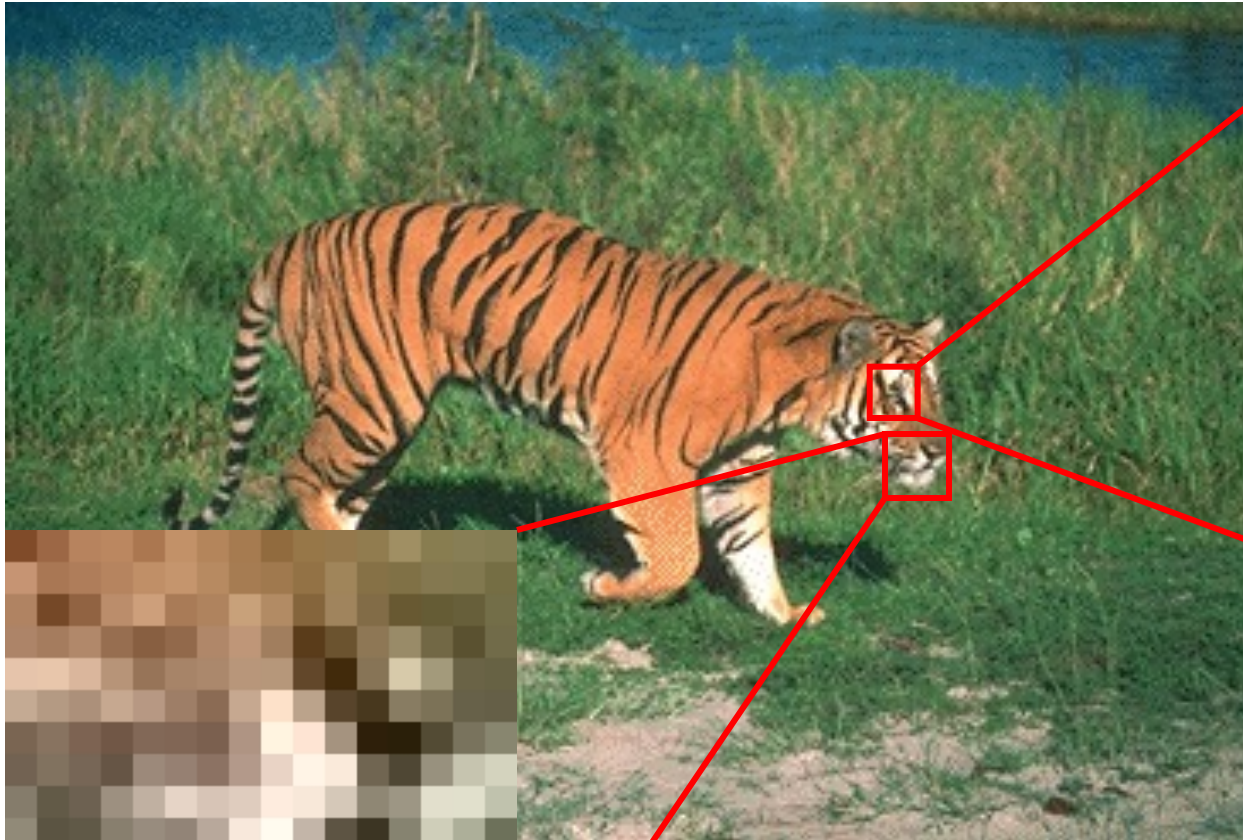


Radiometry of Image Formation

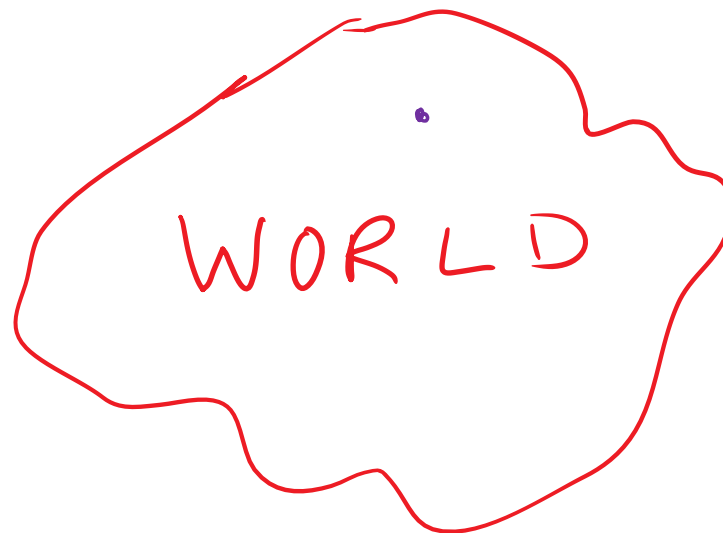
Jitendra Malik

What is in an image?



