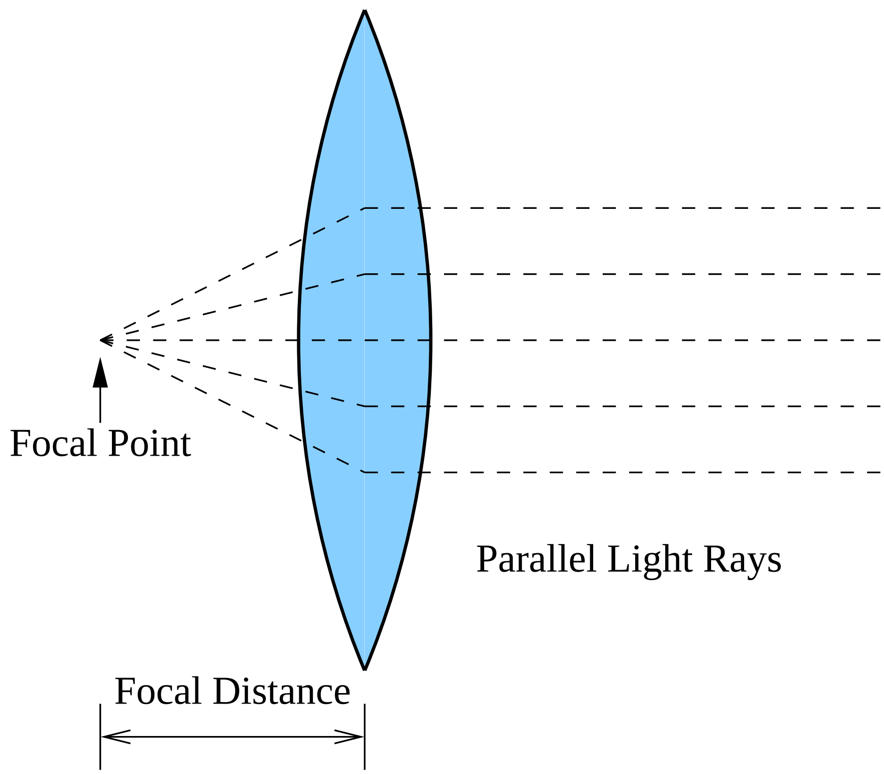
A Modern Digital Camera

- Single Lense Reflex (SLR) Camera
  - A mirror with a prism allows you to see through through the lense.
  - When photo is taken, mirror retracts to expose film and shutter in lense releases.
- Typical specifications (Nikon D200)
  - 23.6 mm$\times 15.8$ mm RGB charge coupled device (CCD) sensor
  - 10.2 Meg pixels (million pixels per photo)
  - 100 to 1600 ISO
  - Street price of $\approx$ $\$3,000$ with lense, flash, and digital media

