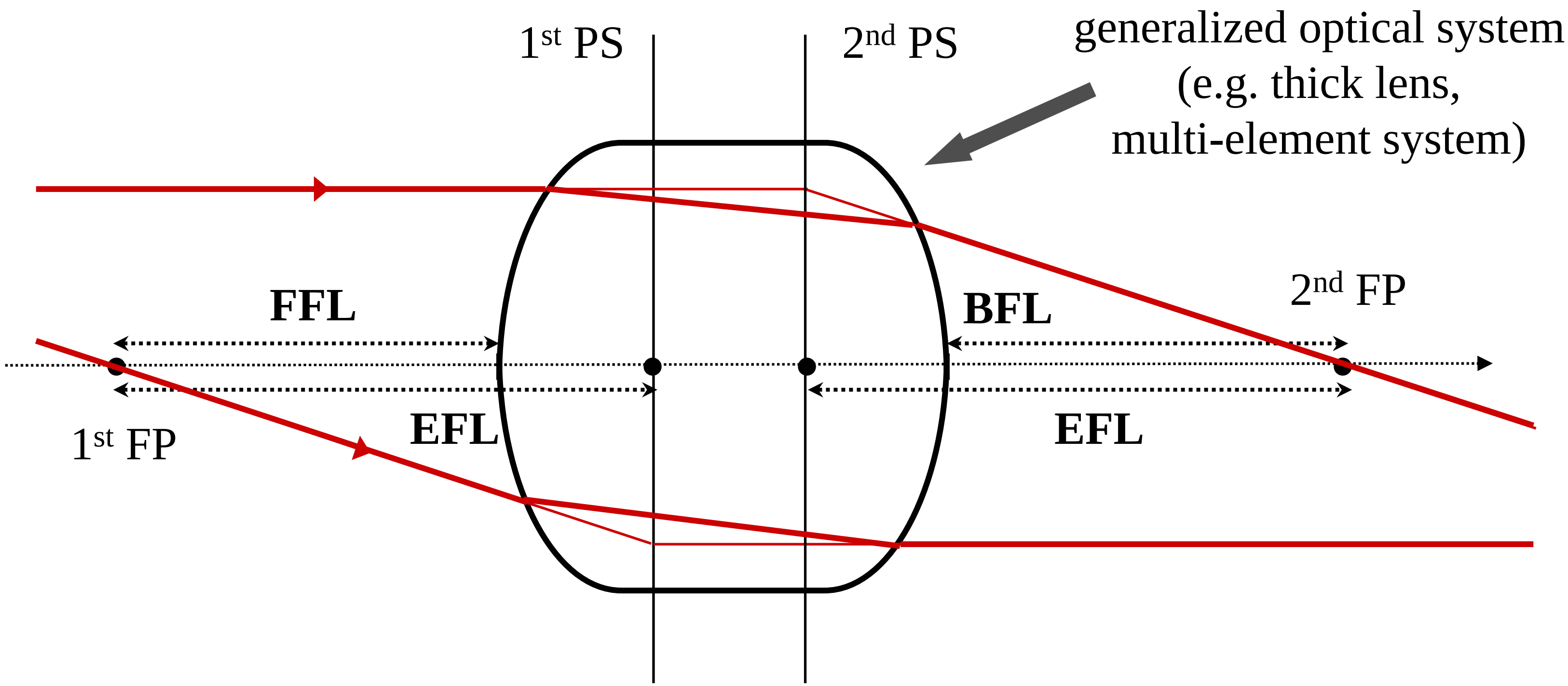
Imaging Instruments (part I)

- Principal Planes and Focal Lengths (Effective, Back, Front)
- Multi-element systems
- Pupils & Windows; Apertures & Stops
- the Numerical Aperture and f/#
- Single-Lens Camera
- Human Eye
- Reflective optics
- Scheimpflug condition

Focal Lengths & Principal Planes



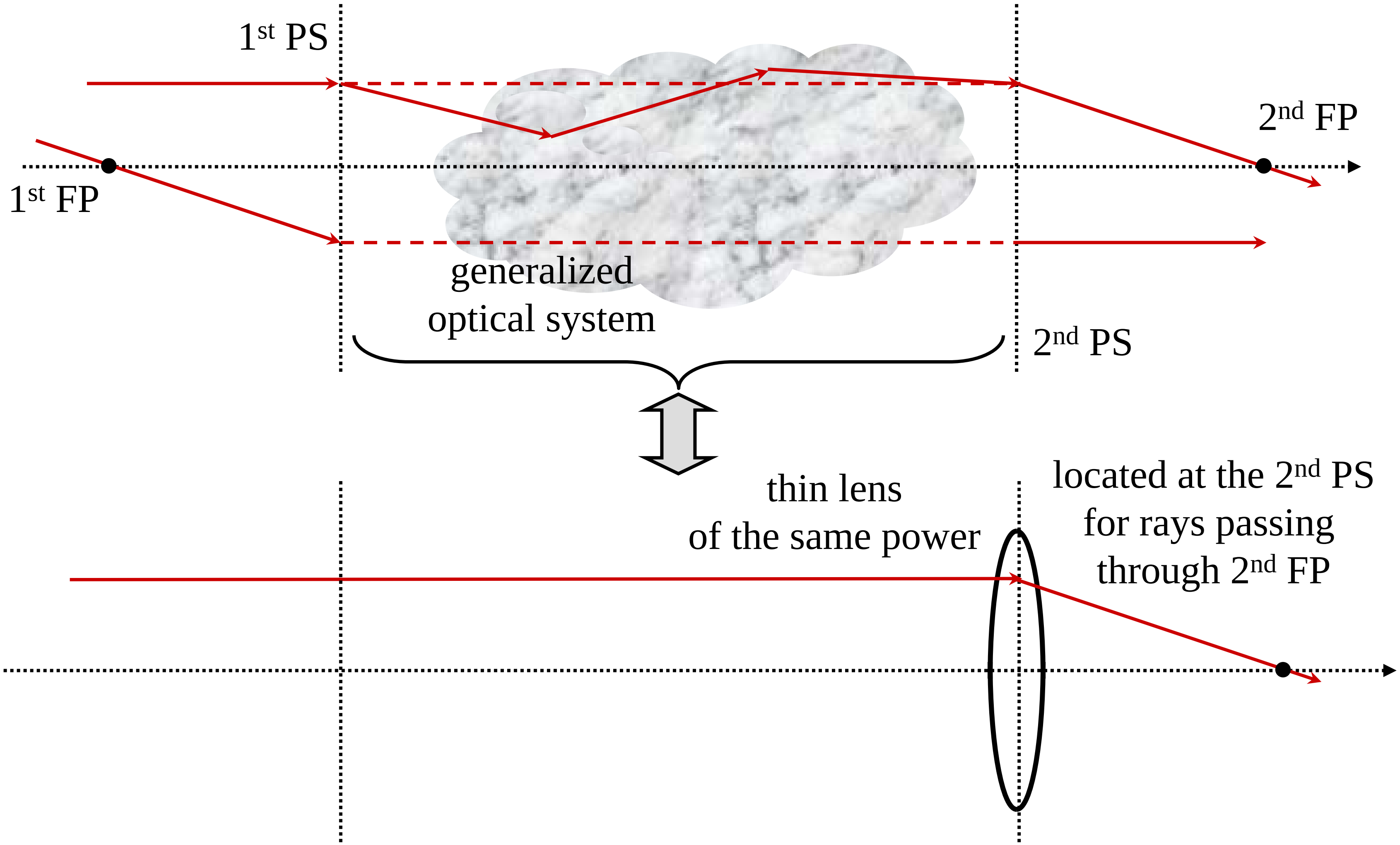
EFL: Effective Focal Length (or simply "focal length")

