CMSC427
L08P3: Shading
BRDF

Credit: slides from Dr. Zwicker

Today

Shading

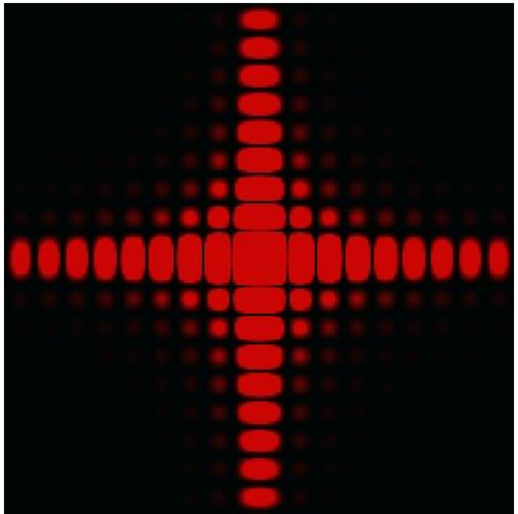
- Introduction
- Radiometry & BRDFs
- Local shading models
- Light sources
- Shading strategies

Material appearance

- What is giving a material its color and appearance?
- How is light reflected by a
  - Mirror
  - White sheet of paper
  - Blue sheet of paper
  - Glossy metal

Radiometry

- Physical units to measure light energy
- Based on the geometrical optics model
- Light modeled as rays
  - Rays are idealized narrow beams of light
    http://en.wikipedia.org/wiki/Ray_%28optics%29
  - Rays carry a spectrum of electromagnetic energy
- No wave effects, like interference or diffraction



Diffraction pattern from square aperture

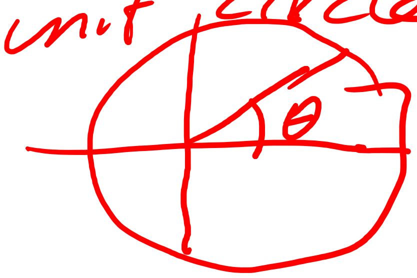
Solid angle

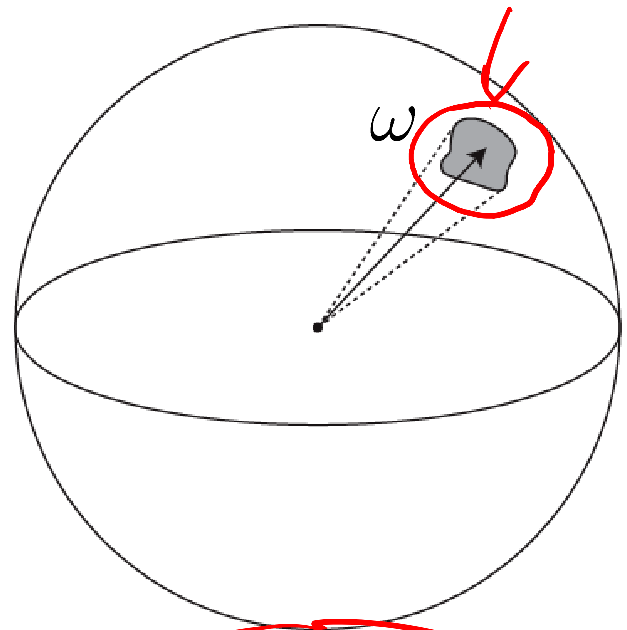
- Area of a surface patch on the unit sphere
  - In our context: area spanned by a set of directions

Solid angle

- Unit: steradian sr
- Directions usually denoted by ω

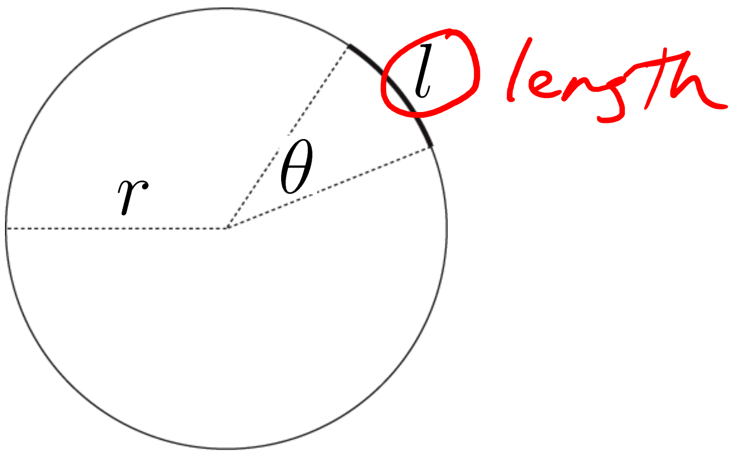
angle = unit circle



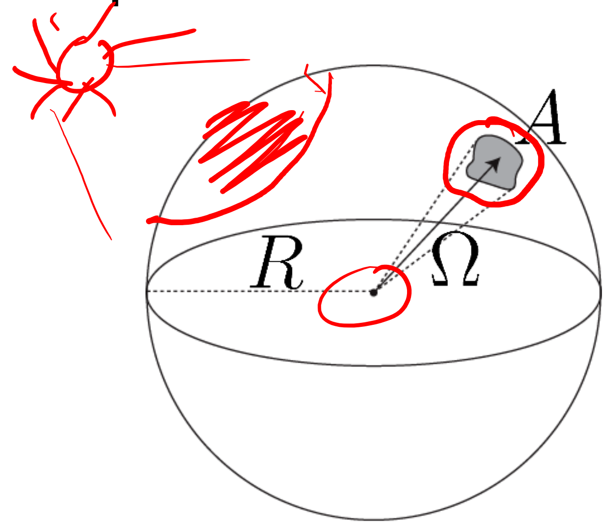


Angle and solid angle

Circle with radius r



Sphere with radius R



- Angle $\theta = l/r$
- Unit circle has 2π radians
- Solid angle $\Omega = A/R^2$
- Unit sphere has 4π steradians

