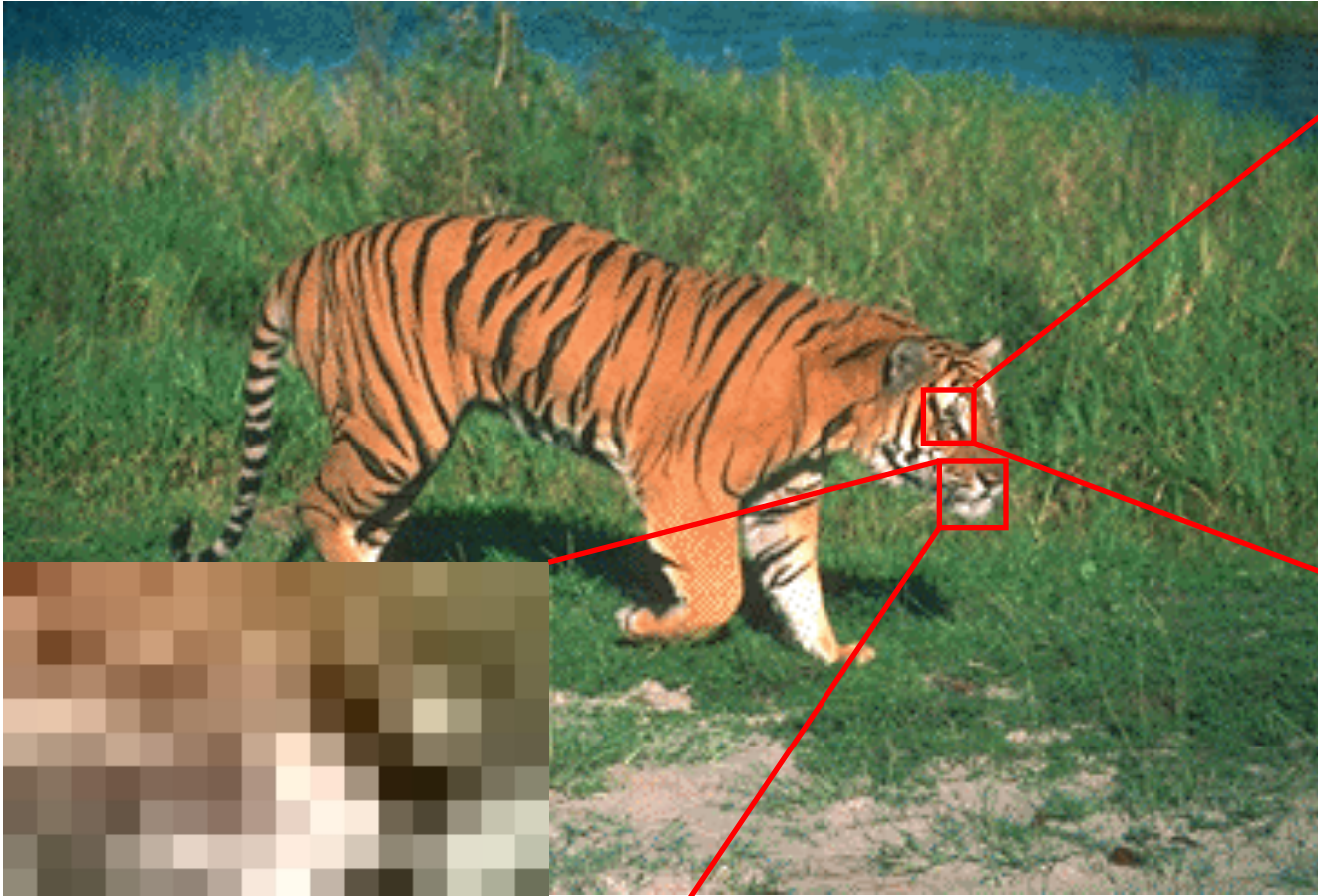# What is in an image?

The image is an array of brightness values (three arrays for RGB images)

