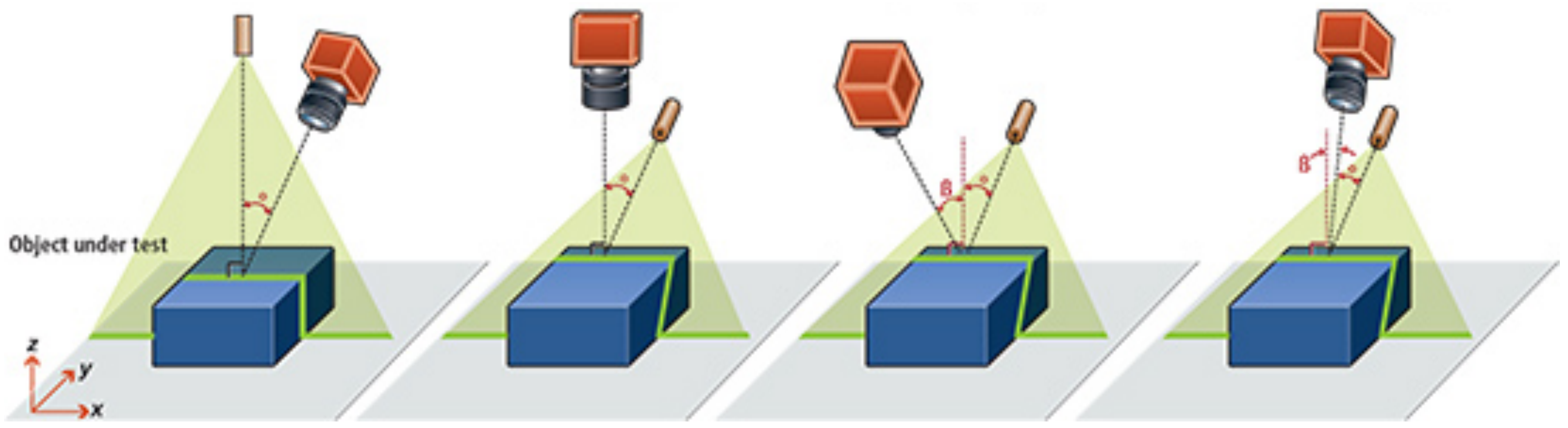
THE UNIVERSITY OF BRITISH COLUMBIA

CPSC 425: Computer Vision



Lecture 3: Image Formation (continued)

(unless otherwise stated slides are taken or adopted from **Bob Woodham, Jim Little** and **Fred Tung**)

Menu for Today (**September 10, 2018**)

Topics:

— Image Formation

— Cameras and **Lenses**

— Projection

— **Human eye** (as camera)

Redings:

— **Today's** Lecture: Forsyth & Ponce (2nd ed.) 1.1.1 — 1.1.3

— **Next** Lecture: Forsyth & Ponce (2nd ed.) 4.1, 4.5

Reminders:

— Complete **Assignment 0** (ungraded) by Wednsday, **September 12**

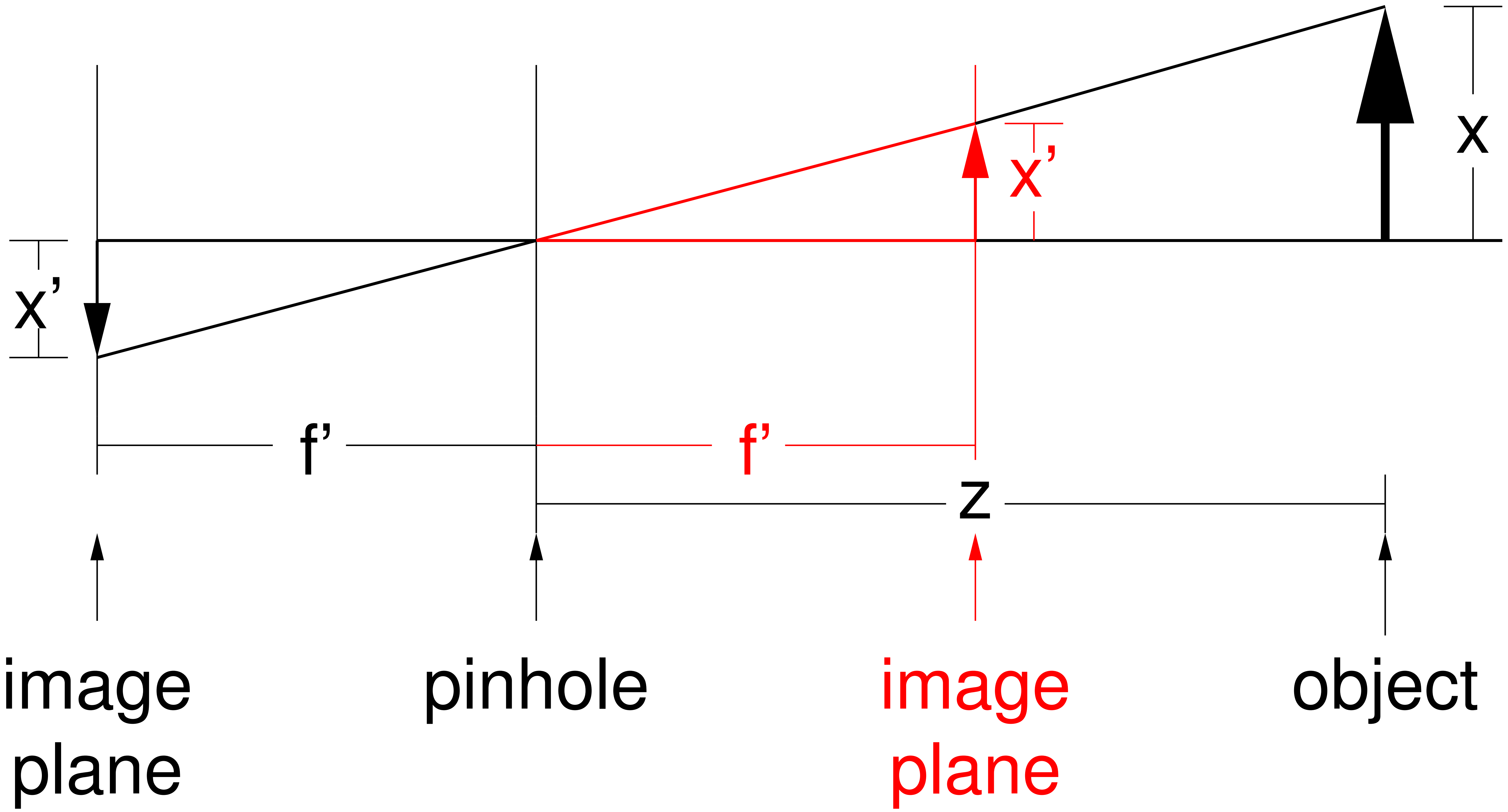
— **Assignment 1** will be out, **September 12**