Radiance

http://en.wikipedia.org/wiki/Radiance

- „Energy carried along a narrow beam (ray) of light“

don't worry

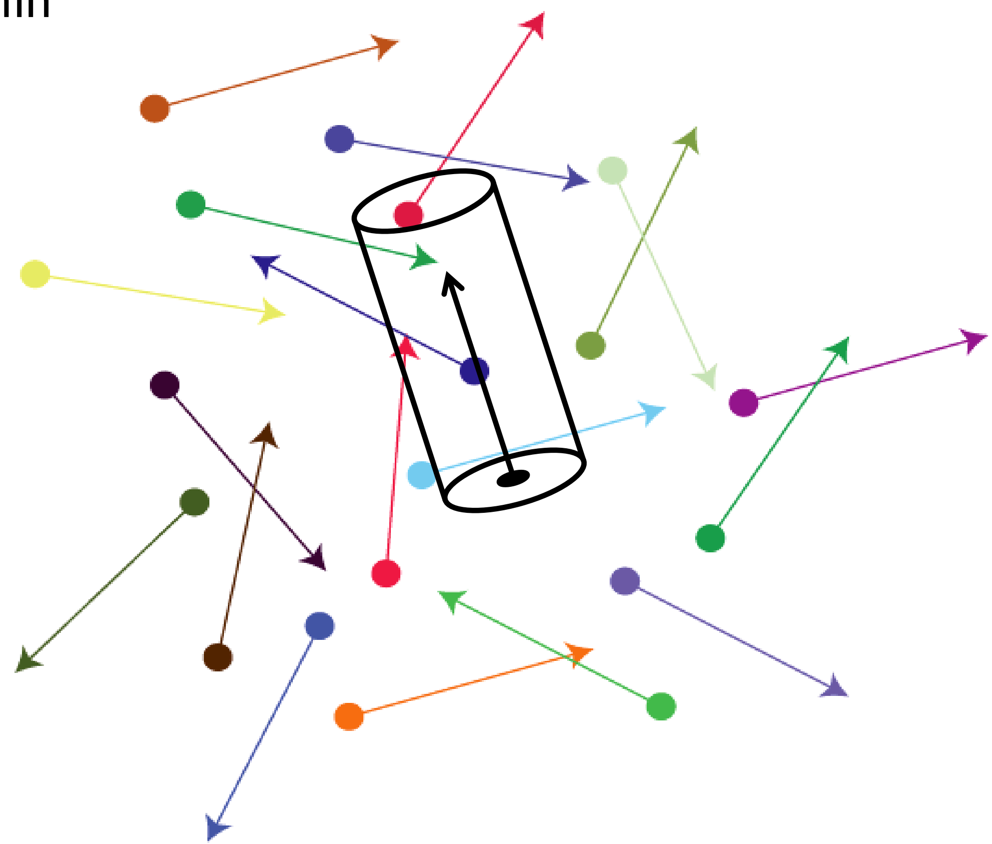
- Energy passing through a small area in a small bundle of directions, divided by area and by solid angle spanned by bundle of directions, in the limit as area and solid angle tend to zero

