Course Updates

- Tutorial this week
  - Ray Tracing and Assignment 3

- Assignment 3
  - **Programming** part is out
  - **Theory** out on Wednesday
  - **Due date:** November 23rd

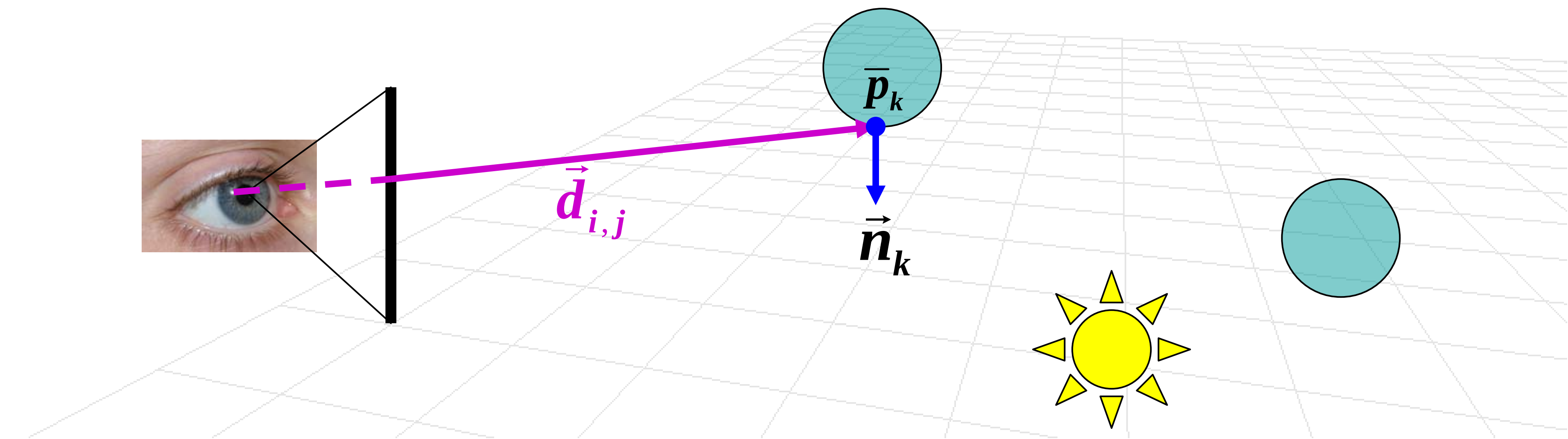
- Assignment 4 (**only programming,** can be done in groups of 2)
  - **Due date:** December 3rd
  - **Demo Day:** December 3rd

Short Ray Tracing Review (so far)

- Ray casting
  - Generate a ray through each pixel (*x*,*y*) in the image plane
- Ray-surface intersection
  - Triangles
  - Planar patches
  - Spheres
  - Conics (briefly)
  - Affinely deformed surfaces
- Computing normal at the "hit point"
  - Affinely deformed surfaces
- Lighting at the point
  - Whitted Model (Phong lighting + recursive global lighting term)
  - Textures

Conventional (Whitted) Ray Tracing

- Cast a ray and find
  - “hit point” and normal at the “hit point”



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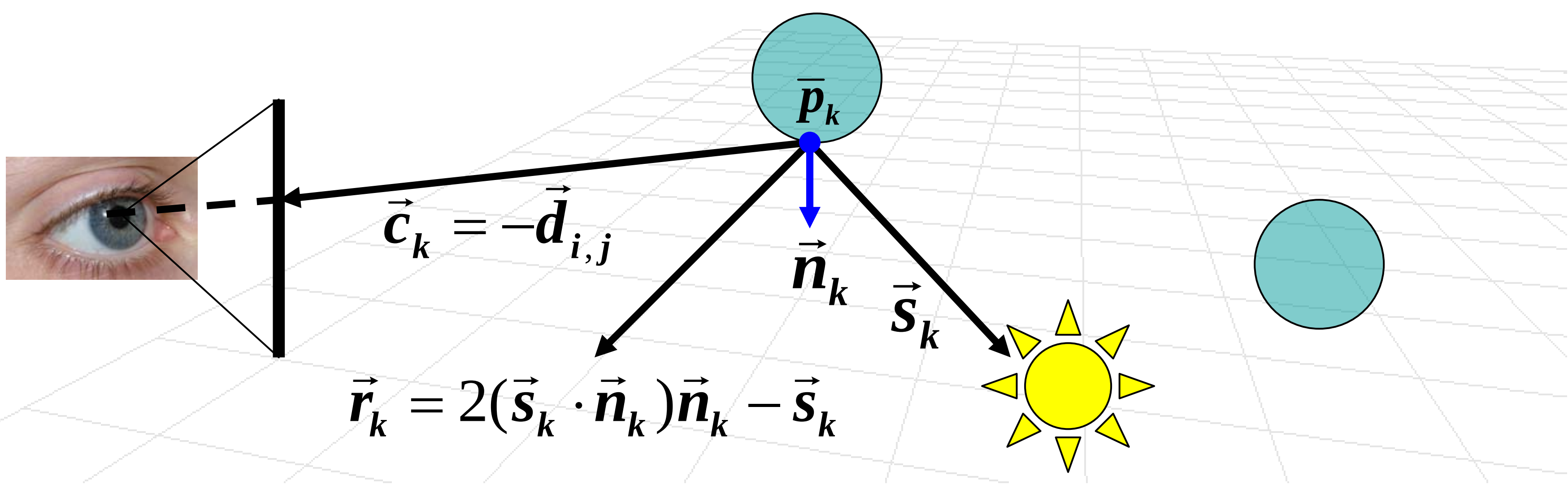