Today's "fun" Example: **Automimicity**

Image Credit: https://en.wikipedia.org/wiki/File:Peablue_October_2007_Osaka_Japan.jpg

Lecture 2: Re-cap

Pinhole Camera Abstraction



Lecture 2: Re-cap

3D object point $P = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$ projects to 2D image point $P' = \begin{bmatrix} x' \\ y' \end{bmatrix}$ where

Perspective	$x' = f' \frac{x}{z}$ $y' = f' \frac{y}{z}$
Weak Perspective	$x' = m\,x$ $y' = m\,y$ $m = \frac{f'}{z_0}$
Orthographic	$x' = x$ $y' = y$

Projection Models: Pros and Cons

Weak perspective (including orthographic) has simpler mathematics

— accurate when object is small and/or distant

— useful for recognition

Perspective is more accurate for real scenes

When **maximum accuracy** is required, it is necessary to model additional details of a particular camera

— use perspective projection with additional parameters (e.g., lens distortion)

Why **Not** a Pinhole Camera?

— If pinhole is **too big** then many directions are averaged, blurring the image

— If pinhole is **too small** then diffraction becomes a factor, also blurring the image

— Generally, pinhole cameras are **dark**, because only a very small set of rays from a particular scene point hits the image plane

— Pinhole cameras are **slow**, because only a very small amount of light from a particular scene point hits the image plane per unit time

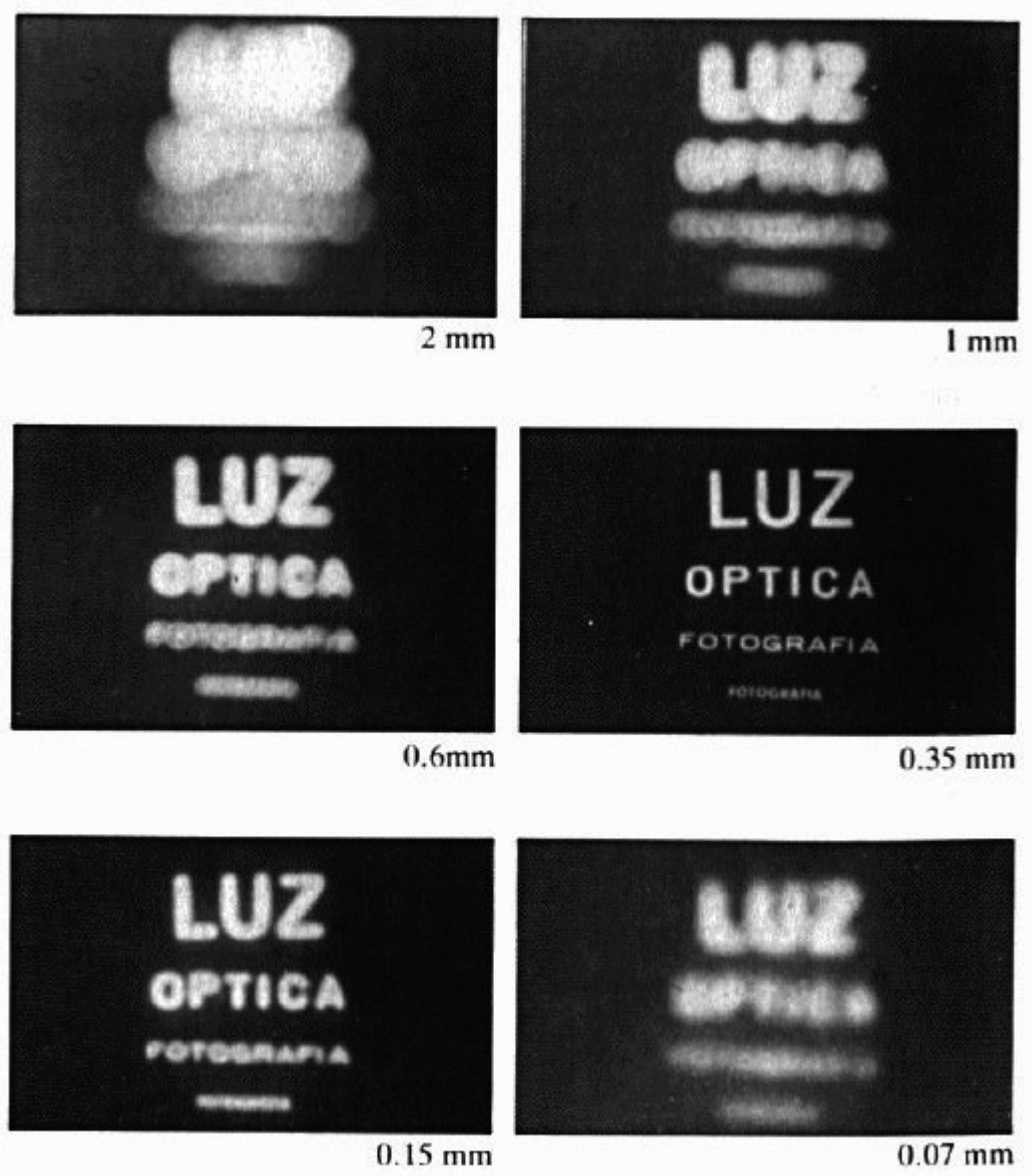
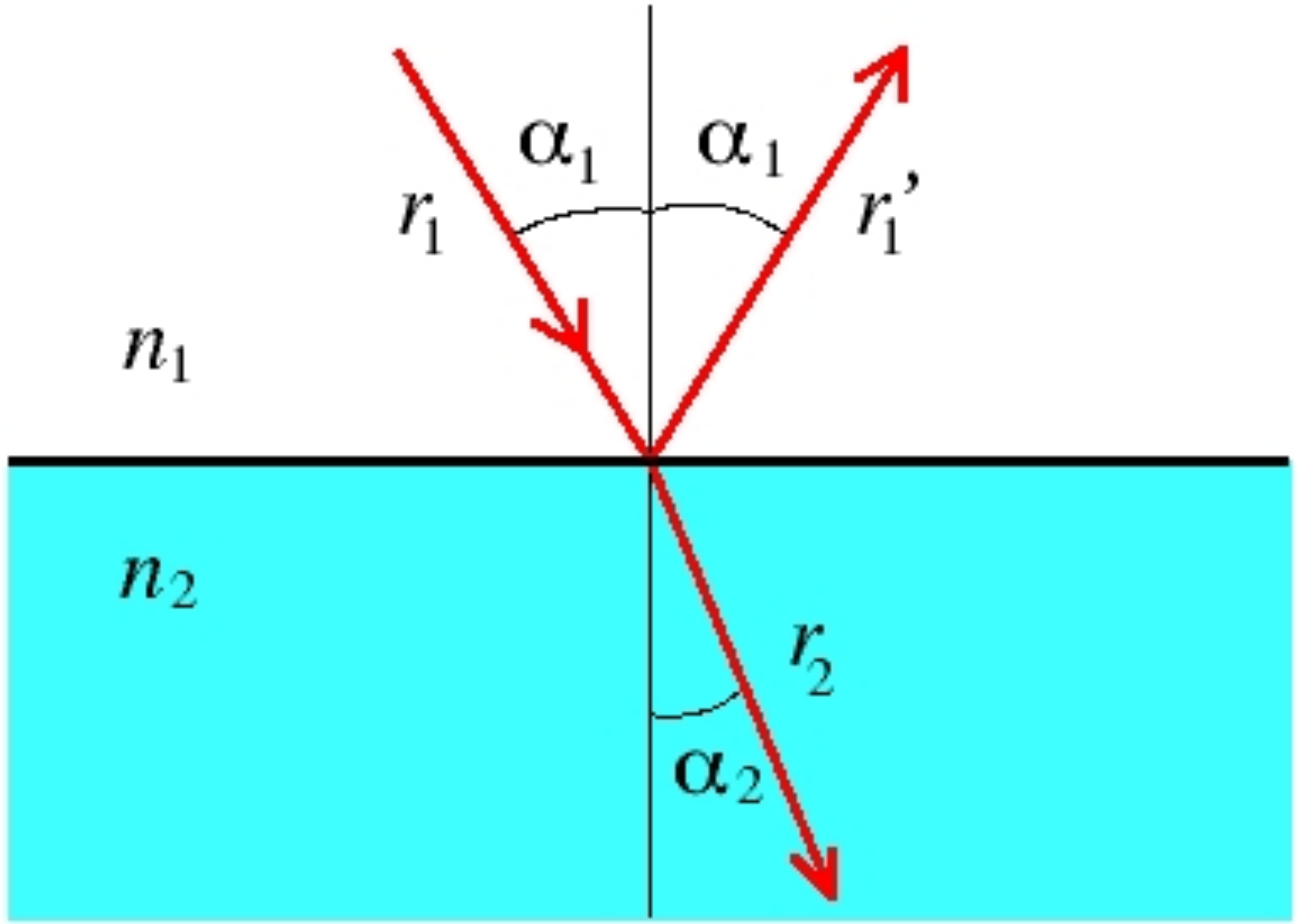