- Units: energy per area per solid angle

$$\left[W \cdot sr^{-1} \cdot m^{-2}\right]$$

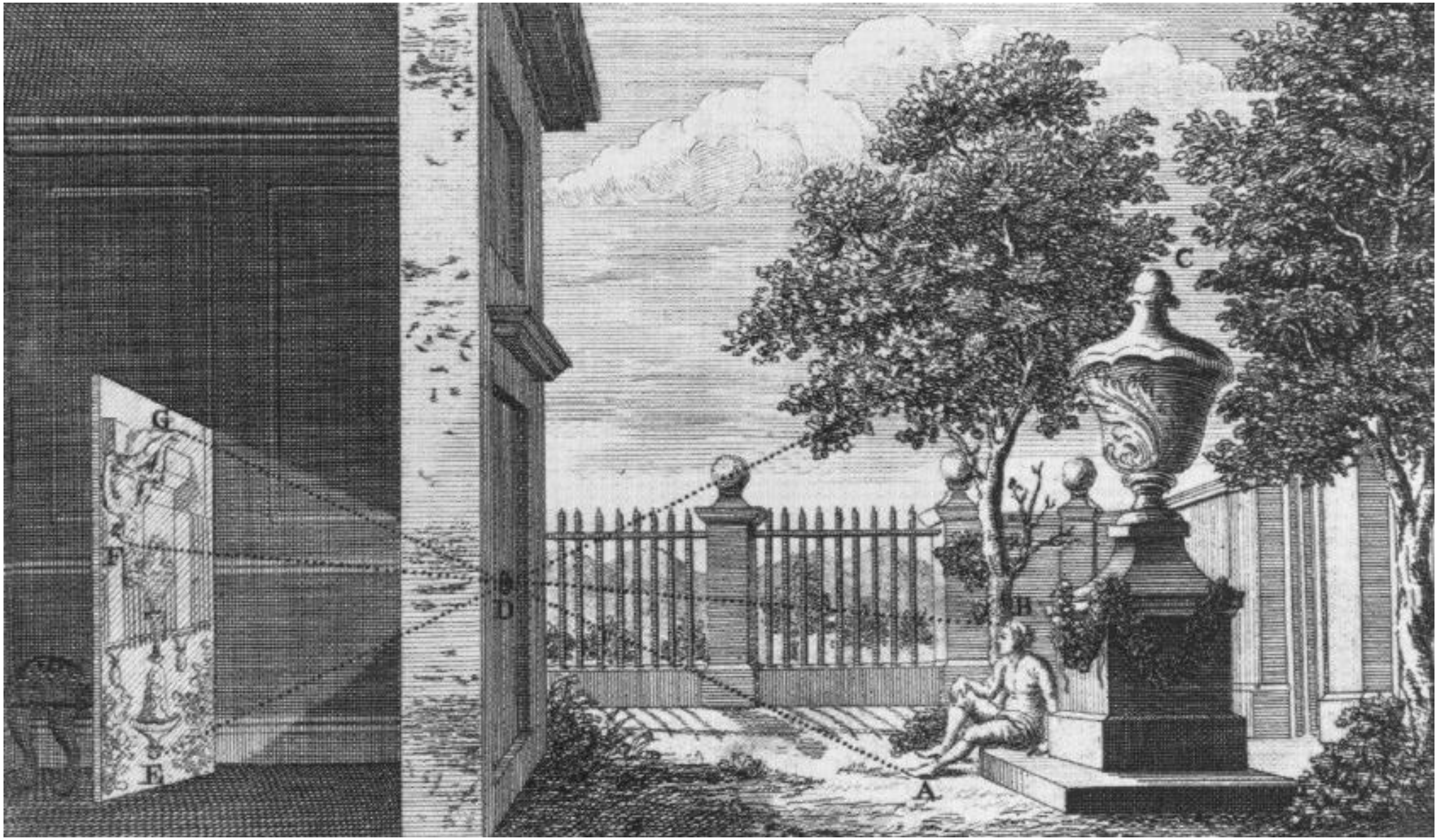
Radiance

- Think of light consisting of photon particles, each traveling along a ray
- Radiance is photon „ray density“
  - Number of photons per area per solid angle
  - „Number of photons passing through small cylinder, as cylinder becomes infinitely thin“



Pinhole camera

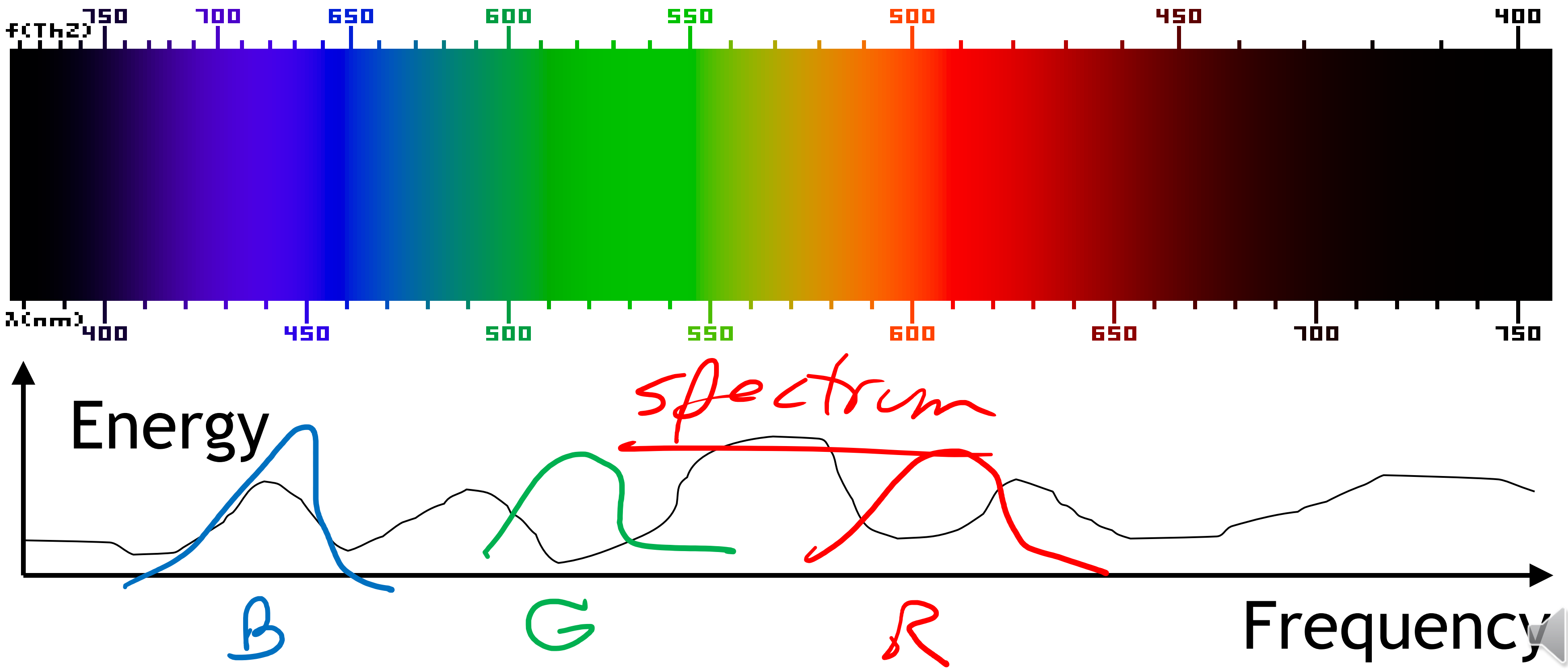
- Records radiance on projection screen



http://en.wikipedia.org/wiki/Pinhole_camera

Radiance

- Spectral radiance: energy at each wavelength/frequency (count only photons of given wavelength)
- Usually, work with radiance for three discrete wavelengths
  - Corresponding to R,G,B primaries