A camera creates an image …
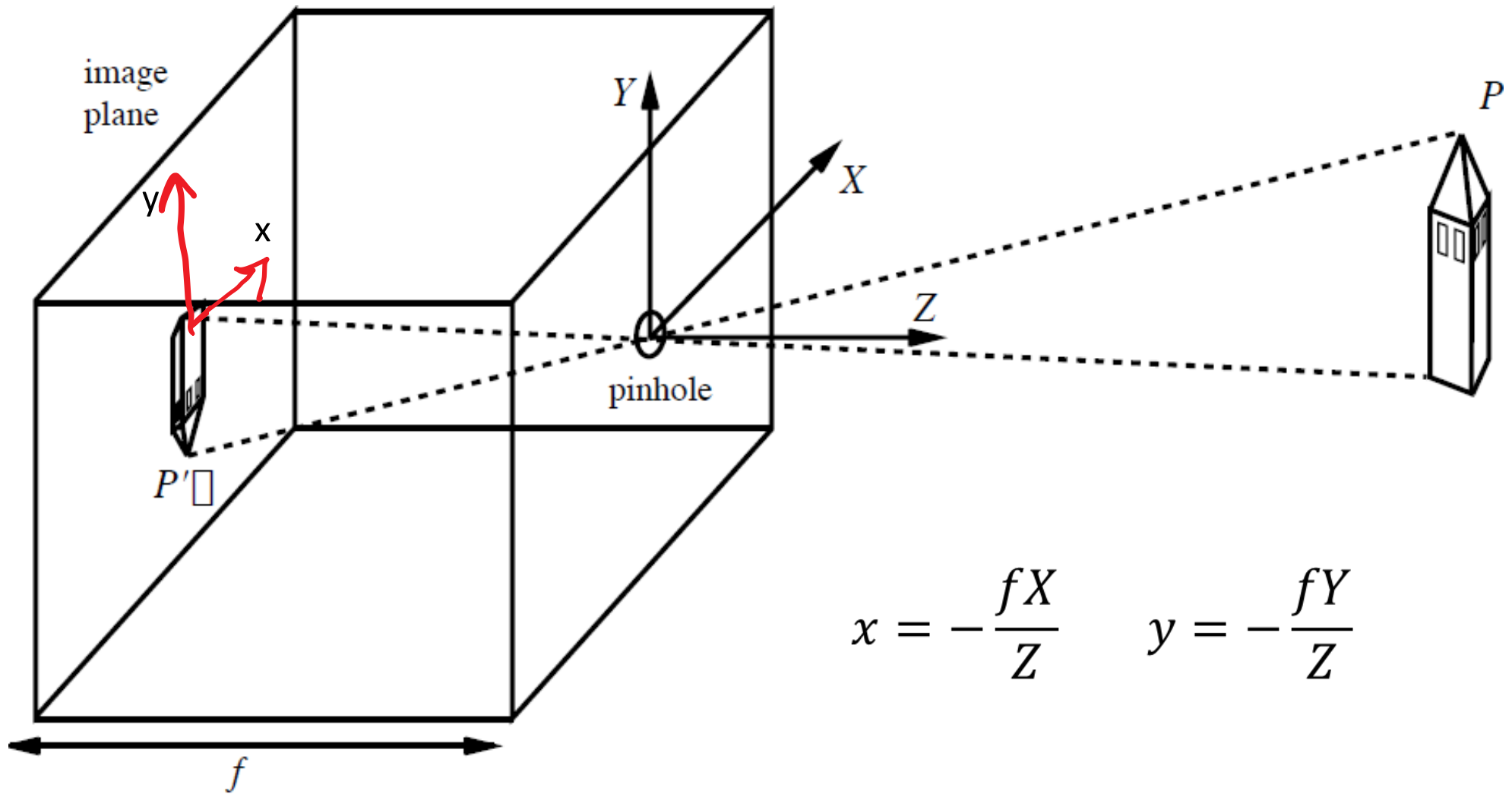

WORLD

The image I(x,y) measures how much light is captured at pixel (x,y)
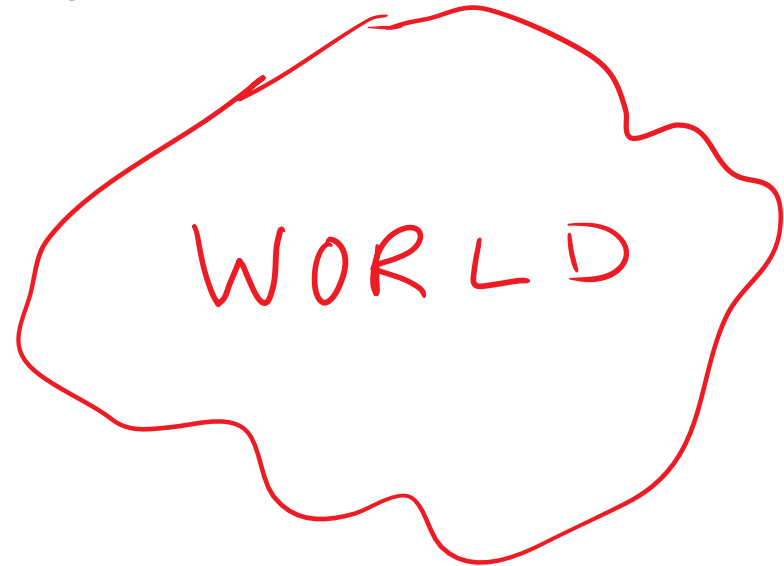
We want to know
- Where does a point (X,Y,Z) in the world get imaged?
- What is the brightness at the resulting point (x,y)?