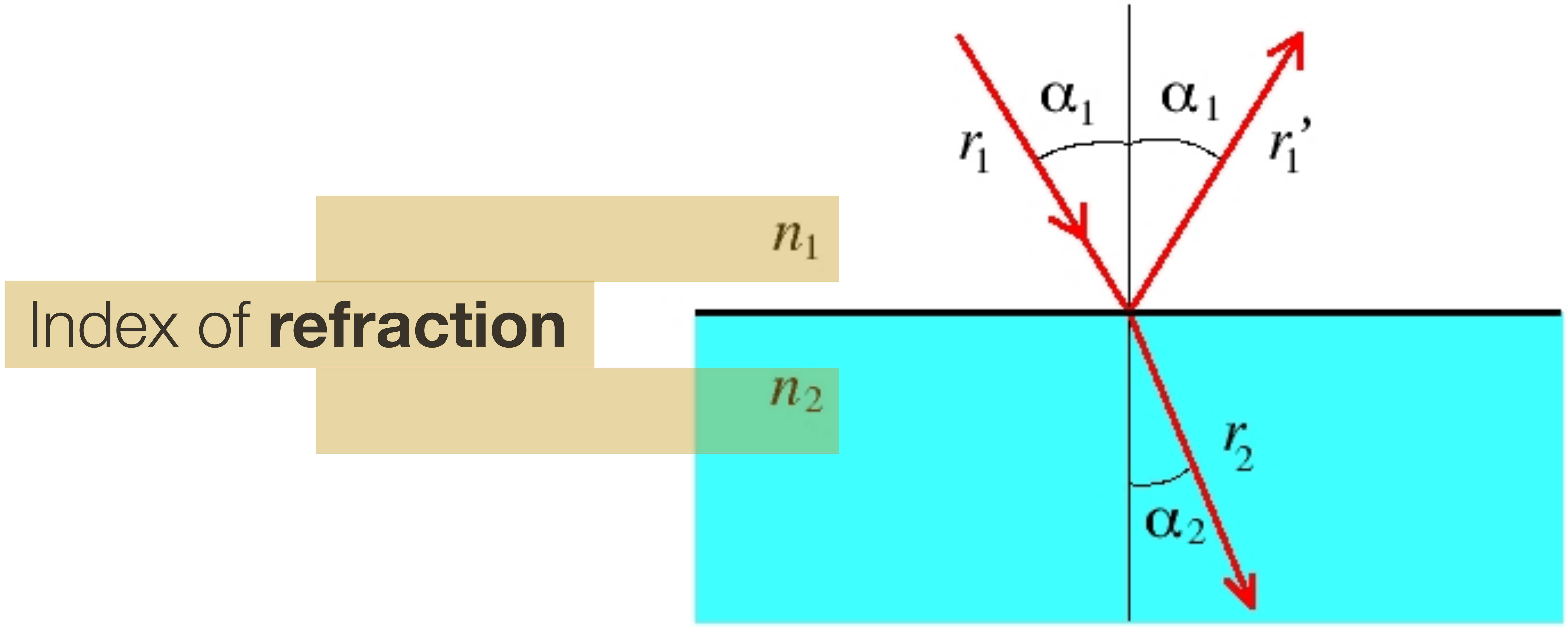
Image Credit: Credit: E. Hecht. “Optics,” Addison-Wesley, 1987

