FPT Education
FPT UNIVERSITY

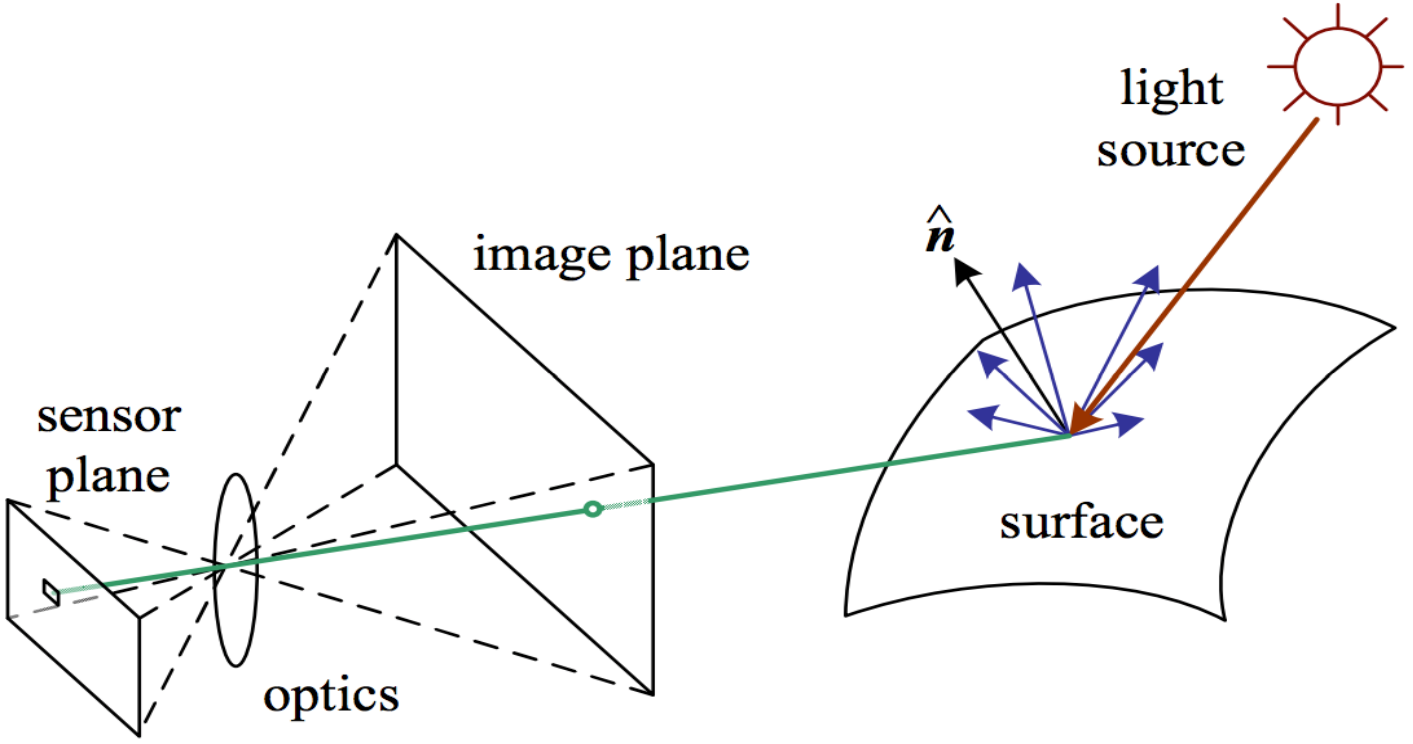
Photometric image formation

Objectives

- Effect of illumination and light source
- Reflectance and shading problems
- Optics: pinhole model

