2009 spring

Microstructural Characterization of Materials

03. 23. 2009

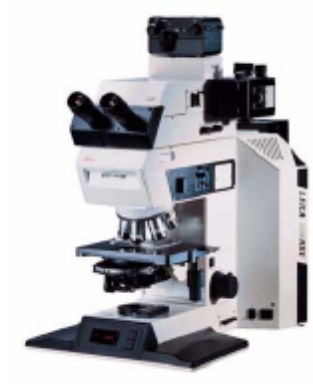
Eun Soo Park

Office: 33-316
Telephone: 880-7221
Email: espark@snu.ac.kr
Office hours: by an appointment

Contents for previous class

- ***Types of optical microscopy***

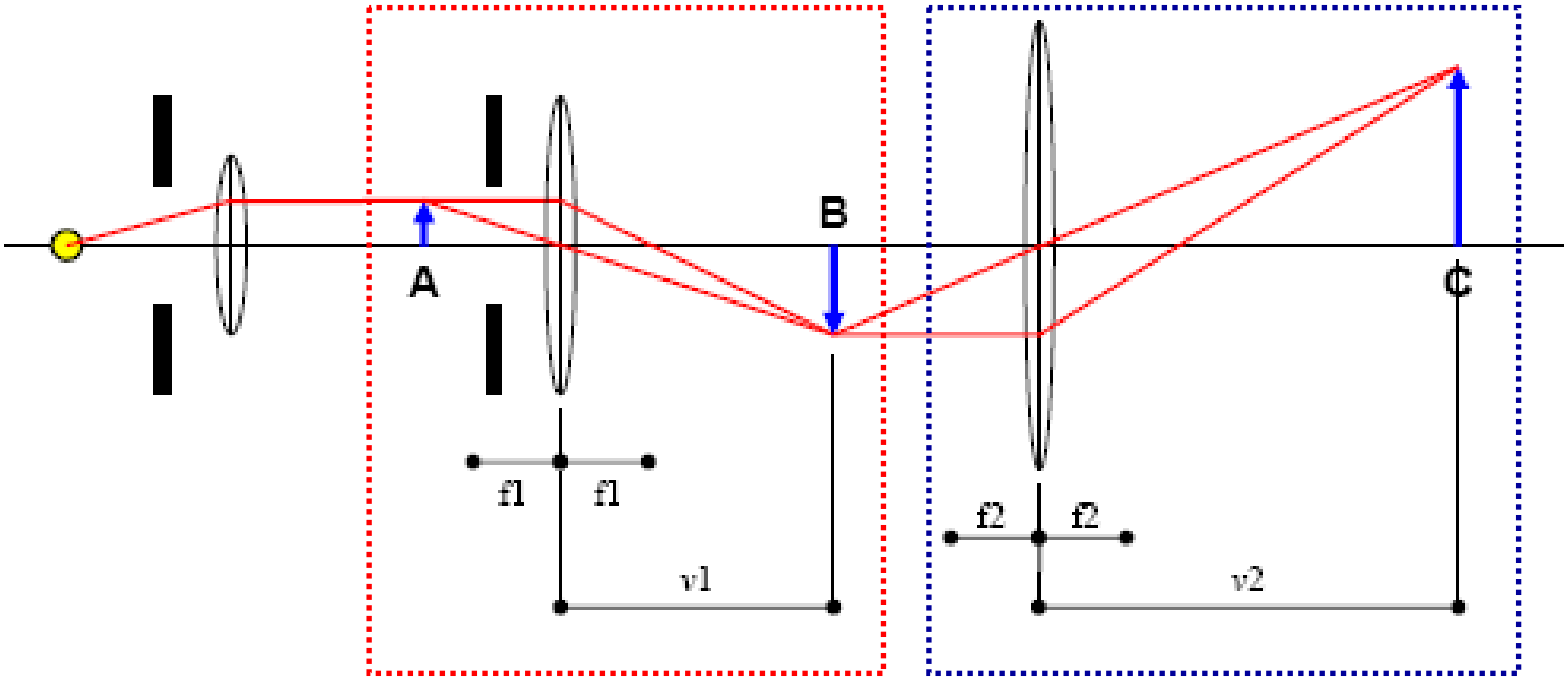
(1) Simple OM:
(2) Stereo OM:
(3) Compound OM:



- ***Microscope Components***

(1) Illumination system: Lamps, Lenses, Filters, Diaphragm

(2) Optical System: Objective Lens, Projector Lens, Eyepiece



- Let v be the distance between the magnified image and the lens (also known as the image distance). Let f be the focal distance

OBJECTIVE LENS MAGNIFICATION

$$M1 = (v1 - f1) / f1$$

PROJECTOR LENS MAGNIFICATION

$$M2 = (v2 - f2) / f2$$

TOTAL MAGNIFICATION

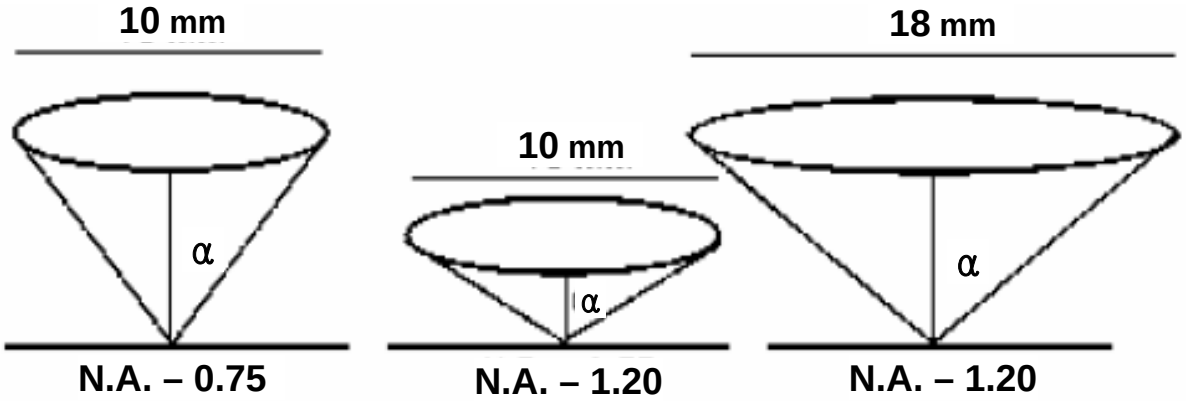
$$M1 \times M2$$

- ***Numerical aperture (N.A.)***

N.A. - the numerical aperture (N.A.) is basically a value which describes the quality of a lens.

$$N.A. = \mu \sin\alpha$$

depends on size of the lens; working distance; refractive index of medium between object and objective lens (μ).



α - the half acceptance angle of the lens.

Optical Performance

Resolution

- Recall: the resolution of a system is the smallest distance between two points or lines that can be observed.
- In the case of optical microscopy it is a function of the wavelength of light and the N.A. of the objective.
- Resolution limits magnification in an optical microscope.

$$d = \frac{0.612\lambda}{\text{N.A.}} = \frac{0.612\lambda}{\mu \cdot \sin\alpha}$$

