Light Reflection and Illumination

CS 4620 Lecture 35

Shading

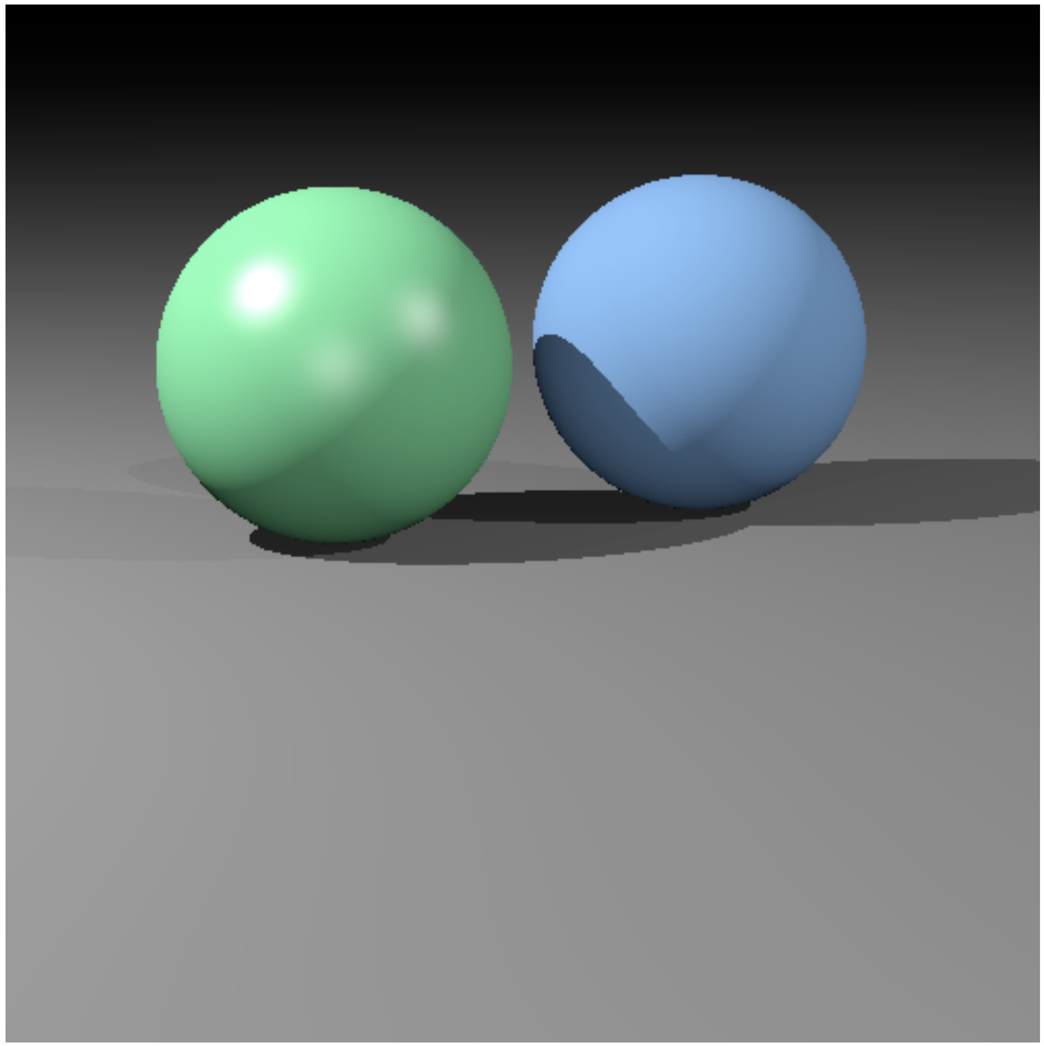
- Variation in observed color across an object
  - strongly affected by lighting
  - present even for homogeneous material
- caused by how a material reflects light
  - depends on
    - geometry
    - lighting
    - material
  - therefore gives cues to all 3

[Philip Greenspun]

Shading for Computer Graphics

- Need to compute an image
  - of particular geometry
  - under particular illumination
  - from a particular viewpoint
- Basic question: how much light reflects from an object toward the viewer?

Diffuse + Phong shading



Mirror reflection

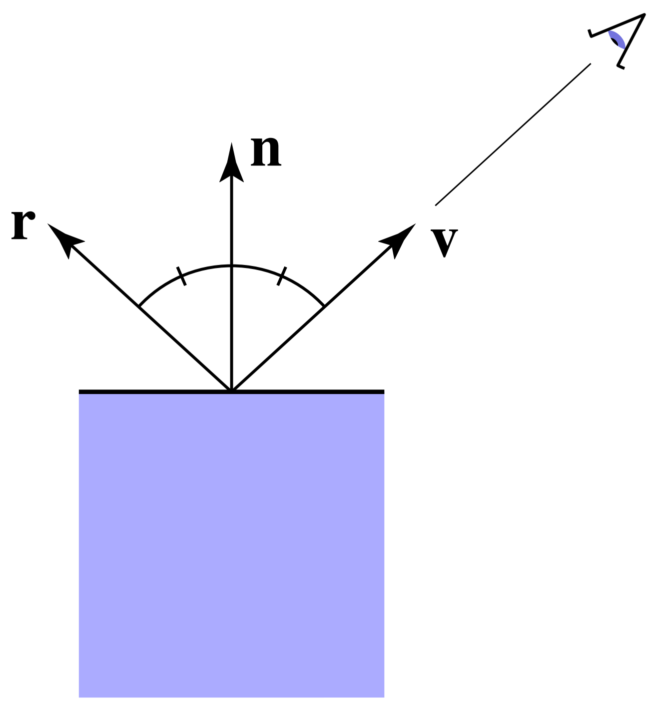
- Consider perfectly shiny surface
  – there isn't a highlight
  – instead there's a reflection of other objects
- Can render this using recursive ray tracing
  – to find out mirror reflection color, ask what color is seen from surface point in reflection direction
  – already computing reflection direction for Phong…
- "Glazed" material has mirror reflection and diffuse