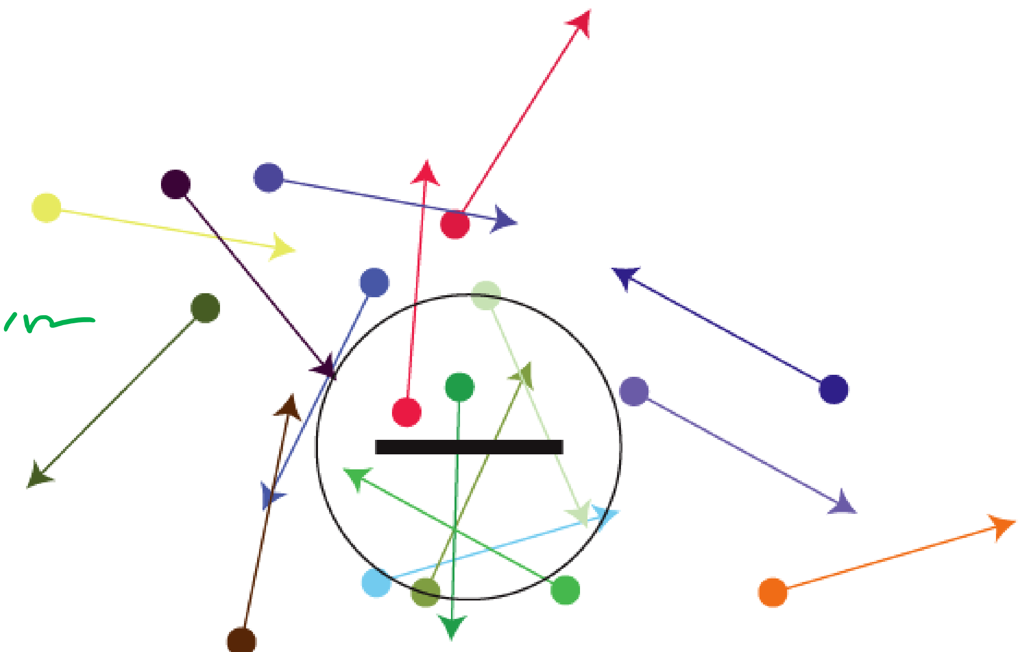
Irradiance

- Energy per area: „energy going through a small area, divided by size of area“
- „Radiance summed up over all directions“
- Units

$$\left[W \cdot m^{-2}\right]$$

irradiance - hit in a region

radiance



Irradiance: Count number of photons per area,
in the limit as area becomes infinitely small

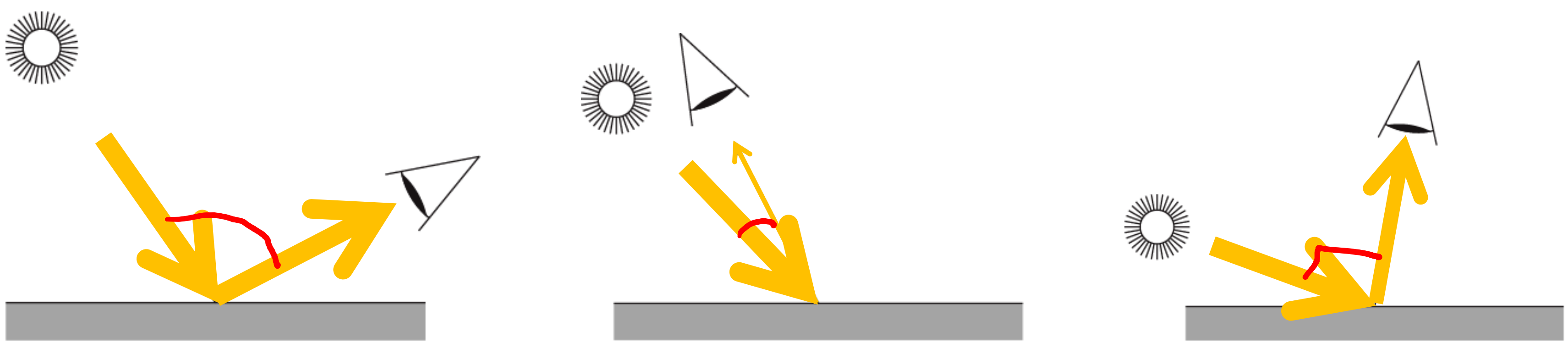
Local shading

- Goal: model reflection of light at surfaces
- Bidirectional reflectance distribution function (BRDF)

"For each pair of light/view direction, BRDF gives fraction of reflected light"