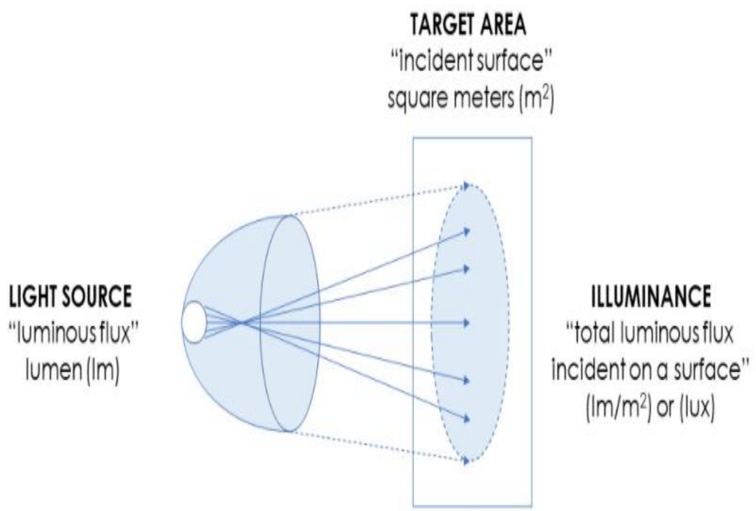
Photometric image formation

- Photometry is the science of the measurement of light, in terms of its perceived brightness to the human eye.



Illumination

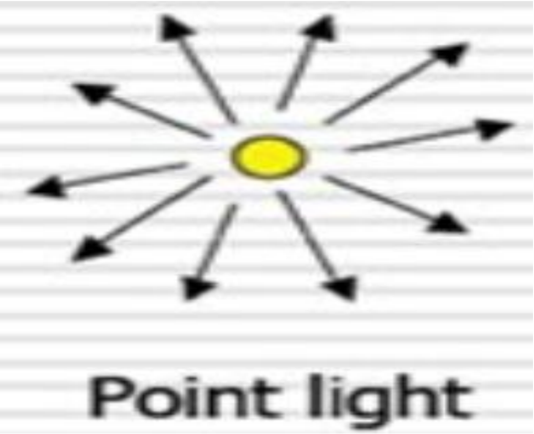
- Source of illumination--> any device serving as a source of visible electromagnetic radiation
- Light source, light -->any device serving as a source of illumination
- An “illimination model” describes inputs, assumption, and outputs used to calculate illumination(color/

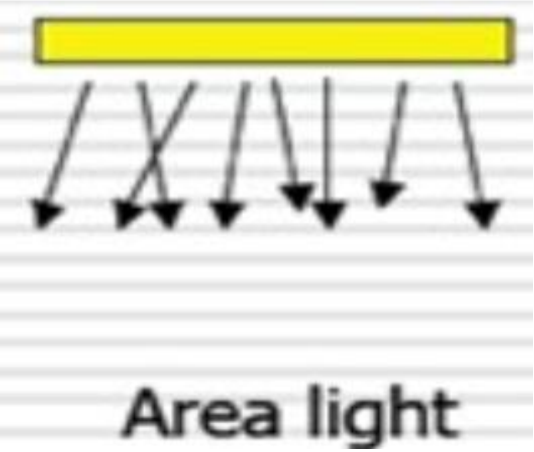


Lighting condition	Foot-candles	Lux
Full daylight	1,000 [3]	10,000
Overcast day	100	1,000
Very dark day	10	100
Twilight	1	10
Deep twilight	0.1	1
Full moon	0.01	0.1
Quarter moon	0.001	0.01
Starlight	0.0001	0.001

Light sources

- Point light sources
  - Position P(x,y,z)
  - Intensity (r,g,b)
  - Color spectrum- distribution over wavel