$$L = L_a + L_d + L_m$$

  – where L_m is evaluated by tracing a new ray

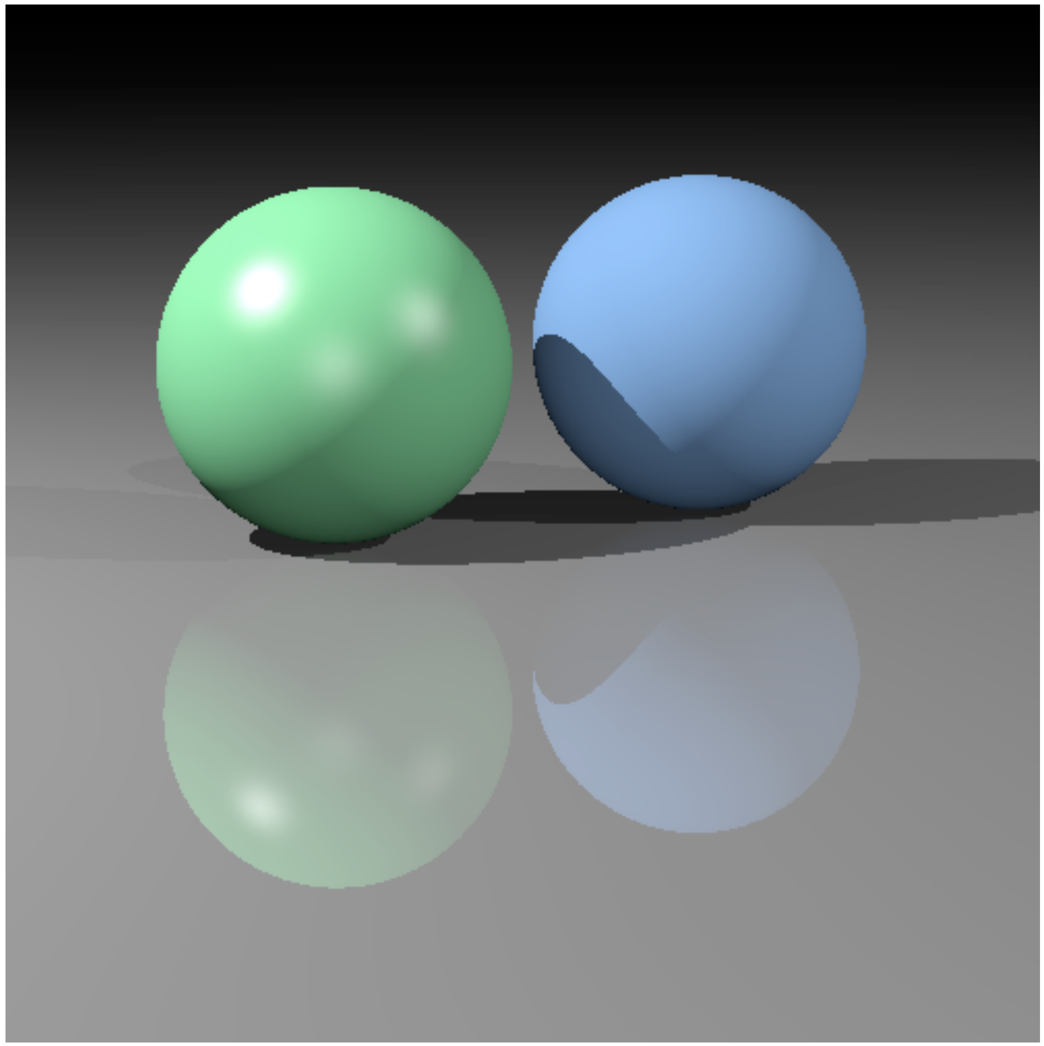
Mirror reflection

- Intensity depends on view direction
  - reflects incident light from mirror direction



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

Diffuse + mirror reflection (glazed)



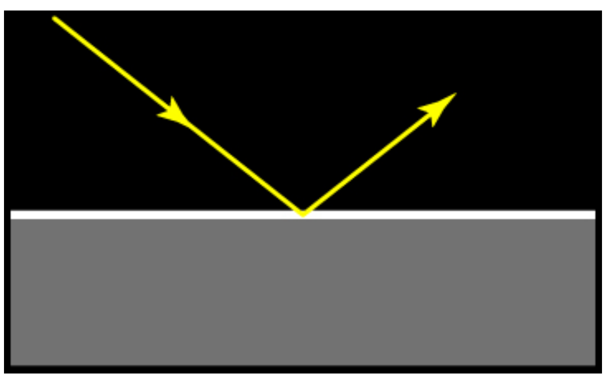
(glazed material on floor)

Fancier shading

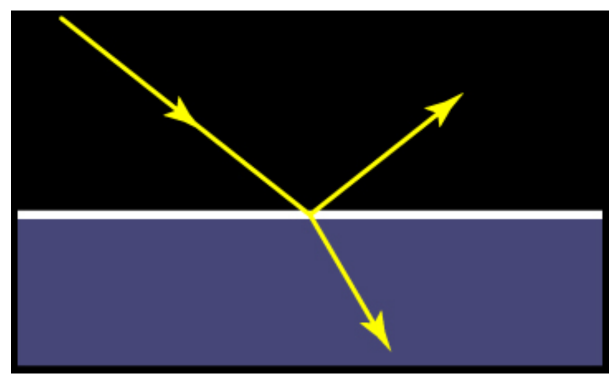
- Diffuse + Phong has long been the heuristic baseline for surface shading
- Newer/better methods are more based on physics
  - when writing a shader, think like a bug standing on the surface
  - bug sees an *incident distribution* of light that is arriving at the surface
  - physics question: what is the *outgoing distribution* of light?

