S_d = \left(S / R^2 \right)$

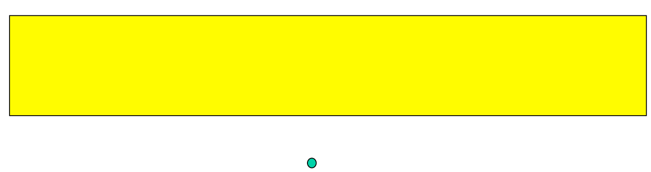
we get $\rho_d(x)\left(N(x) \bullet S_d\right)$

Line sources



Radiosity due to line source varies with inverse distance, if the source is long enough (derivation is through integration of the contributions along the line)

General extended sources



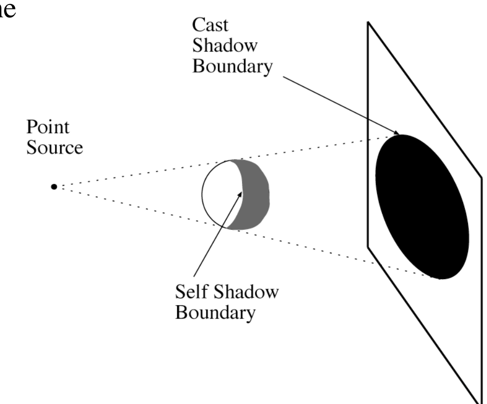
Can be handled by doing the integration (we won't)

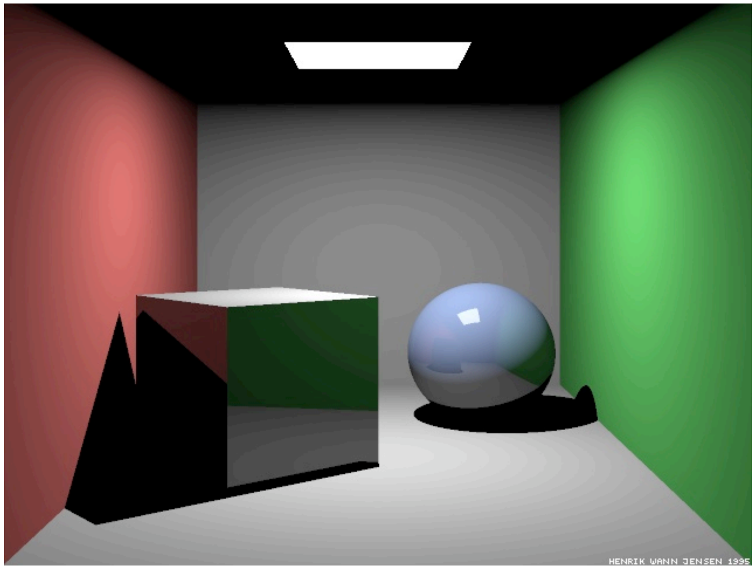
What if the source is large relative to the distance to it?

How about the hemisphere of the sky?

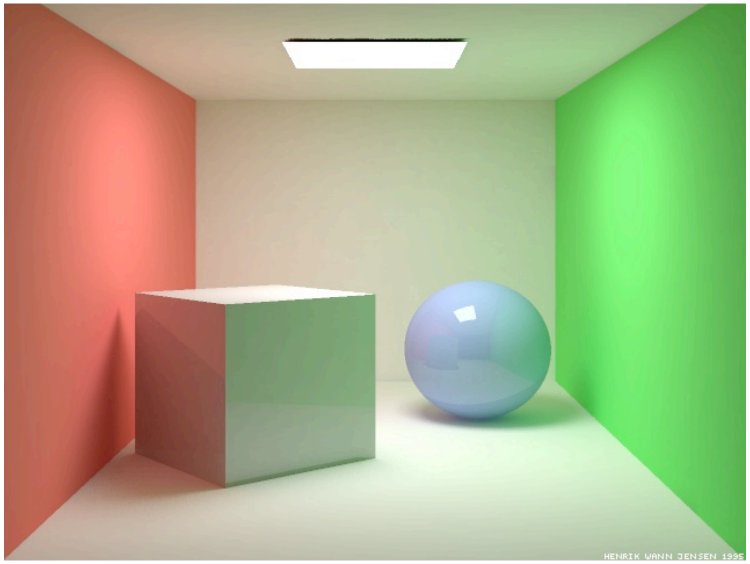
Shadows cast by a point source

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





Ray-traced Cornell box, due to Henrik Jensen,
http://www.gk.dtu.dk/~hwj



Radiosity Cornell box, due to Henrik Jensen,
http://www.gk.dtu.dk/~hwj, rendered with ray tracer

