Computer Vision

Image formation

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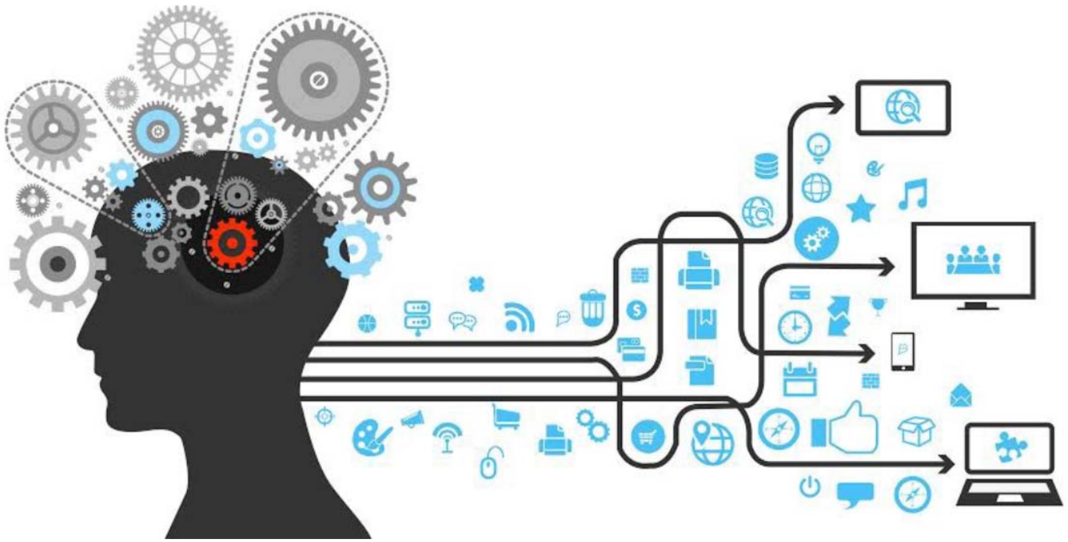
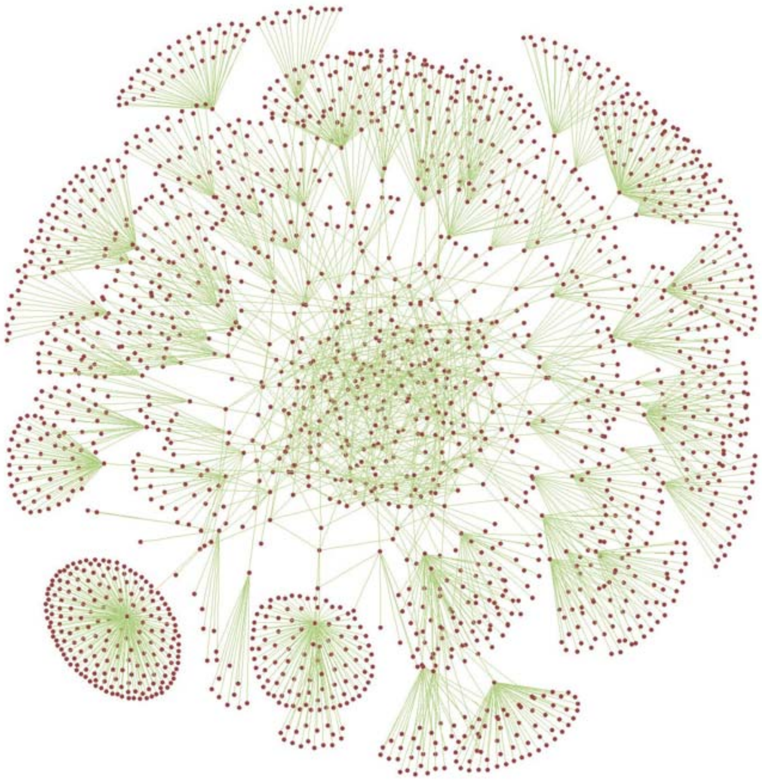
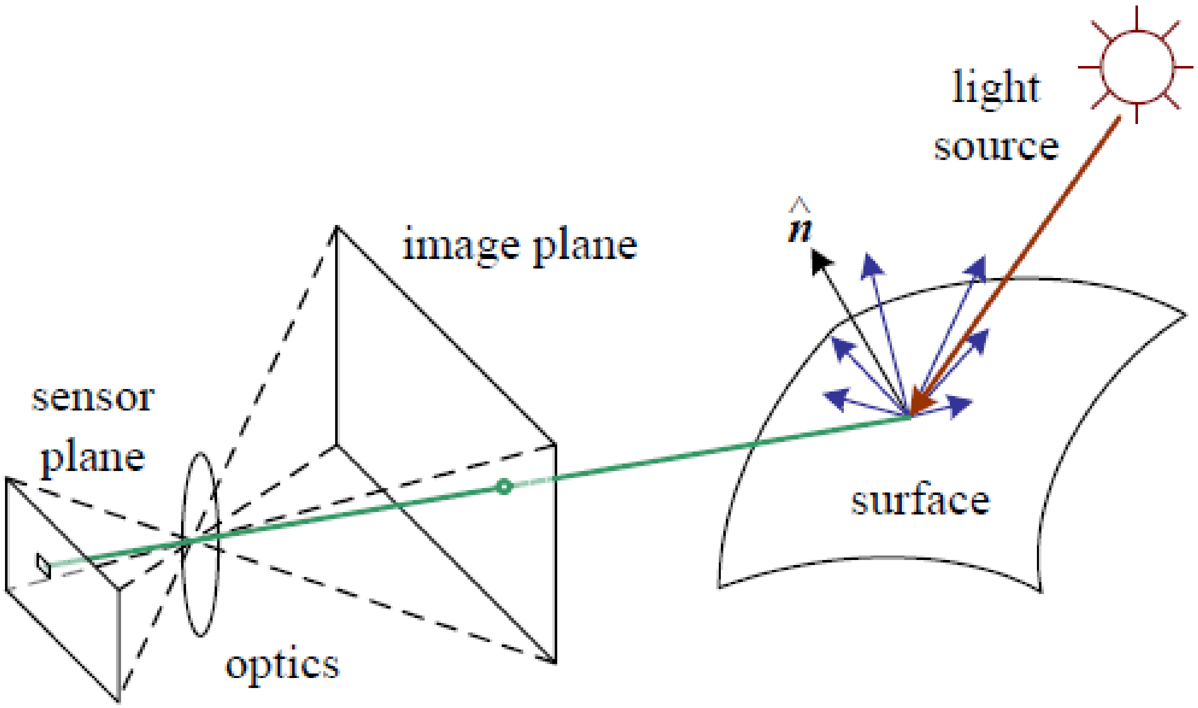