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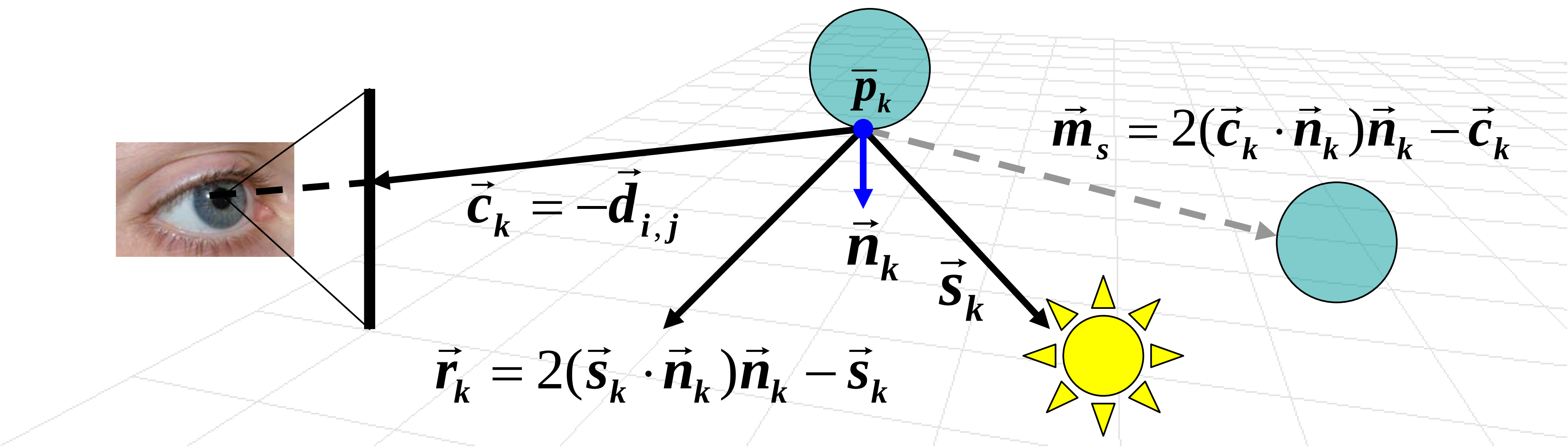

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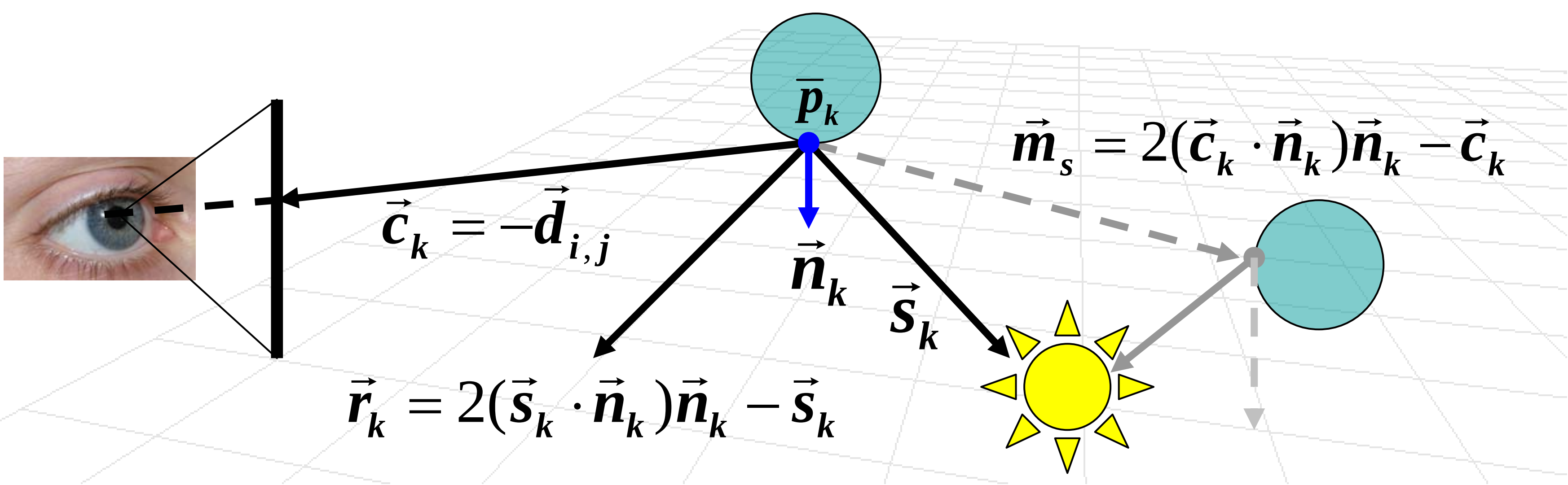