The pinhole camera models where a scene point is projected

$$x = -\frac{fX}{Z} \qquad y = -\frac{fY}{Z}$$

# Now let us try to understand brightness at a pixel (x,y) ...

WORLD

The image I(x,y) measures how much light is captured at pixel (x,y). Proportional to the number of photons captured at the sensor element (CCD/CMOS/Rod/cone/..) in a time interval.

We use the scientific term IRRADIANCE for this concept.
Irradiance is defined as the radiant power per unit area, and has units W/m^2. Usually denoted by E.

Radiance is a directional quantity

Radiant power travelling in a given direction per unit area (measured perpendicular to the direction of travel) per unit solid angle
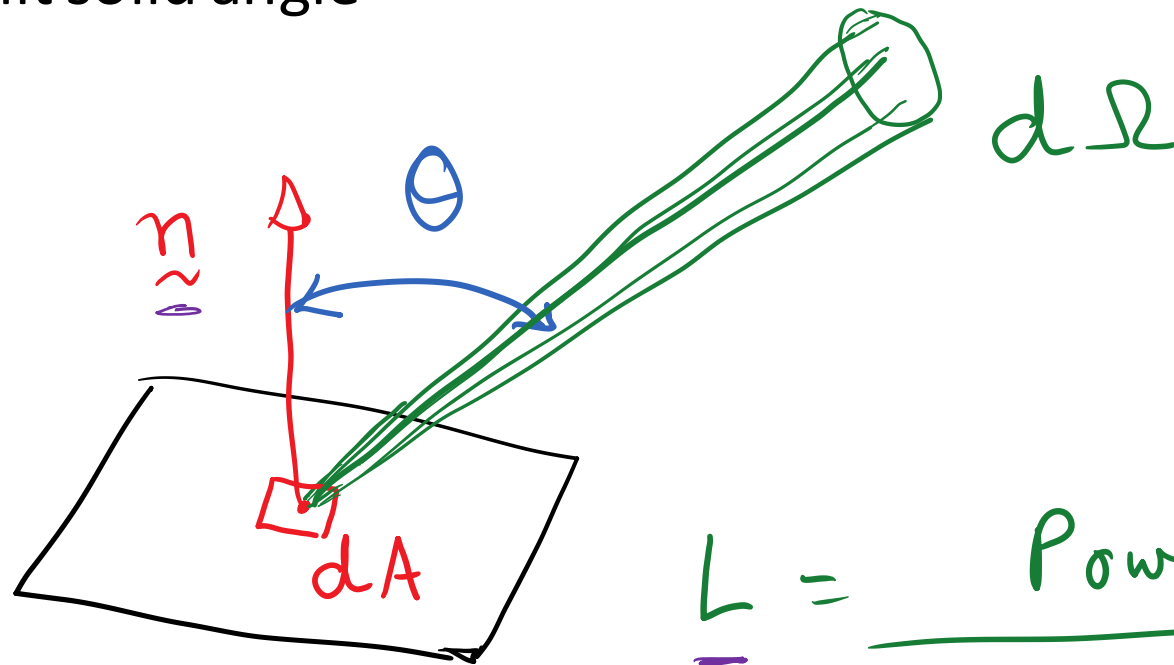
$$L = \frac{Power}{(dA \cos\theta)(d\Omega)}$$