Local shading

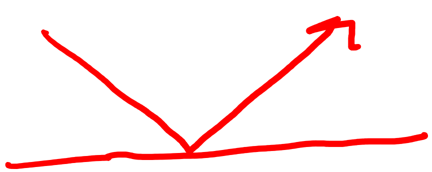
- Goal: model reflection of light at surfaces
- Bidirectional reflectance distribution function (BRDF)
  http://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function
  - "Given light direction, viewing direction, obtain fraction of light reflected towards the viewer"
  - For any pair of light/viewing directions!
  - For different wavelenghts (or R, G, B) separately



"For each pair of light/view direction, BRDF gives fraction of reflected light"

BRDFs

- BRDF describes appearance of material
  - Color
  - Diffuse
  - Glossy
  - Mirror
  - Etc.



intensity
⇒ gray scale

spectrum
⇒ color

- BRDF can be different at each point on surface
  - Spatially varying BRDF (SVBRDF)
  - Textures

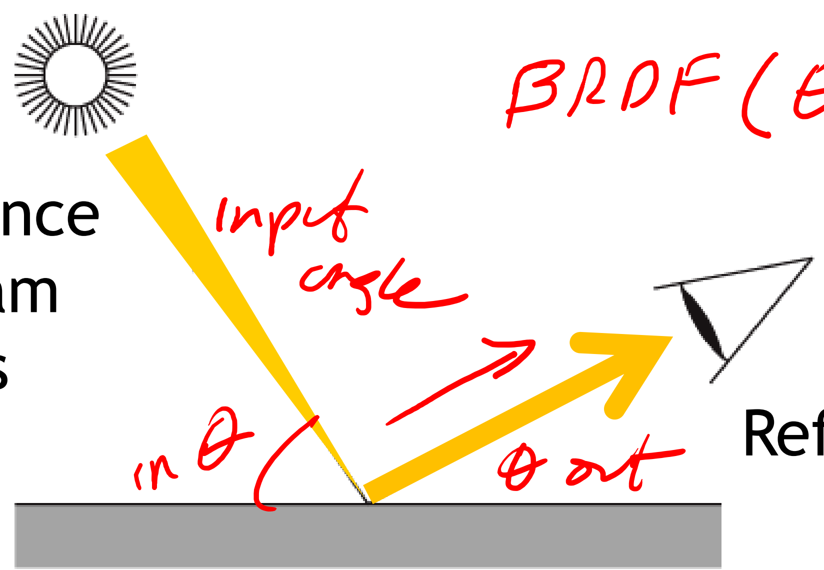
Technical definition

- Given incident and outgoing directions
- BRDF is fraction of ”radiance reflected in outgoing direction” over ”incident irradiance arriving from narrow beam of directions”
- Units $\left[W \cdot sr^{-1} \cdot m^{-2}\right] / \left[W \cdot m^{-2}\right] = sr^{-1}$

BRDF(θin, θout

↑ polar
3D

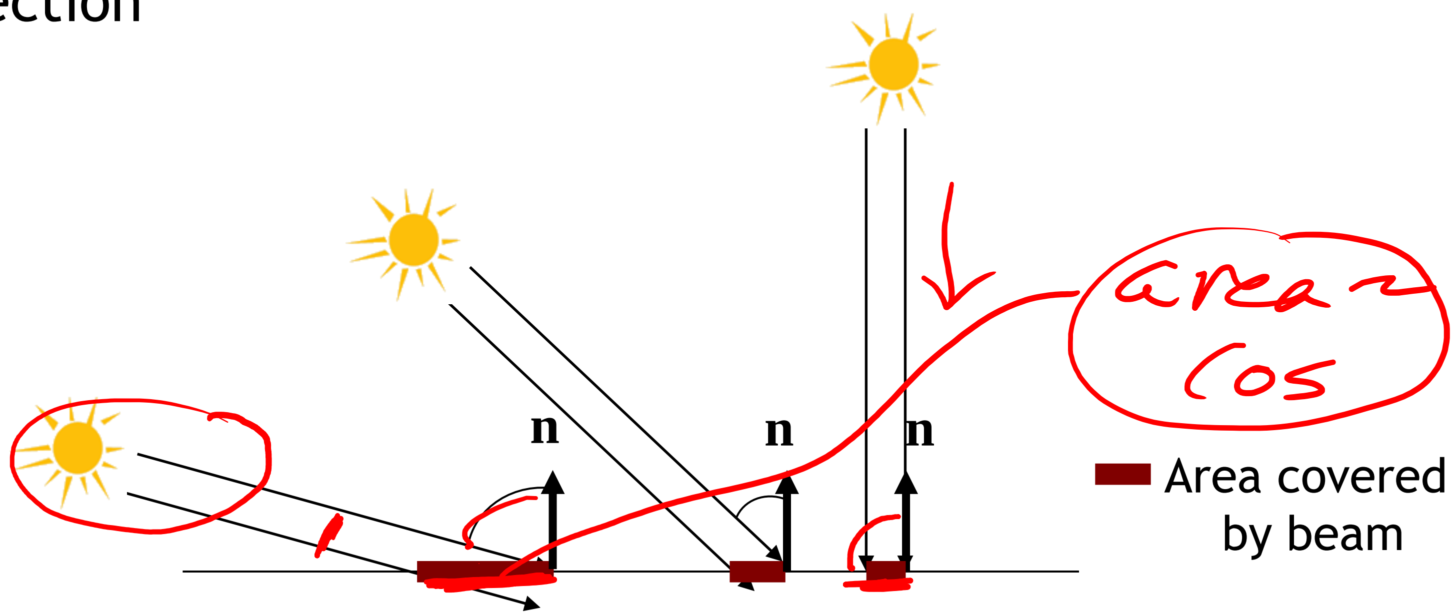
Incident irradiance from small beam of directions