Abbe's Equation

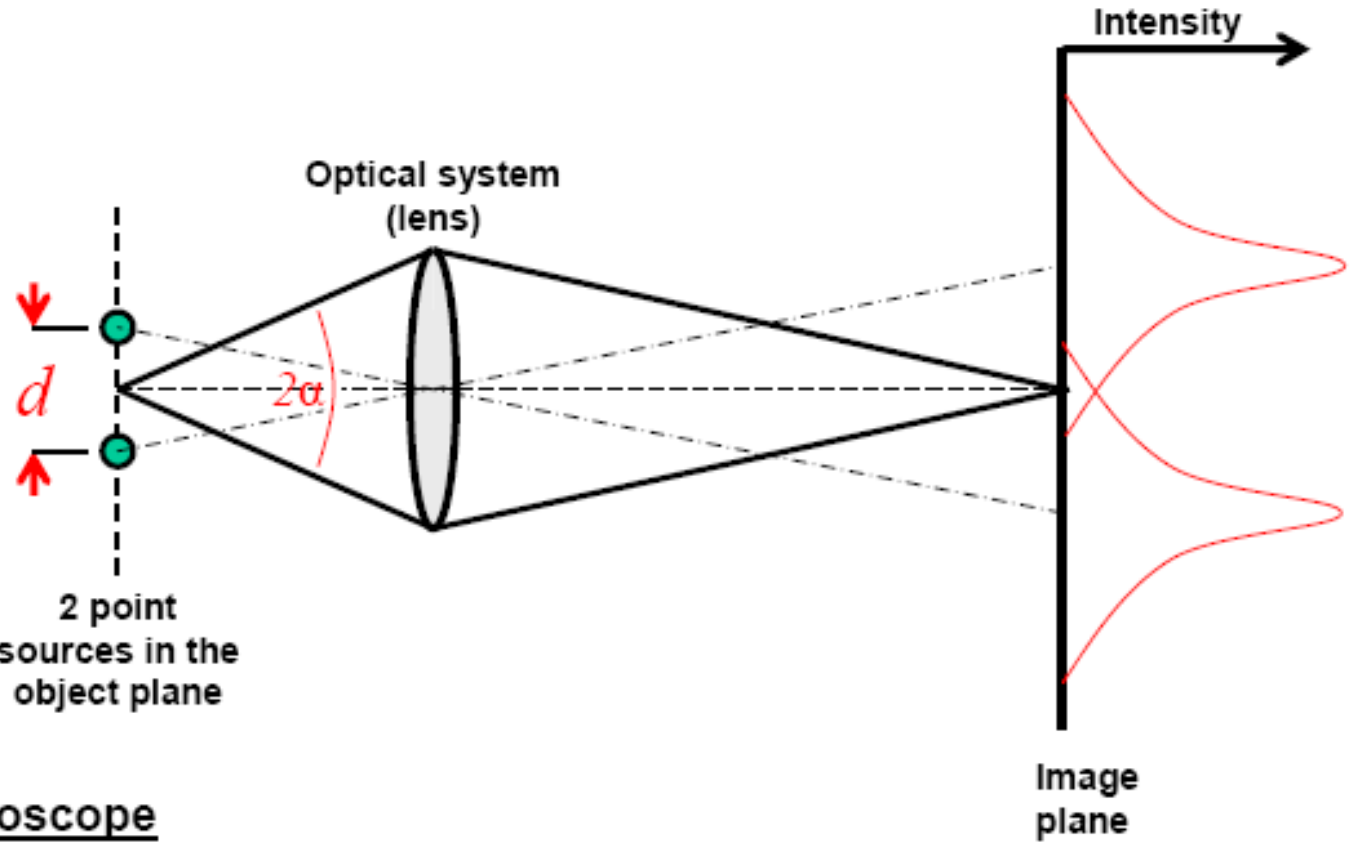
where: d= resolution

λ= wavelength of imaging radiation

μ= index of refraction of medium between point source and lens, relative to free space

α= half the angle of the cone of light from specimen plane accepted by the objective (half aperture angle in radians)

RECALL



Microscope

$$r_1 = \frac{d}{2} \geq \frac{0.612\lambda}{\mu \sin\alpha} = \frac{0.612\lambda}{N.A.}$$

HOW DO WE INCREASE MAGNIFICATION?

Resolution Limit of Light Microscope

- You can decrease λ to 400 nm (green light).
- N.A. is limited to ~1.6.

$$\text{LOM} \quad r_1 = \frac{d}{2} \geq \frac{0.612\lambda}{\mu \sin\alpha} = \frac{0.612\lambda}{N.A.} =$$

- The maximum resolution is around ~150 nm (0.15 μm).
- For comparison, in an electron microscope λ can decrease to 0.001 nm and N.A. is much smaller (on order of 0.1 radians)

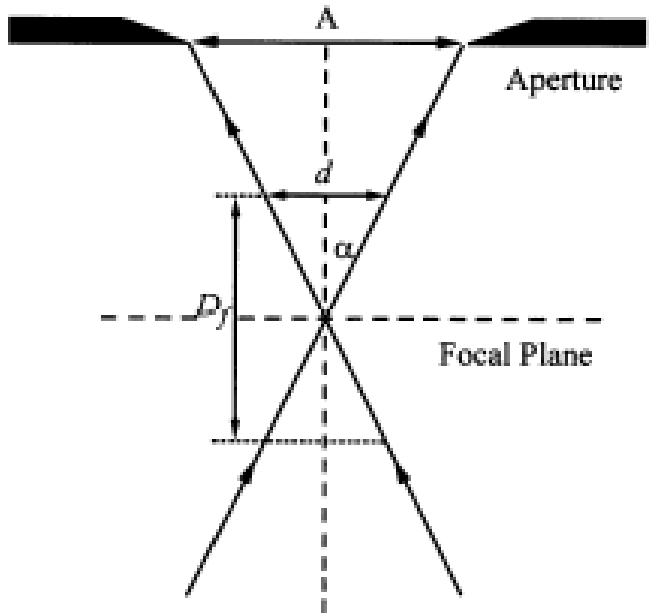
$$\text{EM} \quad r_1 = \frac{d}{2} \geq \frac{0.612\lambda}{\mu \sin\alpha} \simeq$$

For wavelength of 0.0037 nm and α = 0.1 radians, the resolution is about 0.02 nm.