FFL: Front Focal Length

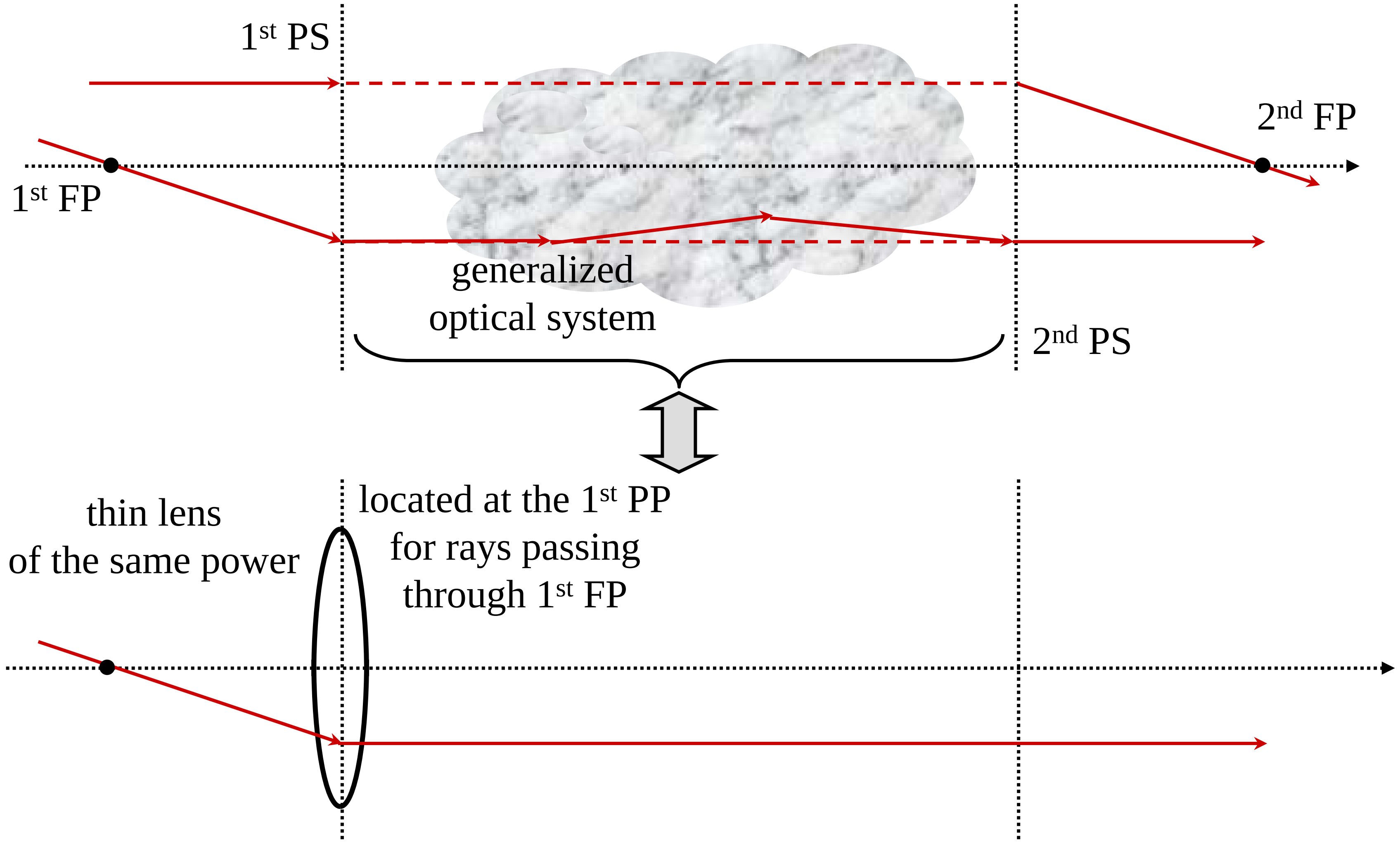
BFL: Back Focal Length

FP: Focal Point/Plane **PS**: Principal Surface/Plane

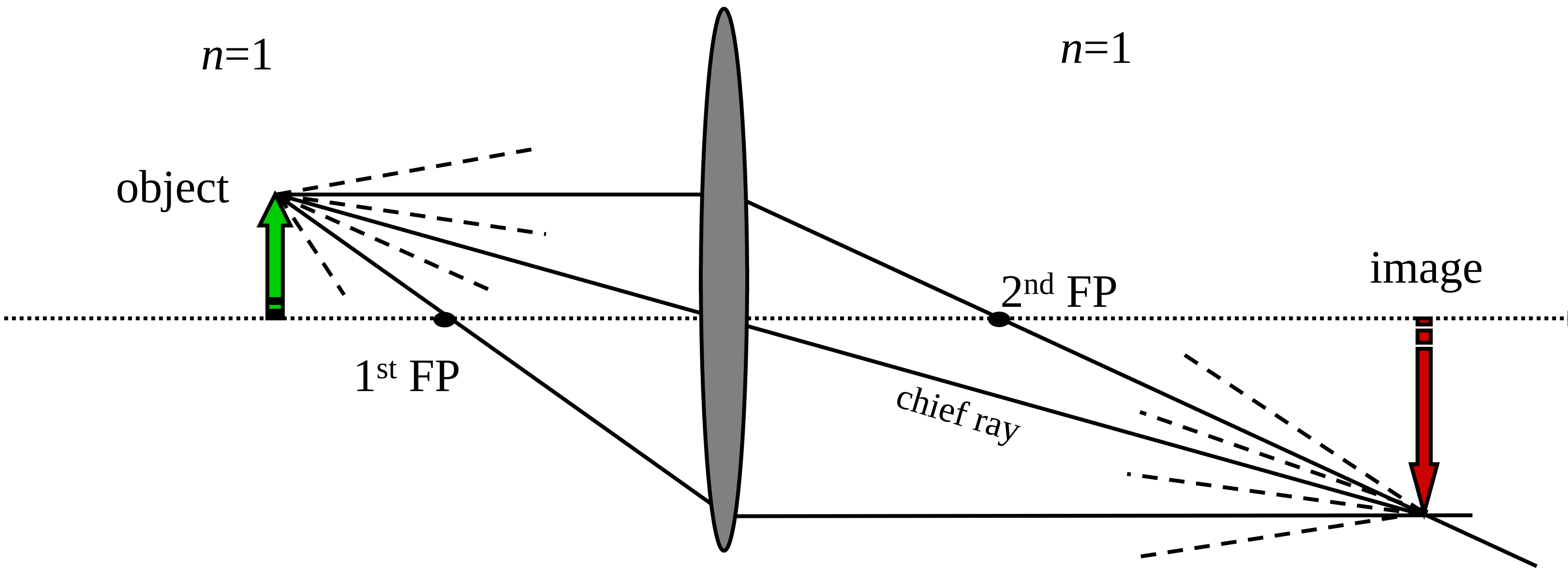
The significance of principal planes /1



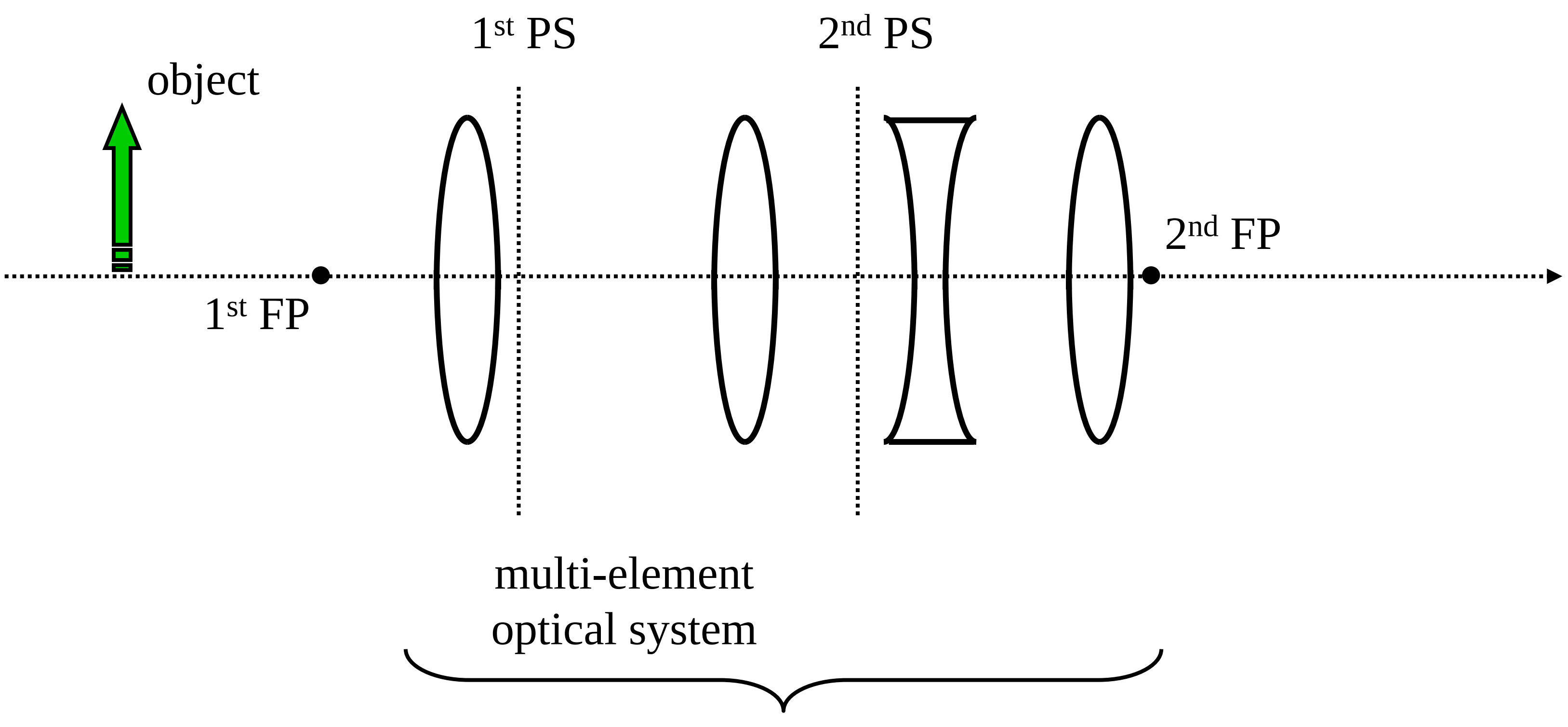
The significance of principal planes /2



Reminder: imaging condition (thin lens)

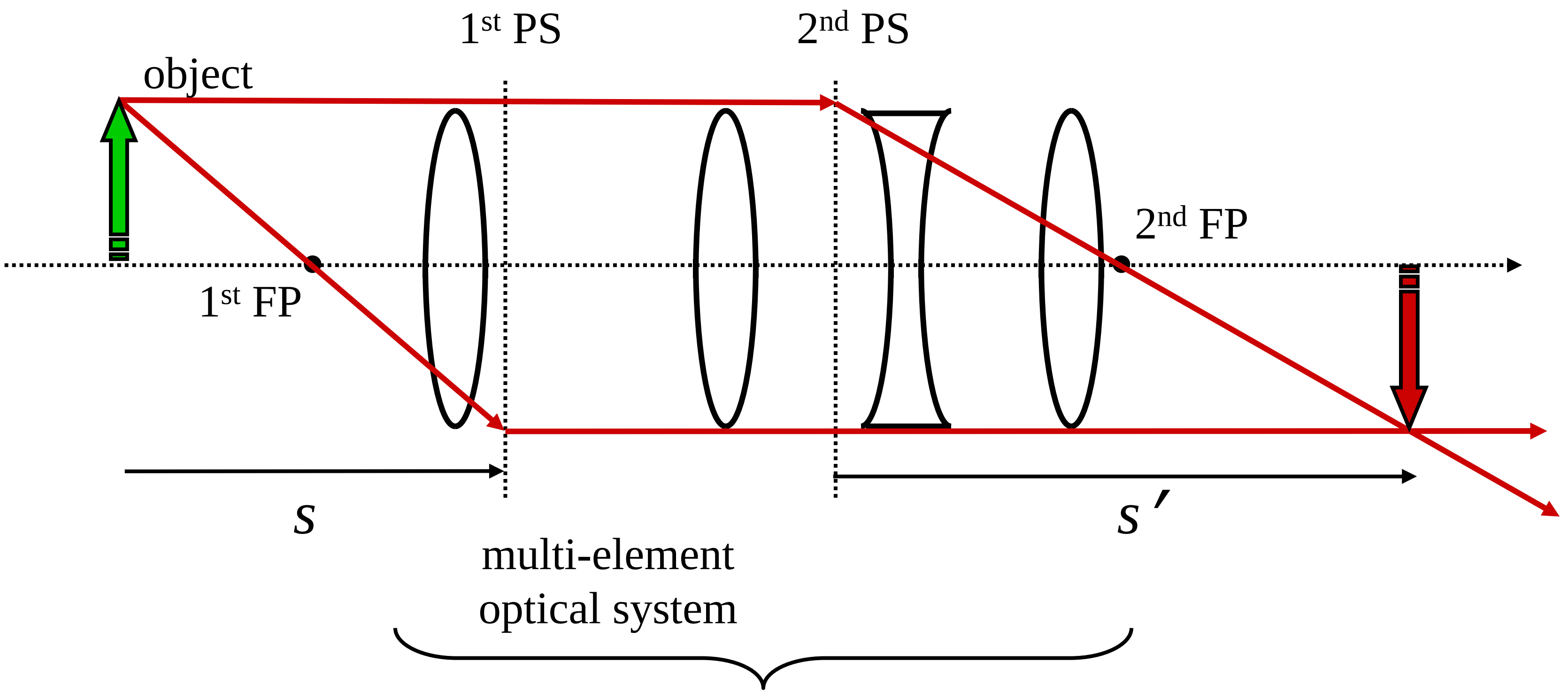


The significance of principal planes /3



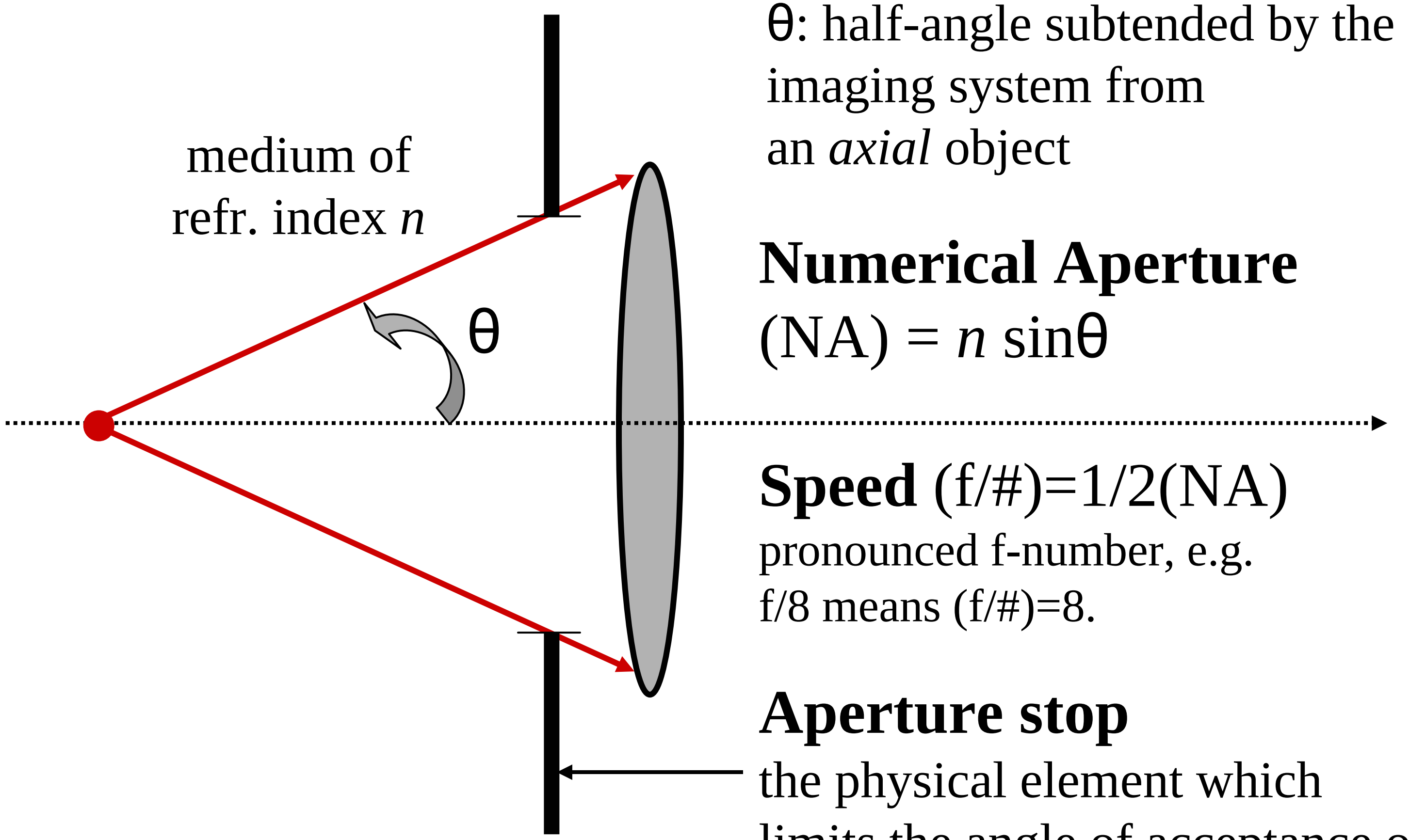
image?
magnification?

The significance of principal planes /4



$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f},\qquad m_{\text{lateral}}=-\frac{s'}{s}$$ hold, where f = (EFL)

Numerical Aperture



θ: half-angle subtended by the imaging system from an *axial* object

Numerical Aperture (NA) = $n \sin\theta$

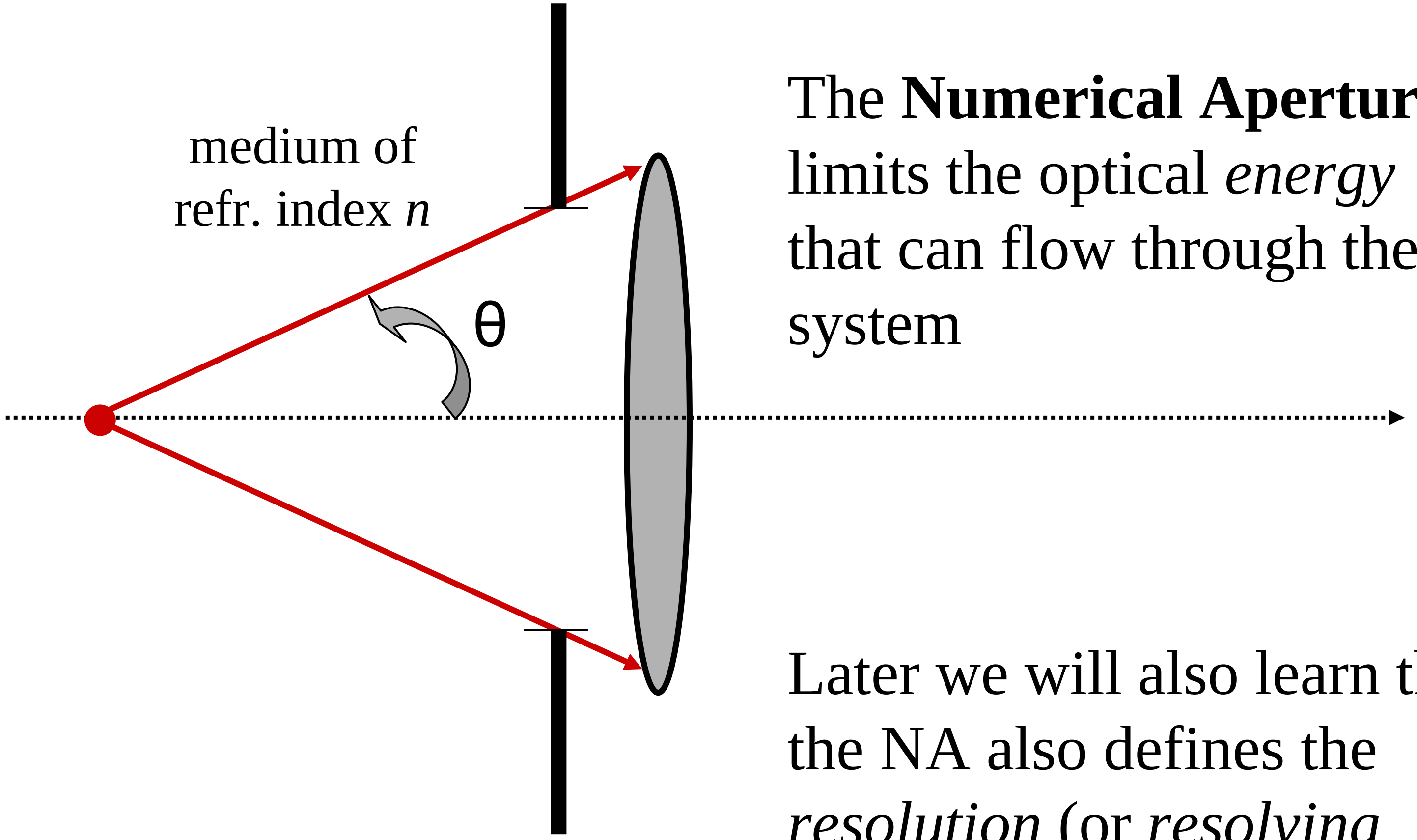
Speed (f/#)=1/2(NA)

pronounced f-number, e.g. f/8 means (f/#)=8.