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

A camera creates an image ...

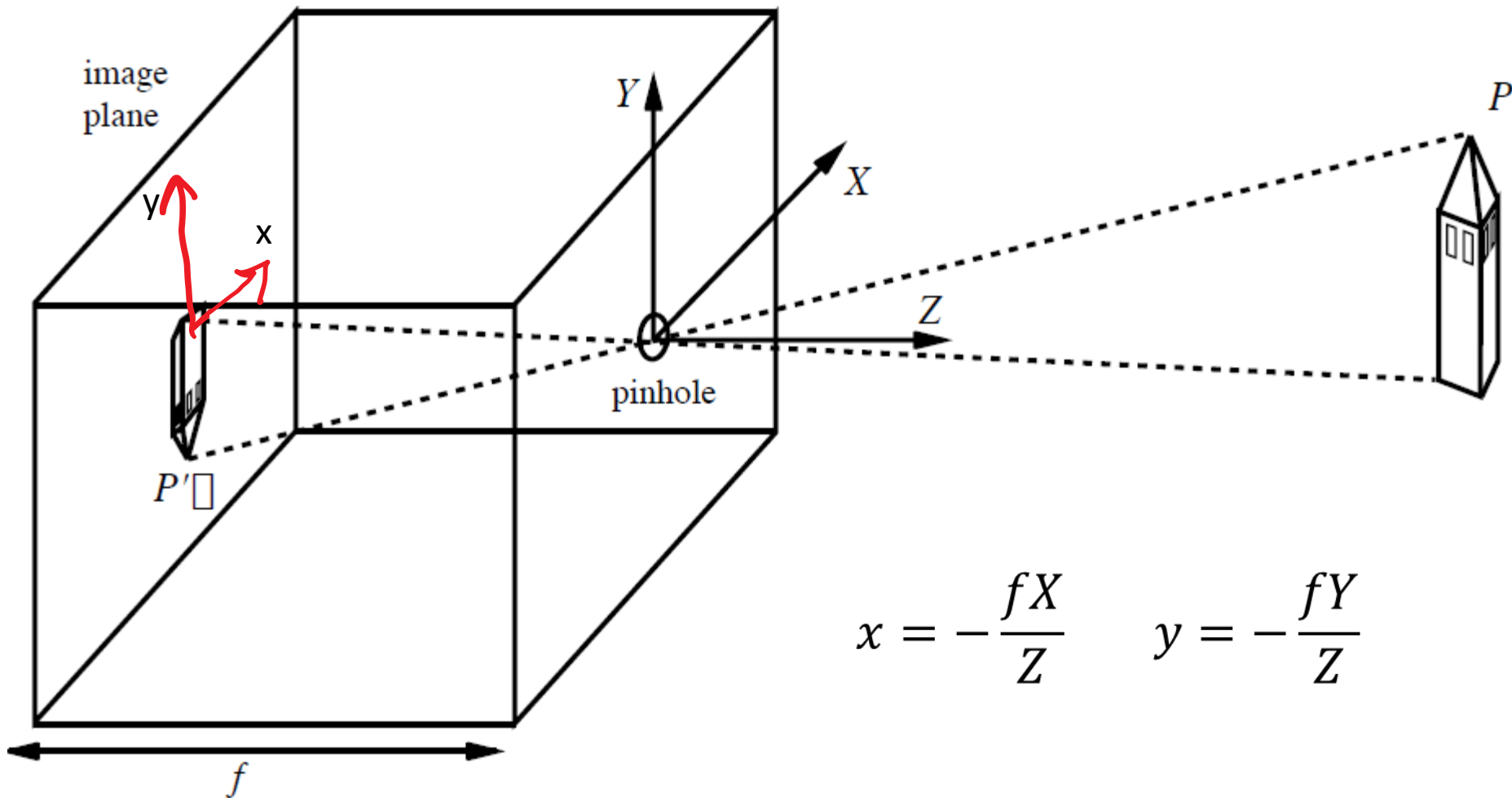


The image $I(x,y)$ measures how much light is captured at pixel (x,y)