Texture

- Texture can be used to modulate diffuse and ambient reflection coefficients, as with Gouraud or Phong shading
- All we need, is a way of mapping a point on the surface (hit point) to a point in the texture space
  - e.g. given a hit point of parametric surface, we can convert the 3D point coordinates to surface parameters, and use them to get texture coordinates (as with standard texture mapping)
- Unlike with Gouraud or Phong shading models we don’t need to interpolate texture coordinates over polygons
- Anti-aliasing and super-sampling we will cover later (next week)

Ray Tracing
Part 3: Refraction and Shadows

Computer Graphics, CSCD18

Fall 2007

Instructor: Leonid Sigal

Transmission or Refraction

- **Physics:** light that penetrates a (partially or fully) transparent surface or material is refracted (bent) to account for change in the speed of light transmission in different media
- Snell's law governs refractions

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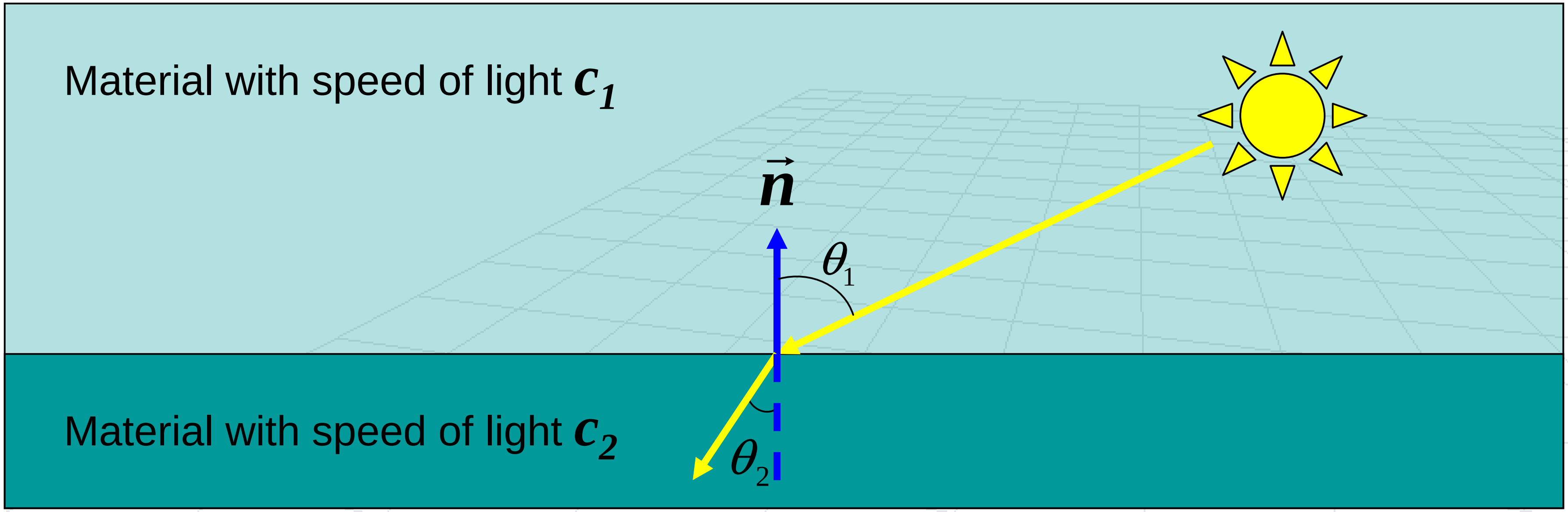

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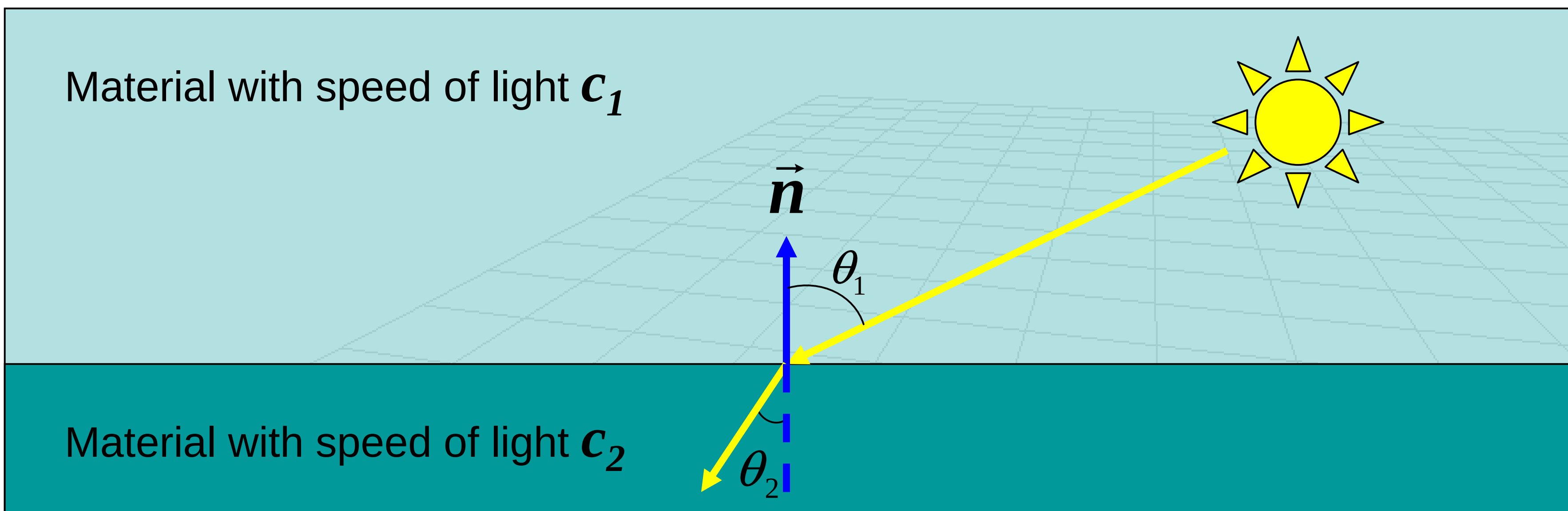
index of refraction