Simple materials

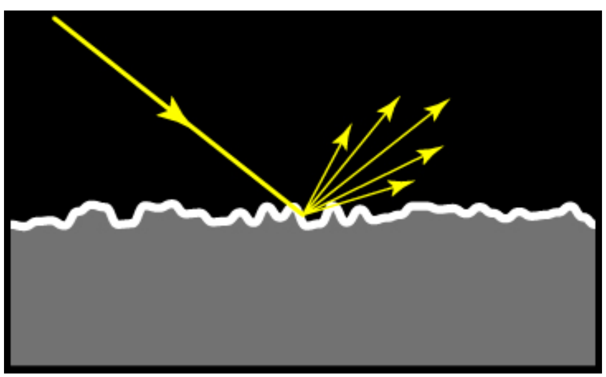
metal

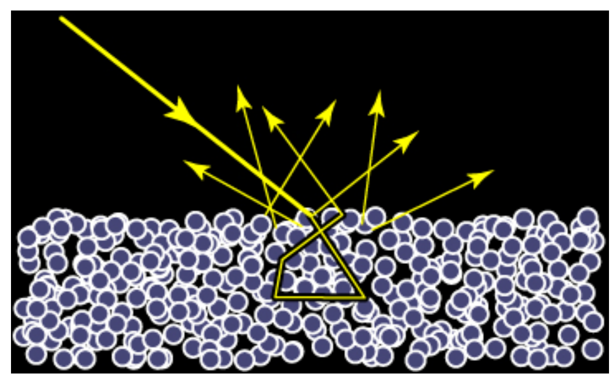


dielectric

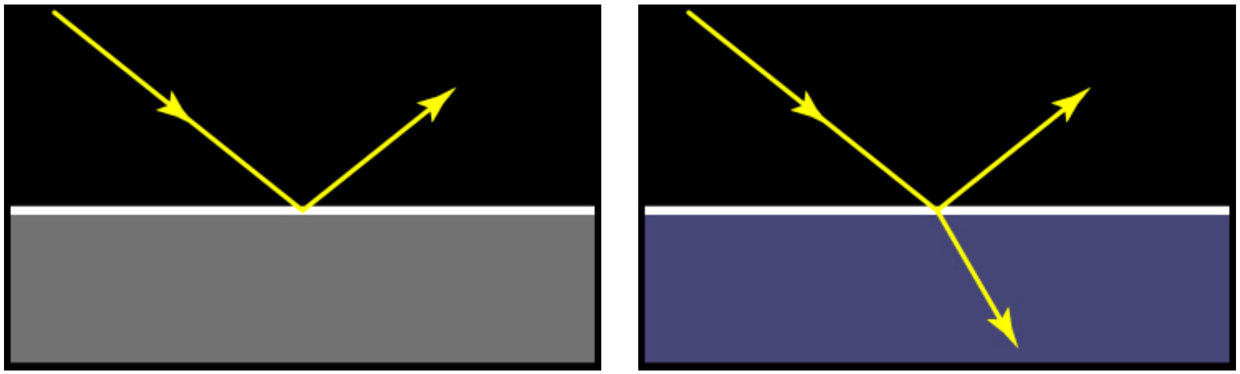


Adding microgeometry

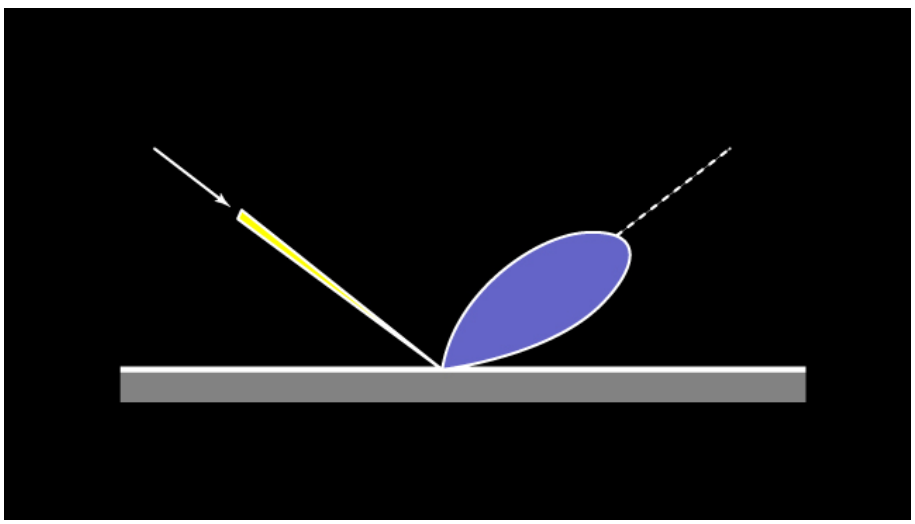




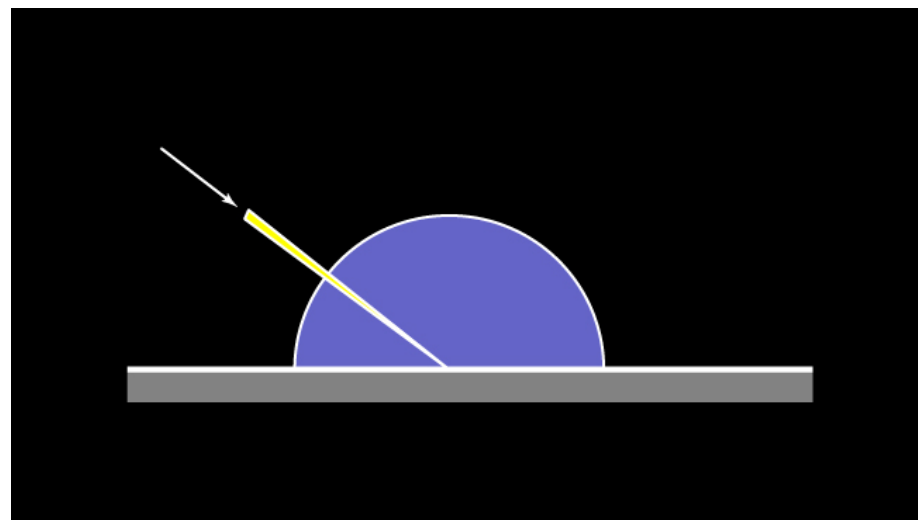
Classic reflection behavior



ideal specular (mirror)



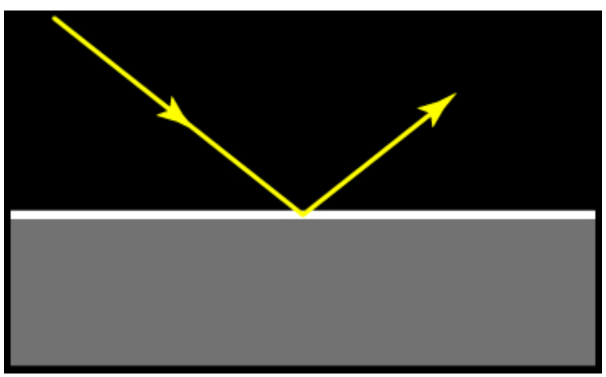
glossy specular



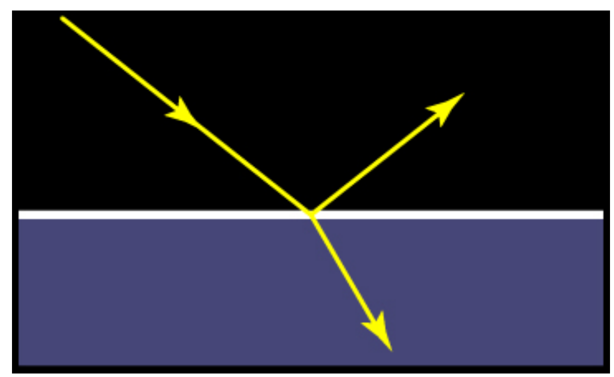
Lambertian

Specular reflection

- Smooth surfaces of pure materials have ideal specular reflection (said this before)
  - Metals (conductors) and dielectrics (insulators) behave differently
- Reflectance (fraction of light reflected) and angle of reflection/refraction depend on angle