Flat shading

- Compute shading value inside polygon using interpolate
- Flat shading
  - Use polygon normal for Lambertian shading
  - Advantages:
    - fast -- one shading value per polygon
  - Disadvantages:
    - inaccurate -- looks blocky

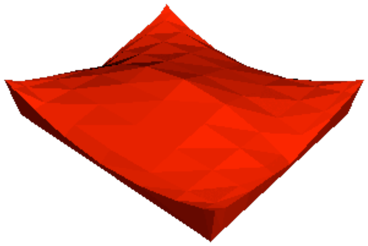
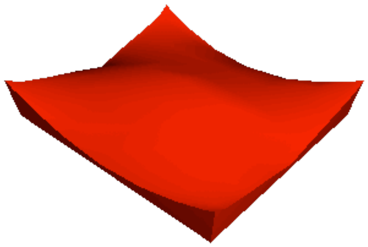


Figure from http://freespace.virgin.net/hugo.elias/graphics/x_polygo.htm

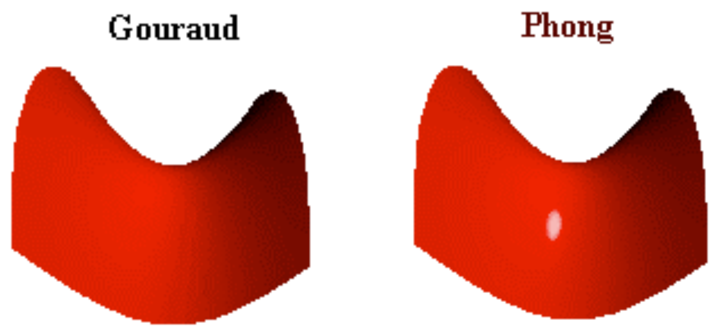
Gouraud (Interpolated) Shading

- Use normal at each vertex of polygon
  - known either from the "mesh" construction, OR, average normals where polygons meet.
- Shade these, and linearly interpolate
- Advantages
  - fast (interpolation can even be put into scan line algorithm)
  - much smoother
- Disadvantages:
  - specularities get lost



Phong Shading

- Interpolate normals instead of pixel values
  - Shade using normal estimate for each point
  - Advantage
    - high quality, narrow specularities
  - Disadvantage
    - more expensive than Gouraud



from
http://www.geocities.com/SiliconValley/Horizon/6933/shading.html

What about the color of the light?

So far, we have not dealt with the color of the light--the implicit assumption being that it is “white” and thus does not change the color of anything.

This is often not the case!

Naïve (but common) model

Consider the color of the light to be specified by its (R,G,B)--technically the color of a perfect uniform reflector (white surface).

Similarly, now specify the albedo as a triple--one for each channel. The color of a Lambertian surface is then:

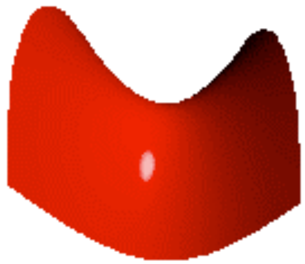
$$(R,G,B)=(\rho_R S_R,\ \rho_G S_G,\ \rho_B S_B)(\mathbf{n}\bullet\mathbf{s})$$

Naïve (but common) model

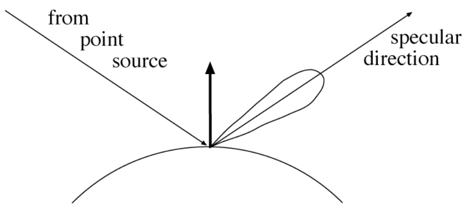
Naïve because we assume that the red part of the light does not interact with green or blue albedos, etc.

(Referred to as the diagonal model)

What about specular surfaces?



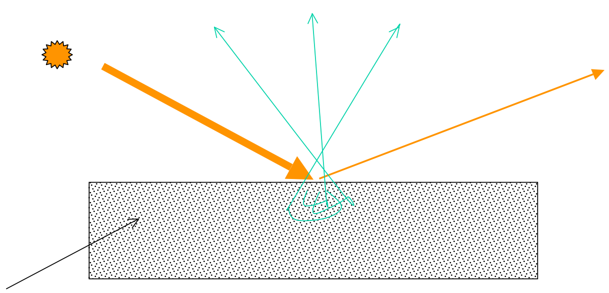
Specular surfaces



- Important point: The specular part of the reflected light usually carries the color of the **light**
- Technically, this is the case for dielectrics--plastics, paints, glass.
- Important exception is metals (e.g. gold, copper)

Example: Dielectrics

- Examples: Paints, plastics
- Reasonably well approximated by a specular part and a Lambertian body part.



Non conductive matrix with scattering particles of the order of the wavelength of light---note: the same general process explains why the sky is blue.