$$\frac{\sin\theta_1}{\sin\theta_2} = \boxed{\frac{c_1}{c_2}}$$

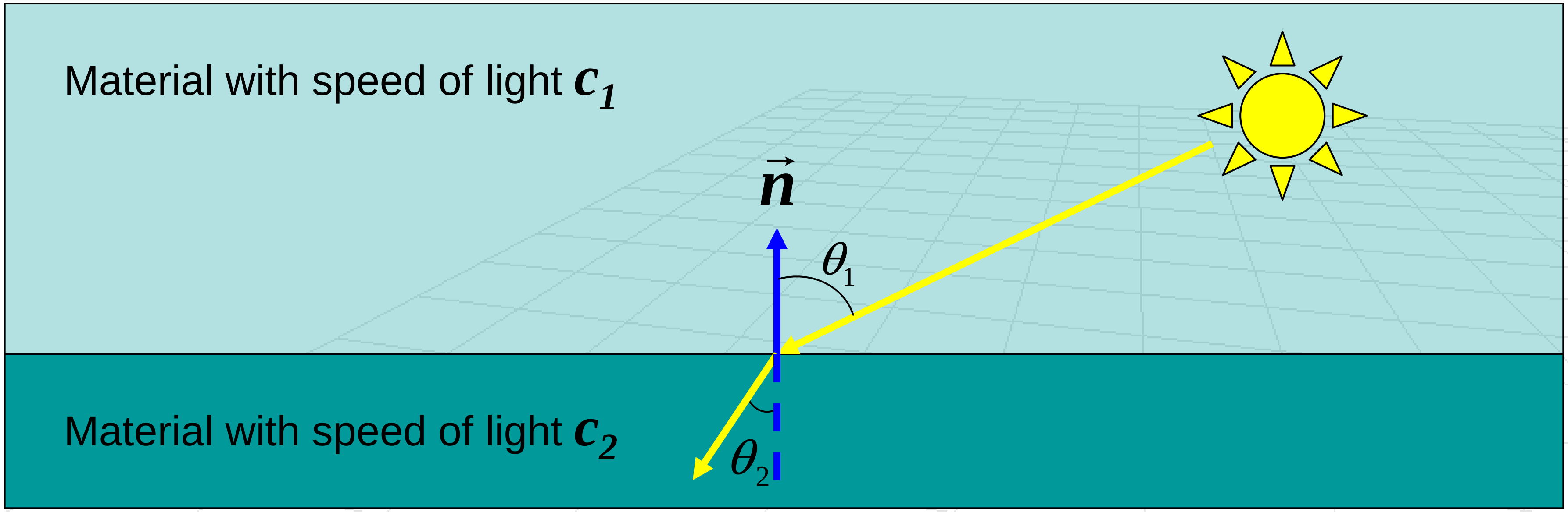


Transmission or Refraction

- For example, $\dfrac{c_{air}}{c_{water}} \approx 1.33$ $\dfrac{c_{air}}{c_{glass}} \approx 1.8$