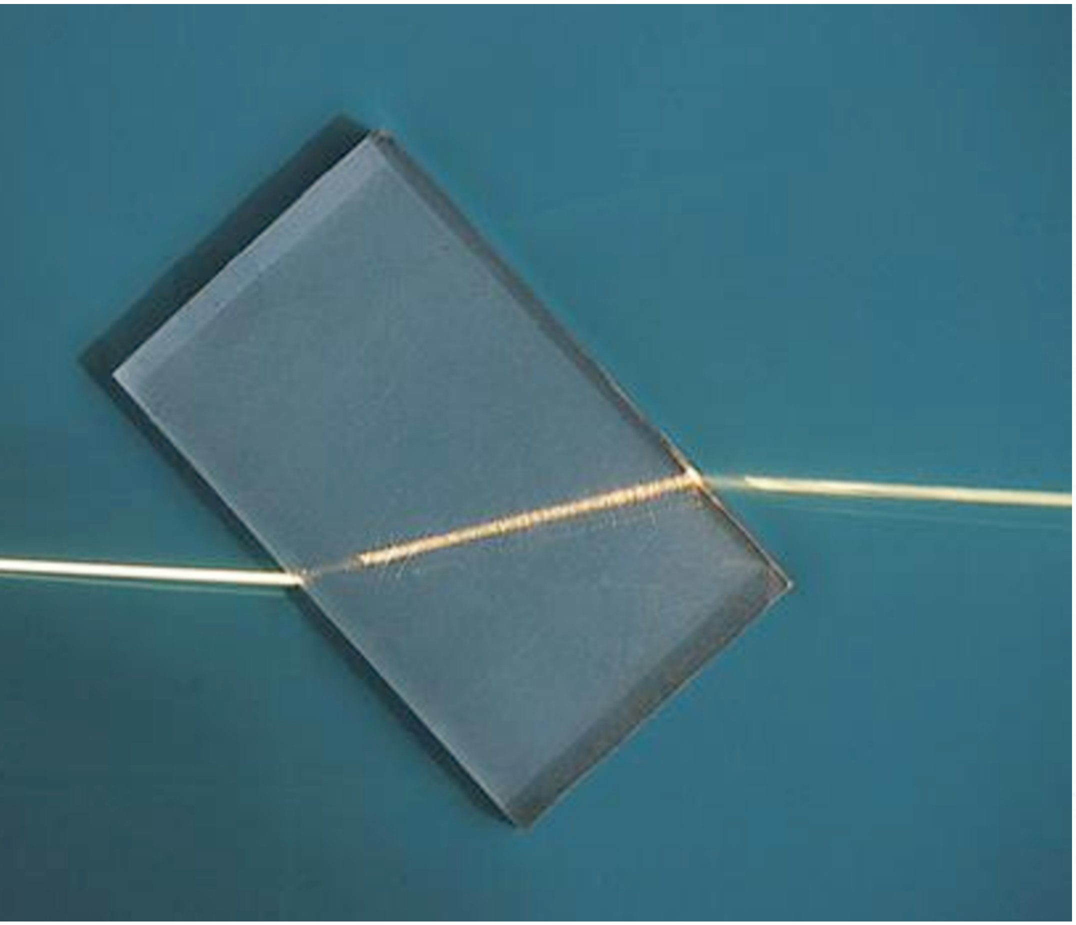


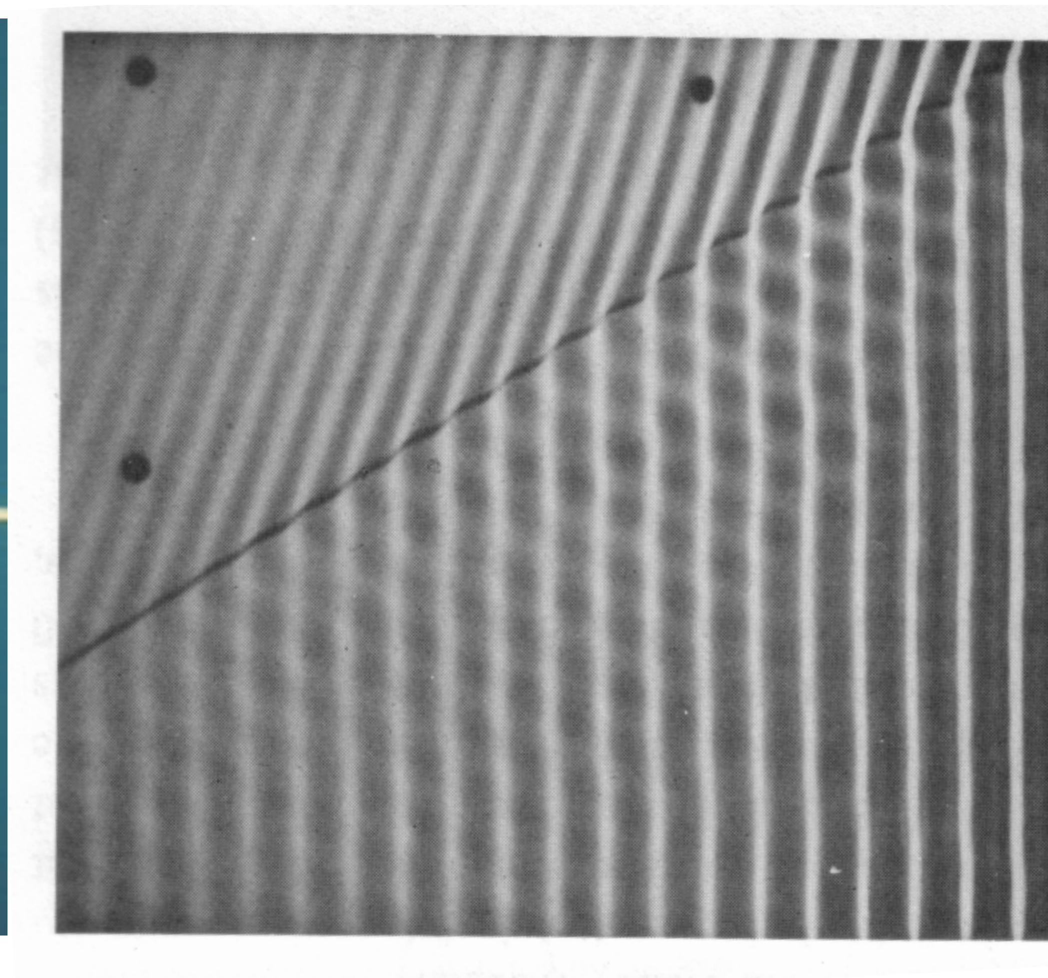
metal



dielectric

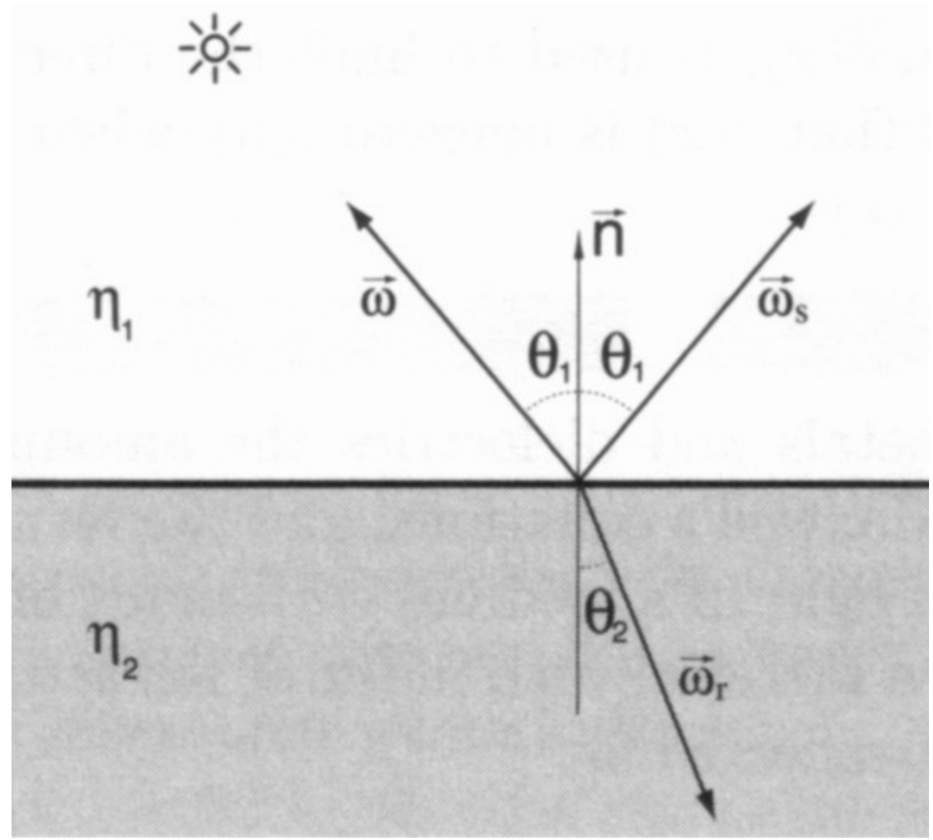
Refraction at boundary of media





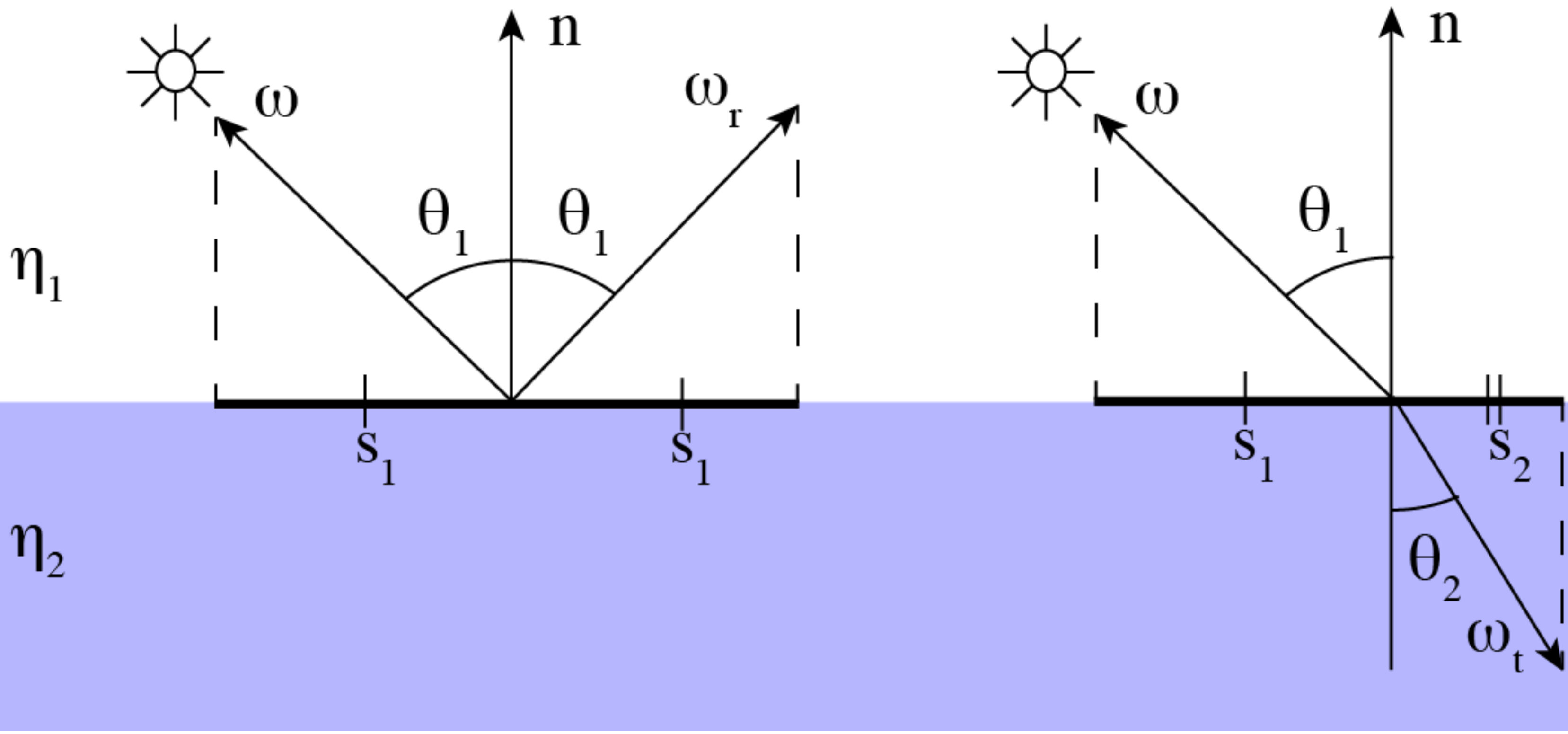
Snell's Law

- Tells us where the refracted ray goes
- Computation
  - ratio of sines is ratio of in-plane components
  - project to surface; scale by eta ratio; recompute normal-direction component
  - total internal reflection