Aperture stop

the physical element which limits the angle of acceptance of the imaging system

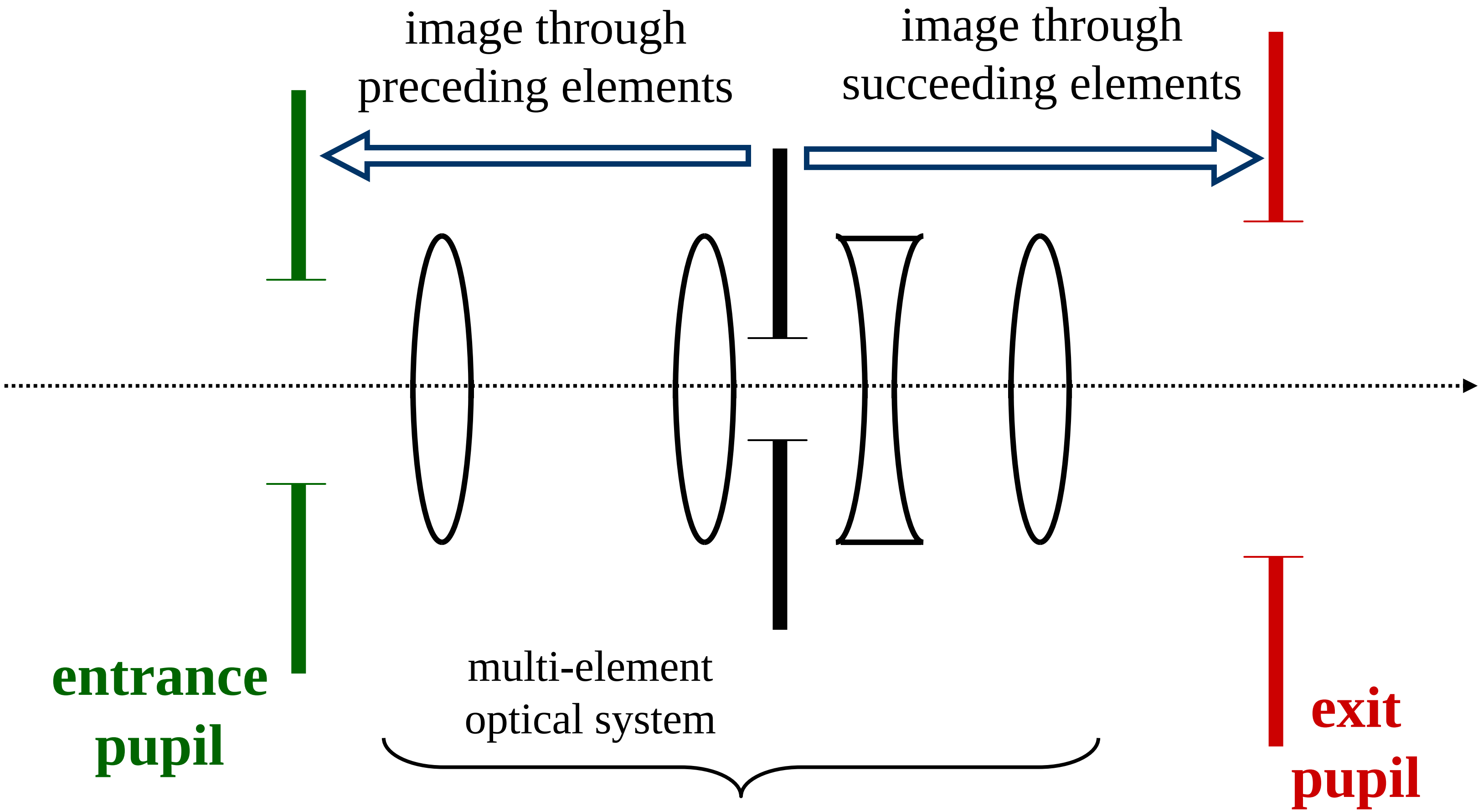
Aperture / NA: physical meaning



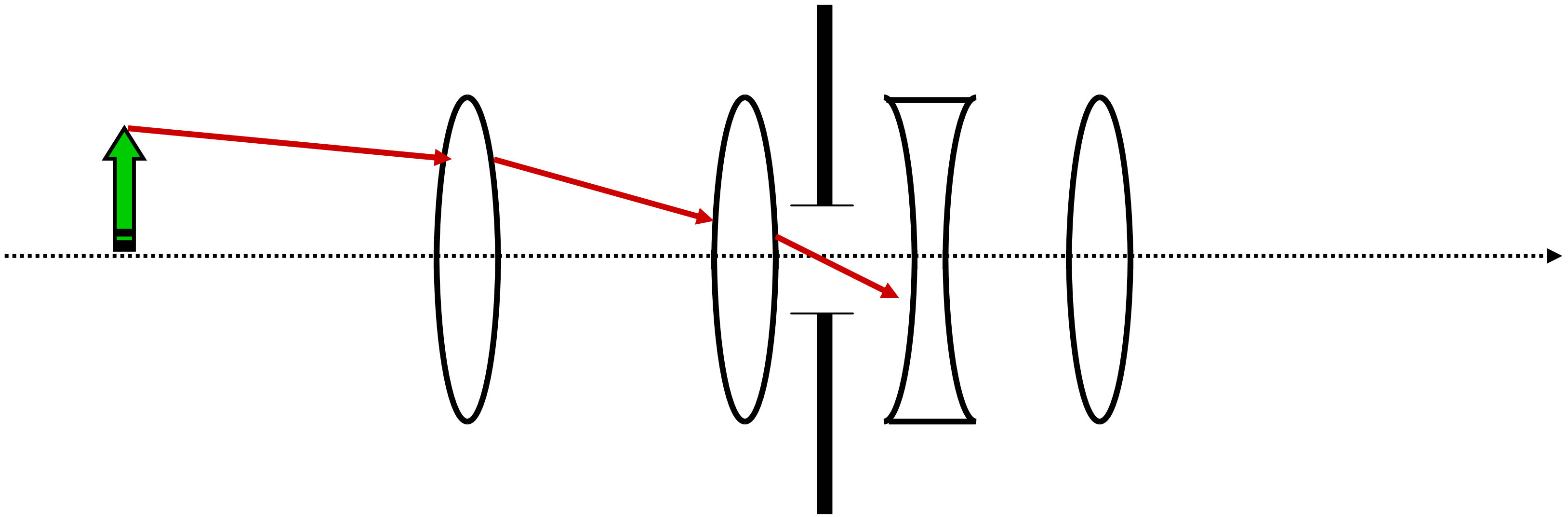
The **Numerical Aperture** limits the optical *energy* that can flow through the system

Later we will also learn that the NA also defines the *resolution* (or *resolving power*) of the optical system