Lens: Focal Length

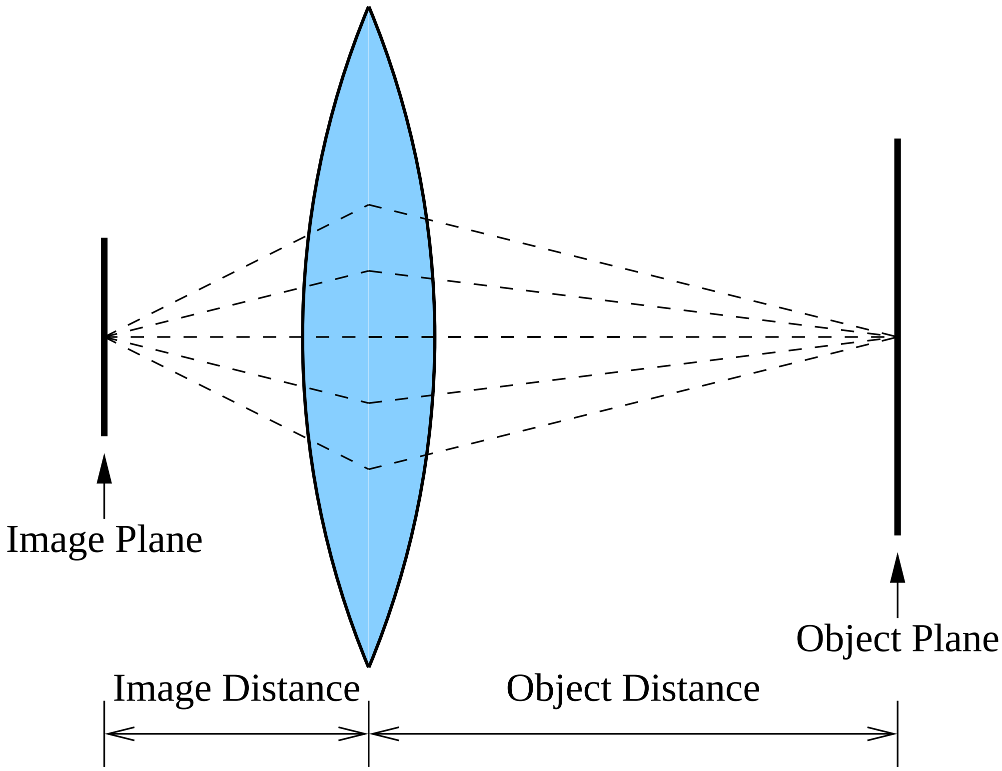


d_f - Focal length of lens

– Focuses incoming parallel rays of light to a point

– Based on a thin lens model

Lens: Image Formation



- Quantities:

  d_f - Focal length of lens

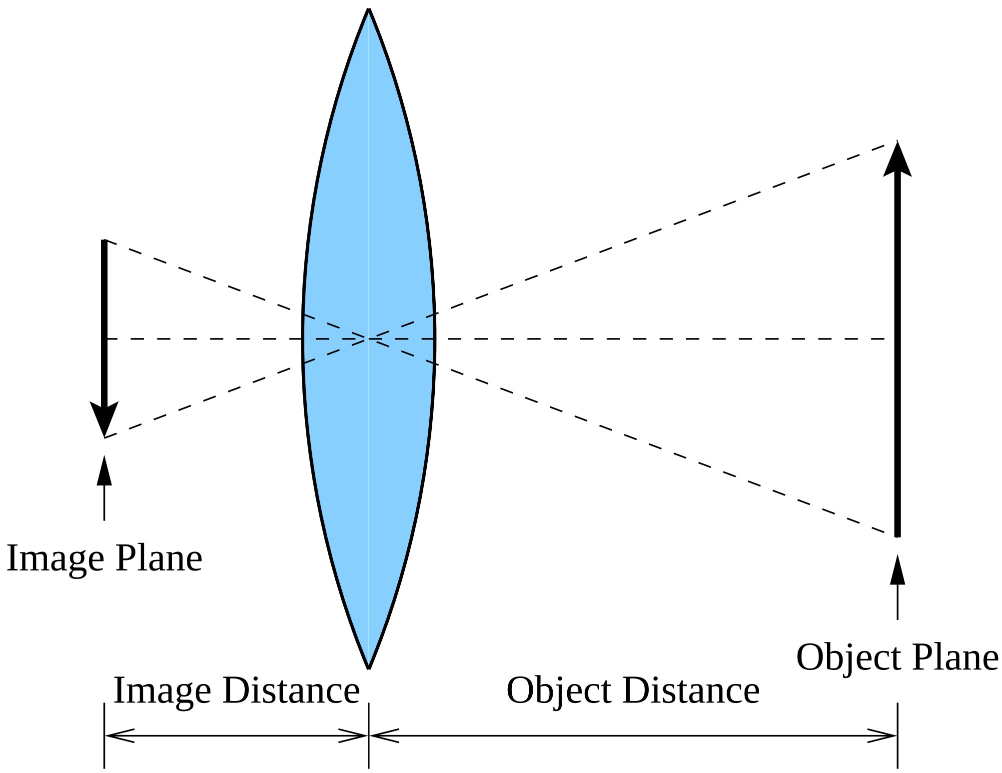
  d_o - Distance to object plane

  d_i - Distance to image plane

- Basic equation

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{d_f}$$

Lens: Magnification



- Quantities:

  d_o - Distance to object plane

  d_i - Distance to image plane

- Basic equation

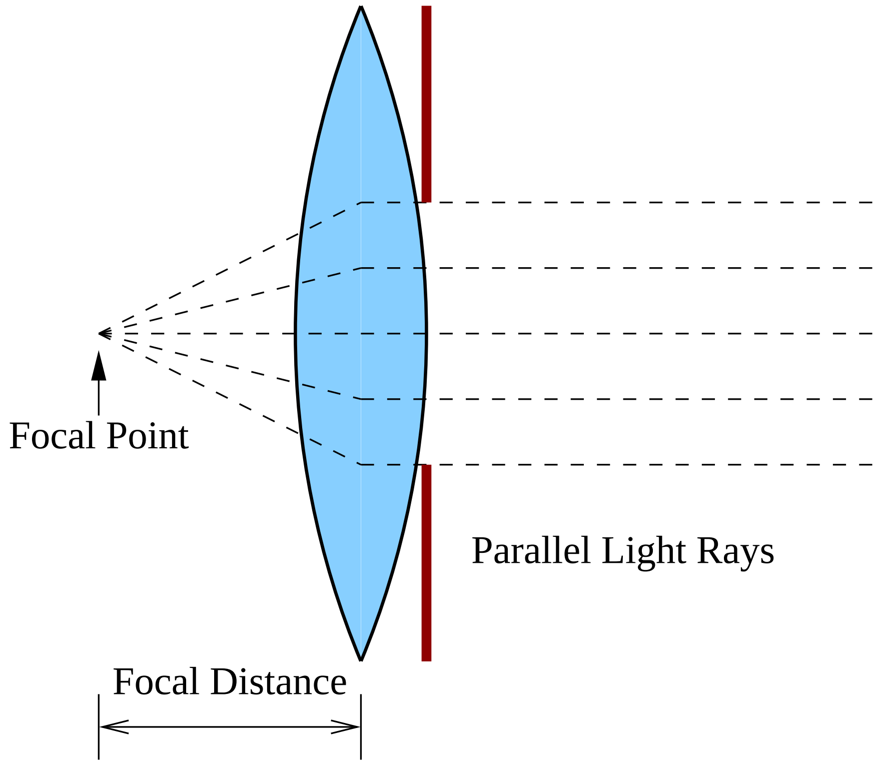
$$M = -\frac{d_i}{d_o}$$

  – Negative sign indicates that image is inverted

Lens: Typical Imaging Scenerios

- Typical case for Photography
  - $d_o >> d_f$
  - $d_i \approx d_f$
  - But in addition $d_i > d_f$
  - $M << 1$
- Typical case for microscopy
  - $d_i >> d_f$
  - $d_o \approx d_f$
  - But in addition $d_o > d_f$
  - $M >> 1$

Lens: Aperture and f-Stop



- Quantities:

  A - Diameter of aperture

  N - f-stop of lens

  d_f - Focal distance of lens

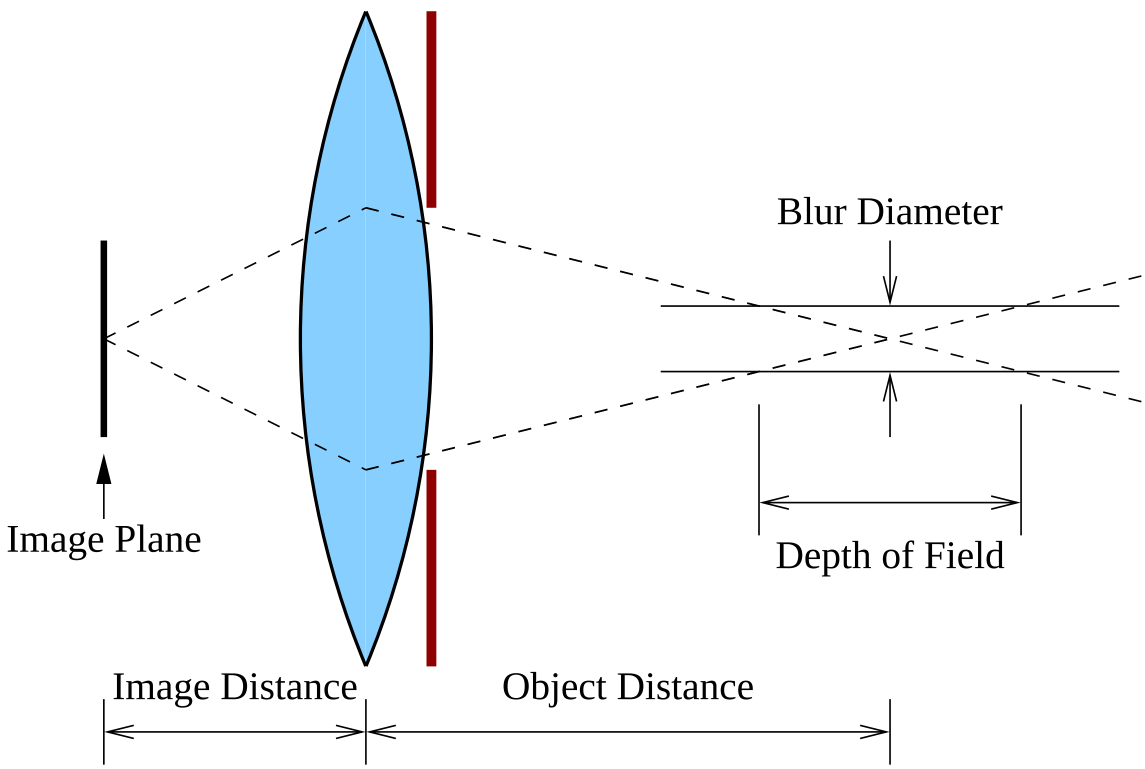
- Basic equation

$$N = \frac{d_f}{A}$$

  – Large $N \Rightarrow$ small aperture $\Rightarrow$ slow lens

  – Small $N \Rightarrow$ large aperture $\Rightarrow$ fast lens

Lens: Depth-of-Field



- Quantities:

  D - depth of field

  c_o - Blur diameter for object plane

  N - f-stop of lens

  M - Magnification

- If object is far away, then

$$\frac{D}{c_o} = \frac{2N}{-M}$$

  – Small aperture increases depth-of-field

Space Domain Models for Optical Imaging Systems

- Consider an imaging system with real world image $f(x, y)$, focal plane image $g(x, y)$, and magnification M. Then the behavior of the system may be modeled as:

$$\begin{aligned} g(x,y) &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\xi,\eta)h(x-M\xi, y-M\eta)d\xi d\eta \\ &= \frac{1}{M^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f\left(\frac{\xi}{M},\frac{\eta}{M}\right)h(x-\xi,y-\eta)d\xi d\eta \end{aligned}$$

Define the function

$$\tilde{f}(x,y) \triangleq f\left(\frac{\xi}{M},\frac{\eta}{M}\right)$$

- Then the imaging system act like a 2-D convolution.

$$g(x,y) = \frac{1}{M^2}h(x,y) * \tilde{f}(x,y)$$

Point Spread Functions for Optical Imaging Systems

- Definition: $h(x, y)$ is known as the *point spread function* of the imaging system.

$$g(x, y) = \frac{1}{M^2} h(x, y) * \tilde{f}(x, y)$$

- Notice that when $f(x, y) = \delta(x, y)$

$$\begin{aligned} g(x, y) &= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \delta(\xi, \eta) h(x - M\xi, y - M\eta) d\xi d\eta \\ &= h(x, y) \end{aligned}$$

Transfer Functions for Optical Imaging Systems

- In the frequency domain,

$$G(u,v) = \tilde{F}(u,v)\,\frac{1}{M^2}H(u,v)$$

$$\begin{aligned} g(x,y) &\overset{CSFT}{\Leftrightarrow} G(u,v) \\ h(x,y) &\overset{CSFT}{\Leftrightarrow} H(u,v) \\ \tilde{f}(x,y) &\overset{CSFT}{\Leftrightarrow} \tilde{F}(u,v) \end{aligned}$$

- The *Optical Transfer Function (OTF)* is

$$\frac{H(u,v)}{H(0,0)}$$

- The *Modulation Transfer Function (MTF)* is

$$\left|\frac{H(u,v)}{H(0,0)}\right|$$