Light and Shading

Lighting

- Light
  - Emitted by light sources and then reflected from an object's surface
  - A portion of this light is directed towards the camera

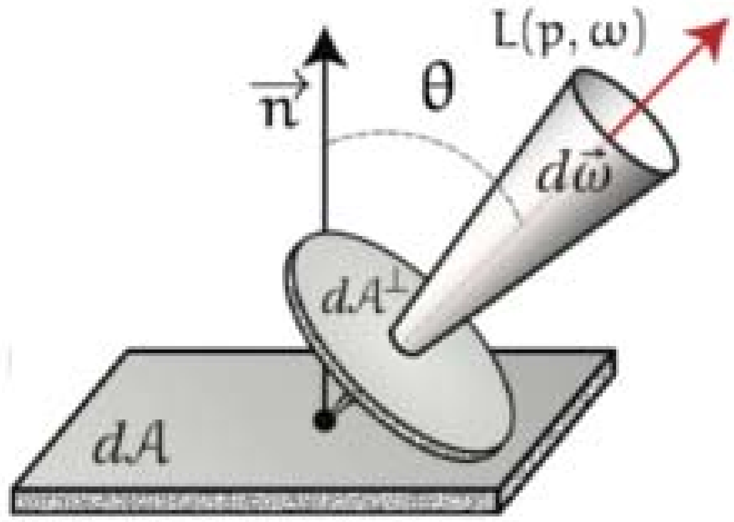


Lighting

- Light distribution: $L(\hat{\boldsymbol{v}}; \lambda)$
  - $\hat{\boldsymbol{v}}$: Light directions
  - λ: Color values (or wavelengths)