Reflected radiance

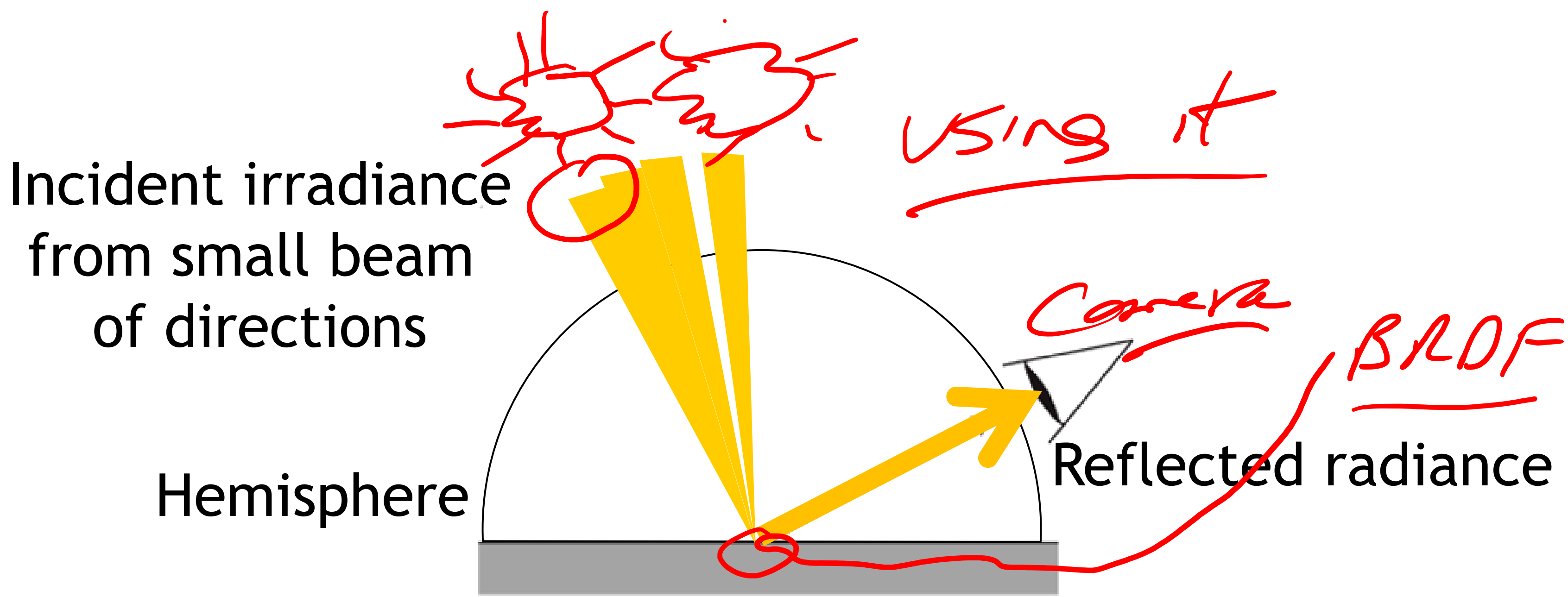
Irradiance from a narrow beam

- Narrow beam of parallel rays shining on a surface
  - Area covered by beam varies with the angle between the beam and the normal **n**
  - The larger the area, the less incident light per area
- Irradiance (incident light per unit area) is proportional to the cosine of the angle between the surface normal **n** and the light rays
- Equivalently, irradiance contributed by beam is radiance of beam times cosine of angle between normal **n** and beam direction