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



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

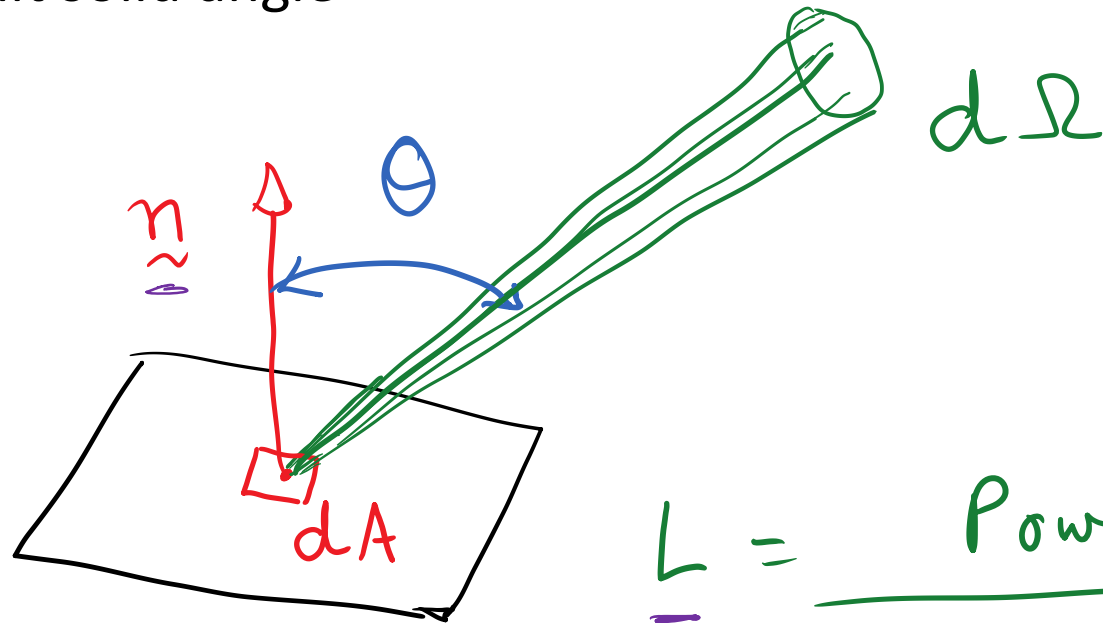


The image $I(x,y)$ measures how much light is captured at pixel (x,y) . Proportional to the number of photons captured at the sensor element (CCD/CMOS/Rod/cone/..) in a time interval.