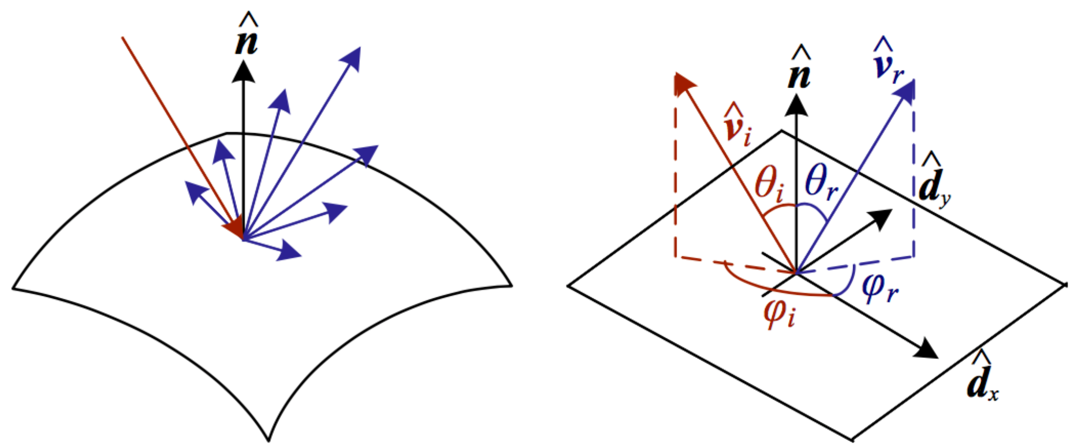
- Area light source
  - such as a fluorescent ceiling light fixtur can be modeled as a finite rectangul light equally in all directions

Reflectance and shading

- When light hits an object's surface, it is scattered and reflected.
- The bidirectional reflectance distribution function (BRDF) describes the proportion of light coming from each incident direction that is redirected to each reflected direction, as a function of wavelength.
- The BRDF is reciprc… and reflected directic…

$$f(\theta_i, \emptyset_i, \theta_r, \emptyset_r; \lambda)$$

θ_i = elevation of incident light
$\emptyset_i$ = azimuth of incident light
θ_r = elevation of reflected light
$\emptyset_r$ = azimuth of reflected light
λ = wavelength



The BRDF

- For isotropic surfaces:

$$f_r(\theta_i, \theta_r, |\phi_r - \phi_i|; \lambda) \text{ or } f_r(\hat{\boldsymbol{v}}_i, \hat{\boldsymbol{v}}_r, \hat{\boldsymbol{n}}; \lambda)$$

- To calculate the amount of light exiting a surface point p in a direction $\hat{\boldsymbol{v}}_r$
- We integrate the product of the incoming light $L_i(\hat{\boldsymbol{v}}_i; \lambda)$ with the BRDF
- Takir … cos+ θi, we o

$$L_r(\hat{v}_r; \lambda) = \int L_i(\hat{v}_i; \lambda) f_r(\hat{v}_i, \hat{v}_r, \hat{n}; \lambda) \cos^+ \theta_i \, d\hat{v}_i,$$

where Foreshortening effect due to surface orientation

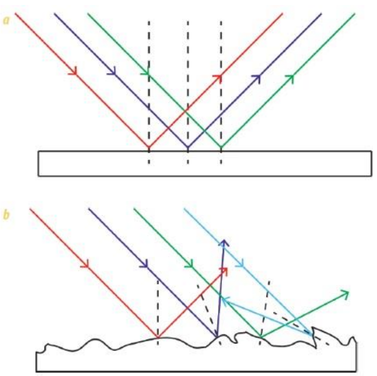
$$\cos^+ \theta_i = \max(0, \cos \theta_i).$$

Diffuse(Lambertian, Matte) reflection

- The diffuse component of the BRDF scatters light uniformly, giving rise to Lamberitan shading.
- Light is scattered uniformly in all directions

$$f_d(\hat{\boldsymbol{v}}_i, \hat{\boldsymbol{v}}_r, \hat{\boldsymbol{n}}; \lambda) = f_d(\lambda)$$

- The amount of light depends on the angle between the incident light direction and the surface normal.
- Lambert's cosine law :



$$L_d(\hat{\boldsymbol{v}}_r; \lambda) = \sum_i L_i(\lambda) f_d(\lambda) \cos^+ \theta_i = \sum_i L_i(\lambda) f_d(\lambda) [\hat{\boldsymbol{v}}_i \cdot \hat{\boldsymbol{n}}]^+$$

where $[\hat{\boldsymbol{v}}_i \cdot \hat{\boldsymbol{n}}]^+ = \max(0, \hat{\boldsymbol{v}}_i \cdot \hat{\boldsymbol{n}})$