Snell's Law



$$n_1 \sin \alpha_1 = n_2 \sin \alpha_2$$

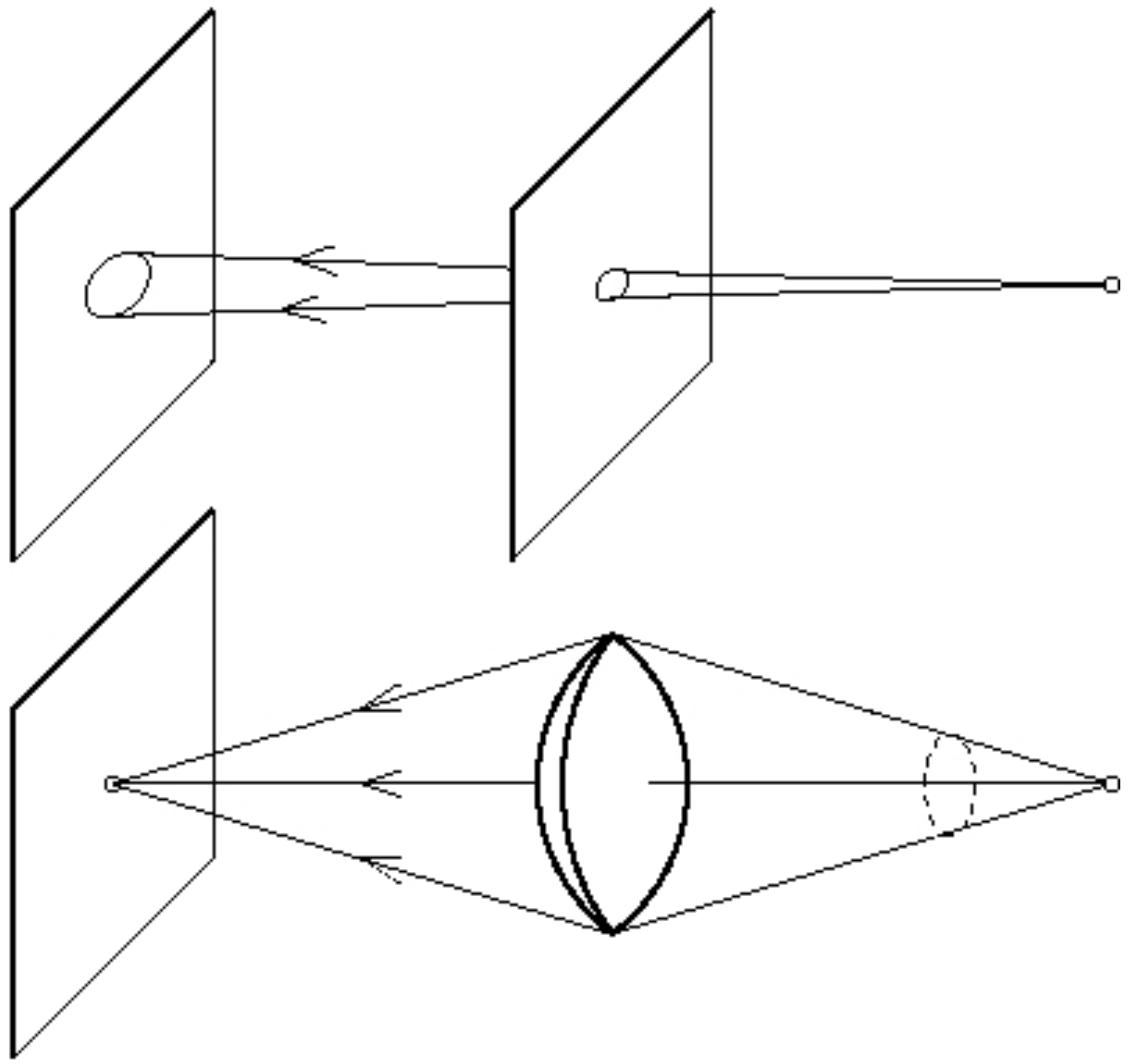
Snell's Law



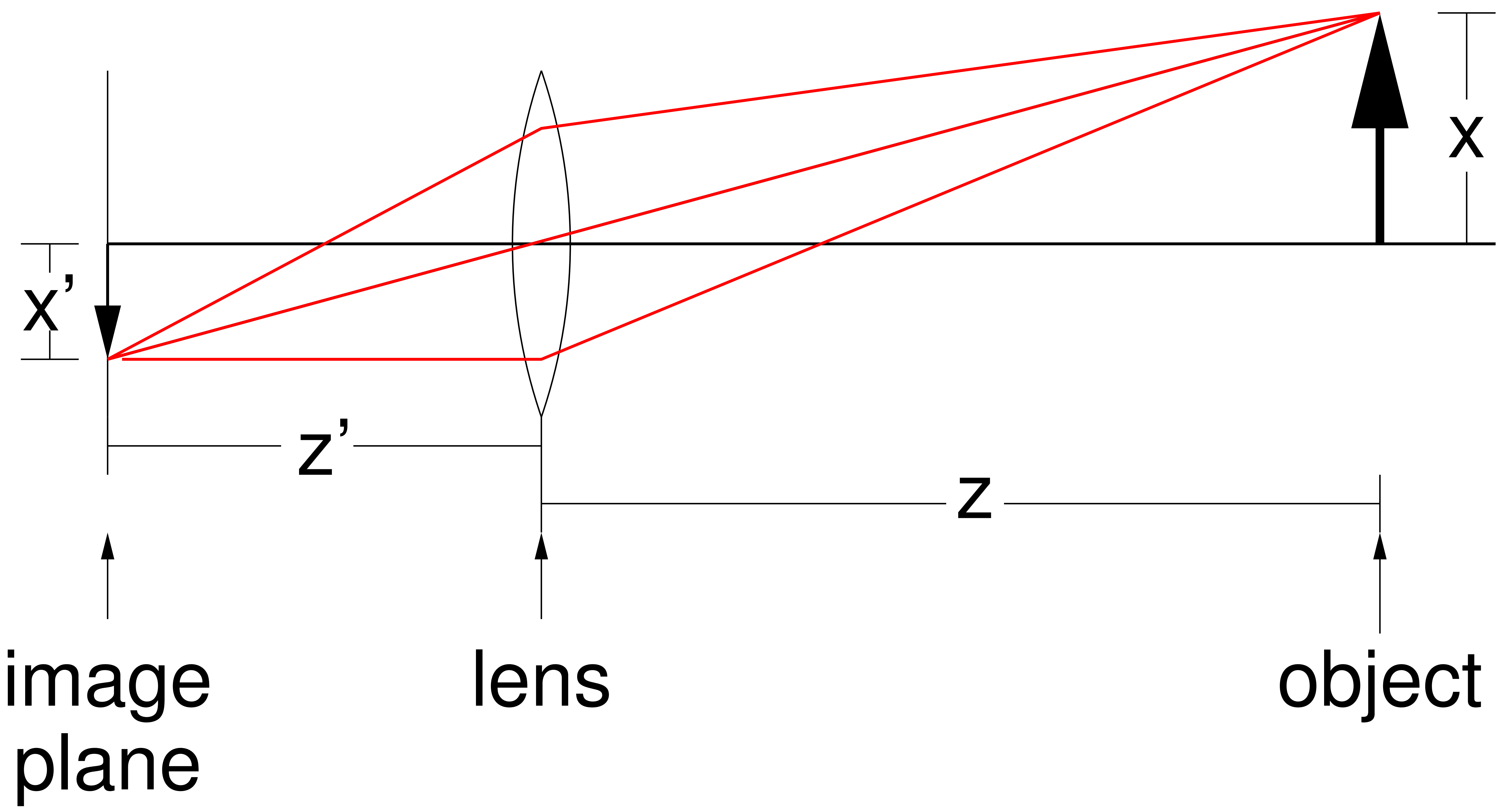
$$n_1 \sin \alpha_1 = n_2 \sin \alpha_2$$