$$\eta_1 \sin\theta_1 = \eta_2 \sin\theta_2$$

Computing Ray Directions



$$s_2 = (\eta_1/\eta_2)\ s_1$$

Total Internal Reflection

- Occurs when $s_2 > 1$
- All light is reflected; no refraction

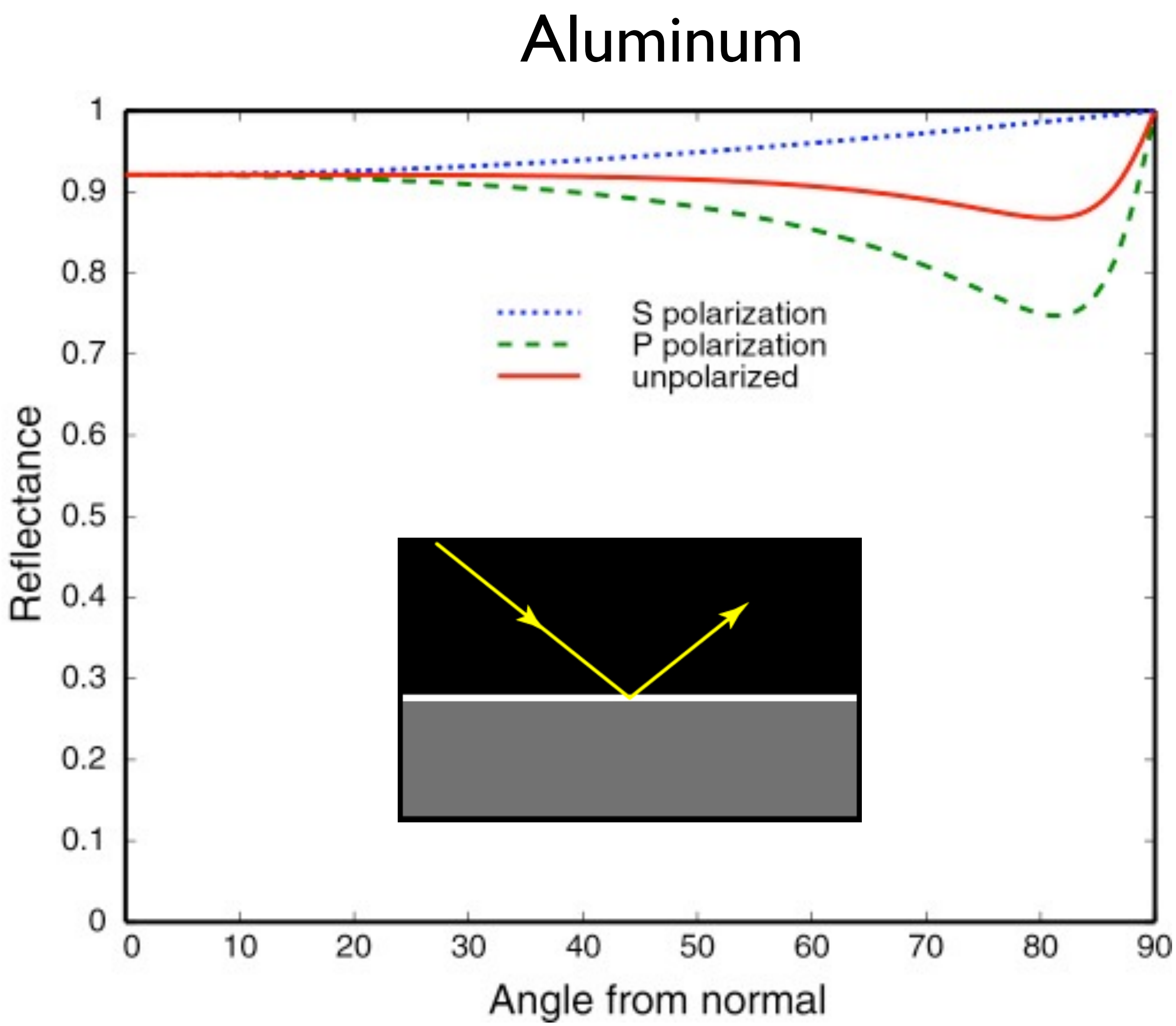
Photo by Brocken Inaglory

Ray tracing dielectrics

- Like a simple mirror surface, use recursive ray tracing
- But we need two rays
  – One reflects off the surface (same as mirror ray)
  – The other crosses the surface (computed using Snell's law)
    - Doesn't always exist (total internal reflection)
- Splitting into two rays, recursively, creates a ray tree
  – Very many rays are traced per viewing ray
  – Ways to prune the tree
    - Limit on ray depth
    - Limit on ray attenuation

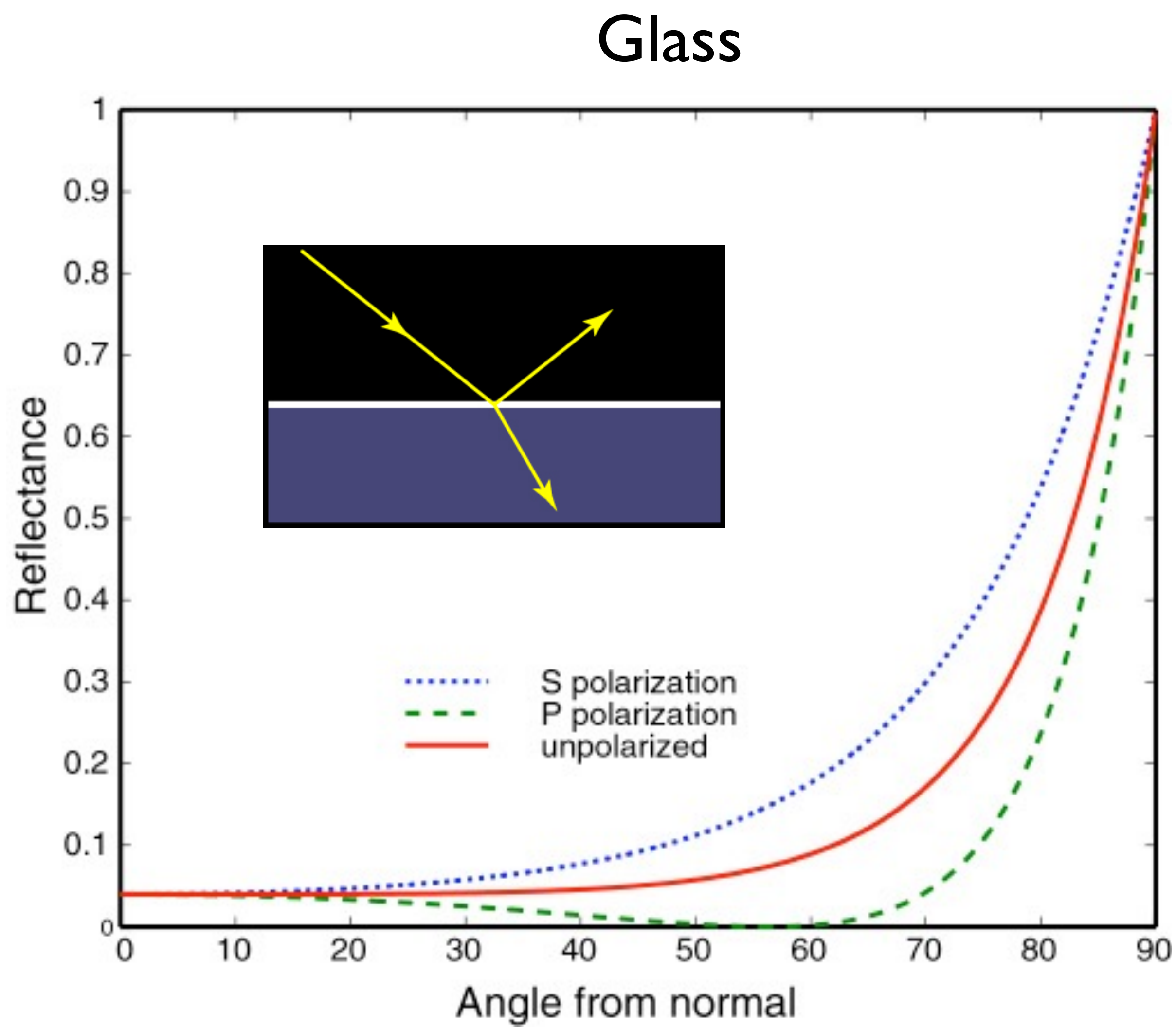
Specular reflection from metal

- Reflectance does depend on angle
  – but not much
  – safely ignored in basic rendering