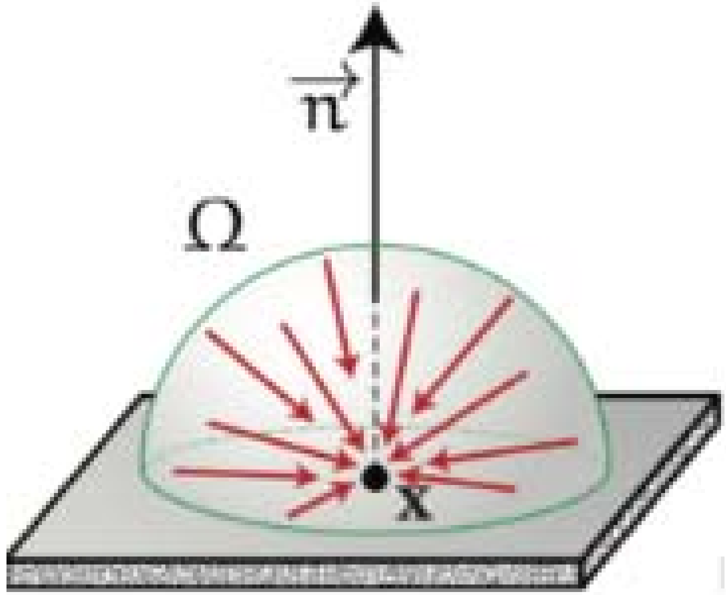
Radiance

- $L(P, \theta, \varphi)$
- Power ***emitted from a surface*** patch
- Function of position and direction



Irradiance

- $L(x, \theta, \varphi)$
- Power ***falling on a surface*** patch
- Function of incoming angle



Lighting

- Many effects when light strikes a surface
  - Absorbed
  - Transmitted
  - Reflected
  - Scattered
  - Travel along the surface and leave at some other point

- Assume that
  - surfaces do not generate light internally
  - all the light leaving a point is due to that arriving at that point

BRDF

- Bidirectional Reflectance Distribution Function (BRDF)
  - ***Ratio*** of the radiance in the ***outgoing*** direction to the ***incident*** irradiance

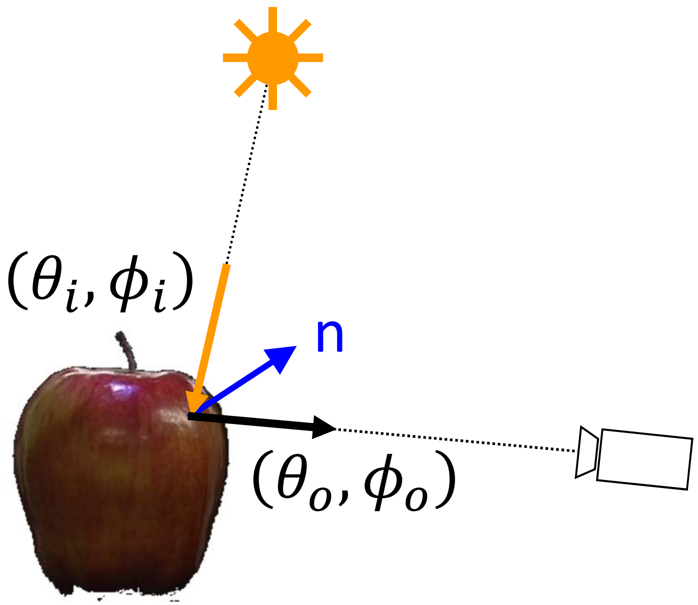
$$\rho_{bd}(P,\theta_o,\phi_o,\theta_i,\phi_i) = \frac{L_o(P,\theta_o,\phi_o)}{L_i(P,\theta_i,\phi_i)\cos\theta_i\,dw}$$

  - Function of incoming (θ_i,ϕ_i) and outgoing light direction (θ_o,ϕ_o)
  - Tells ***how bright a surface*** appears when viewed from one direction while light falls on it from another