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



$$\underline{L} = \frac{\text{Power}}{(dA \cos \theta)(d\Omega)}$$

units are $\text{W m}^{-2} \text{sr}^{-1}$

Read more
on Wikipedia

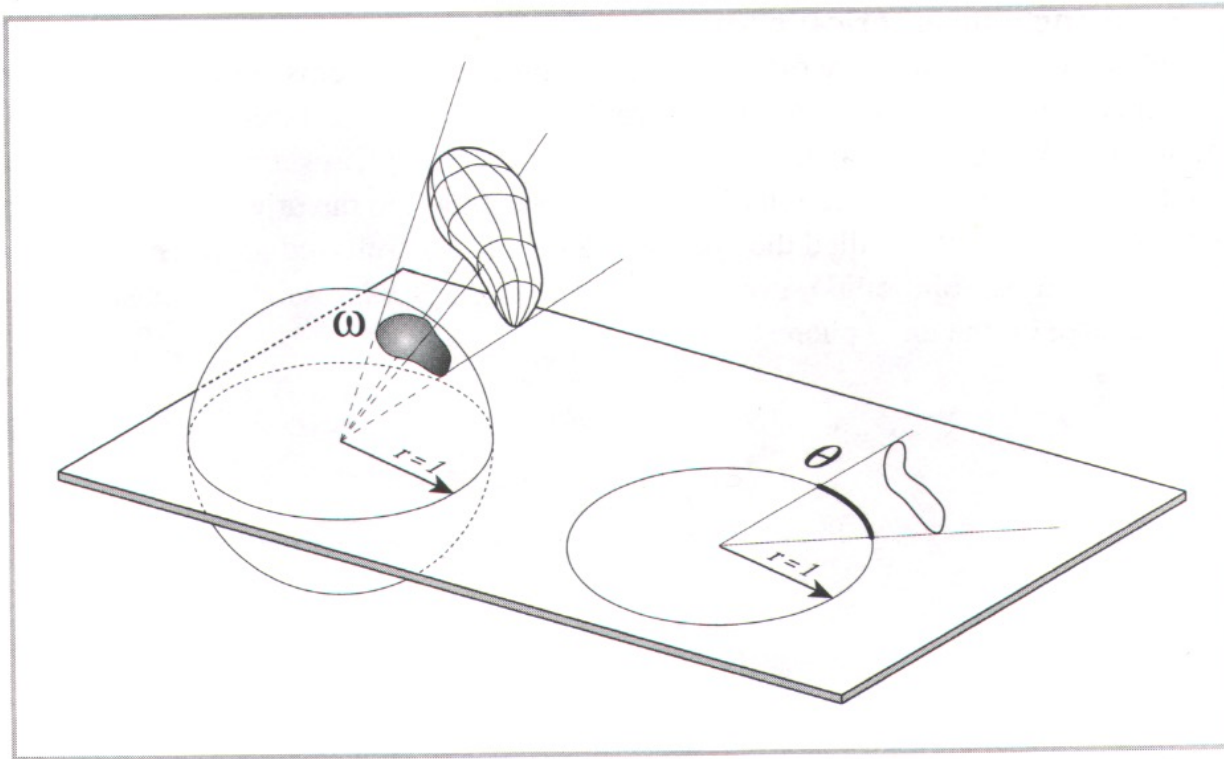
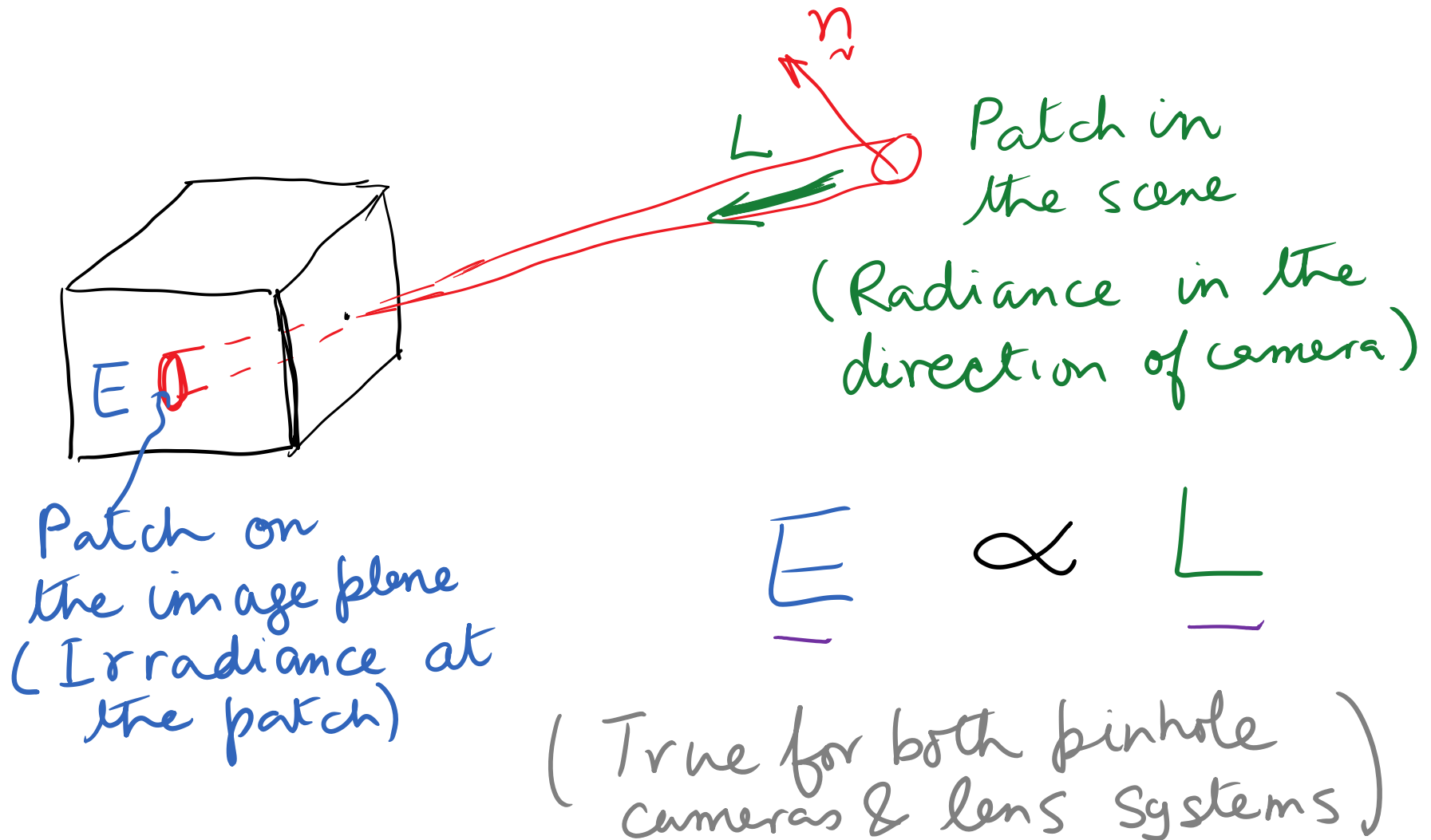