Specular reflection

- Specularity depends strongly on the direction of the outgoing light.
- Mirror-like reflection: incoming light is reflected off the surface in a single direction (which is the rotation of 180 degrees around the surface normal)
  - Specular reflection direction $\hat{s}_i$

$$\hat{\boldsymbol{s}}_i = \boldsymbol{v}_{\parallel} - \boldsymbol{v}_{\perp} = (2\hat{\boldsymbol{n}}\hat{\boldsymbol{n}}^T - \boldsymbol{I})\boldsymbol{v}_i$$

The amount of light reflected in a given direction $\hat{v}_r$ thus depends on the angle $\theta_s = \cos^{-1}(\hat{v}_r \,.\, \hat{s}_i)$ between the view direction $\hat{v}_r$ and the specular direction $\hat{s}_i$, Phong model:

$$f_s(\theta_s; \lambda) = k_s(\lambda) \cos^{k_e} \theta_s$$

Colour

Colour

Phong Shading

- The full Phong model combines diffuse and specular components contributed by the main illuminant with an ambient term that attempts to account for all other light incidents upon the surface from other parts of the scene (sky, walls, etc.).

Ambient light

$$L_r(\hat{\boldsymbol{v}}_r;\lambda) = k_a(\lambda)L_a(\lambda) +$$

$$k_d(\lambda)\sum_i L_i(\lambda)[\hat{\boldsymbol{v}}_i \cdot \hat{\boldsymbol{n}}]^+ +$$

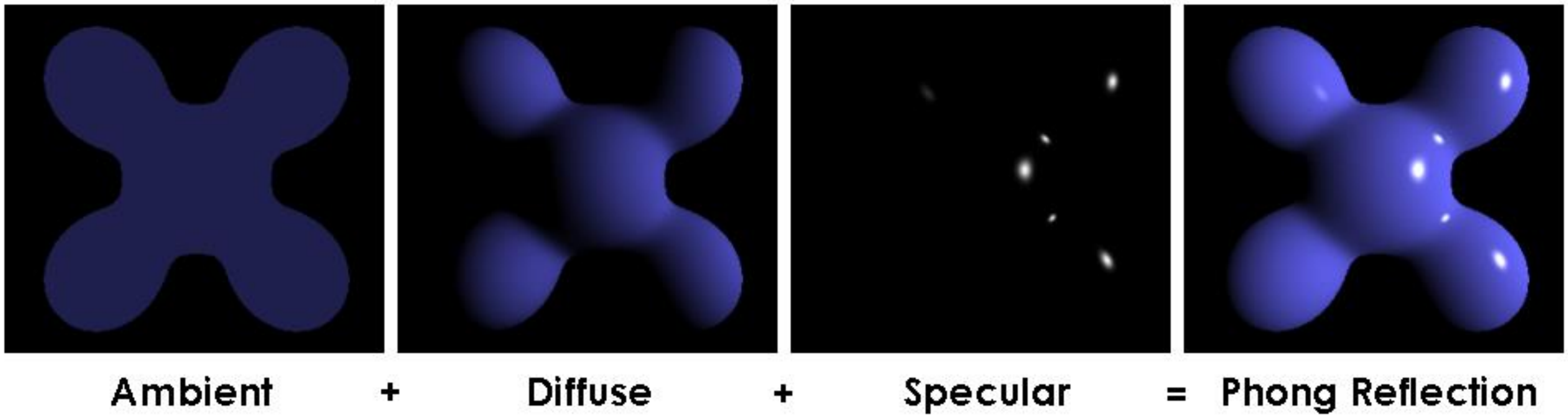
Diffuse Reflectance

$$k_s(\lambda)\sum_i L_i(\lambda)(\hat{\boldsymbol{v}}_r \cdot \hat{\boldsymbol{s}}_i)^{k_e}$$