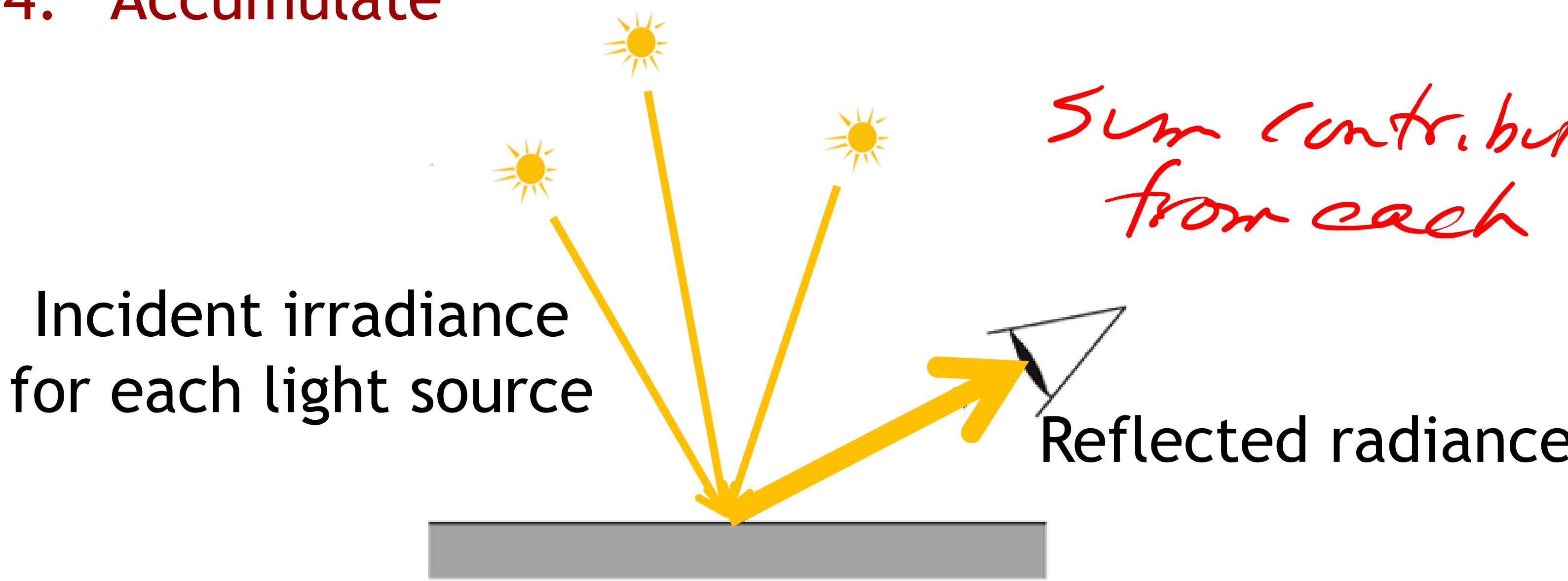
Shading with BRDFs

- Given radiance arriving from each direction, outgoing direction
- For all incoming directions over the hemisphere
  1. Compute irradiance from incoming beam
  2. Evaluate BRDF with incoming beam direction, outgoing direction
  3. Multiply irradiance and BRDF value
  4. Accumulate
- Mathematically, a hemispherical integral ("shading integral") have BRDF
  https://en.wikipedia.org/wiki/Rendering_equation



Shading with BRDFs

- If only discrete number of small light sources taken into account, need minor modification of algorithm
- For each light source
  1. Compute irradiance arriving from light source
  2. Evaluate BRDF with direction to light source, outgoing direction
  3. Multiply irradiance and BRDF value
  4. Accumulate

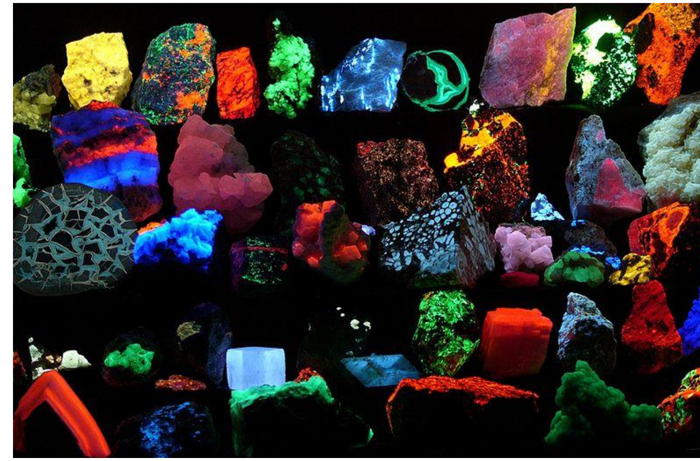


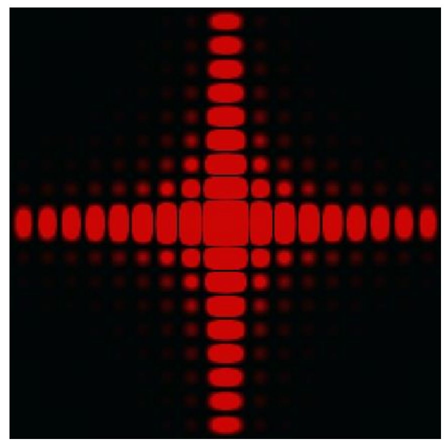
Sum contribution from each

Limitations of BRDF model

Cannot model

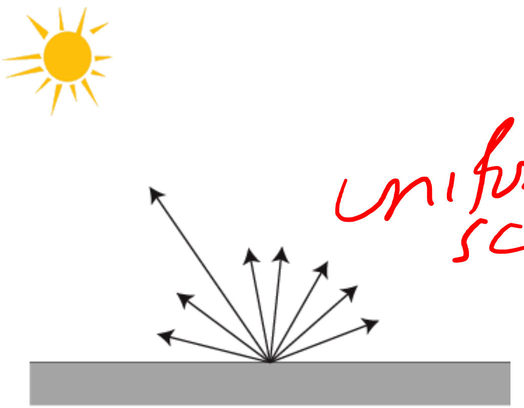
- Fluorescence
- Subsurface and volume scattering
- Polarization
- Interference/diffraction



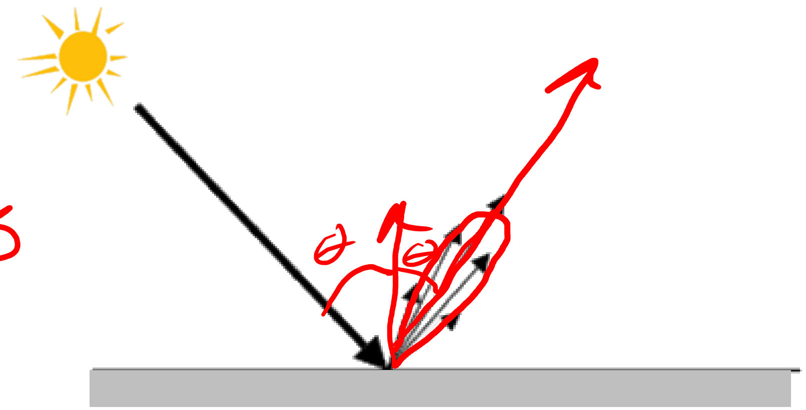


Visualizing BRDFs

- Given viewing or light direction, plot BRDF value over sphere of directions
- Illustration in „flatland“ (1D slices of 2D BRDFs)