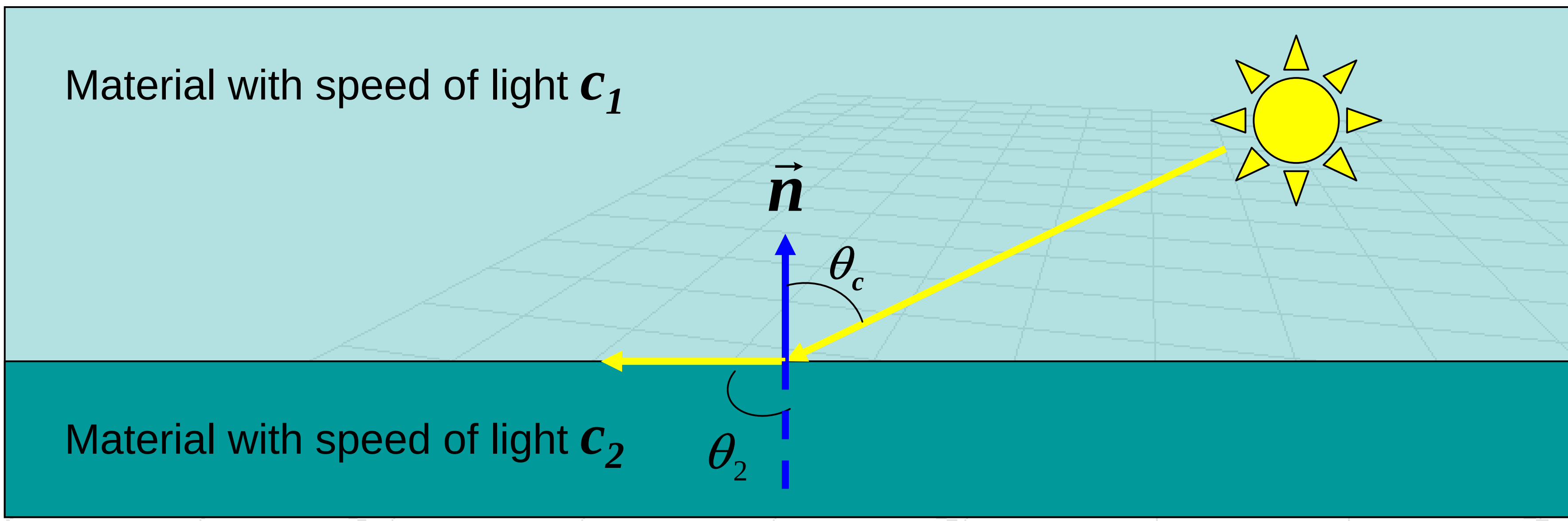
$c_2 < c_1$ light bends toward the normal (eg. air to water)

$c_2 > c_1$ light bends away from the normal (eg. water to air)



Transmission or Refraction

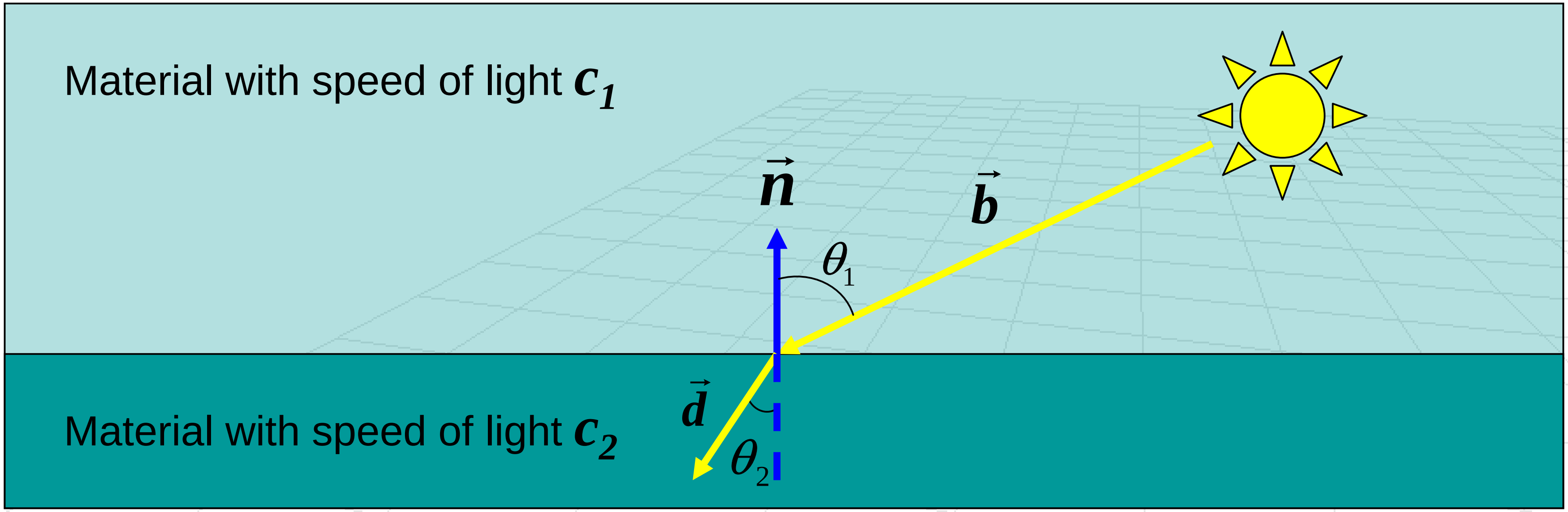
- Critical angle (for $c_2 > c_1$)
  - As incoming angle approaches critical angle, the outgoing angle approaches 90 degrees
  - No light enters the material



Refraction in Ray Tracing

- We can treat global refraction/transmission just like global specular reflection (i.e. cast one ray)
  - Need to keep track of the speed of light in the current medium
- Perfect refraction direction

$$\vec{d} = \frac{c_2}{c_1}\vec{b} + \left(\frac{c_2}{c_1}\left(\vec{n}\cdot\vec{b}\right) - \cos\theta_2 \right)\vec{n}$$