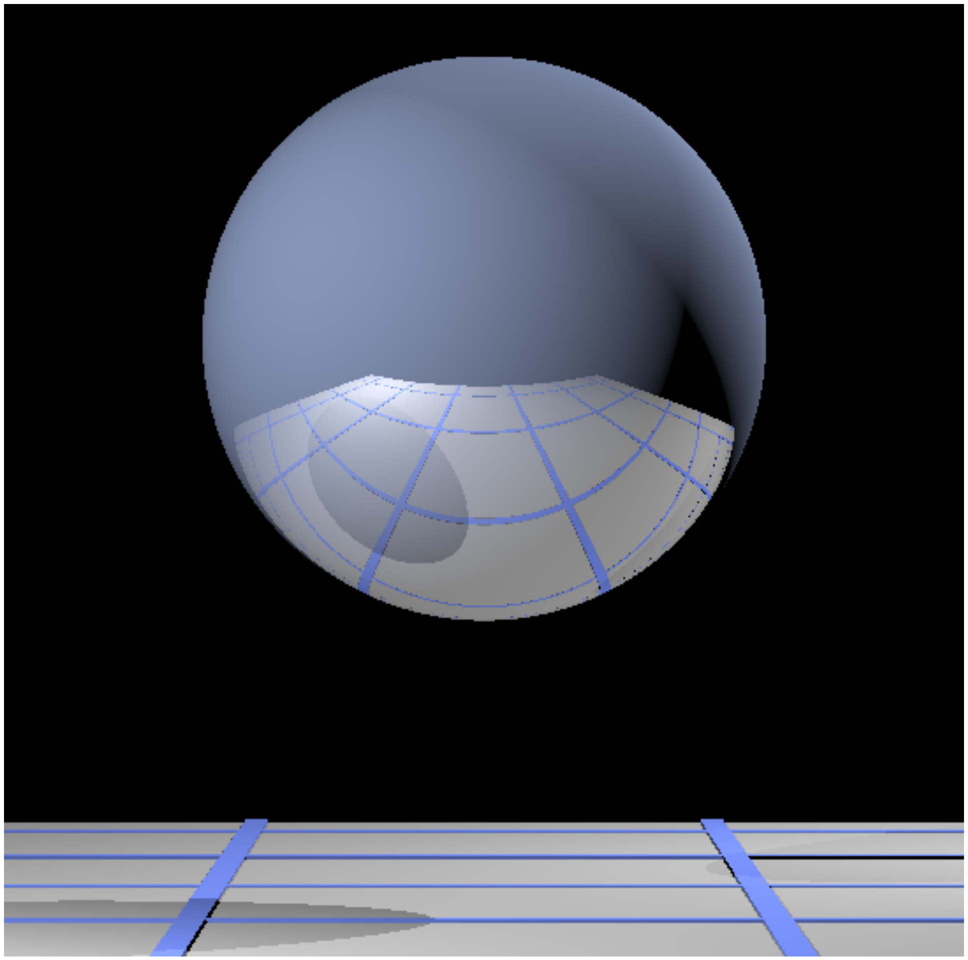


Specular reflection from glass/water

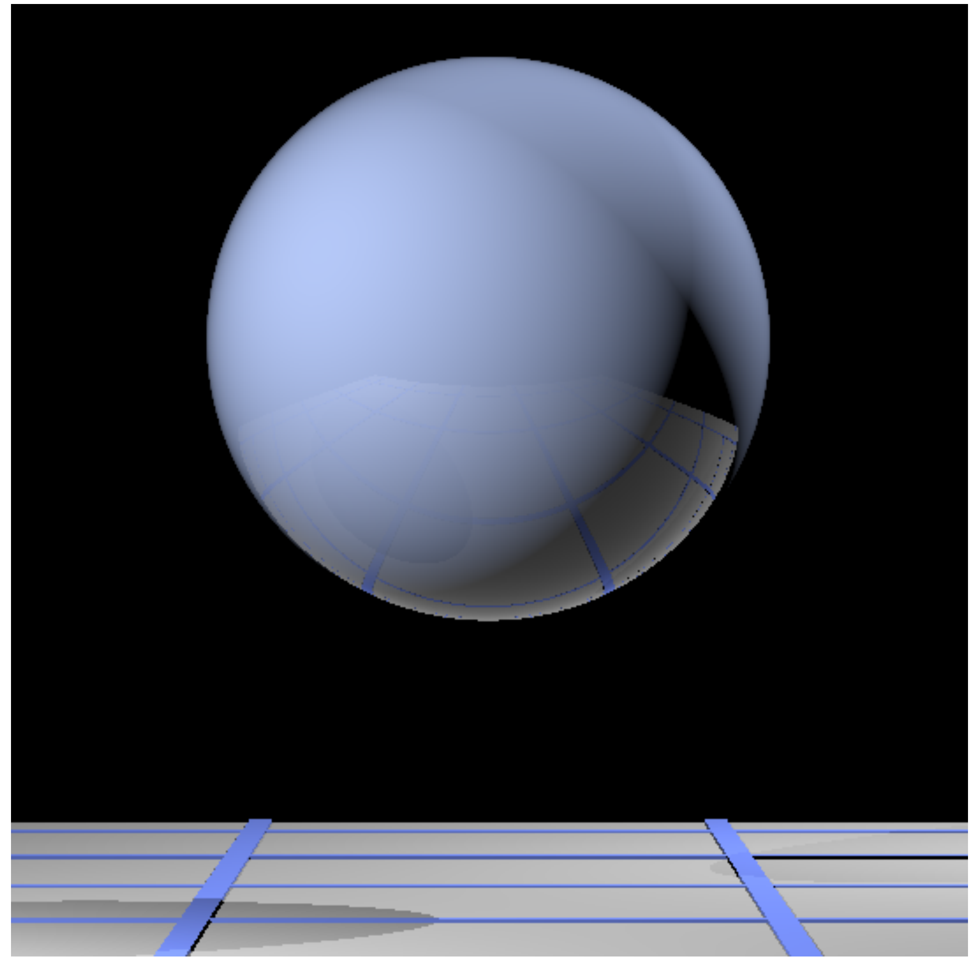
- Dependence on angle is dramatic!
  - about 4% at normal incidence
  - always 100% at grazing
  - remaining light is transmitted
- This is important for proper appearance



Fresnel reflection



constant reflectance



Fresnel reflectance

Fresnel's formulas

- They predict how much light reflects from a smooth interface between two materials
  – usually one material is empty space

$$F_p = \frac{\eta_2 \cos\theta_1 - \eta_1 \cos\theta_2}{\eta_2 \cos\theta_1 + \eta_1 \cos\theta_2}$$

$$F_s = \frac{\eta_1 \cos\theta_1 - \eta_2 \cos\theta_2}{\eta_1 \cos\theta_1 + \eta_2 \cos\theta_2}$$

$$R = \frac{1}{2}\left(F_p^2 + F_s^2\right)$$

– R is the fraction that is reflected

– $(1 - R)$ is the fraction that is transmitted

Schlick’s approximation

- For graphics, a quick hack to get close with less computation:

$$\tilde{R} = R_0 + (1 - R_0)(1 - \cos\theta)^5$$

- R_0 is easy to compute:

$$F_p = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}$$

$$F_s = \frac{\eta_1 - \eta_2}{\eta_1 + \eta_2}$$

$$R_0 = \left(\frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}\right)^2$$

[Josh Wills | 2003 UCSD Rendering Competition]