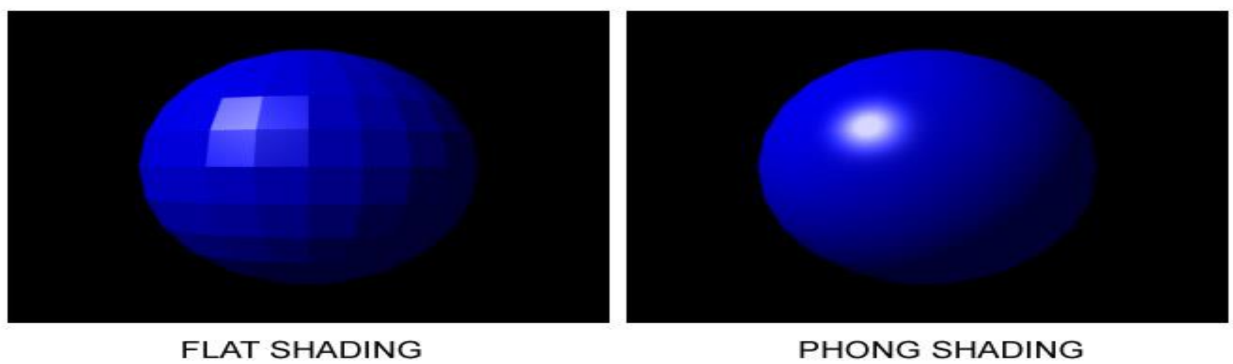
Specular Reflectance

Phong Shading

- Phong reflection model



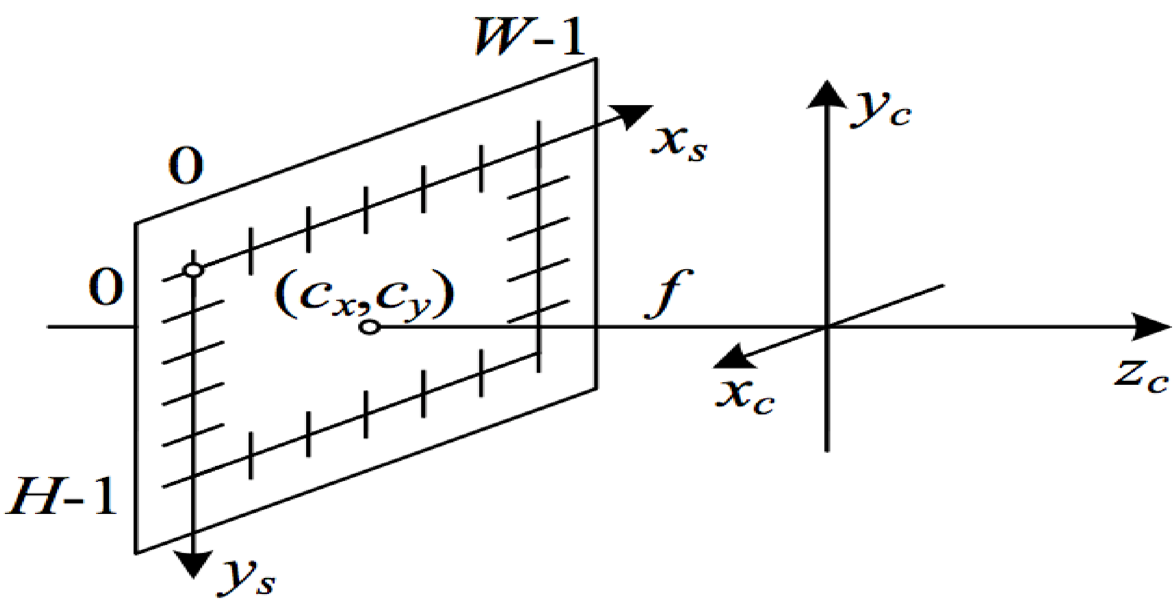
- Phong interpolation



Ray Tracing

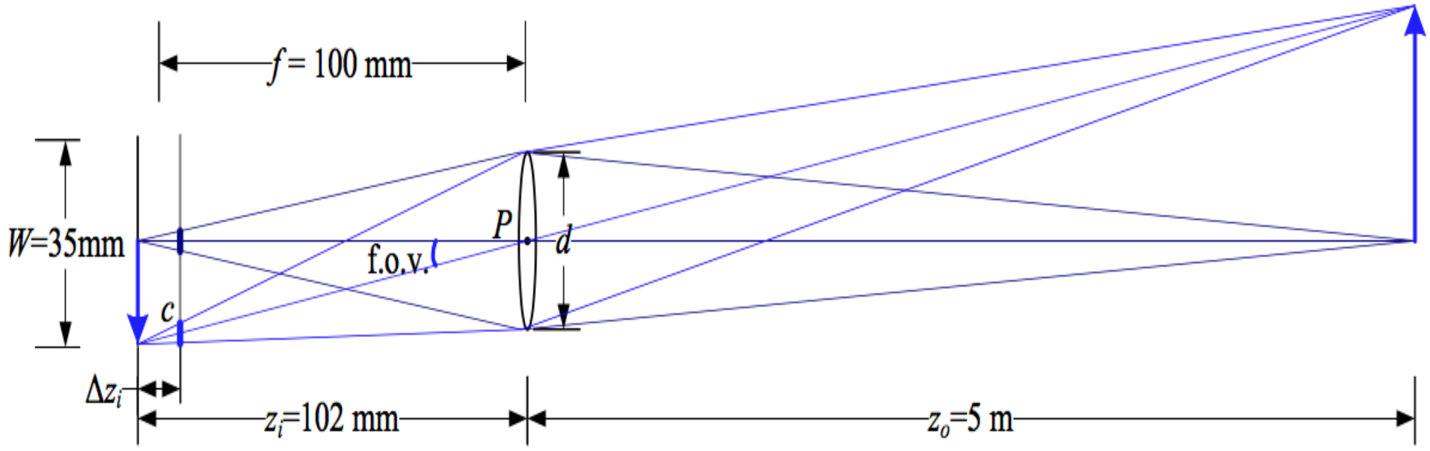
- The Phong model assumes a finite number of discrete light sources.
- Light emitted by these sources bounces off the surface and into the camera.
- In reality, some of these sources may be shadowed by other objects, and the surface is generally also illuminated by inter-reflections (multiple bounces)
- Two methods have traditionally been used to model such effects
  - If mostly specular, use ray tracing→ Follow each ray from camera across multiple bounces toward light sources
  - If mostly matte, use radiosity→ Model light interchanged between all pairs of surface patches, and then solve as linear system with light sources as forcing function.
- Phong interpolation

- Simplified camera intrinsics showing the focal length f and the optical center (cx,cy). The image width and height are W and H.
- Once the light from a scene reaches the camera→ it must still pass through the lens → reaching the sens