BRDF

- Symmetric in incoming and outgoing directions

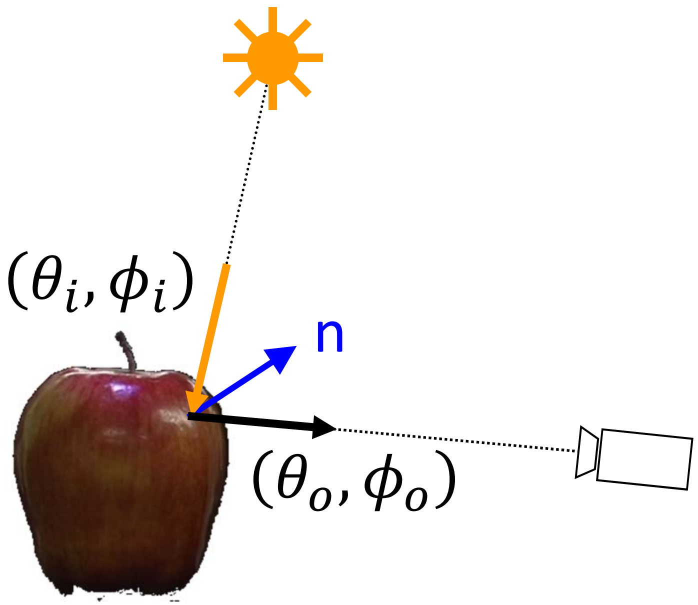
$$\rho_{bd}(P, \theta_o, \phi_o, \theta_i, \phi_i) = \rho_{bd}(P, \theta_i, \phi_i, \theta_o, \phi_o)$$



BRDF

- Radiance leaving a surface in a particular direction
  - Add contributions from every incoming direction

$$L_o(P,\theta_o,\phi_o) = \int \rho_{bd}(P,\theta_o,\phi_o,\theta_i,\phi_i) L_i(P,\theta_i,\phi_i) \cos\theta_i \, dw$$



Radiosity

- In many situations, we do not need angle coordinates
  - E.g.) Cotton cloth: The reflected light is not dependent on angle

- Radiosity: Suppress angles
  - Appropriate radiometric unit
  - ***Total power*** leaving a point on the surface, per unit area on the surface
  - Independent to the direction

- Radiosity from radiance
  - Sum radiance leaving surface over all exit directions,
    multiplying by a cosine as this is per unit area, not per unit foreshortened area

$$B(P) = \int L_o(P, \theta, \phi) \cos\theta \, dw$$

Surface reflectance

- ***Diffuse*** reflection (scattering)
  - Re-emit uniformly in all directions
  - Color strongly depends on the nature of a surface

- ***Specular*** reflection
  - Mirror-like → Produce highlights
  - Highly directional
  - Same color as incident light (assume independent to material)

- Reflection coefficient (***albedo***)
  - The ratio of the total reflected power to the total incident power

Lambertian surfaces

- Lambertian surfaces
  - Ideal diffuse surfaces
  - Light uniformly in all directions
  - It appears to have the same brightness from all viewpoints
    - E.g.) cotton cloth, carpets, etc.
  - For such surfaces, radiance leaving the surface is independent of angle

Lambertian surfaces

- Lambert's law
  - The intensity of reflected light energy (I_d)
    is proportional to the cosine of the angle θ
    between the surface normal (N) and the illumination direction (S)

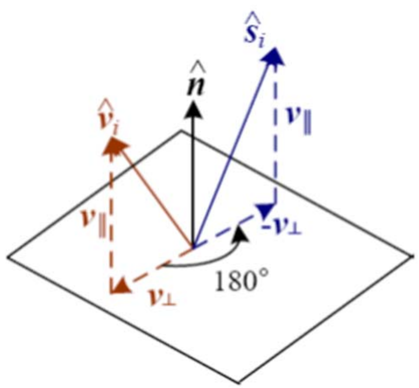
$$I_d = \rho_d L_i \cos\theta = \rho_d L_i (N \cdot S)$$

, where ρ_d: diffuse albedo

Specular surfaces

- Specular surfaces
  - Mirror-like surfaces
  - Radiation arriving along a direction leaves along the specular direction
  - Reflect about normal
  - Some fraction is absorbed, some reflected
  - A highlight on an object is a bright spot caused by the specular reflection
  - Highlights indicate that the object is waxy, metallic, or glassy, etc.