Reason for **Lenses**

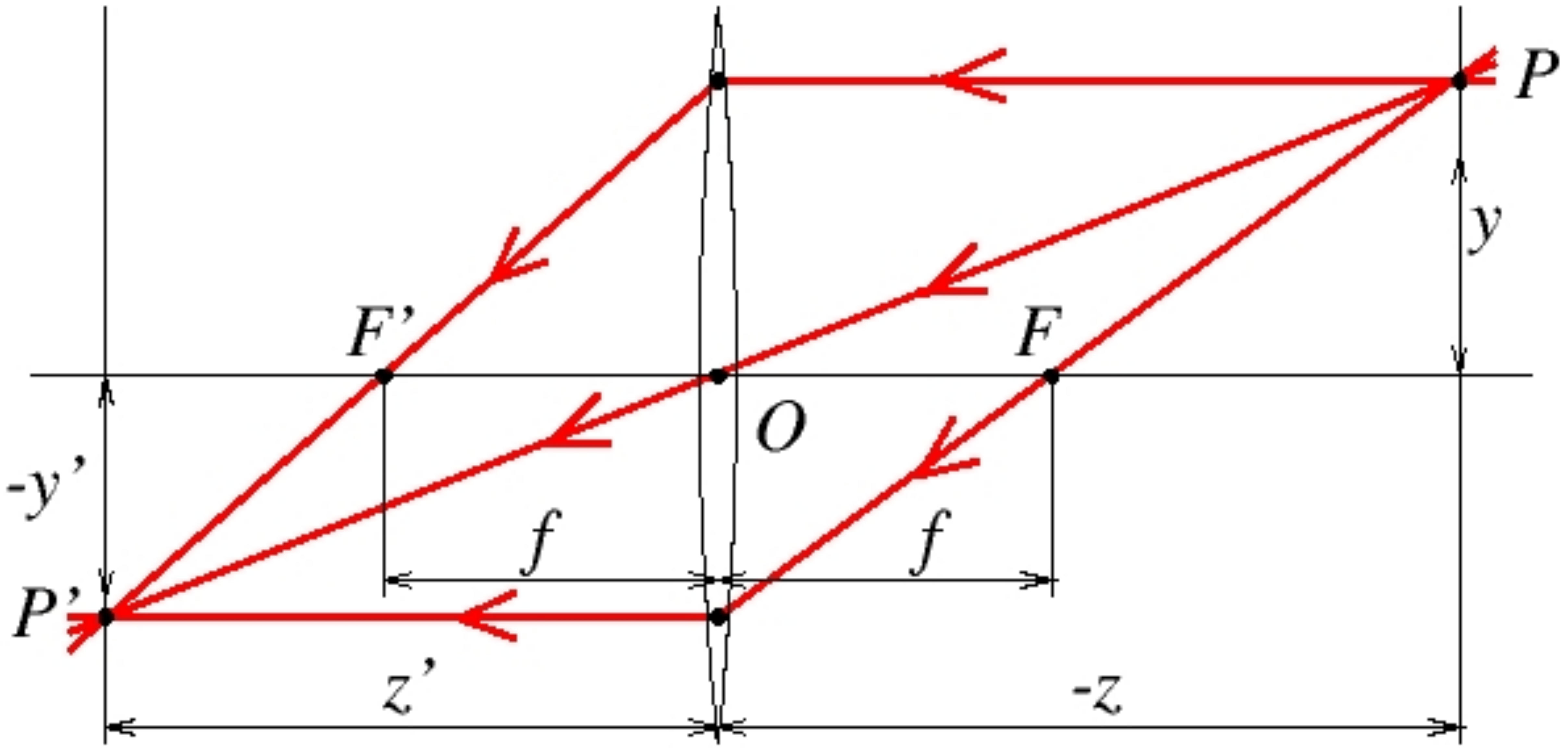
The role of a lens is to **capture more light** while preserving, as much as possible, the abstraction of an ideal pinhole camera.