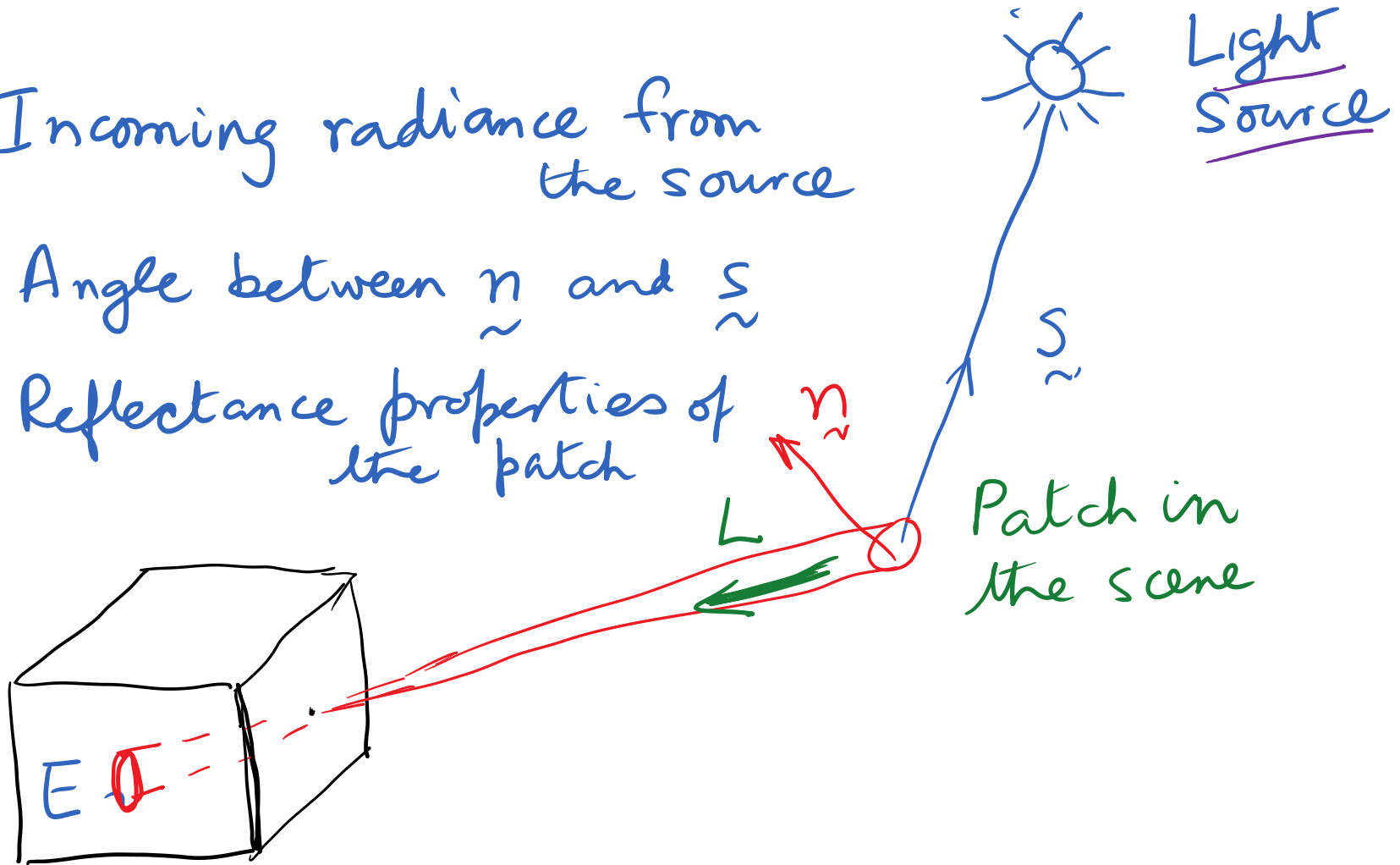
FIGURE 2.1 Definitions of angle and solid angle. θ , the angle subtended by a curve in the plane, is the length of the corresponding arc on the unit circle. ω , the solid angle subtended by an object, is the surface area of its projection onto the unit sphere.