Entrance & exit pupils

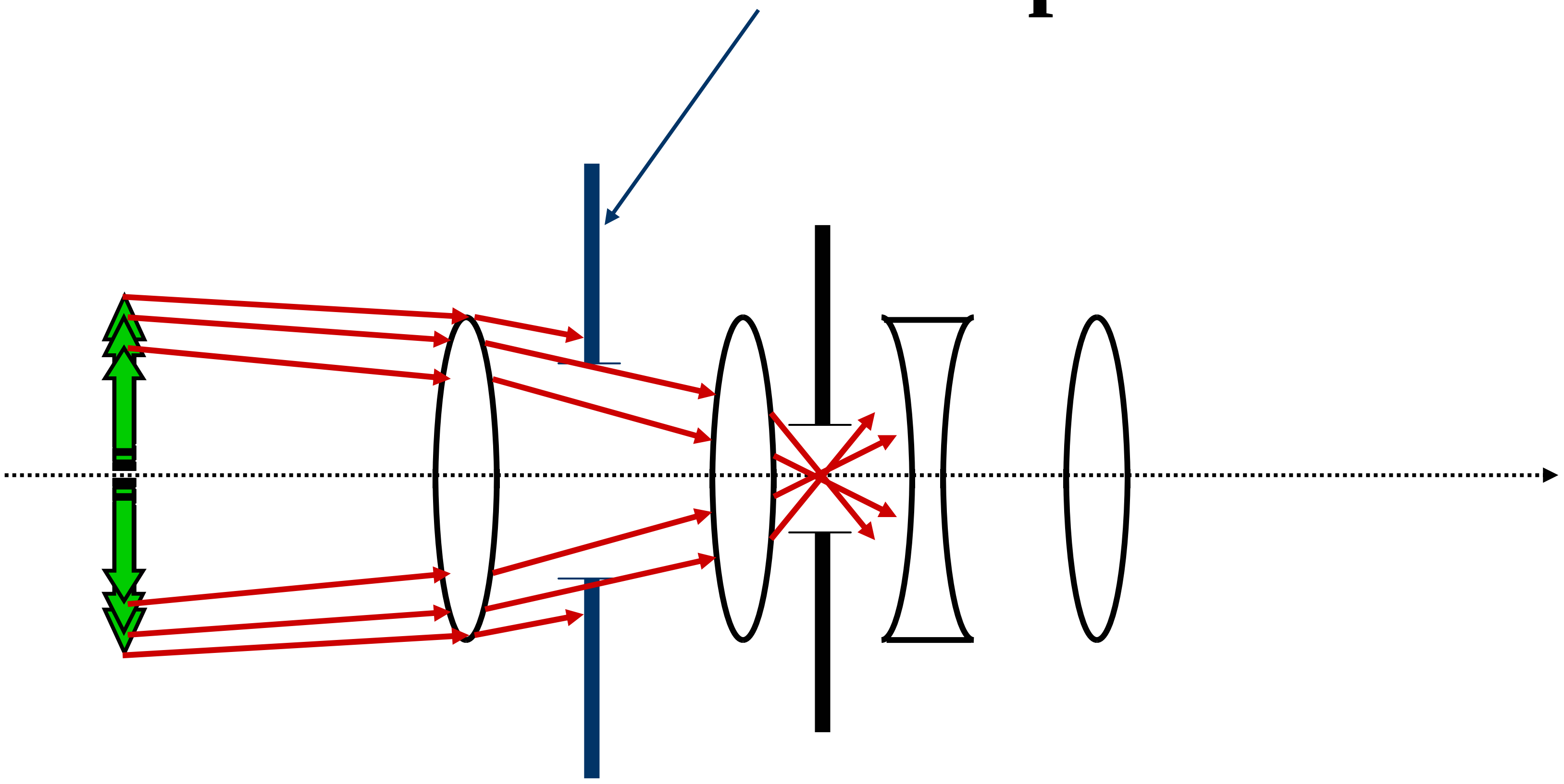


The Chief Ray



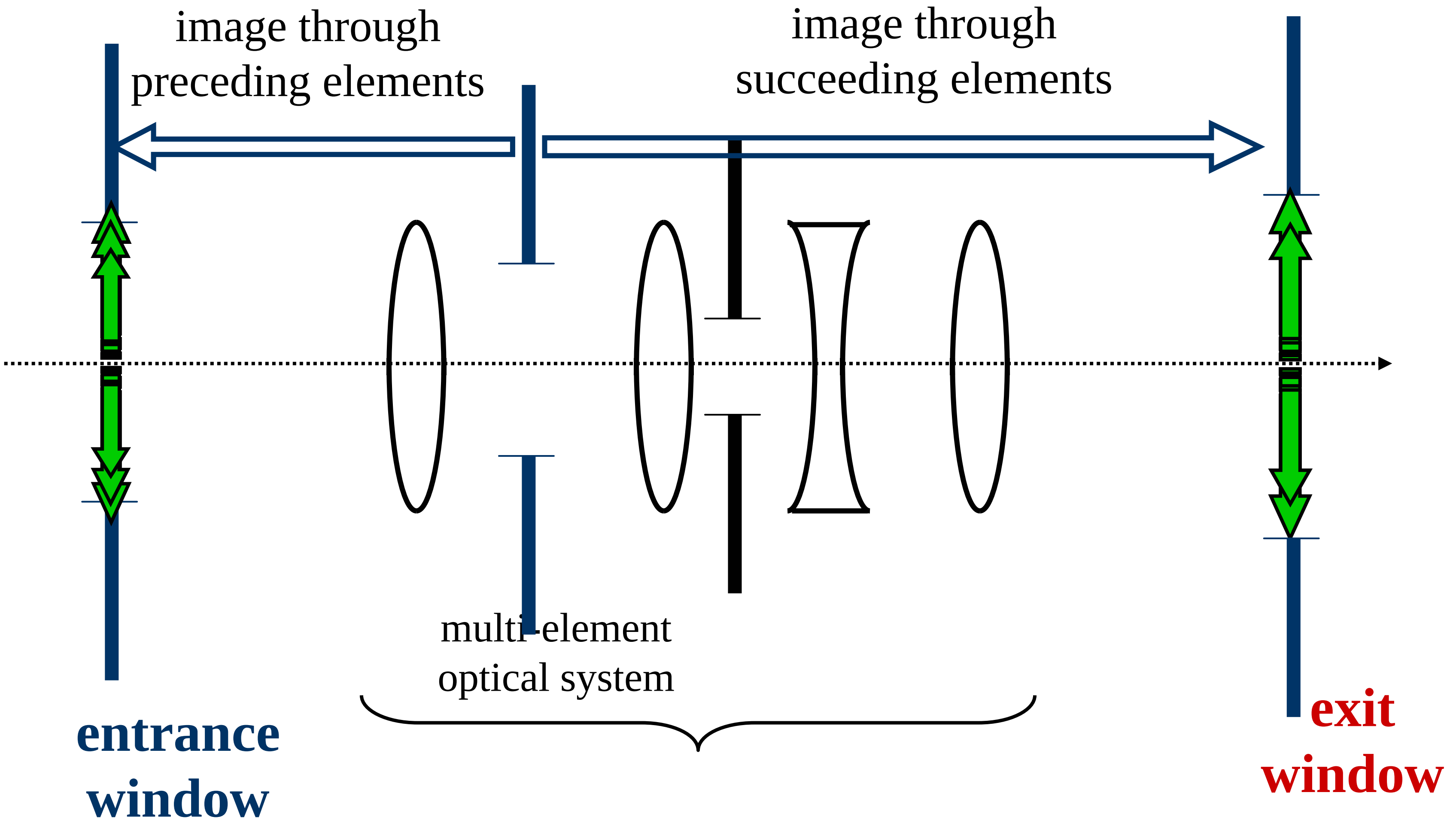
Starts from off-axis object,
Goes through the center of the Aperture