units are $W\, m^{-2}\, sr^{-1}$
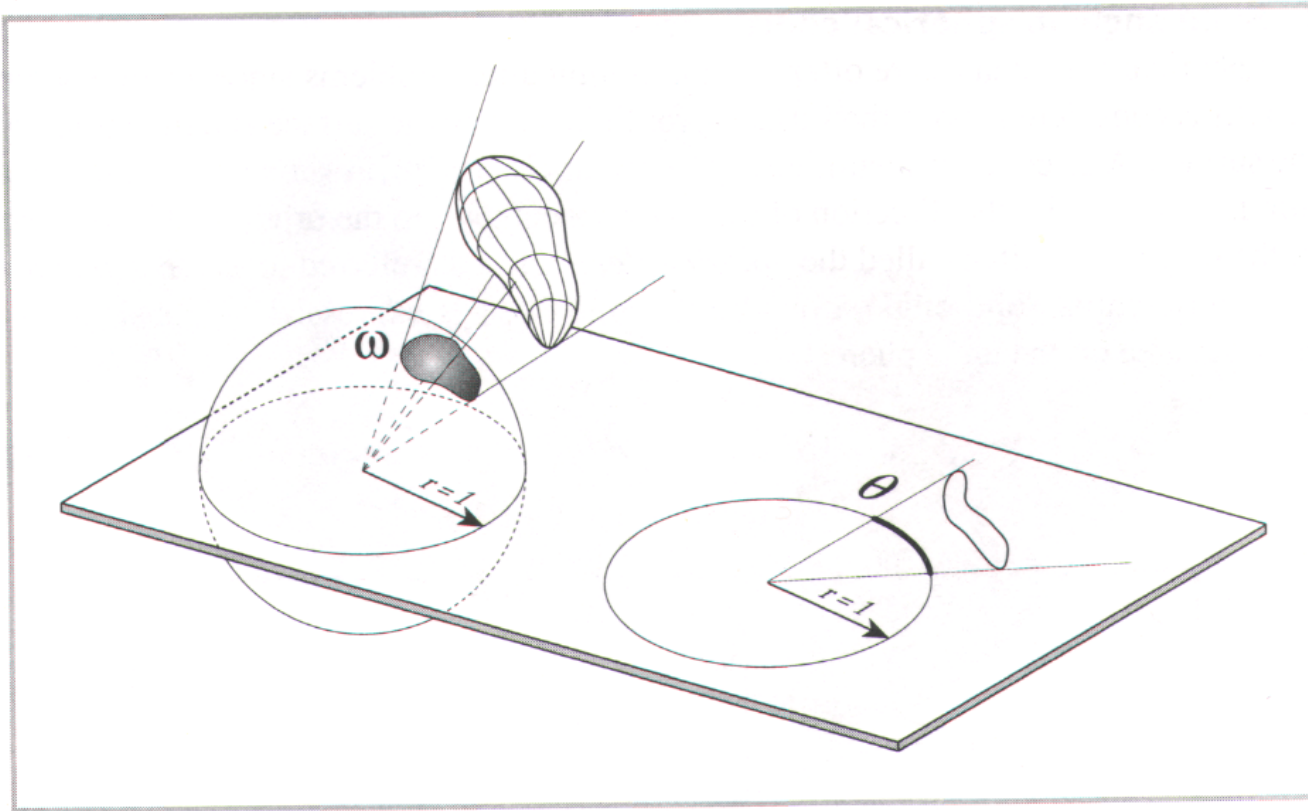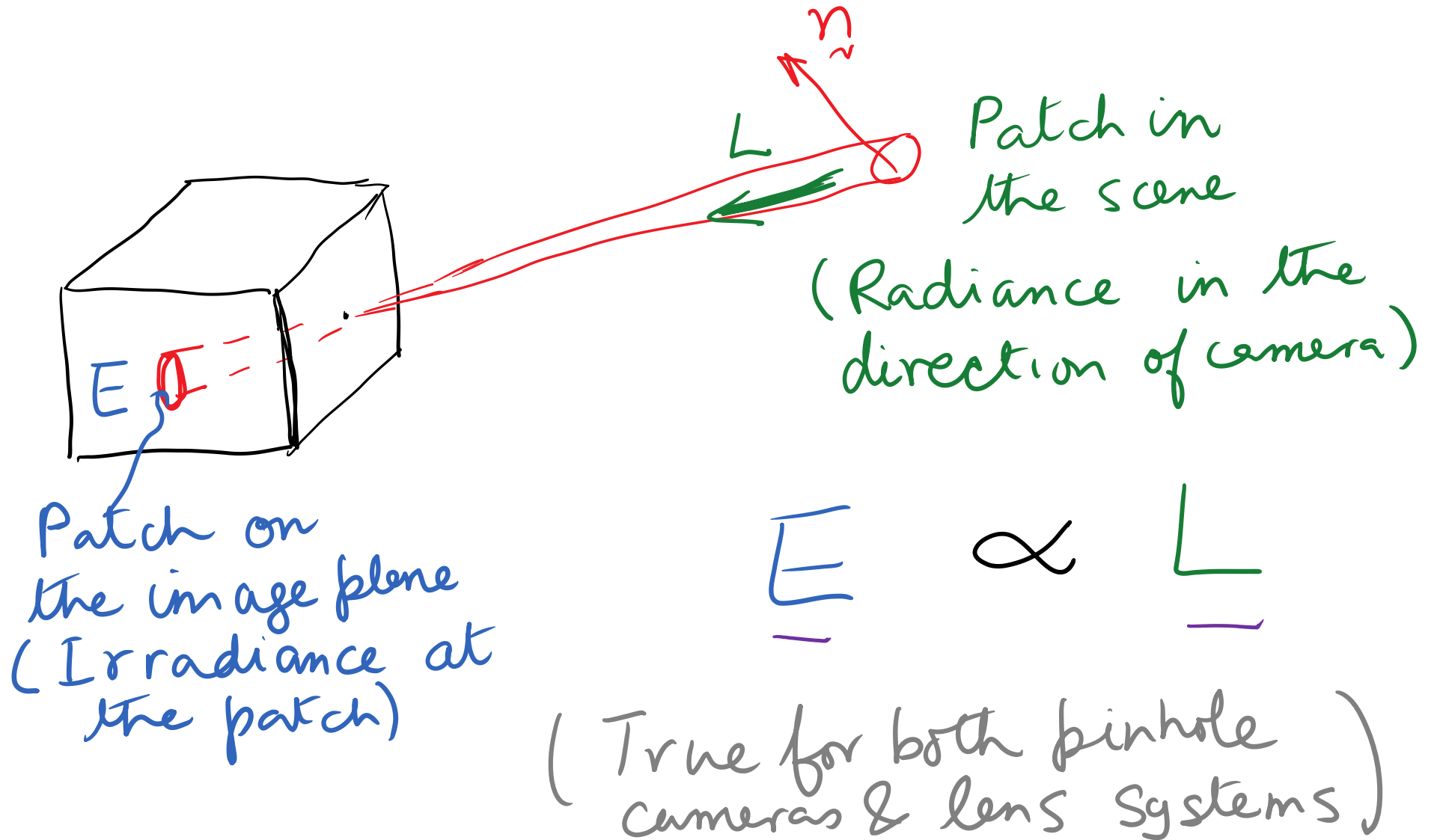
Read more on Wikipedia