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



What causes the outgoing radiance at a scene patch?

- Incoming radiance from the source
- Angle between \vec{n} and \vec{s}
- Reflectance properties of the patch

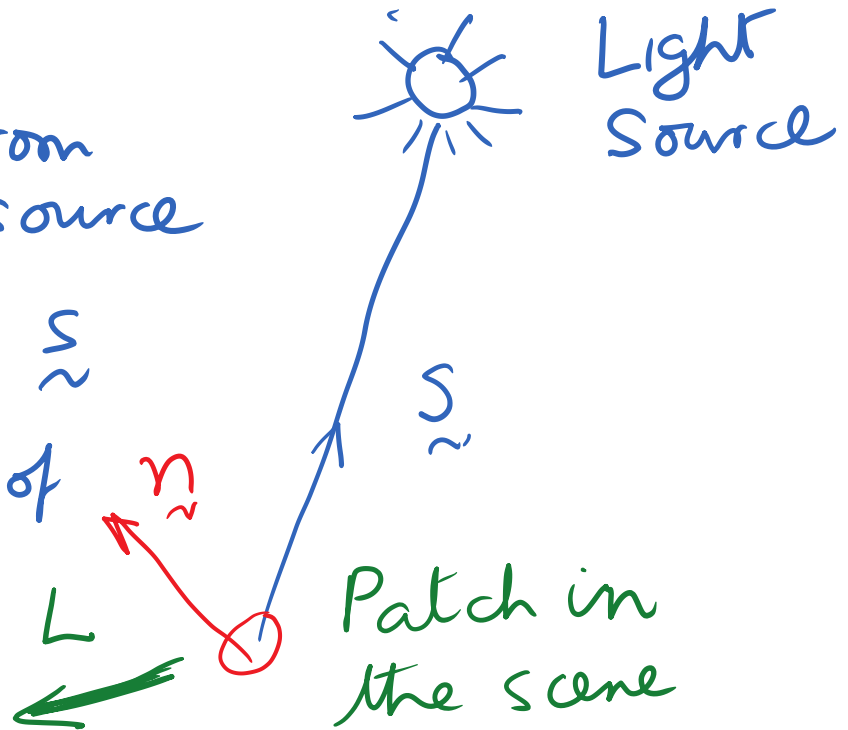


What causes the outgoing radiance at a scene patch?