The Field Stop

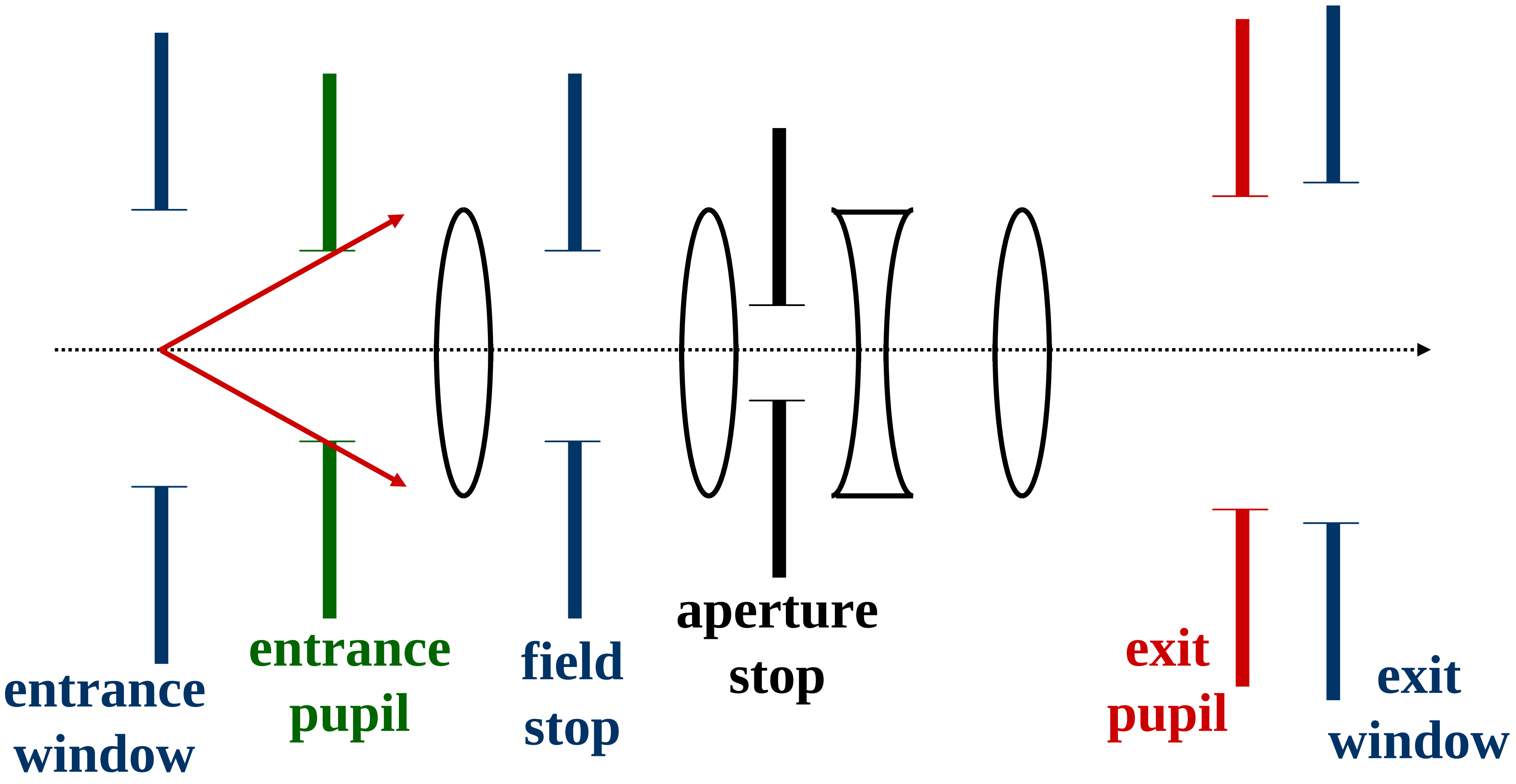


Limits the angular acceptance
of Chief Rays

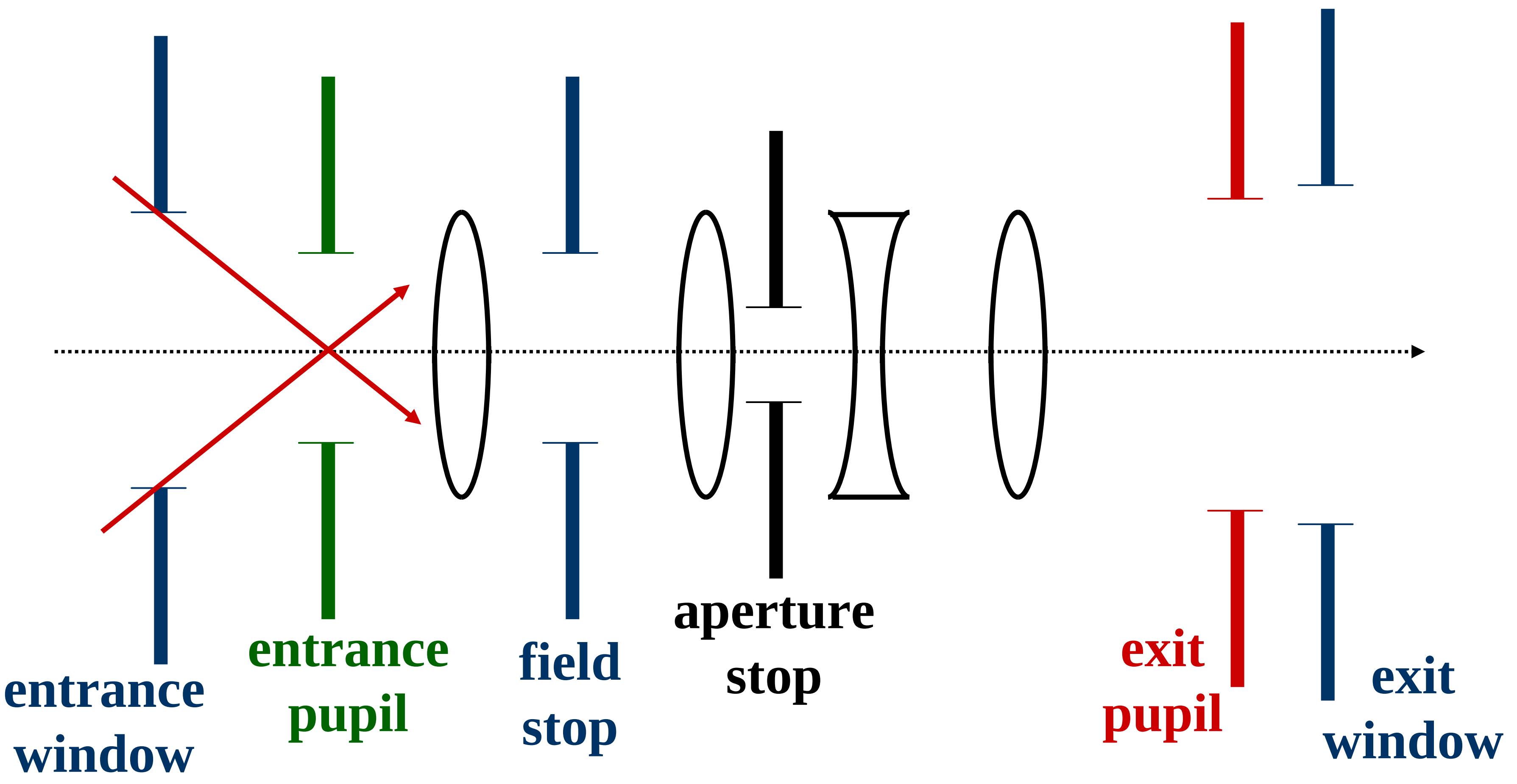
Entrance & Exit Windows



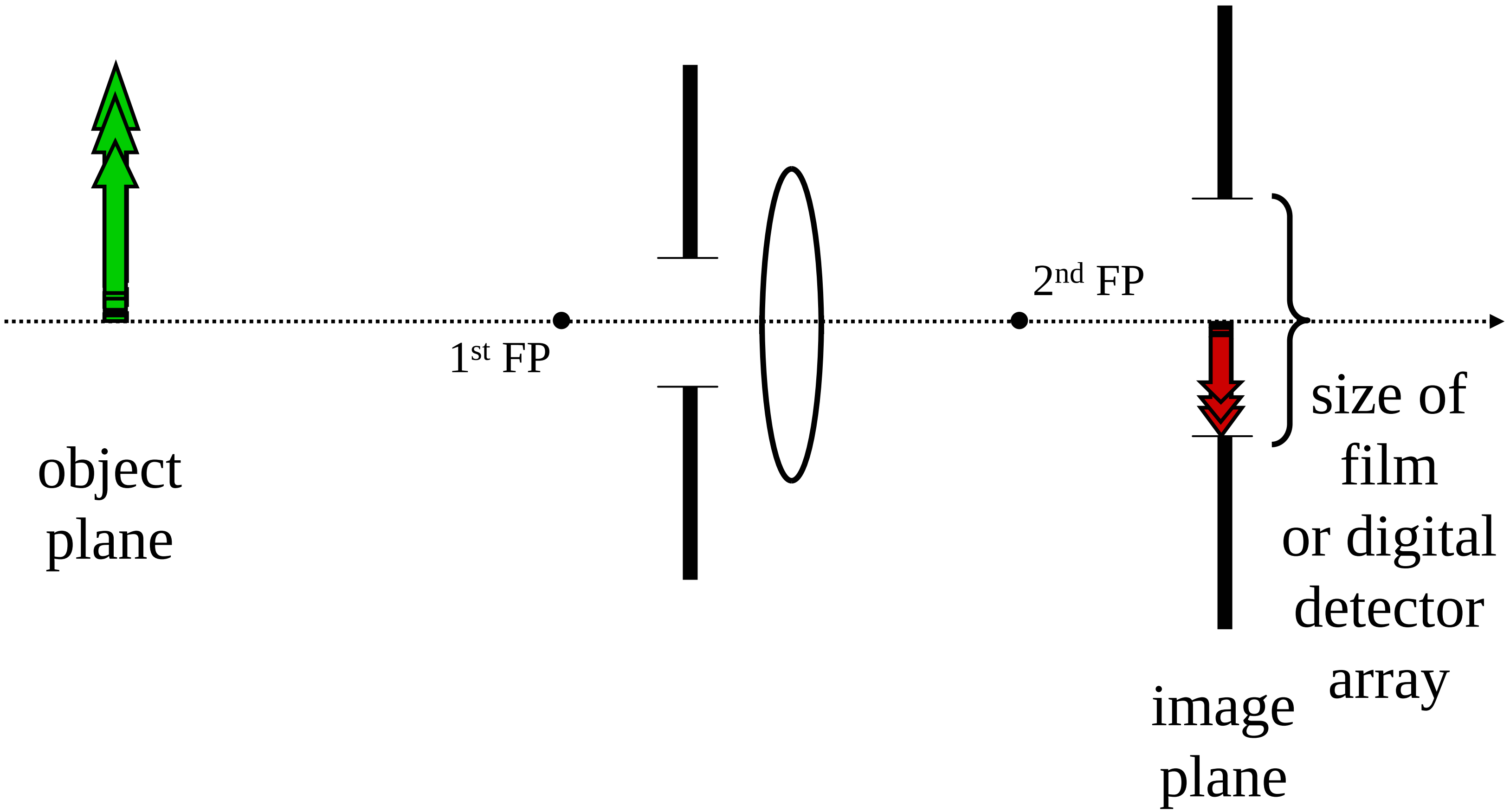
All together



All together



Example: single-lens camera



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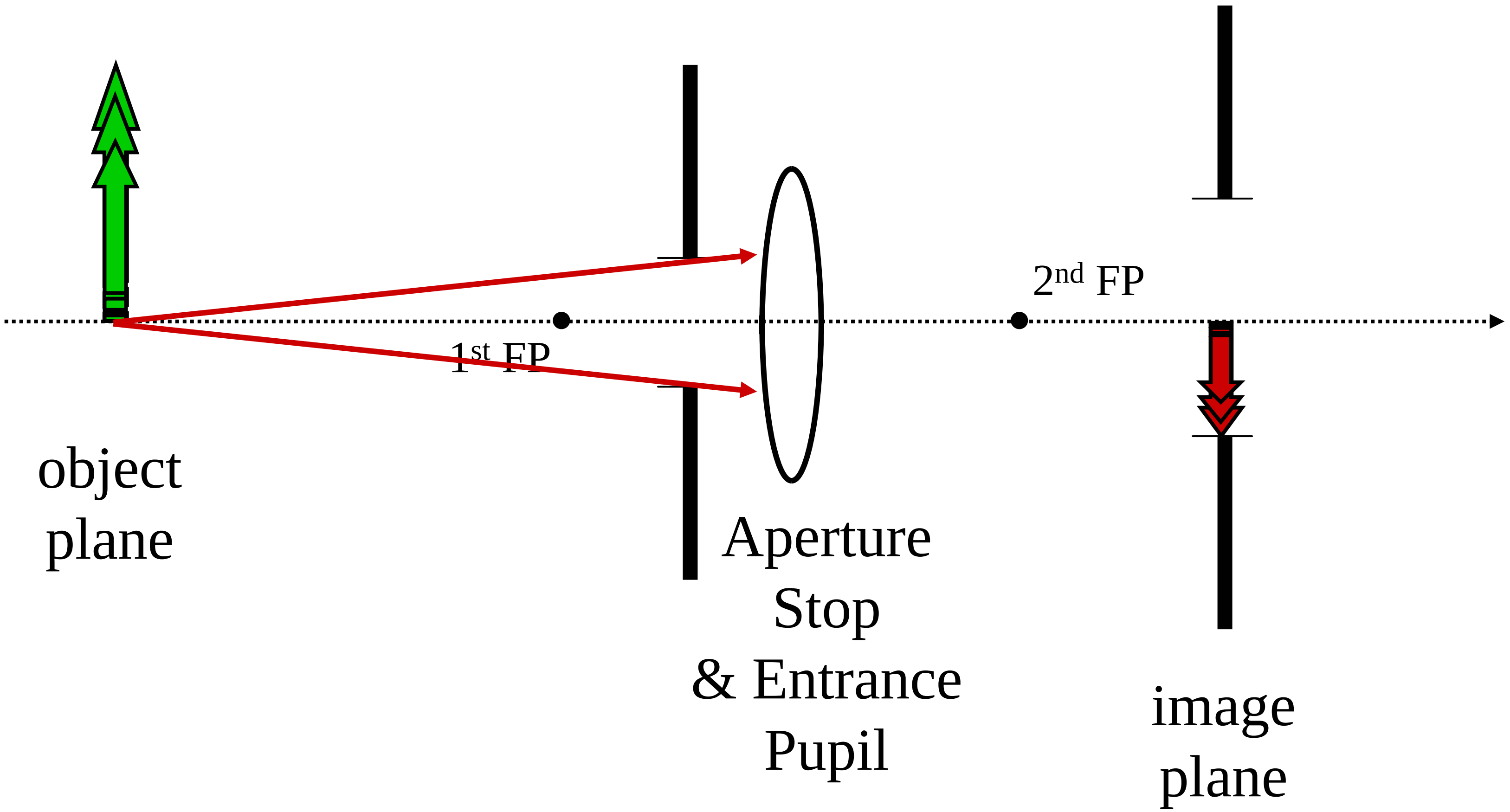

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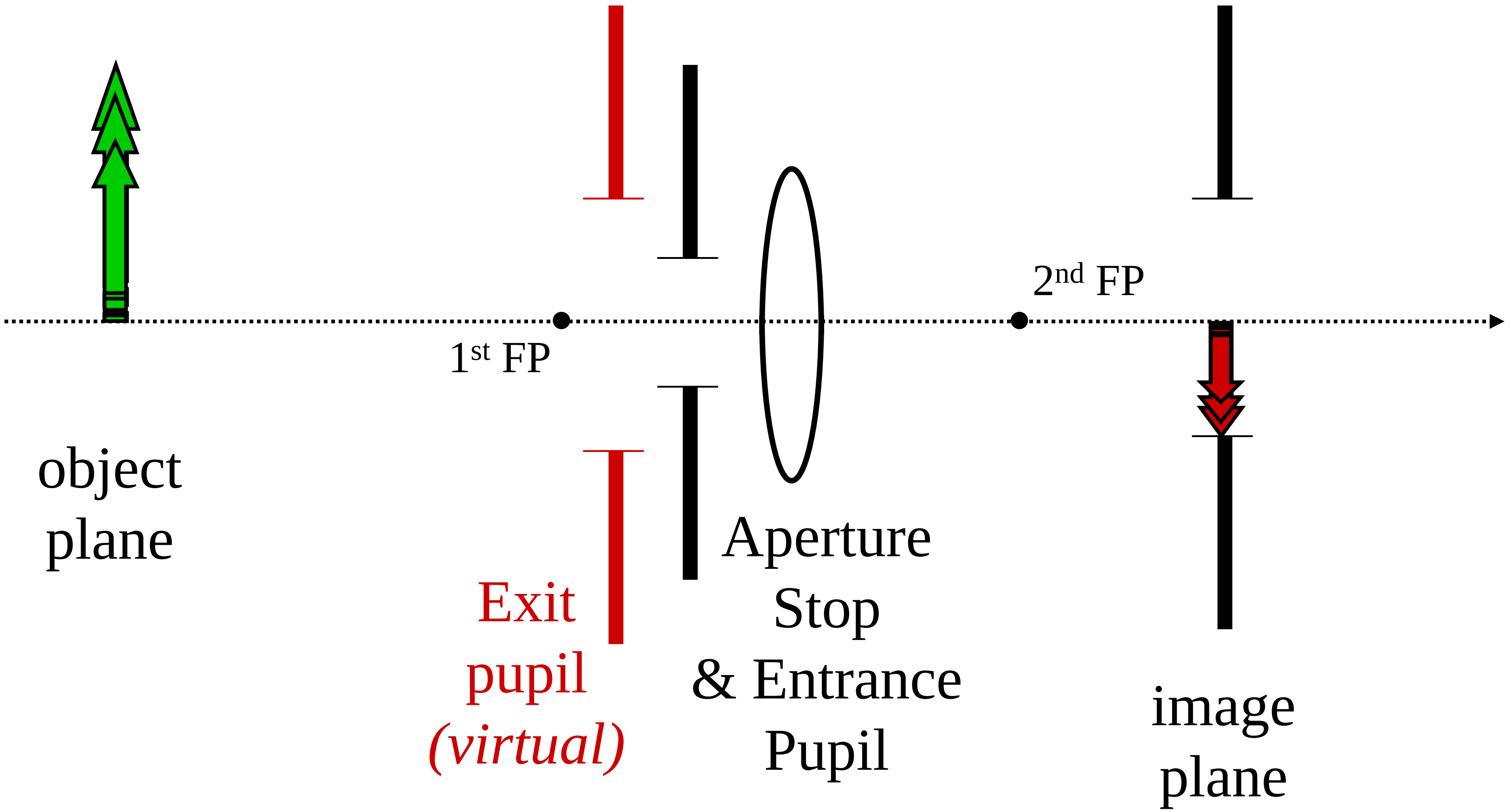