FIGURE 2.1 Definitions of angle and solid angle. θ, the angle subtended by a curve in the plane, is the length of the corresponding arc on the unit circle. ω, the solid angle subtended by an object, is the surface area of its projection onto the unit sphere.

# Image irradiance is proportional to scene radiance in the direction of the camera

n

L

Patch in the scene

(Radiance in the direction of camera)

E

Patch on the image plane (Irradiance at the patch)

$$E \propto L$$

(True for both pinhole cameras & lens systems)

What causes the outgoing radiance at a scene patch?

- Incoming radiance from the source

- Angle between $\underset{\sim}{n}$ and $\underset{\sim}{S}$

- Reflectance properties of the patch

Light Source

$\underset{\sim}{S}$

$\underset{\sim}{n}$

L

Patch in the scene

E
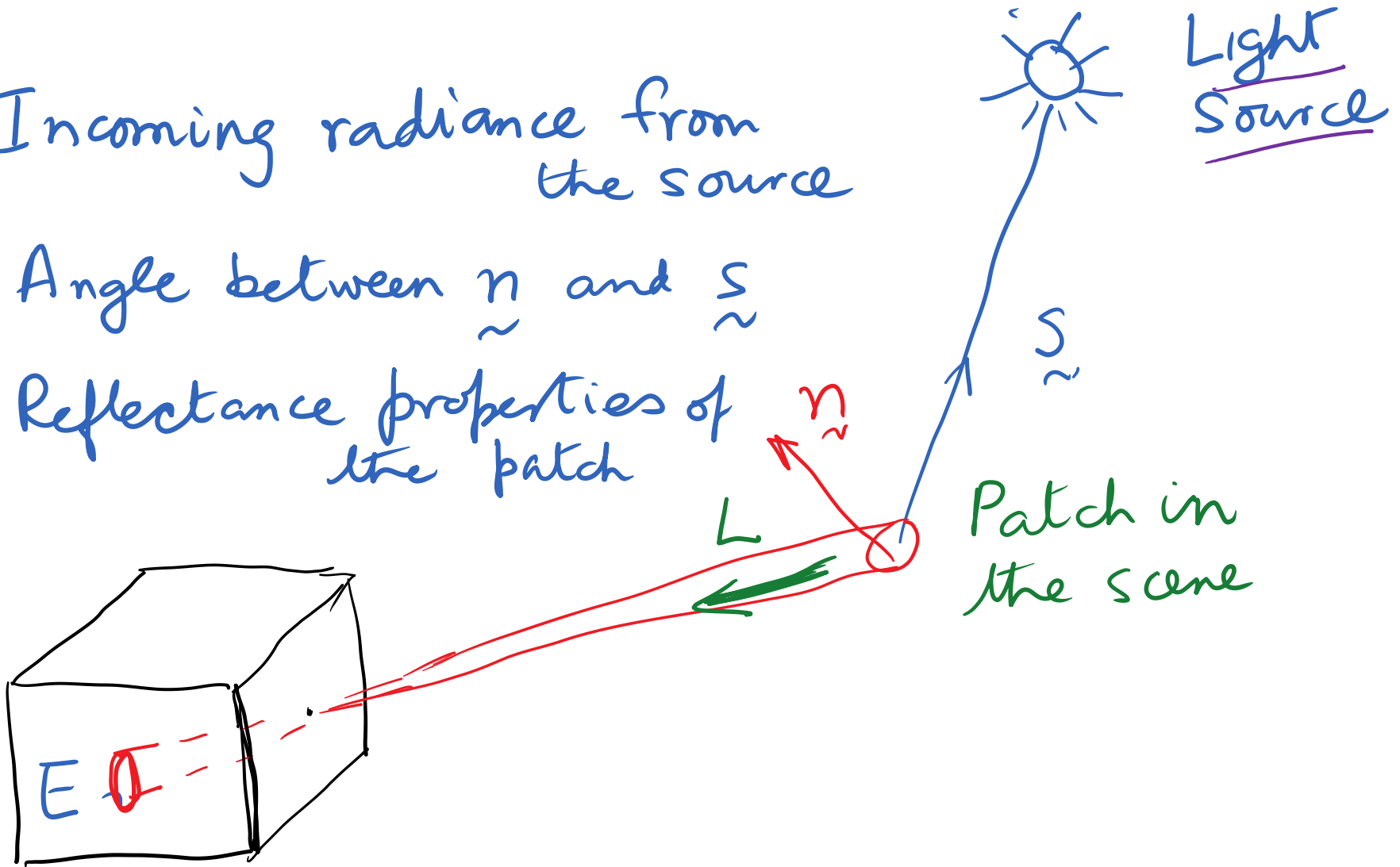
What causes the outgoing radiance at a scene patch?