Pinhole Model (Simplified) **with Lens**



Thin Lens Equation



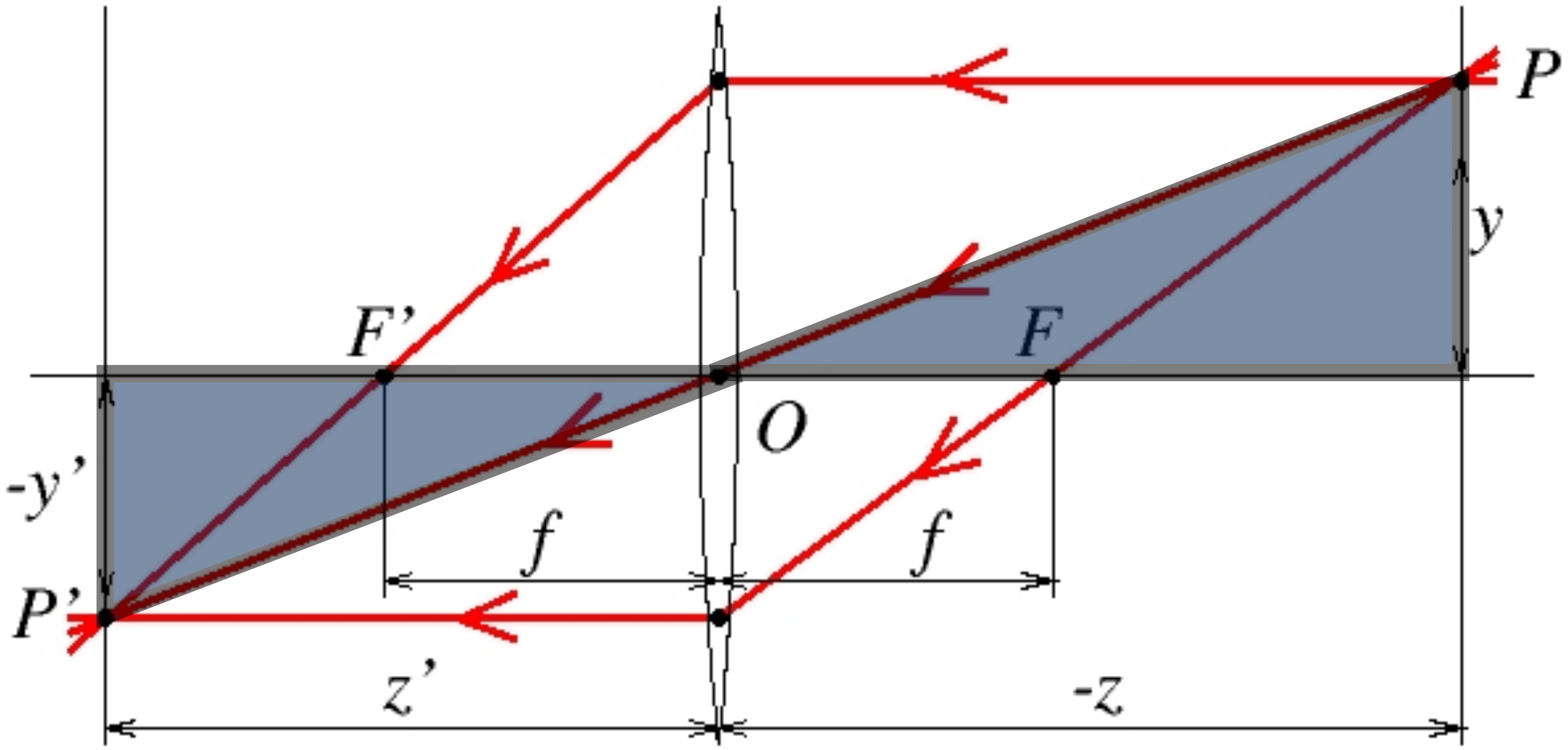
Forsyth & Ponce (1st ed.) Figure 1.9

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

Thin Lens Equation: Derivation

$$\frac{y}{-z} = \frac{-y'}{z'}$$

$$\frac{y}{y'} = \frac{z}{z'}$$



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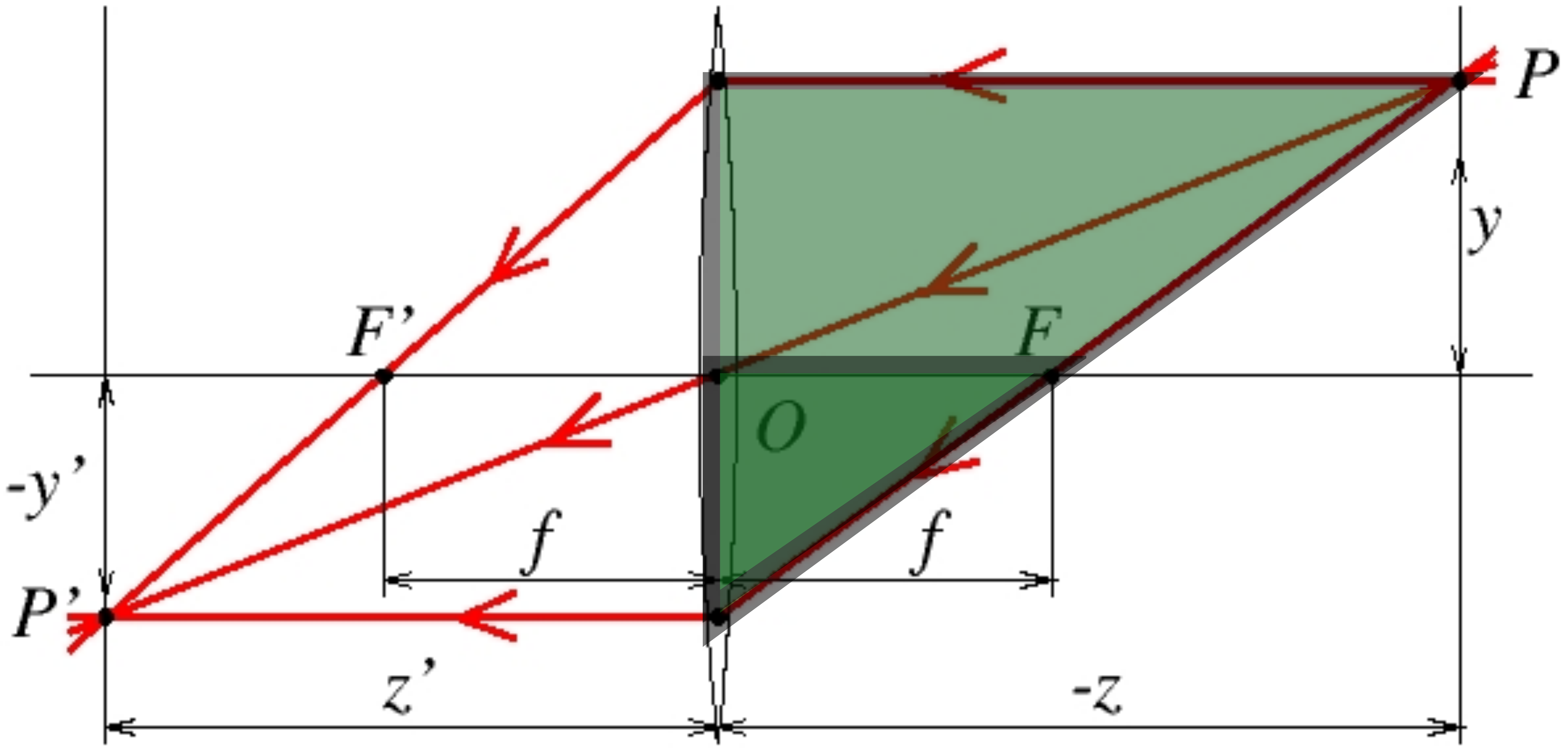