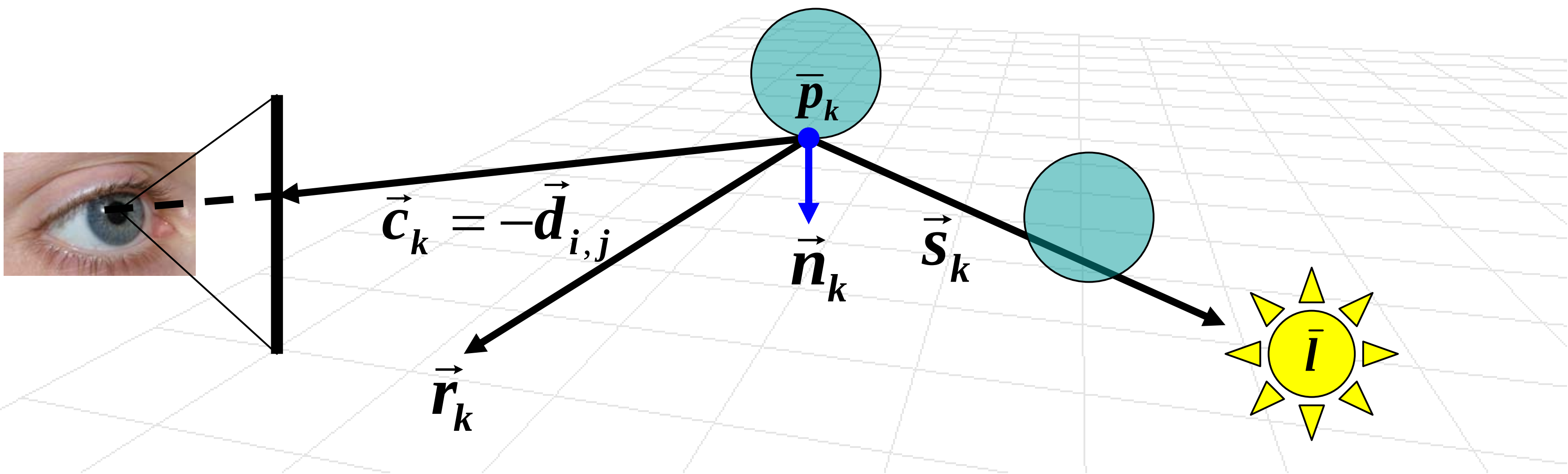
Shadows

- Easy to deal with in ray tracing
  - When point is in shadow, turn off local reflection
- To do so, cast a ray towards a light source

$$\bar{r}(\lambda) = \bar{p}_k + \lambda(\bar{l} - \bar{p}_k)$$

if there is a hit point $0 \le \lambda \le 1$, turn of local reflection (diffuse and specular components of Phong)

$$E_k = r_d I_d \max(0, \vec{s}_k \cdot \vec{n}_k) + r_a I_a + r_s I_s \max(0, \vec{r}_k \cdot \vec{c}_k)^\alpha + r_g I_{spec}$$



Radiometry
Part 1: Introduction

Computer Graphics, CSCD18

Fall 2007

Instructor: Leonid Sigal

Radiometry

- Previously we treated light and material reflectance heuristically
  - Not physically plausible (e.g. no accounting for conservation of energy)
- To move to more advanced rendering techniques, it is necessary to treat light and reflectance more rigorously
- This involves physics and some more advance geometry

Basic Assumptions and Setup

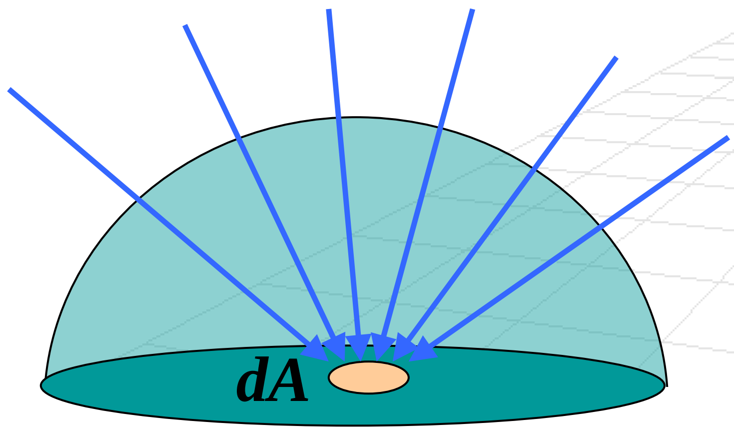
- Basic assumptions
  - Light travels along straight lines
  - There are no delays due to the light travel through space
  - Light is scattered not absorbed (i.e. is conserved)

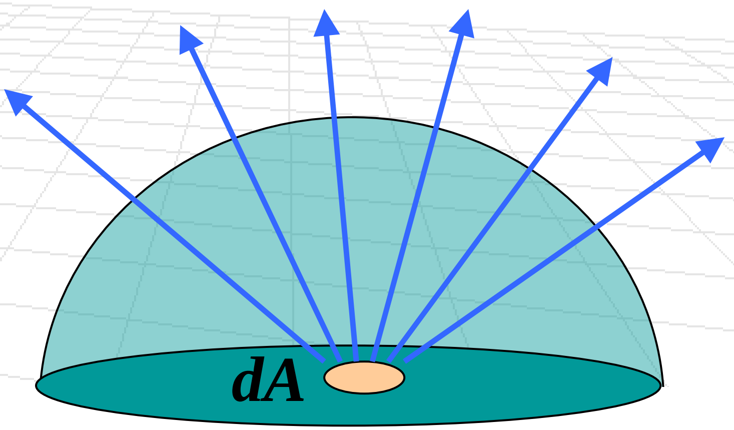
- With these assumptions we only need to concentrate on the geometry of lighting