- Incoming radiance from the source

- Angle between \vec{n} and \vec{s}

- Reflectance properties of the surface patch



Two special cases:

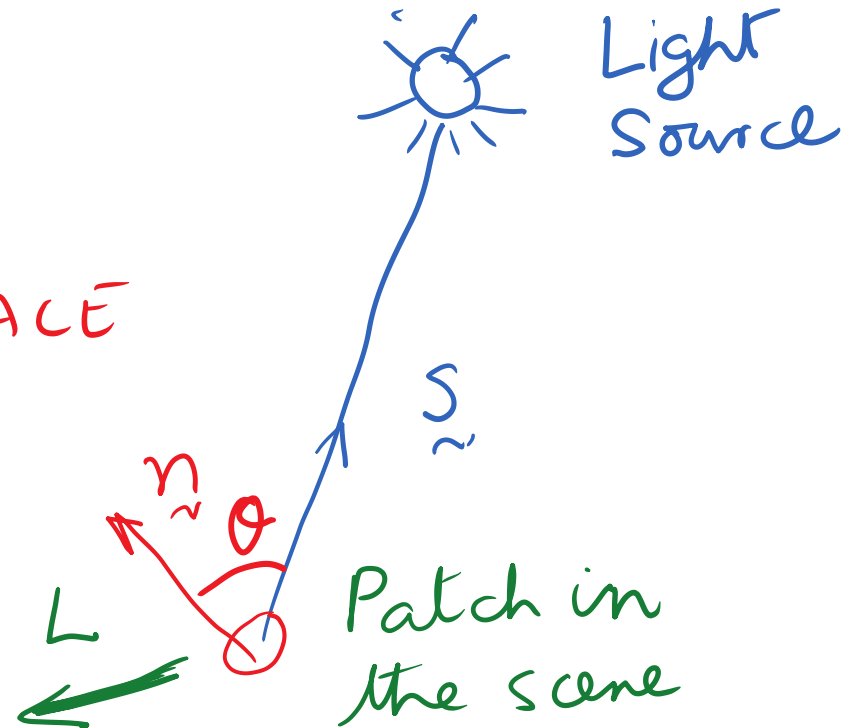
- **Specular surfaces** - Outgoing radiance direction obeys angle of incidence=angle of reflection, and co-planarity of incident & reflected rays & the surface normal.
- **Lambertian surfaces** - Outgoing radiance same in all directions