Forsyth & Ponce (1st ed.) Figure 1.9

$$\frac{-y'}{f} = \frac{y - y'}{-z}$$

$$\frac{1}{f} = \frac{y - y'}{zy'}$$

$$= \frac{y}{zy'} - \frac{y'}{zy'}$$

$$= \frac{y}{zy'} - \frac{1}{z}$$

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

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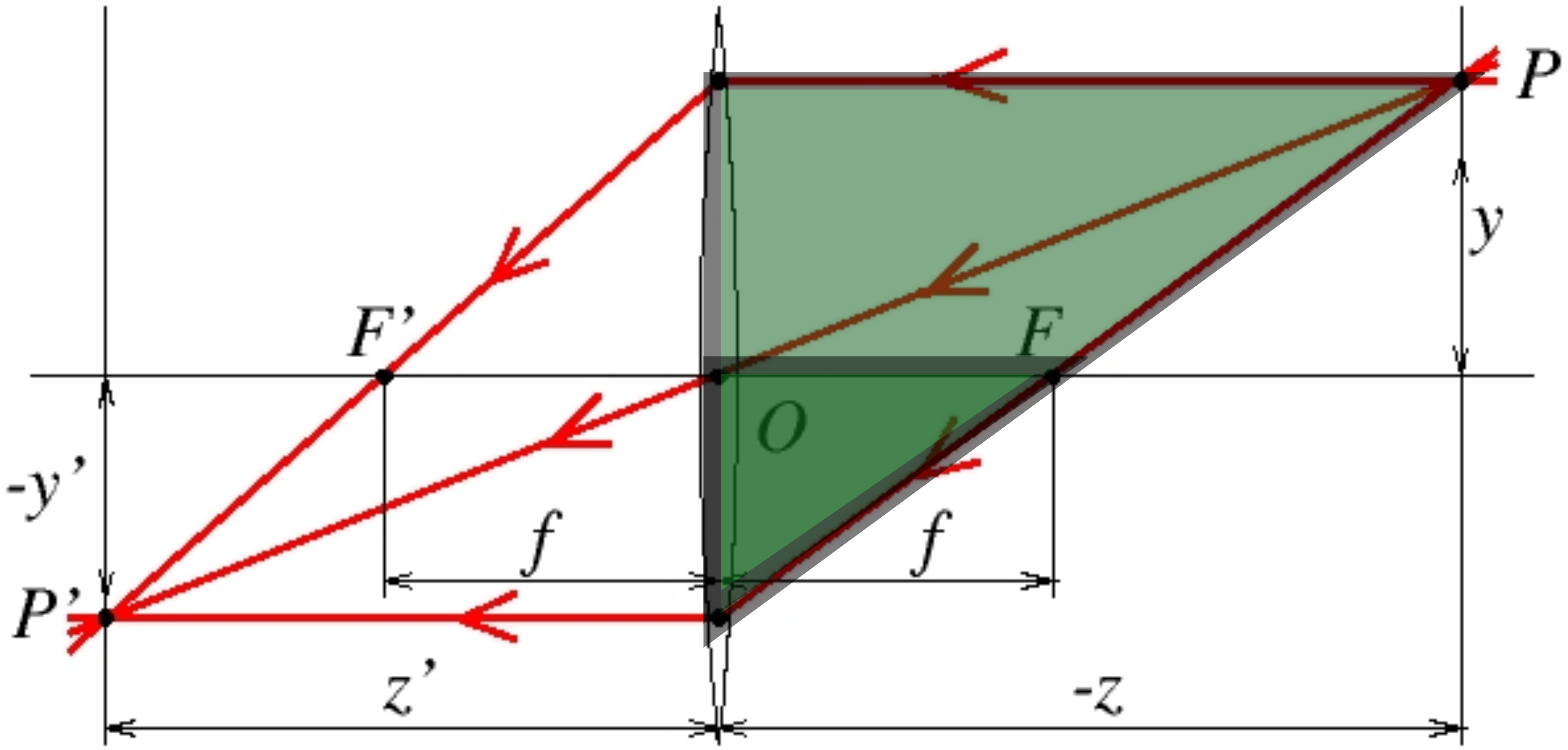

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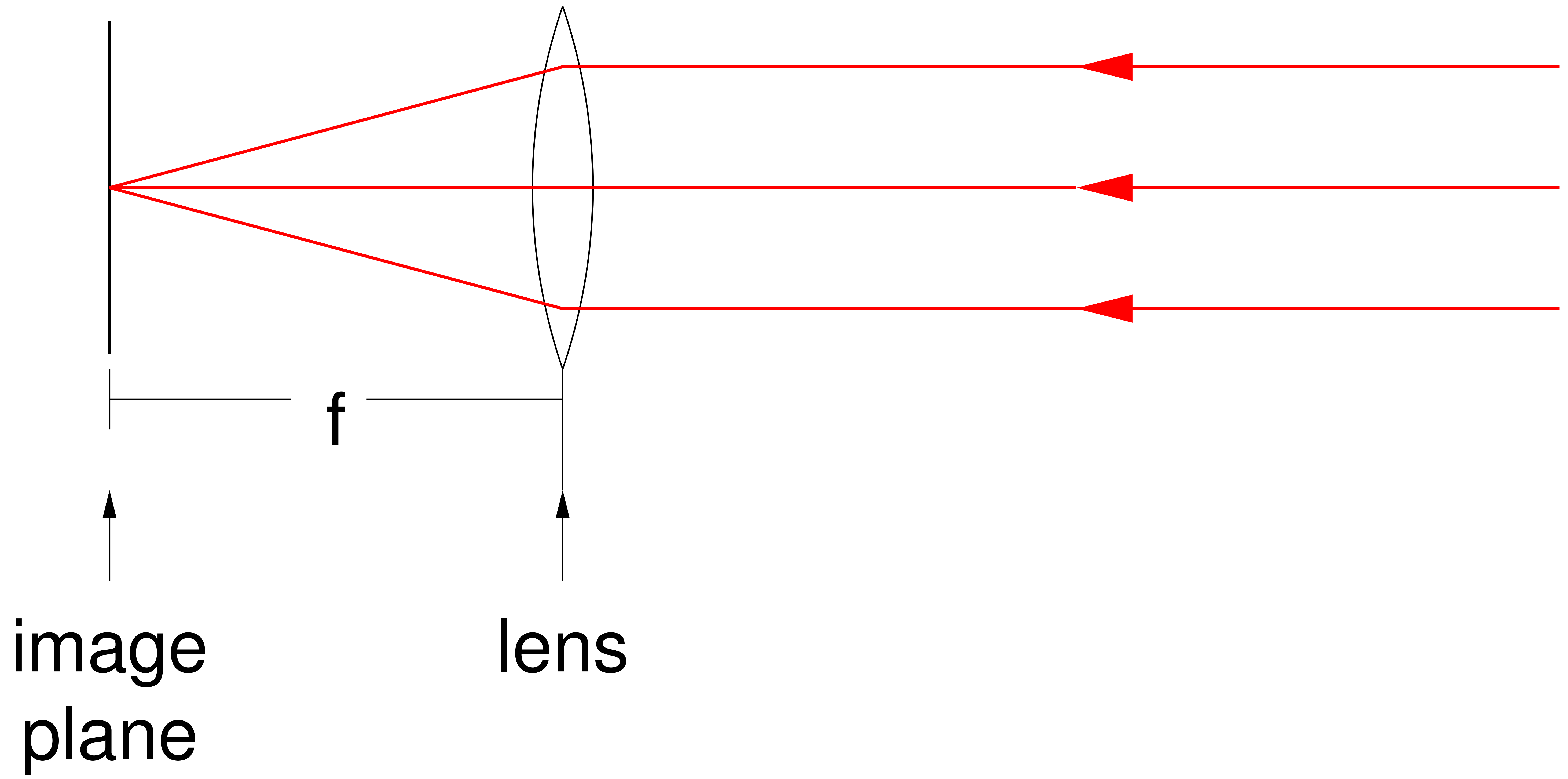
$$= \frac{y}{zy'} - \frac{1}{z}$$

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

Substitute: $\frac{1}{f} = \frac{1}{\cancel{z}}\frac{\cancel{z}}{z'} - \frac{1}{z}$