- Basic light related quantities
  - Light energy is measured in Joules
  - Power (flux) is measured in Watts = Joules / seconds
    - Rate at which light energy is emitted (*eg.* 100 Watt bulb = 100 J/sec)
    - In general, power is a function of the wavelength, but we'll ignore that

Light

- Light is manifested as photons
  - Number of photons at a point is zero
  - Hence, we going to talk about flux density (*i.e.* number of photons per unit area)
- **Irradiance** – amount of the light falling on the surface patch (measured in Watts/meters^2)
- **Radiance** – amount of light leaving the point per area (measured in Watts/(sr * meters^2))



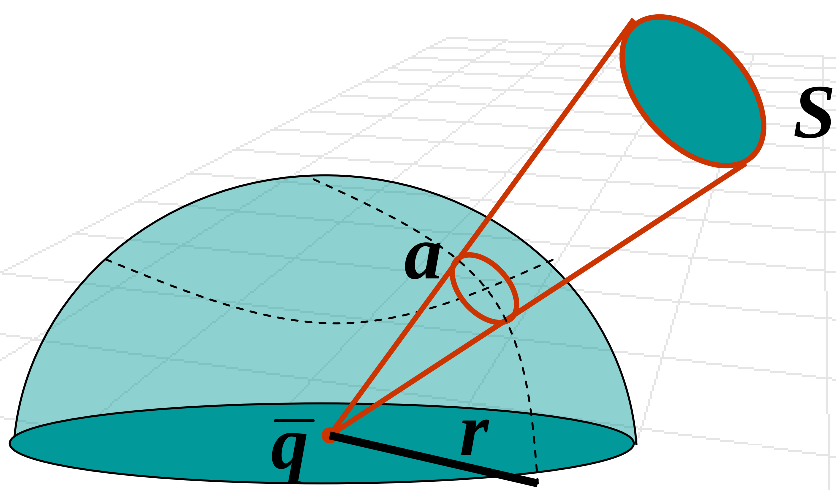


Solid Angle

- **Solid Angle** - measured as the area $\boldsymbol{a}$ of a patch of a sphere, divided by the squared radius $\boldsymbol{r}$ of the sphere

$$\omega = \frac{\boldsymbol{a}}{\boldsymbol{r}^2}$$

  - The unit measure for solid angle is the *steradian* (sr)
  - A solid angle of 2π corresponds to hemisphere of directions
  - A solid angle of 4π corresponds to full sphere of directions
- Solid angle of the surface $\boldsymbol{S}$ with respect to a point $\boldsymbol{q}$



Irradiance

- What is irradiance at surface patch $\boldsymbol{S}$ at point $\overline{\boldsymbol{p}}$ due to point light source at $\overline{\boldsymbol{e}}$ in direction $\vec{\boldsymbol{d}}$, with radiance $\boldsymbol{I}$?
- First compute the solid angle of $\boldsymbol{S}$ with respect to $\boldsymbol{e}$

$$d\omega = \frac{dA_s}{\left\|\overline{p}-\overline{e}\right\|^2}\boxed{(\vec{n}\cdot\vec{d})}$$