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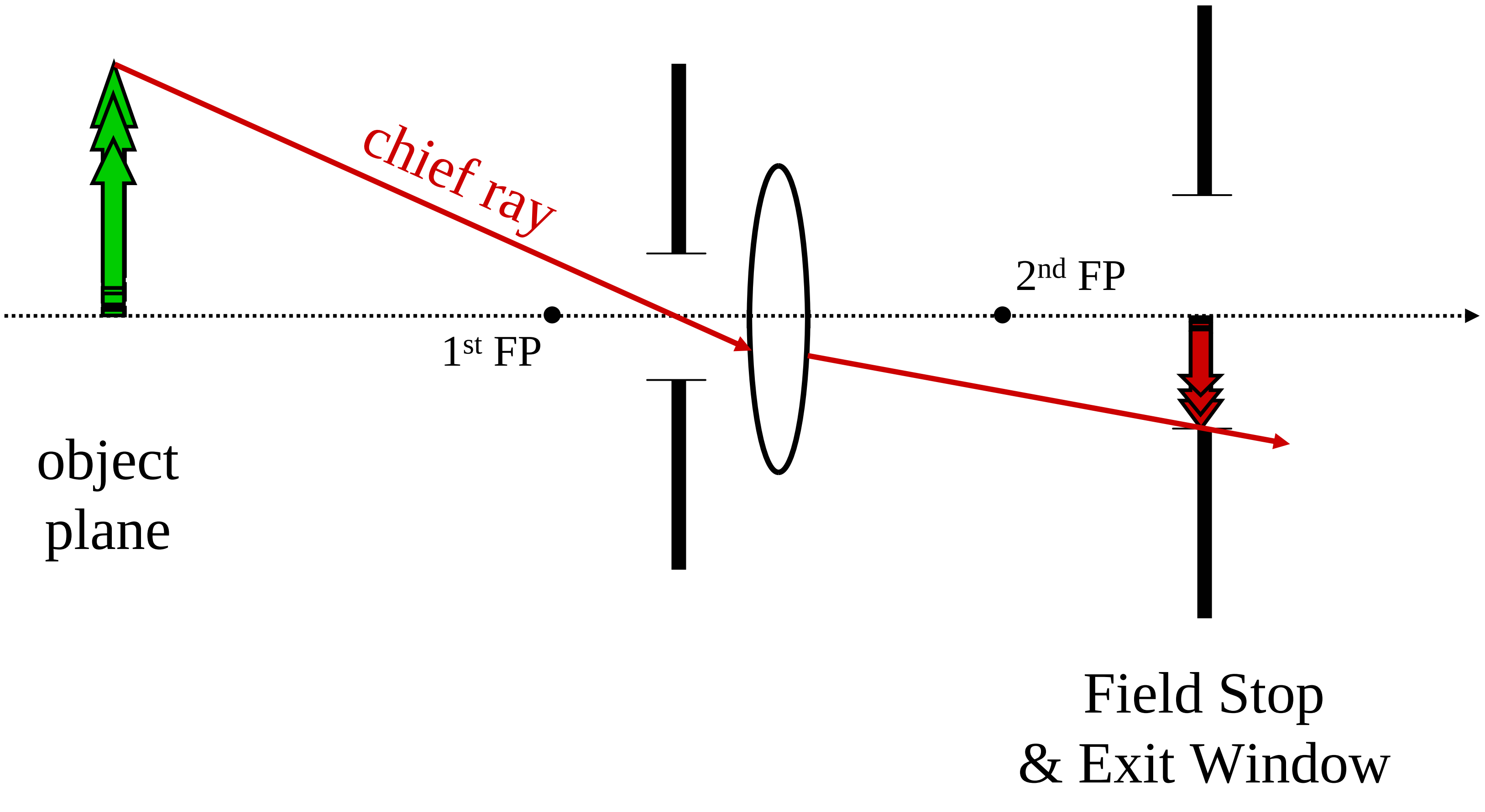
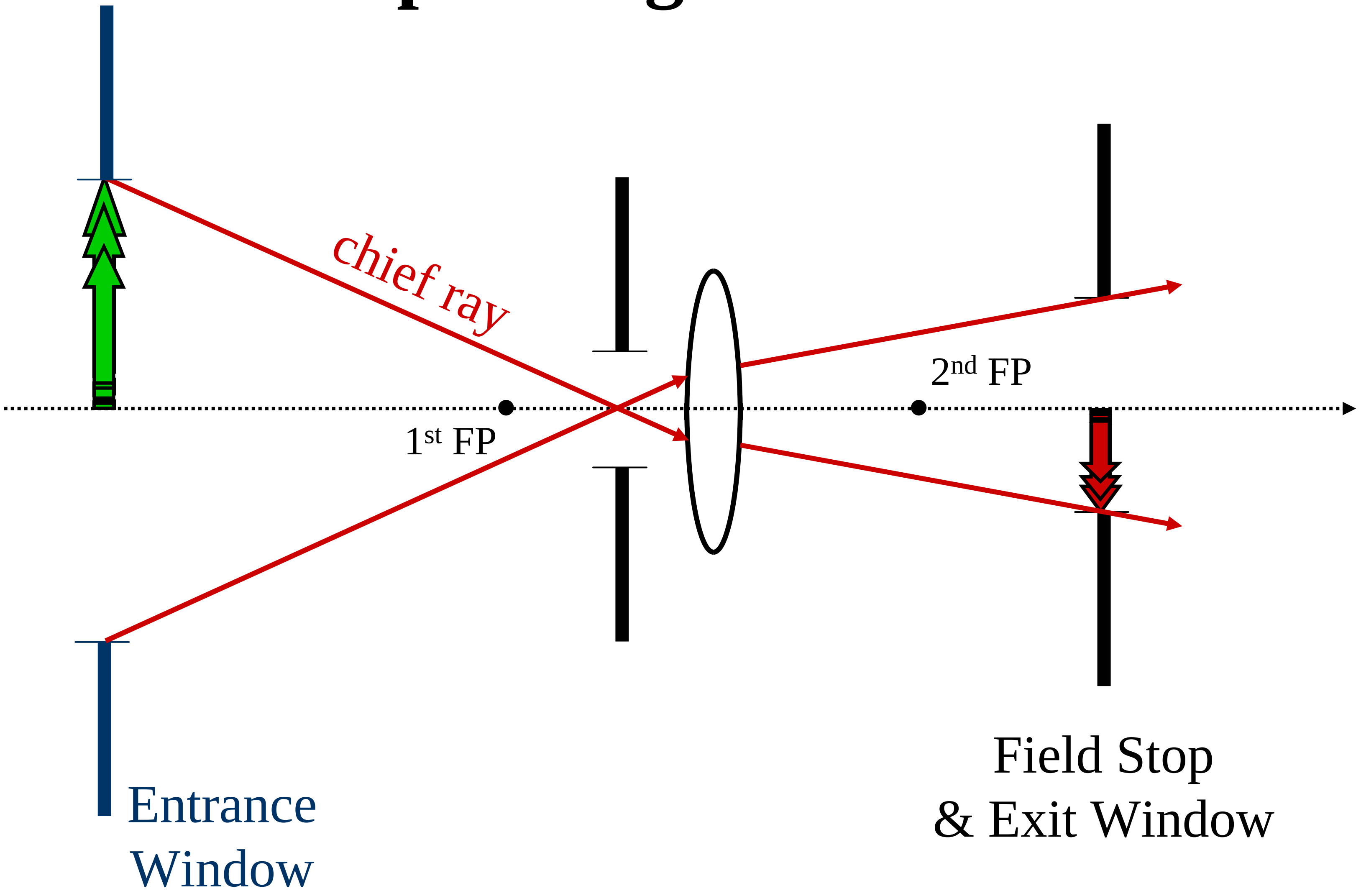
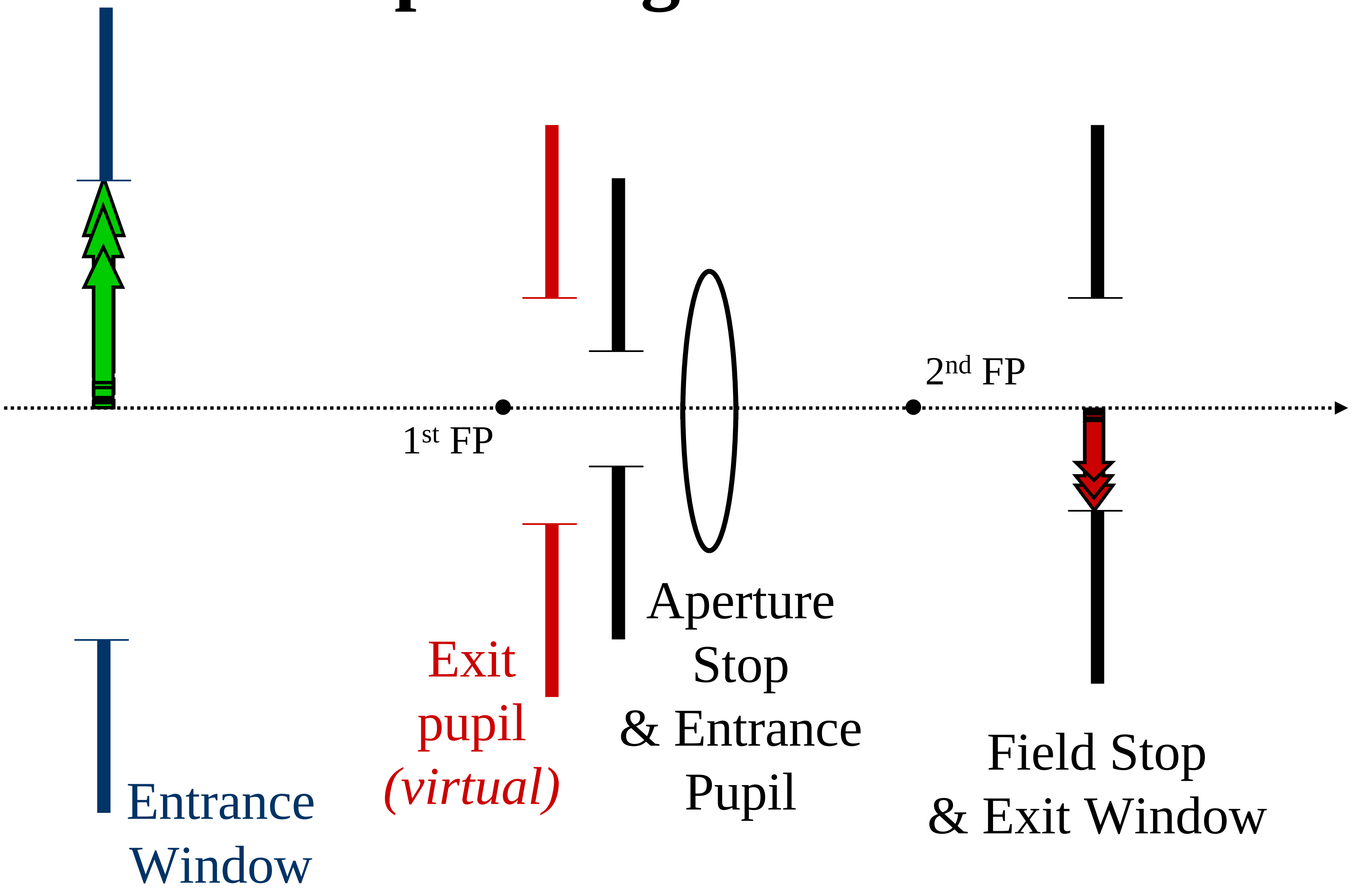


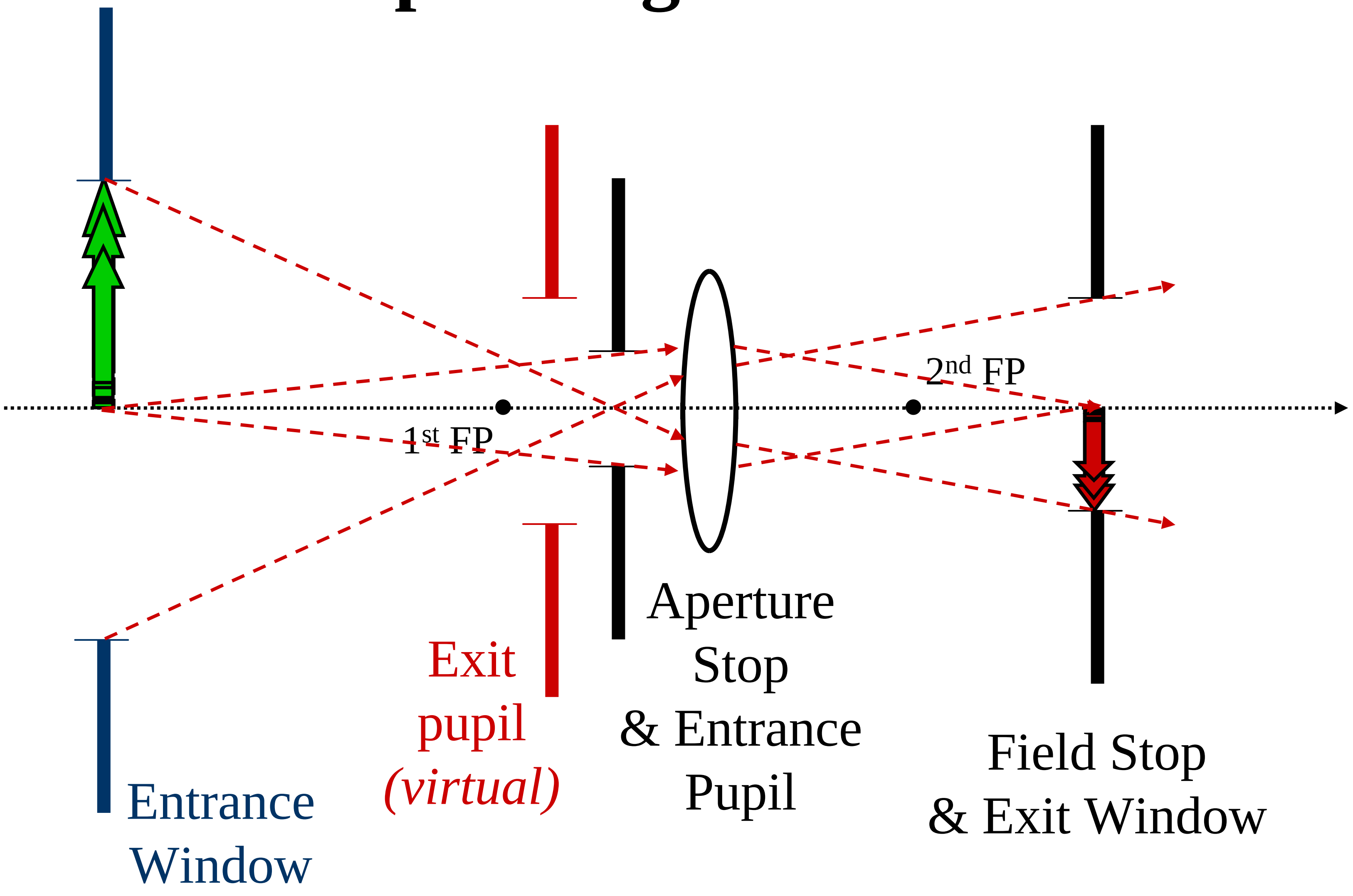
Example: single-lens camera



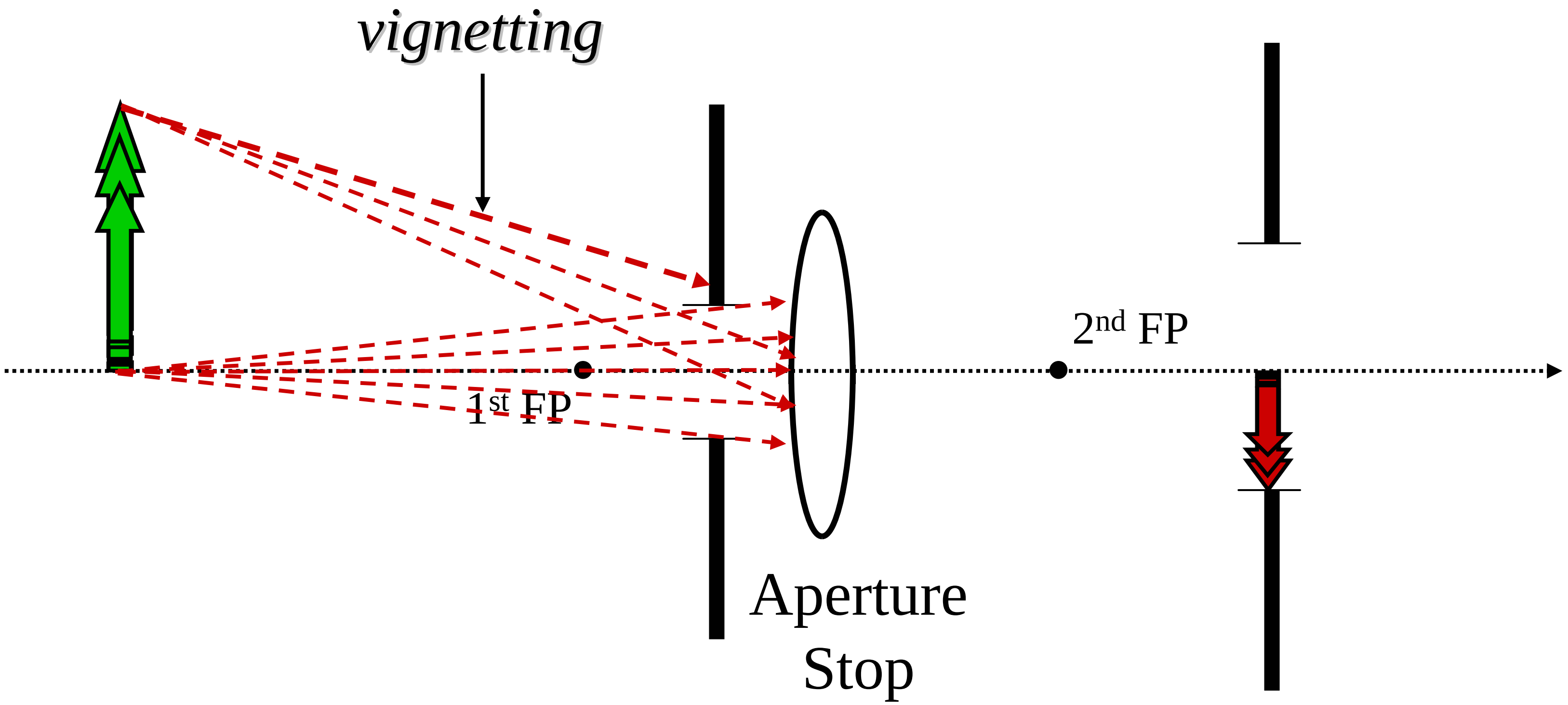
Example: single-lens camera



Example: single-lens camera



Example: single-lens camera



Imaging systems in nature

- “Physical” architecture matches survival requirements and processing capabilities