- Incoming radiance from the source
- Angle between $\underset{\sim}{n}$ and $\underset{\sim}{s}$
- Reflectance properties of the surface patch

Light Source

$\underset{\sim}{s}$

$\underset{\sim}{n}$

L
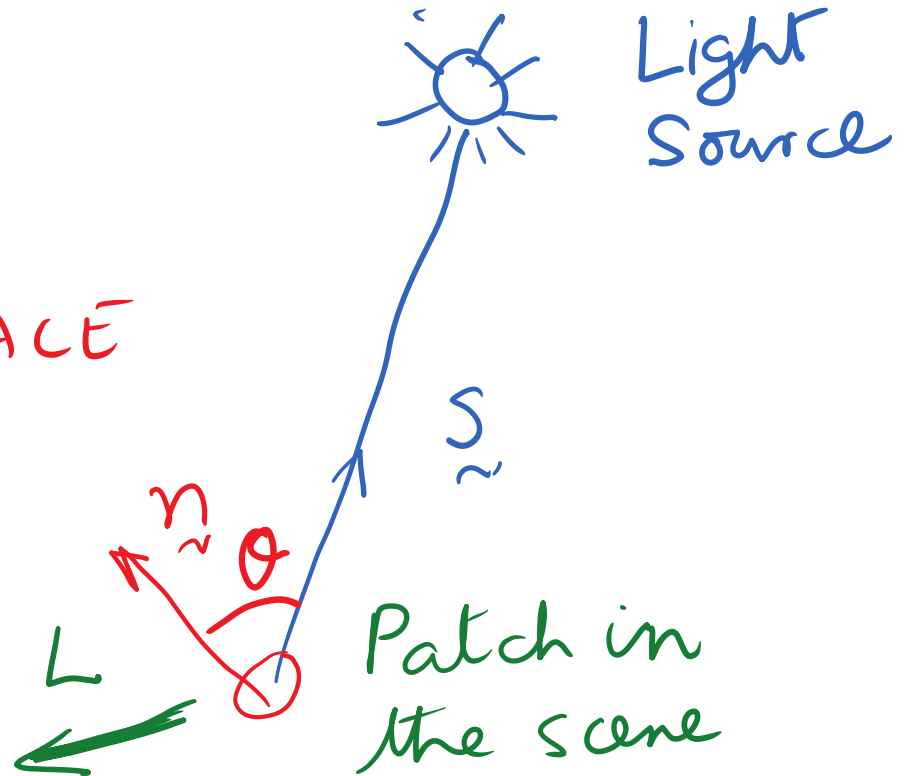
Patch in the scene
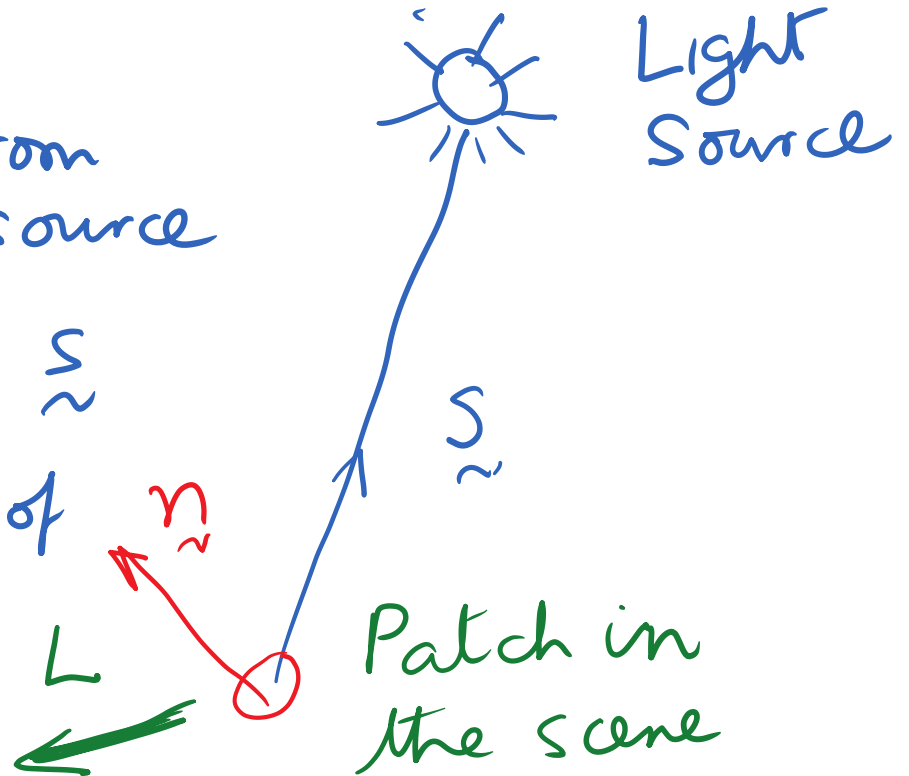
Two special cases:
- **Specular surfaces** - Outgoing radiance direction obeys angle of incidence=angle of reflection, and co-planarity of incident & reflected rays & the surface normal.
- **Lambertian surfaces** - Outgoing radiance same in all directions