Depth of Field

- The distance along the optic axis over which image details can be observed with acceptable clarity.
- The same factors that effect resolution effect the depth of field but in the opposite way; therefore, a compromise must be reached between these two factors.

$$D_f = \frac{d}{\tan\alpha} = \frac{2r}{\tan\alpha} = \frac{1.22\lambda}{\mu \sin\alpha \tan\alpha}$$



- Object will be sharp if it is anywhere within the range D_f.

Optical Performance

Resolution & Depth of Field

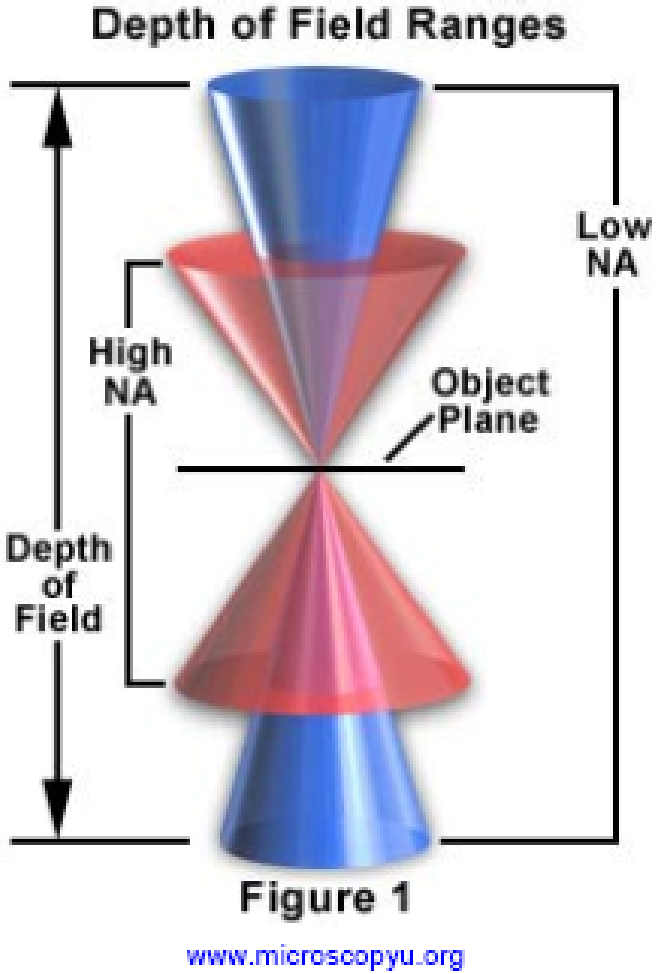
-Resolution

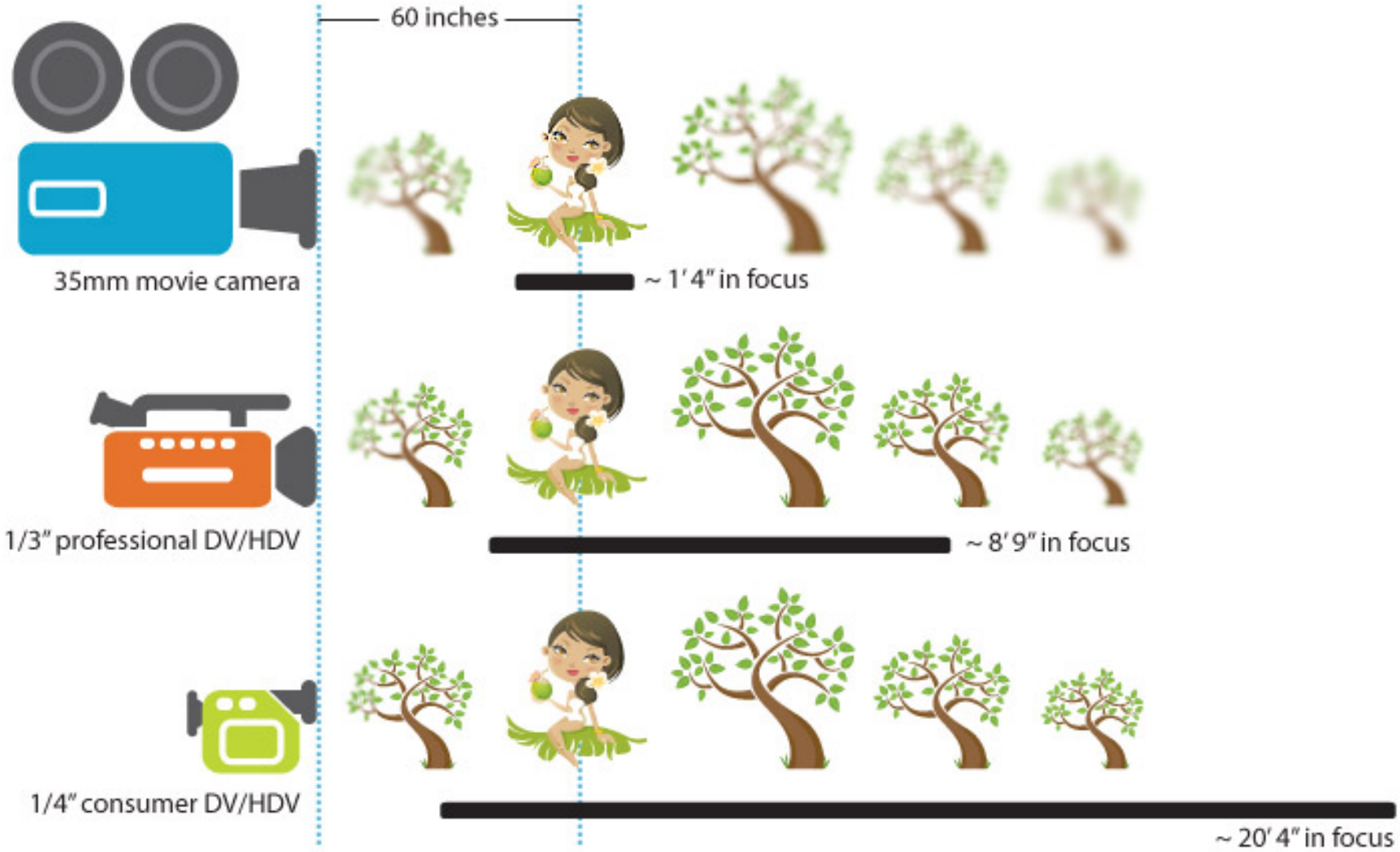
$$r_1 = \frac{d}{2} \geq \frac{0.612\lambda}{\mu \sin\alpha} = \frac{0.612\lambda}{N.A.}$$

-Depth of Field

$$D_f = \frac{1.22\lambda}{\mu \sin\alpha \tan\alpha}$$

- Large D_f and r_1 cannot be obtained simultaneously.
- Large D_f means larger r_1 and worse resolution.




60 inches
35mm movie camera
~ 1′ 4″ in focus
1/3″ professional DV/HDV
~ 8′ 9″ in focus
1/4″ consumer DV/HDV
~ 20′ 4″ in focus

Optical Performance

Resolution & Depth of Field – cont'd

$$D_f = \frac{1.22\lambda}{\mu \sin\alpha \tan\alpha}$$

- For a light microscope, α is around 45°. Thus, D_f is not much different from resolution.

- In comparison, in an electron microscope, α and λ are much smaller.

$$D_f = \frac{0.61\lambda}{\alpha^2}$$

- In an electron microscope, D_f is nearly ten times the resolution.