- Human eye: evolved for
  - adaptivity (e.g. brightness adjustment)
  - transmission efficiency (e.g. mexican hat response)
  - bypass structural defects (e.g. blind spot)
  - other functional requirements (e.g. stereo vision)

- Insect eye: similar, but *much* simpler processor

  (human brain = $\sim 10^{11}$ neurons; insect brain = $\sim 10^{4}$ neurons)

Anatomy of the human eye

Images removed due to copyright concerns

W. J. Smith, “Modern Optical Engineering,” McGraw-Hill

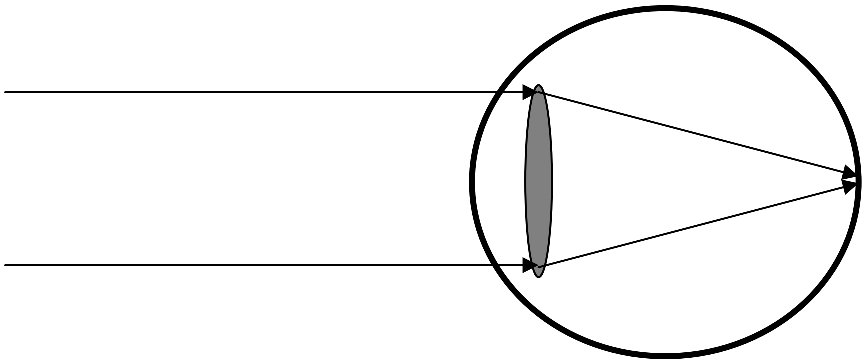
Image removed due to copyright concerns

Eye schematic with typical dimensions

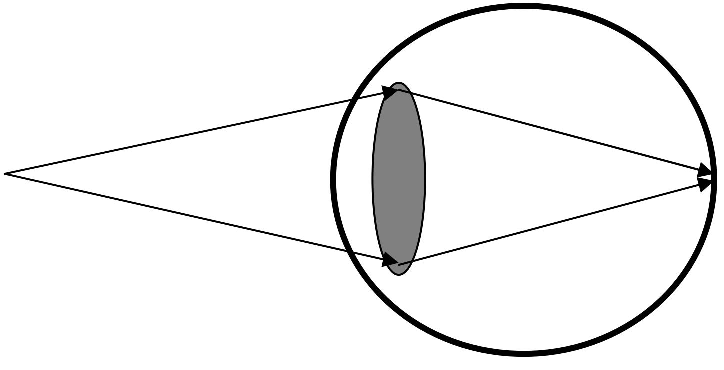
Photographic camera

Image removed due to copyright concerns

Accommodation (focusing)



Remote object (unaccommodated eye)



Proximal object (accommodated eye)

Comfortable viewing up to 2.5cm away from the cornea

Eye defects and their correction

Images removed due to copyright concerns

from *Fundamentals of Optics*
by F. Jenkins & H. White

The eye's "digital camera": retina

Images removed due to copyright concerns

http://www.mdsupport.org

The eye's "digital camera": retina

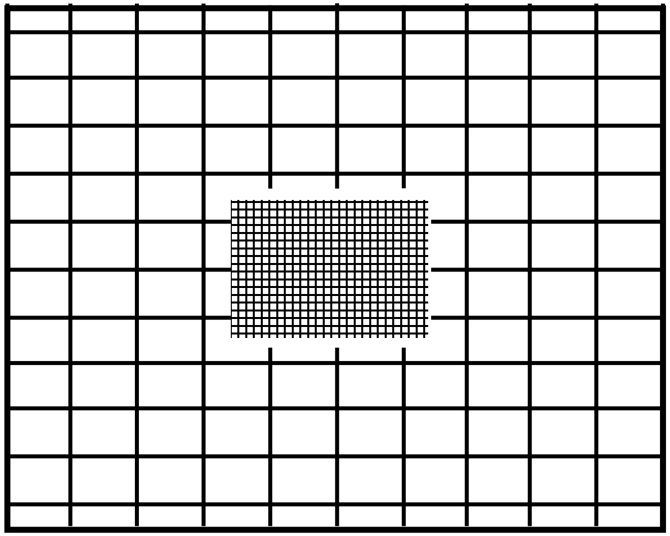
rods: intensity (grayscale) cones: color (R/G/B)

Images removed due to copyright concerns

http://www.phys.ufl.edu/~avery/

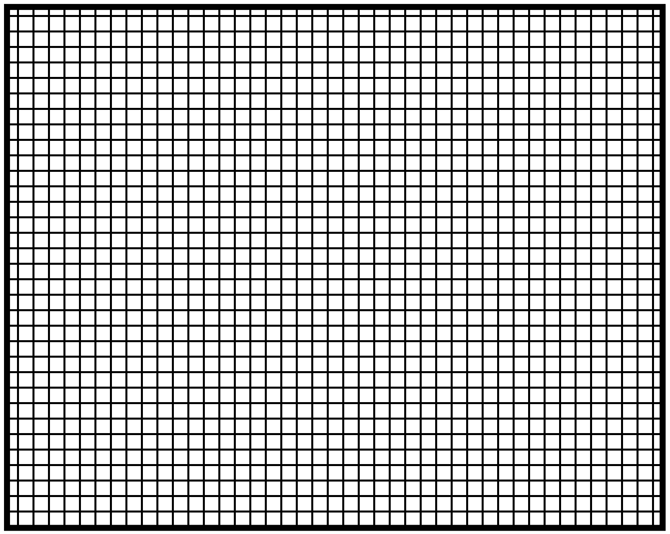
Retina *vs* your digital camera

Retina:
variant sampling rate



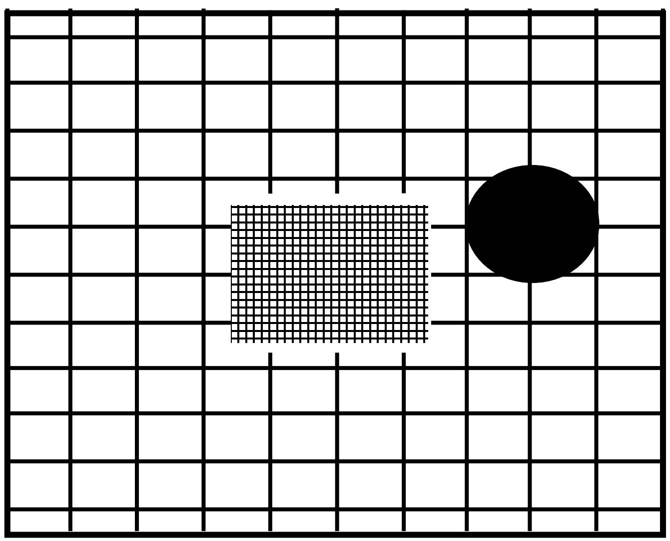
(grossly exaggerated; in actual retina transition from dense to sparse sampling is much smoother)

Digital camera:
fixed sampling rate

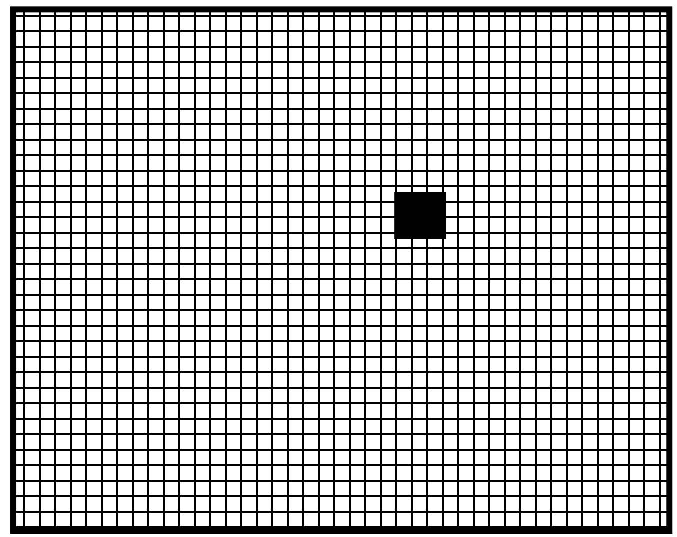


Retina *vs* your digital camera

<u>Retina:</u>
blind spot not noticeable



<u>Digital camera:</u>
bad pixels destructive



Retina *vs* your digital camera

Images removed due to copyright concerns

Retinal image

CCD image

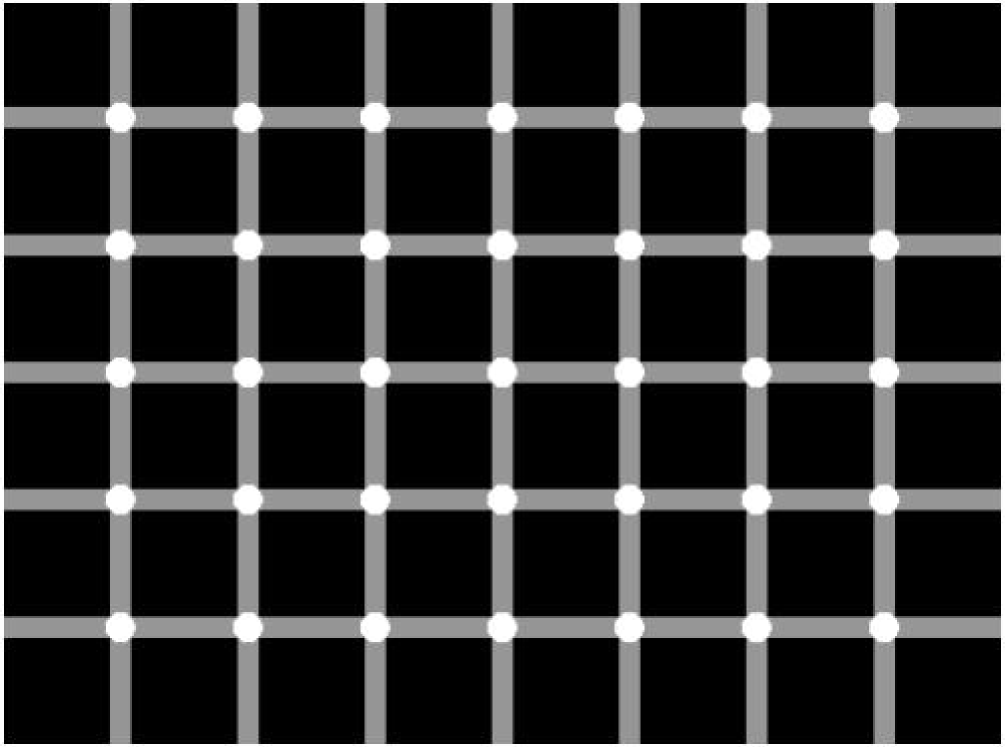
http://www.klab.caltech.edu/~itti/

Spatial response of the retina – lateral connections

Image removed due to copyright concerns

http://webvision.med.utah.edu/

Spatial response of the retina – lateral connections



http://www.phys.ufl.edu/~avery/

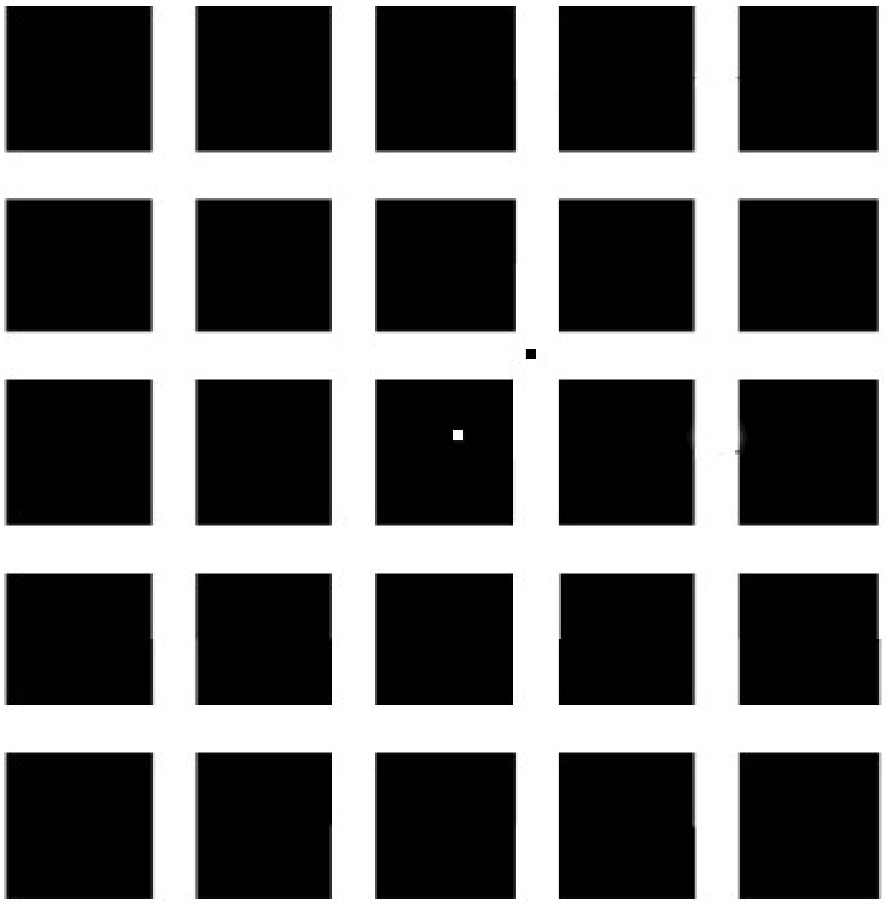
Spatial response of the retina – lateral connections