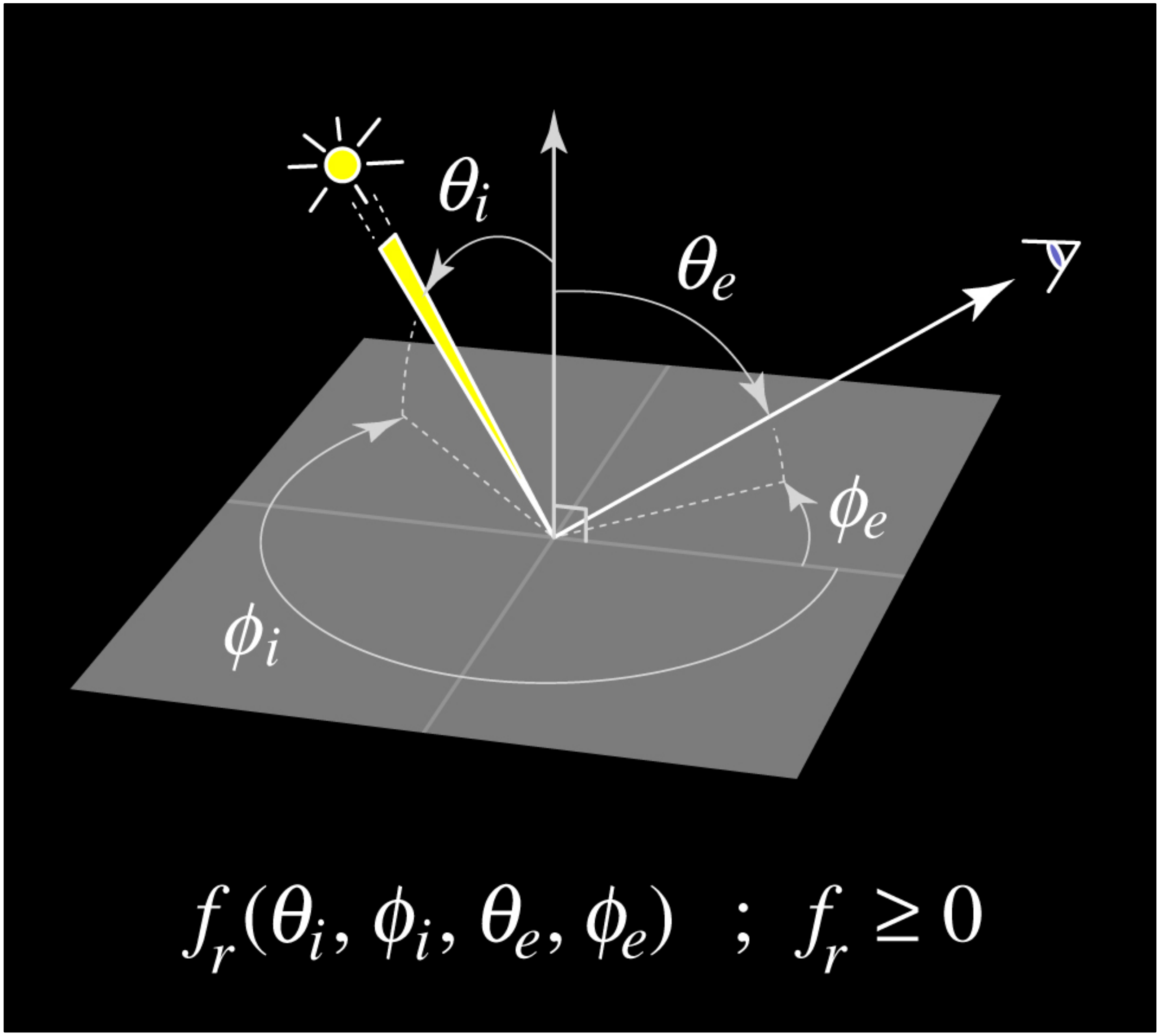
Fresnel reflection

[Mike Hill & Gaain Kwan | Stanford cs348 competition 2001]

	diffuse	glossy	mirror
indirect	soft indirect illumination	blurry reflections of other objects	reflected images of other objects
environment	soft shadows	blurry reflection of environment	reflected image of environment
area	soft shadows	shaped specular highlight	reflected image of source
point/ directional	hard shadows	simple specular highlight	point reflections

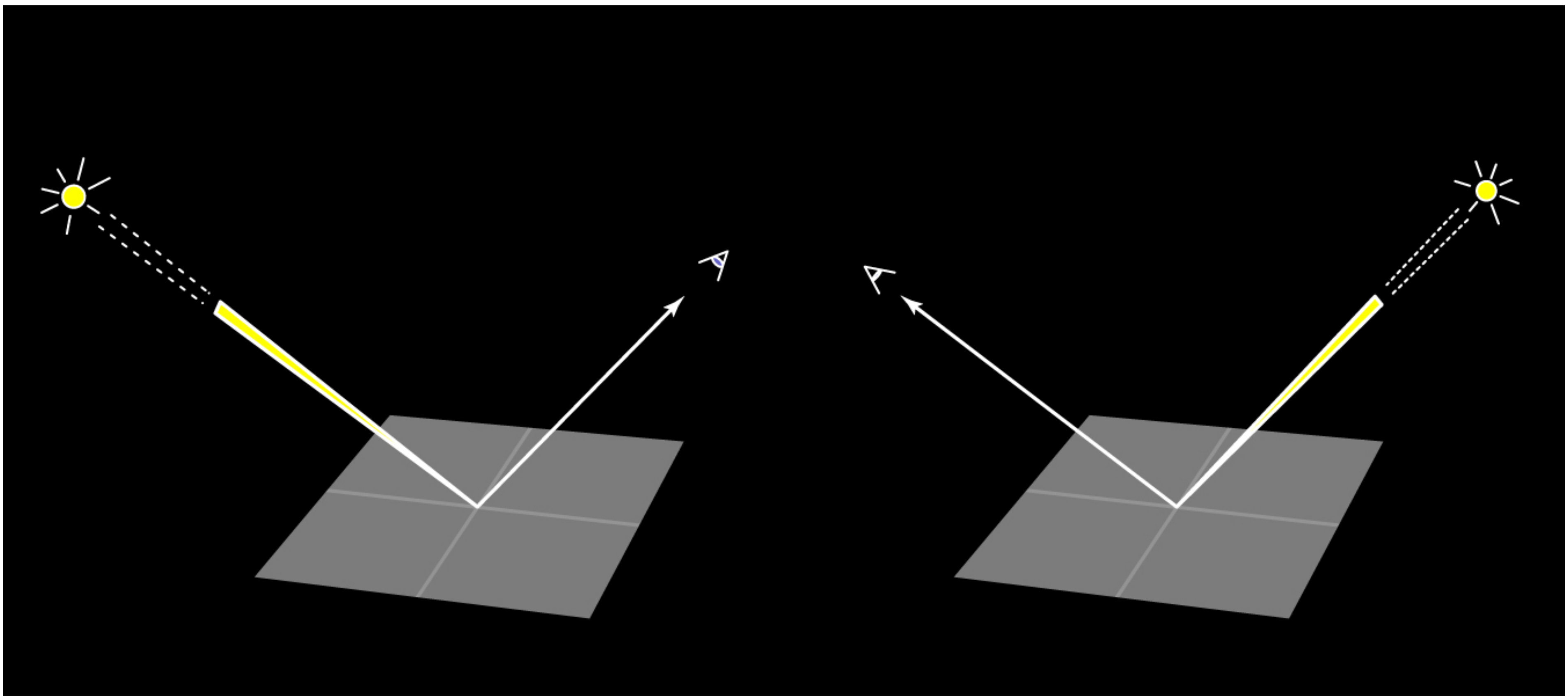
= easy to include in "classic" ray tracer

BRDF



Reciprocity

- Interchanging arguments
- Physical requirement



Energy Conservation

- Reflected power < incident power
- Physical requirement