How to improve depth of field

1. Reduce *N.A.* by closing down aperture diaphragm, or use a lower *N.A.* objective lens.

2. Lower the magnification for a given *N.A.*

3. Use a high-power eyepiece with a low-power, high-*N.A.* objective lens.

4. Reduce zoom factor

5. Use longest possible wavelength light.

Depth of Focus

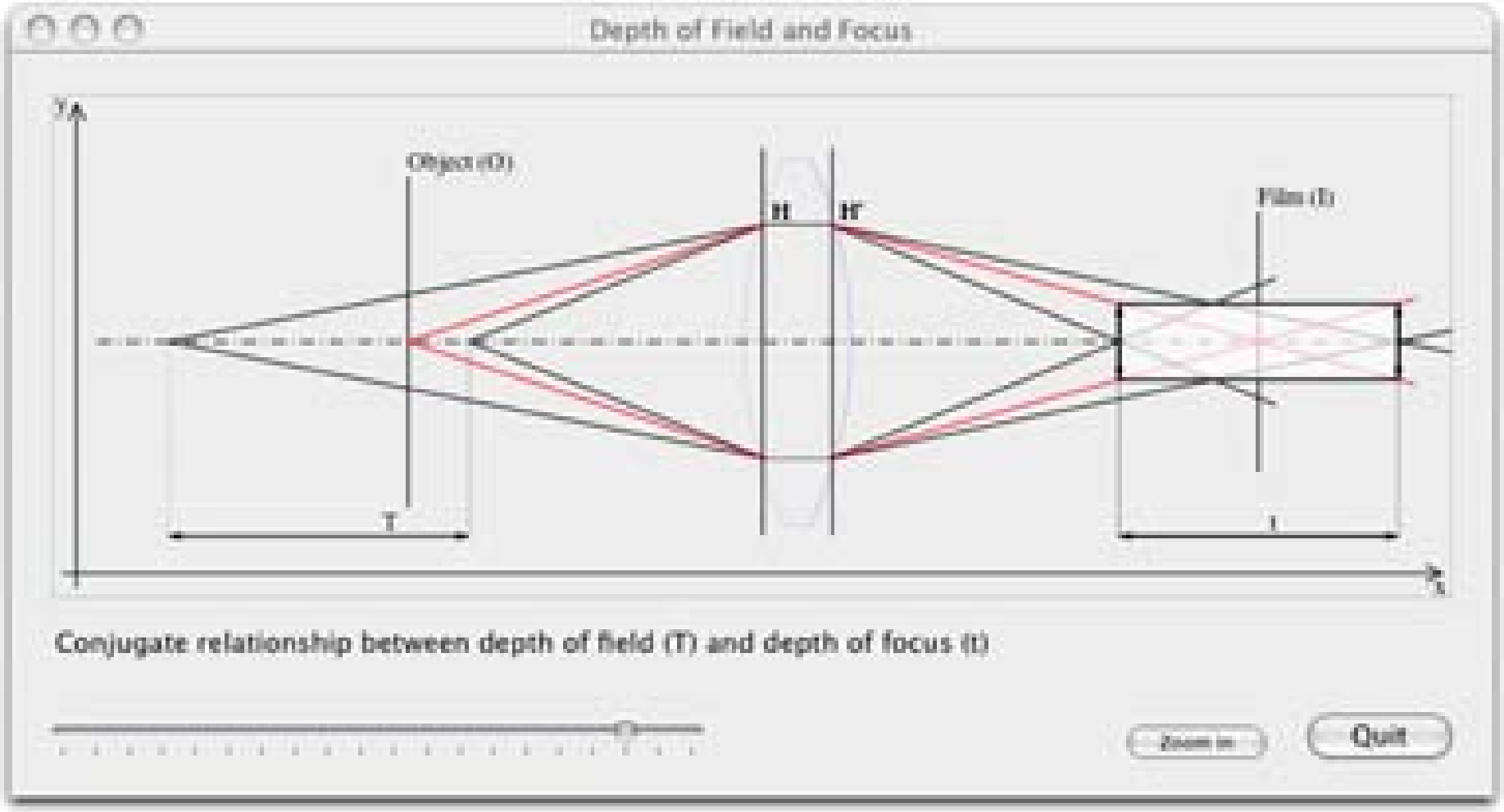
- The range of image plane position at which the image can be viewed without appearing out of focus for a fixed position of object.

  – Often confused with depth of field

  – Not as important as depth of field

  - Depth of focus is M^2 times depth of field

$$D_{focus} = D_f \times M^2 = \frac{1.22\lambda}{\mu \sin\alpha \tan\alpha} \times M^2$$


Depth of Field and Focus
Object (O)
H
H'
Film (I)
T
i
Conjugate relationship between depth of field (T) and depth of focus (t)
Zoom in
Quit