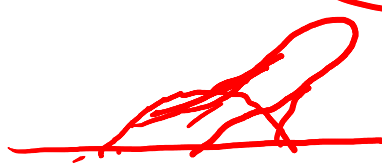


uniform scattering



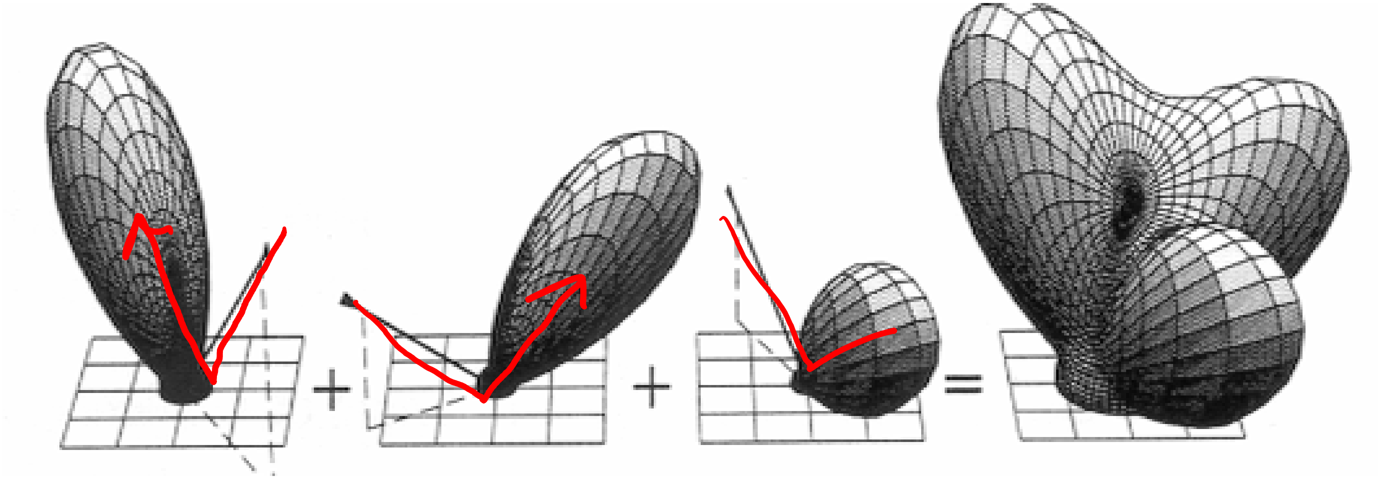
Diffuse reflection

Glossy reflection



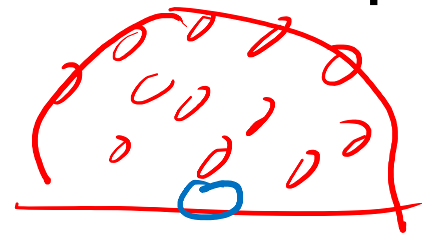
Visualizing BRDFs

- Can add up several BRDFs to obtain more complicated ones



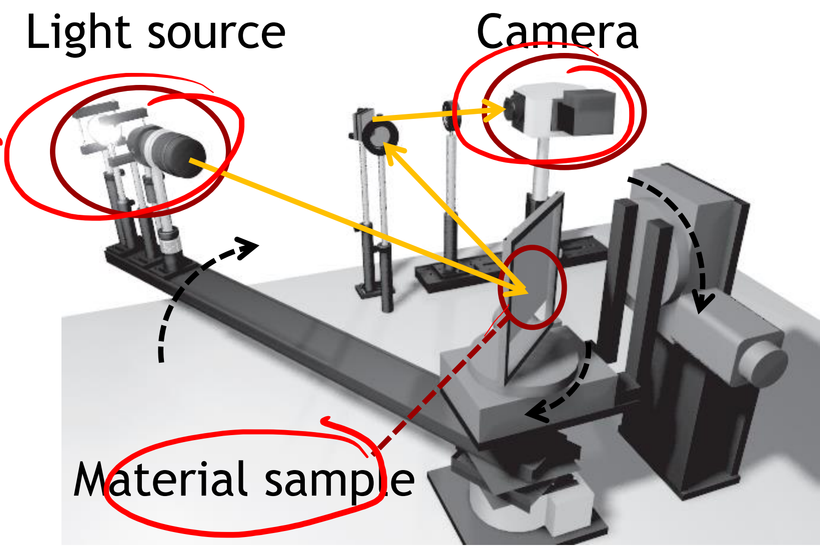
BRDF representation

- How to define and store BRDFs that represent physical materials?



- Physical measurements
  - Gonioreflectometer: robot with light source and camera
  - Measures reflection for each light/camera direction
  - Store measurements in table

empirical BRDF



Cornell University Gonioreflectometer

- Too much data for interactive application
  - 4 degrees of freedom!

BRDF representation

- Analytical models
  - Try to describe phyiscal properties of materials using mathematical expressions
- Many models proposed in graphics
  http://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function
  http://en.wikipedia.org/wiki/Cook-Torrance
  http://en.wikipedia.org/wiki/Oren-Nayar_diffuse_model
- Will restrict ourselves to simple models here