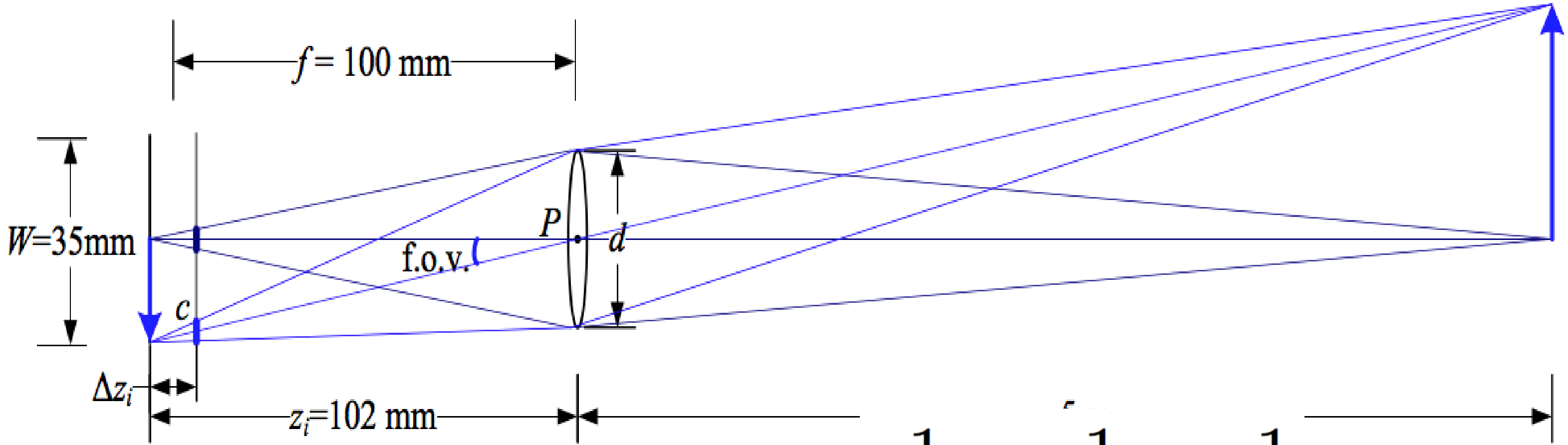


Thin Lens model

- F = focal lenght
- W = sensor width
- Z0 = distance from optical center to object
- Z1 = distance from optical center to where focused image of object is formed
- d = aperture
- c = circle of confusion



Lens Equation



$$\frac{1}{z_o} + \frac{1}{z_i} = \frac{1}{f}$$

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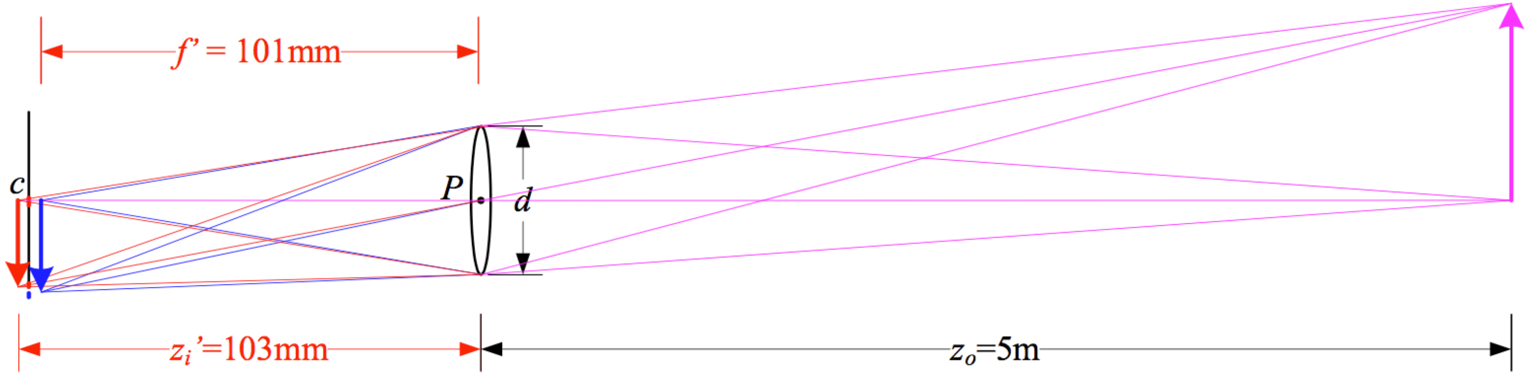
Chromatic aberration

- Index of refraction of glass varies slightly as a function of wavelength.
- As a result, different wavelengths focus at slightly different distances.
- To reduce aberrations, most photographic lenses are compound lenses using multiple elements.



Summary

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- Optics: pinhole model