Explanation of the "flipping dot" illusion: the Mexican hat response

Image removed due to copyright concerns

http://faculty.washington.edu/wcalvin

Temporal response: after-images

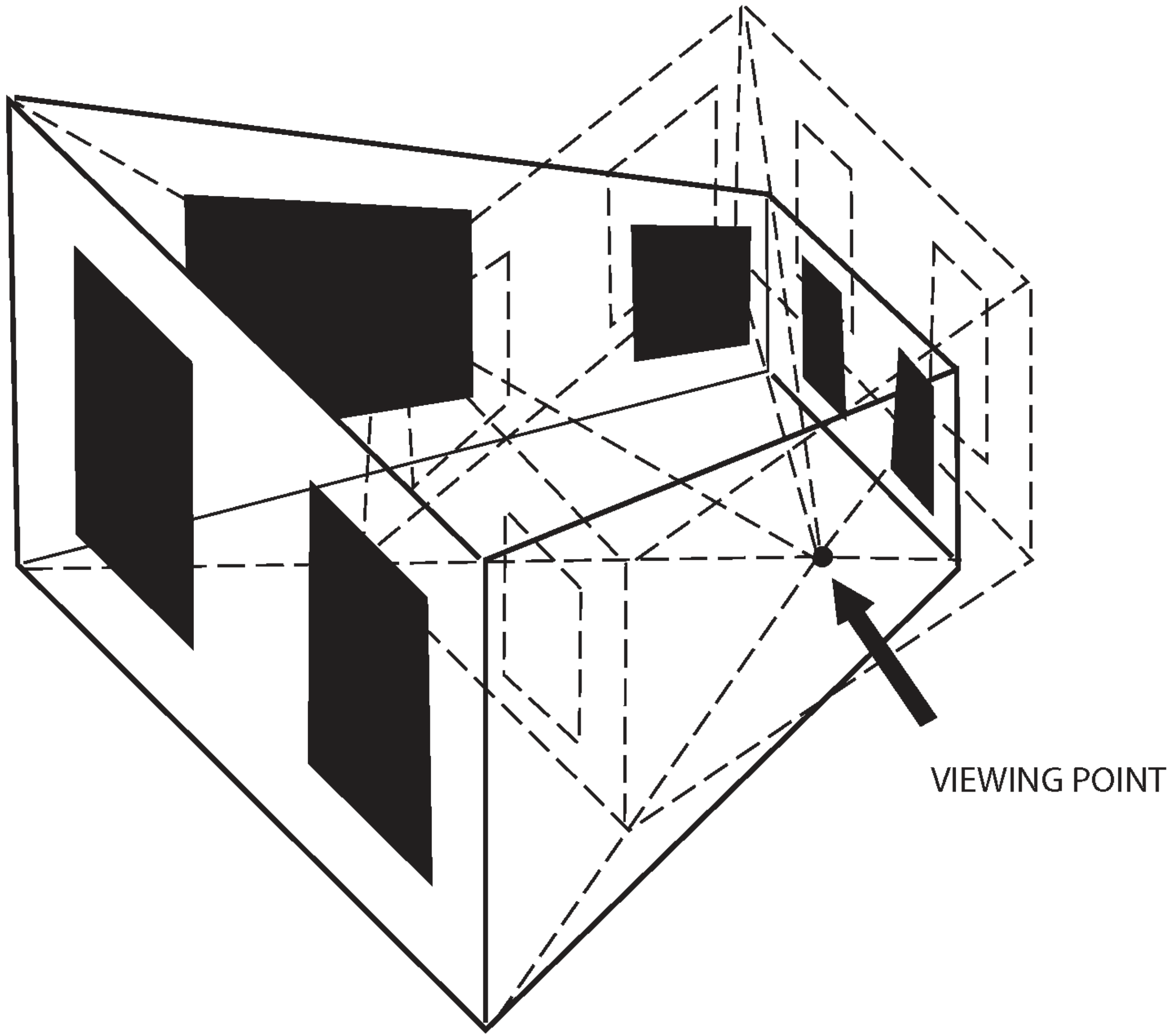


http://dragon.uml.edu/psych/

Seeing 3D

Images removed due to copyright concerns

http://www.ccom.unh.edu/vislab/VisCourse


VIEWING POINT

The compound eye

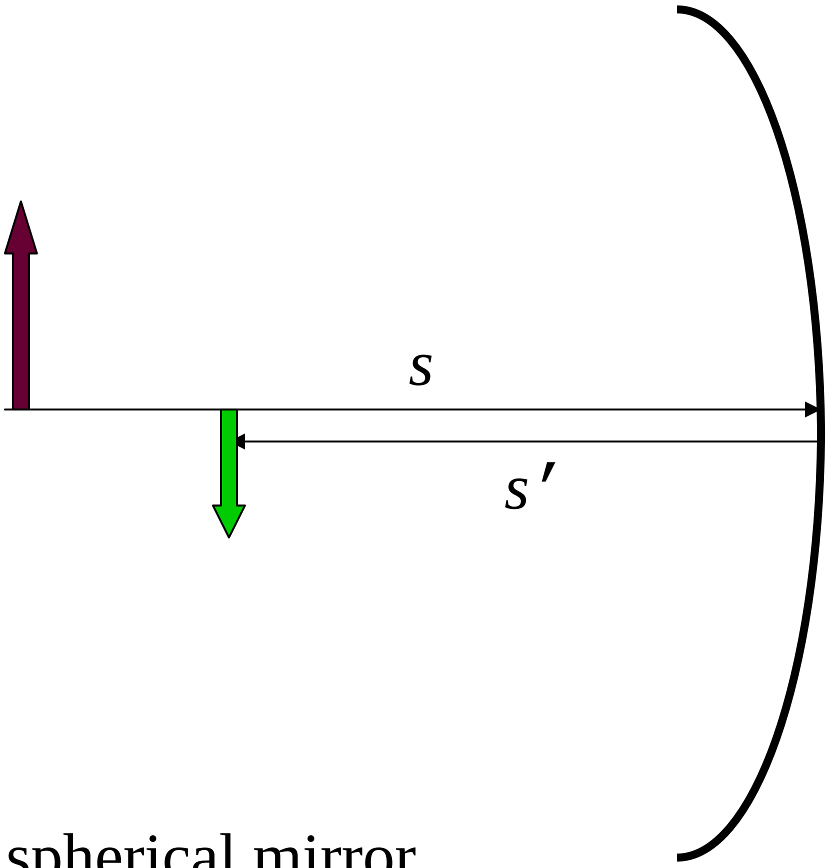
Images removed due to copyright concerns

Elements of the compound eye: ommatidia (=little eyes)

Images removed due to copyright concerns

"image" formation:
blurry, but
computationally efficient
for moving-edge detection

Reflective Optics



Example:
imaging by a spherical mirror

Sign conventions for reflective optics

- Light travels from left to right *before reflection and from right to left after reflection*
- A radius of curvature is positive if the surface is convex towards the left
- Longitudinal distances *before reflection* are positive if pointing to the right; *longitudinal distances after reflection are positive if pointing to the left*
- Longitudinal distances are positive if pointing up
- Ray angles are positive if the ray direction is obtained by rotating the +z axis counterclockwise through an acute angle

Reflective optics formulae

Imaging condition

$$\frac{1}{s}+\frac{1}{s'}=-\frac{2}{R}$$

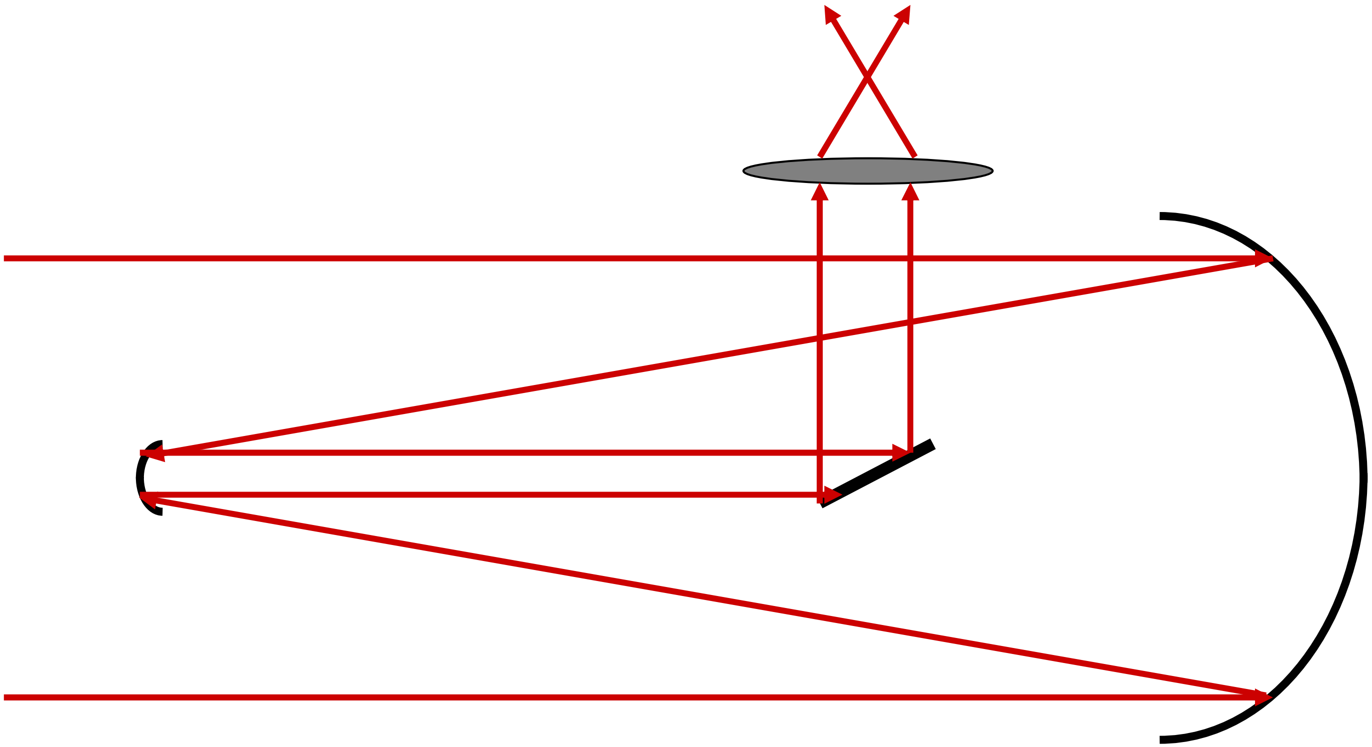
Focal length

$$f=-\frac{R}{2}$$

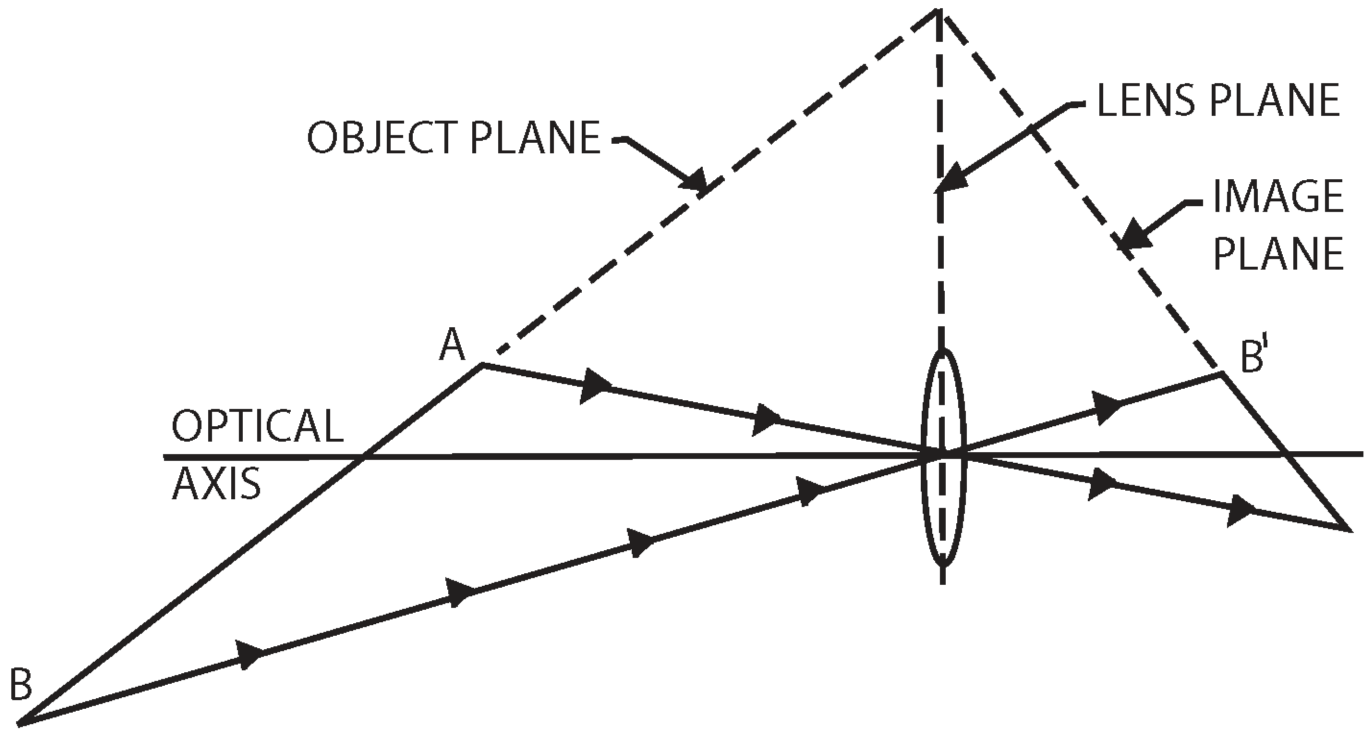
Magnification

$$m_x=-\frac{s'}{s} \qquad m_\alpha=-\frac{s}{s'}$$

The Cassegrain telescope



The Scheimpflug condition



The object plane and the image plane intersect at the plane of the lens.