The Lambertian model

$$L = \rho \lambda \, \underset{\sim}{n} \cdot \underset{\sim}{S}$$

$\rho =$ ALBEDO OF SURFACE
  $0 \Longleftrightarrow$ BLACK
  $1 \Longleftrightarrow$ WHITE
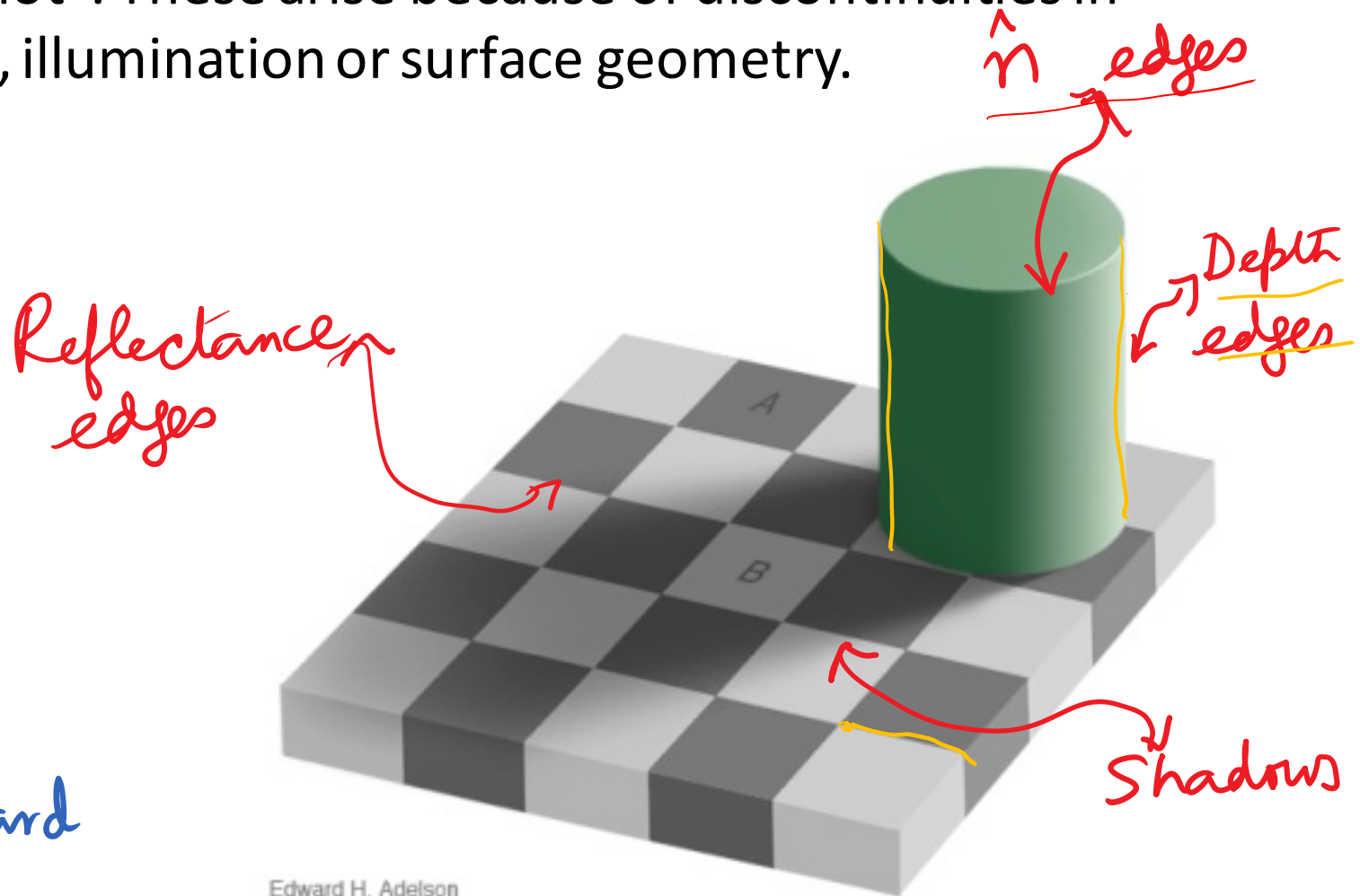
λ depends on radiance of light source