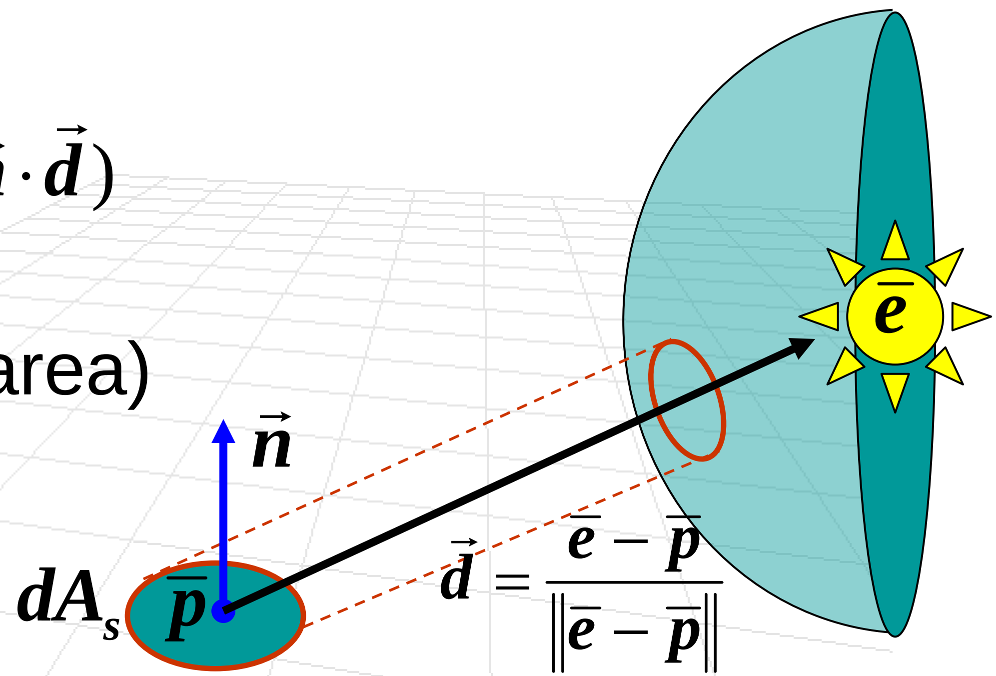
foreshortening

- Light reaching $\boldsymbol{S}$

$$S = I\,d\omega = I\,\frac{dA_s}{\left\|\overline{p}-\overline{e}\right\|^2}(\vec{n}\cdot\vec{d})$$

- Irradiance (divide by area)

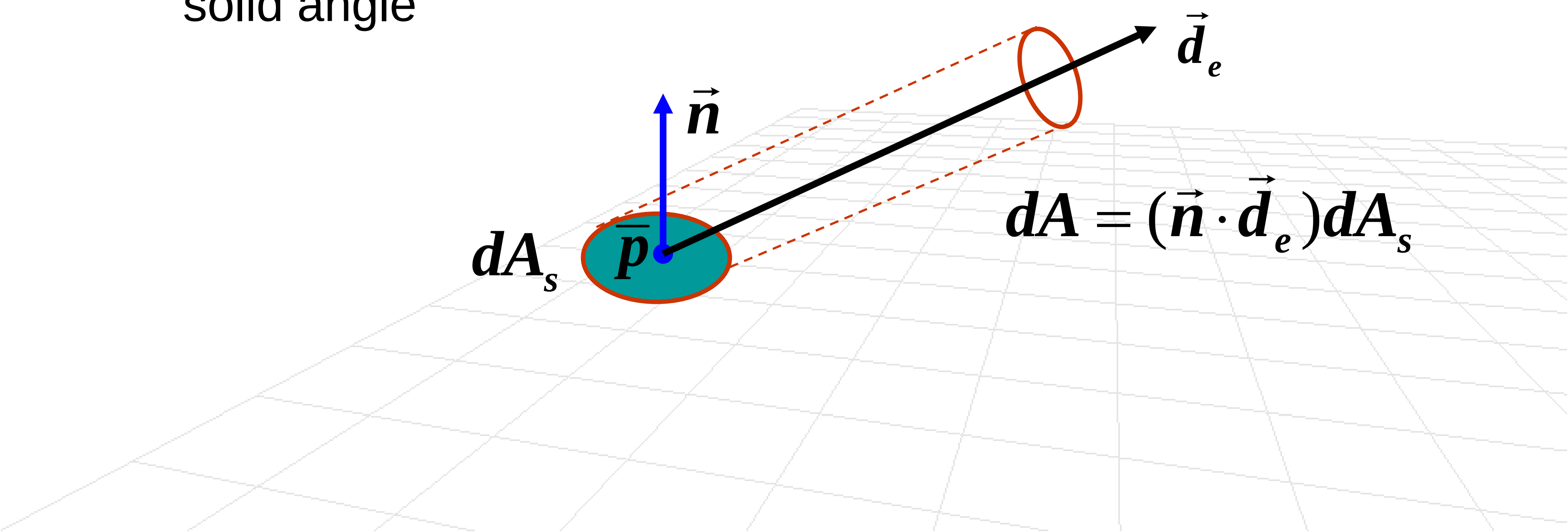
$$H(\overline{p}) = \frac{I\,d\omega}{dA_s} = \frac{I(\vec{n}\cdot\vec{d})}{\left\|\overline{p}-\overline{e}\right\|^2}$$



Radiance

- Light emitted in direction d_e through small surface patch S at point $\bar{p}$, is called radiance $L(\bar{p},\vec{d})$

- We need to integrate this quantity over all possible directions to obtain the radiosity (or radiant exitance)
  - But we need to account for foreshortened surface are per solid angle



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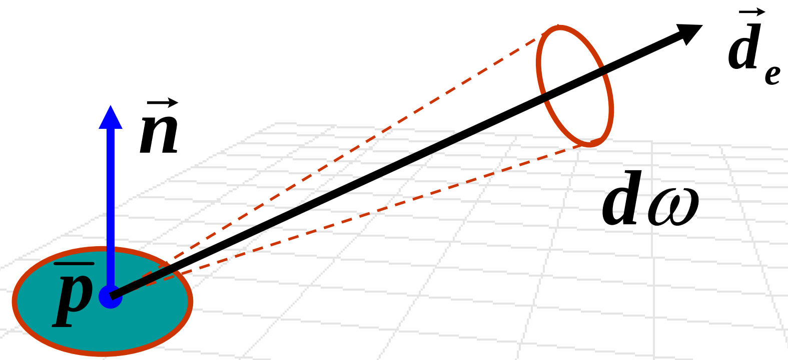

- Taking this into account we get

$$\boldsymbol{E(\bar{p}) = \int\int_{\vec{d}_e \in \Omega_e} L(\bar{p},\vec{d}_e)(\vec{n}\cdot\vec{d}_e)\,d\omega}$$