The Lambertian model

$$L = \rho \lambda \vec{n} \cdot \vec{s}$$

ρ = ALBEDO OF SURFACE
0 \leftrightarrow BLACK
1 \leftrightarrow WHITE

λ depends on
radiance of
light source

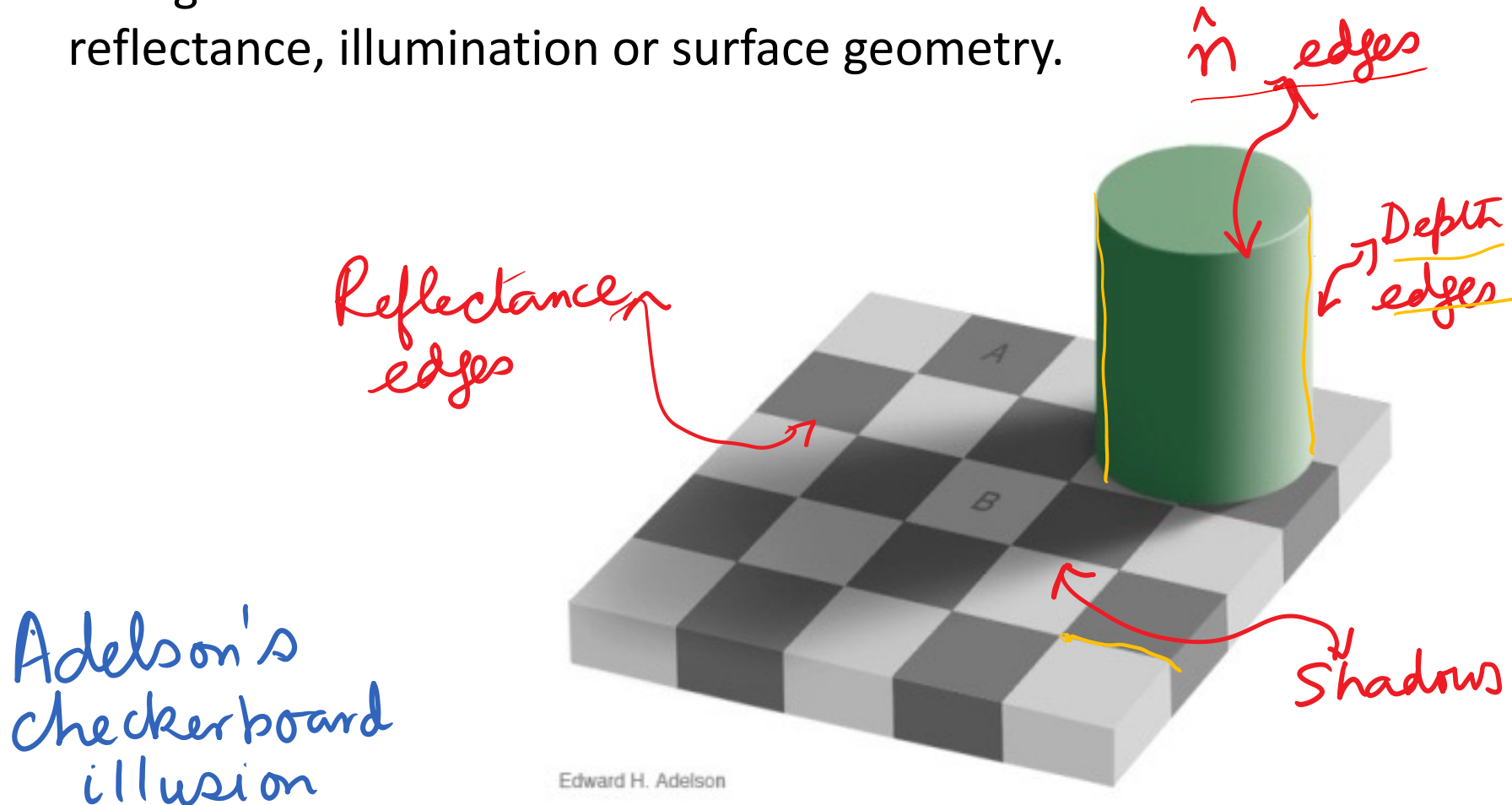


$\vec{n} \cdot \vec{s} = \cos \theta$ corresponds to foreshortening

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

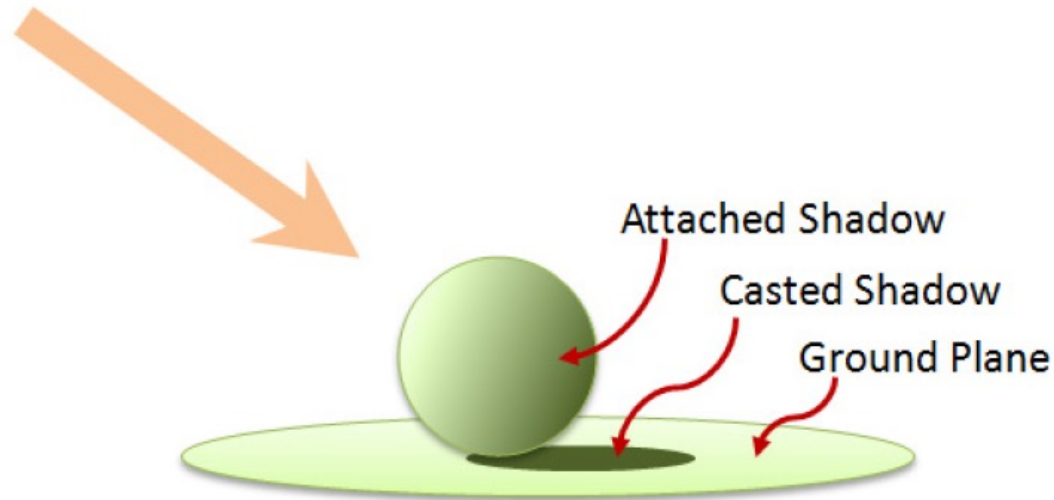
- Edges are curves in the image, across which the brightness changes “a lot”. These arise because of discontinuities in reflectance, illumination or surface geometry.



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



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 much 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.