$$\underset{\sim}{n} \cdot \underset{\sim}{S} = \cos \theta \quad \text{corresponds to foreshortening}$$

Light Source

$\underset{\sim}{S}$

$\underset{\sim}{n}$ θ

L Patch in the scene

We often model reflectance by a combination of a Lambertian term and a specular term. If we want to be precise, we use a BRDF (Bidirectional Reflectance Distribution function) which is a 4D function corresponding to the ratio of outgoing radiance in a particular direction to the incoming irradiance in some other direction. This can be measured empirically.

Edges are important

- Edges are curves in the image, across which the brightness changes "a lot". These arise because of discontinuities in reflectance, illumination or surface geometry.

$\hat{n}$ edges

Depth edges

Reflectance edges

Shadows

Adelson's checkerboard illusion

Edward H. Adelson

Real world scenes have additional complexity…

- Objects are illuminated not just by light sources, but also by reflected light from other surfaces. In computer graphics, ray tracing and radiosity are techniques that address this issue.

- Shadows

Point Light Source

Attached Shadow

Casted Shadow

Ground Plane
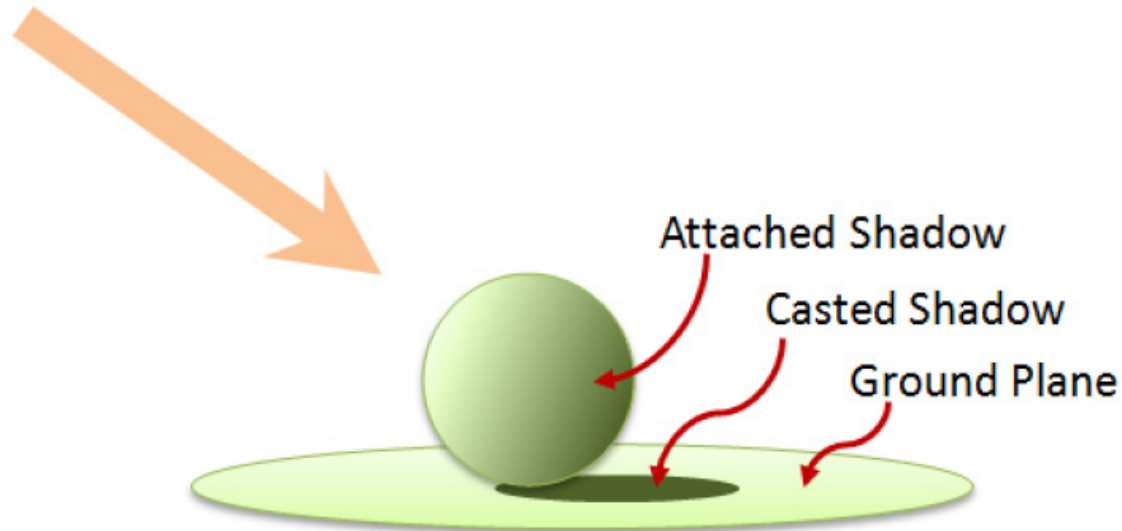
Inverting the physics of image formation is hard

- Shape-from-shading (SFS) seeks to go from the measured irradiance values in the image to the scene geometry, reflectances and illumination that caused it.

- This is the inverse of the computer graphics rendering problem where the goal is to produce the image, given the scene.

- The inverse problem is <u>much</u> harder than the forward problem; traditional SFS only works under gross simplifying assumptions on the physics.

- Computer vision has been much more successful in exploiting the geometry of image formation with multiple views.