Specular reflectance

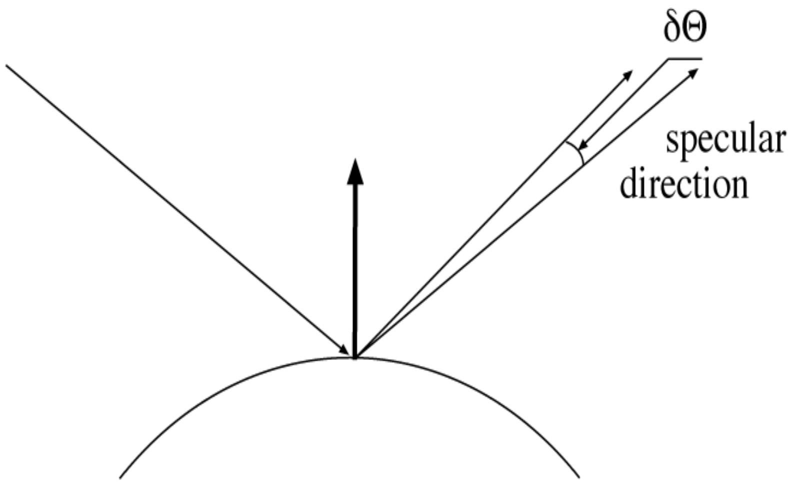


Phong's model

- The intensity of reflected light energy falls off with $\cos^n(\delta\theta)$

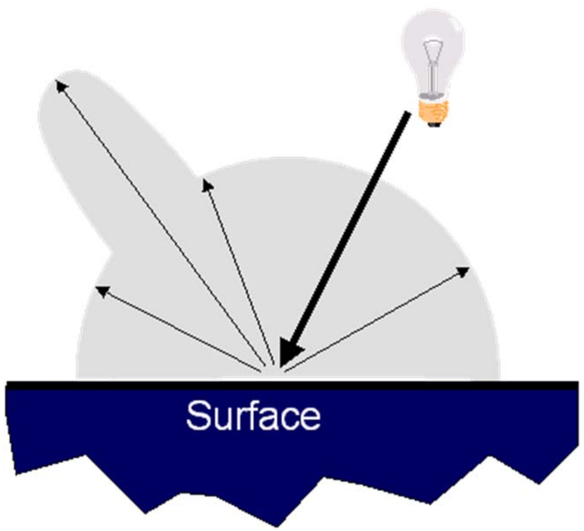
$$I_s = \rho_s L_s \cos^{\mathrm{n}}(\delta\theta)$$

, where ρ_s: specular albedo



Lambertian + specular surfaces

- All surfaces are Lambertian + Specular component
- Advantage
  - Easy to manipulate
  - Very often quite close true
- Disadvantage
  - Very little advantage in modeling behavior of light at a surface in more detail

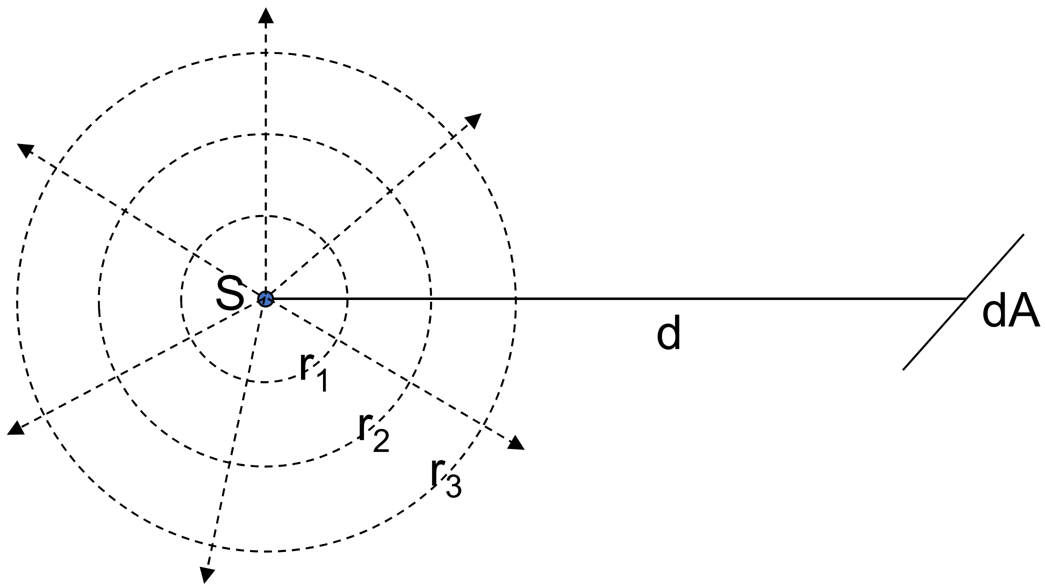


Sources

- Source
  - How bright are objects?
  - The internally generated power radiated per unit area on the radiating surface
  - A source can have both
    - Radiosity (∵ it reflects)
    - Exitance (∵ it emits)
  - Light sources to be considered
    - Point light source
    - Ambient light source

Sources

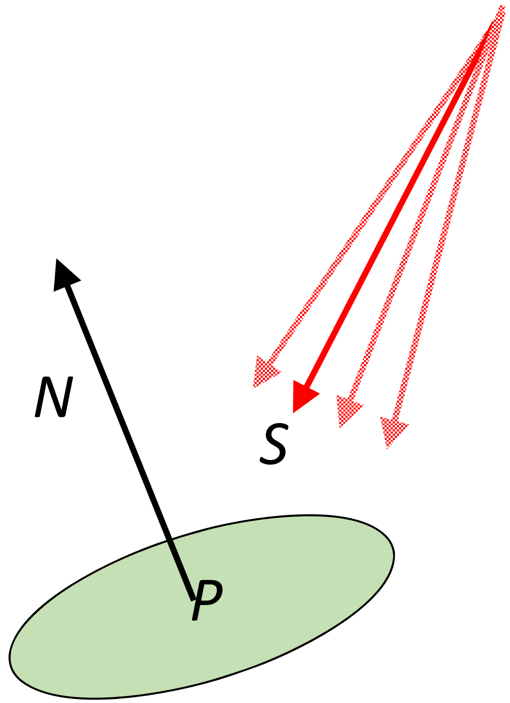
- Darkening with distance
  - The intensity of light received by any object surface decreases with the square of its distance from the source



A nearby point source

$$\rho_d(P)\left(\frac{N(P)\cdot S(P)}{r(P)^2}\right)$$

- N: Surface normal
- ρ_d: Diffuse albedo
- S: Source vector

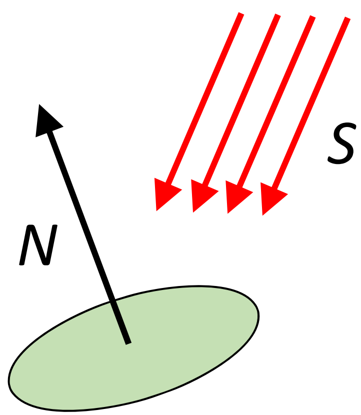


A distant point source

- Issue: Nearby point source gets bigger if one gets closer

- A distant point source
  - Assume that all points in the model are close to each other with respect to the distance to the source
  - Then, the source vector S and distance does not vary much
  - Roll the constants together

$$\rho_d(P)(N(P) \cdot S)$$



Shading

- Local shading model
  - Surface has radiosity due only to sources visible at each point
  - Advantages
    - Easy to manipulate
    - Supports simple theories how shape information is extracted from shading

- Global shading model
  - Surface radiosity is due to radiance reflected from other surfaces as well as from sources
  - Advantage
    - Usually very accurate
  - Disadvantage
    - Extremely difficult to infer anything from shading values

Phong shading model

- Popular shading model used in computer graphics
- It accounts for
  - Ambient light
  - Diffuse reflection
  - Specular reflection
  - Darkening with distance

reflection ray

ambient reflectivity

intensity of light source m

viewing direction

$$I_\lambda(x,y) = I_{a\lambda}\rho_{a\lambda} + \sum_{m=1}^{s}\left(\frac{1}{cd_m^2} I_{m\lambda}[\rho_{d\lambda}(N\cdot S) + \rho_{s\lambda}(R_m\cdot V)^n]\right)$$

specular reflectivity

ambient illumination

distance from the surface

diffuse reflectivity