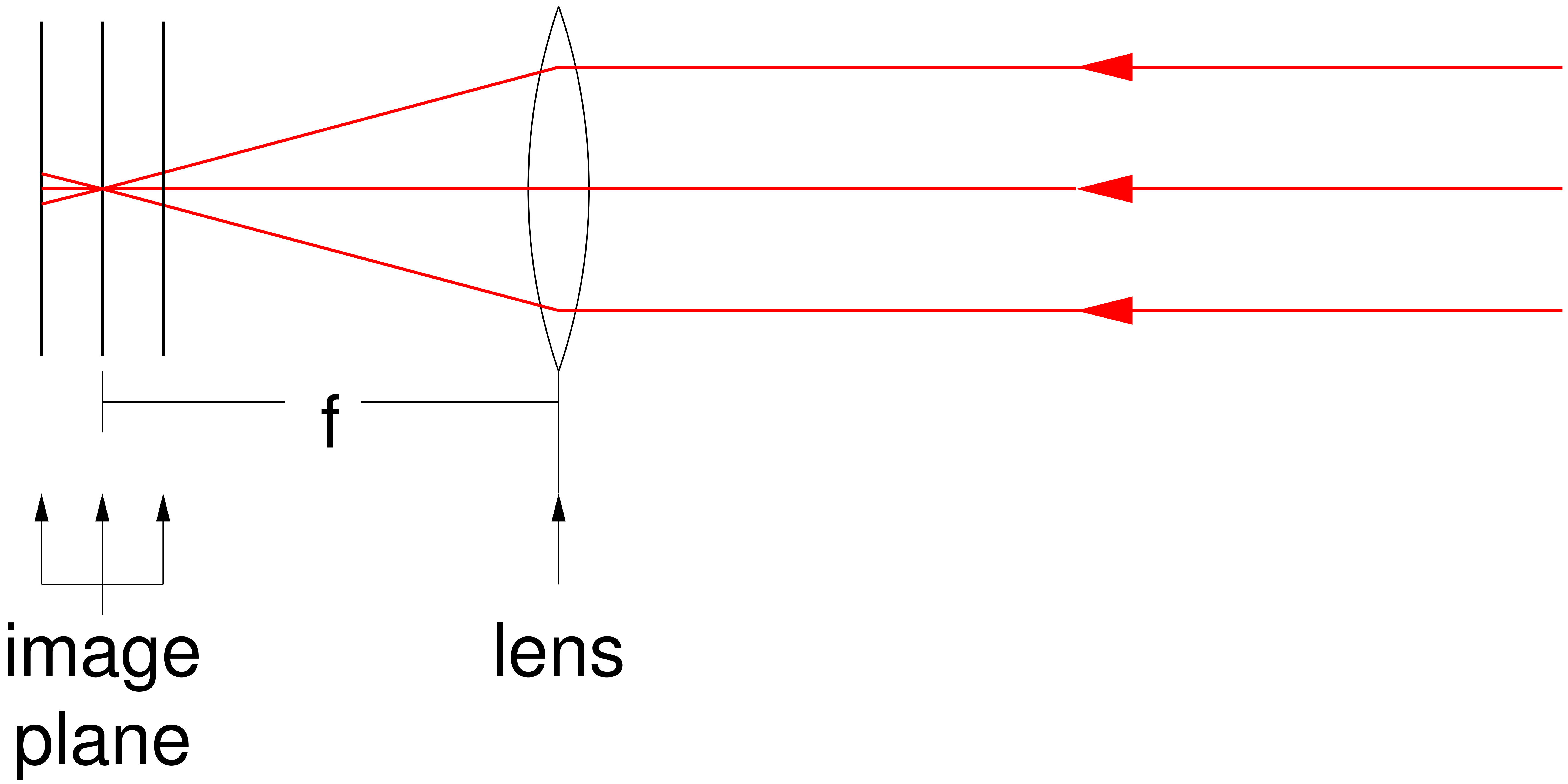
Focal Length

Another way of looking at the **focal length** of a lens. The incoming rays, parallel to the optical axis, **converge to a single point a distance f behind the lens**. This is where we want to place the image plane.

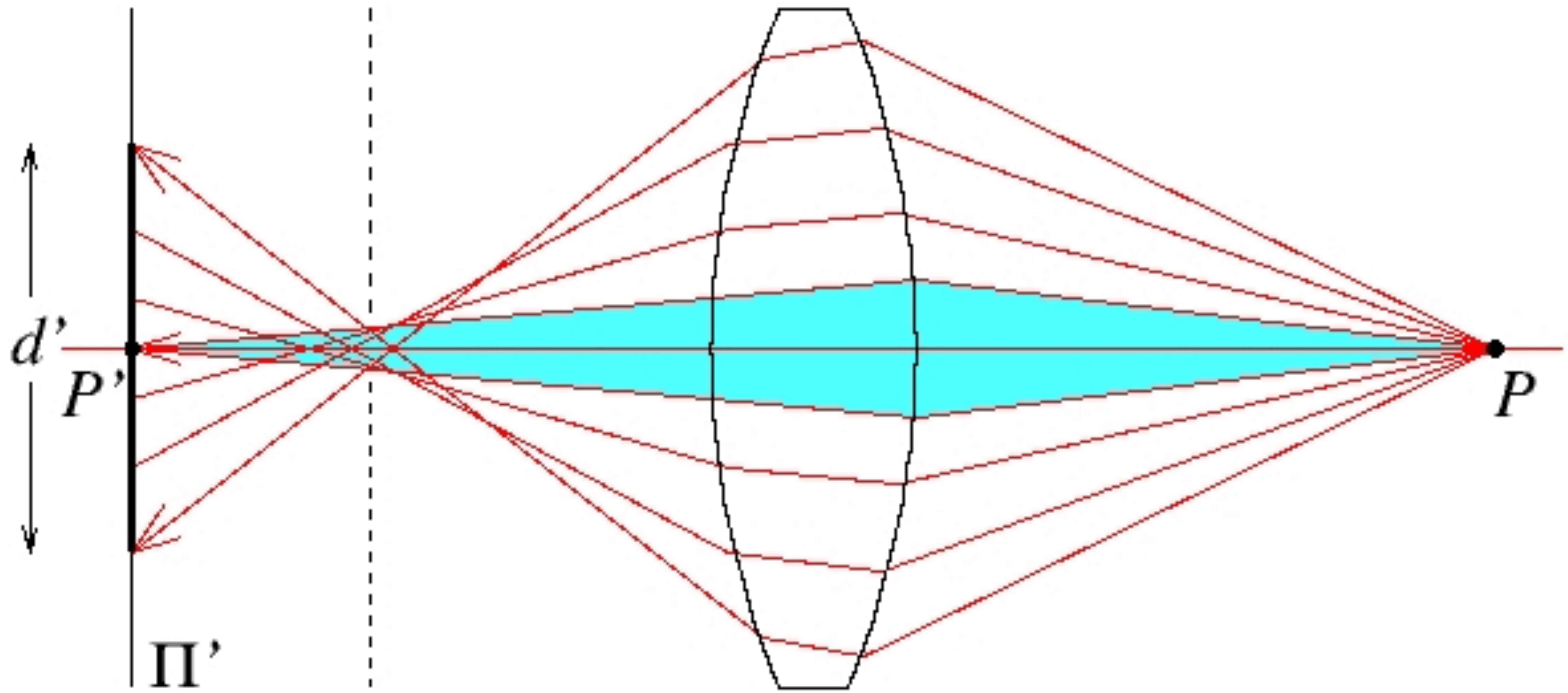


Out-of-Focus

The image plane is in the wrong place, either slightly closer than the required focal length, f, or slightly further than the required focal length, f.

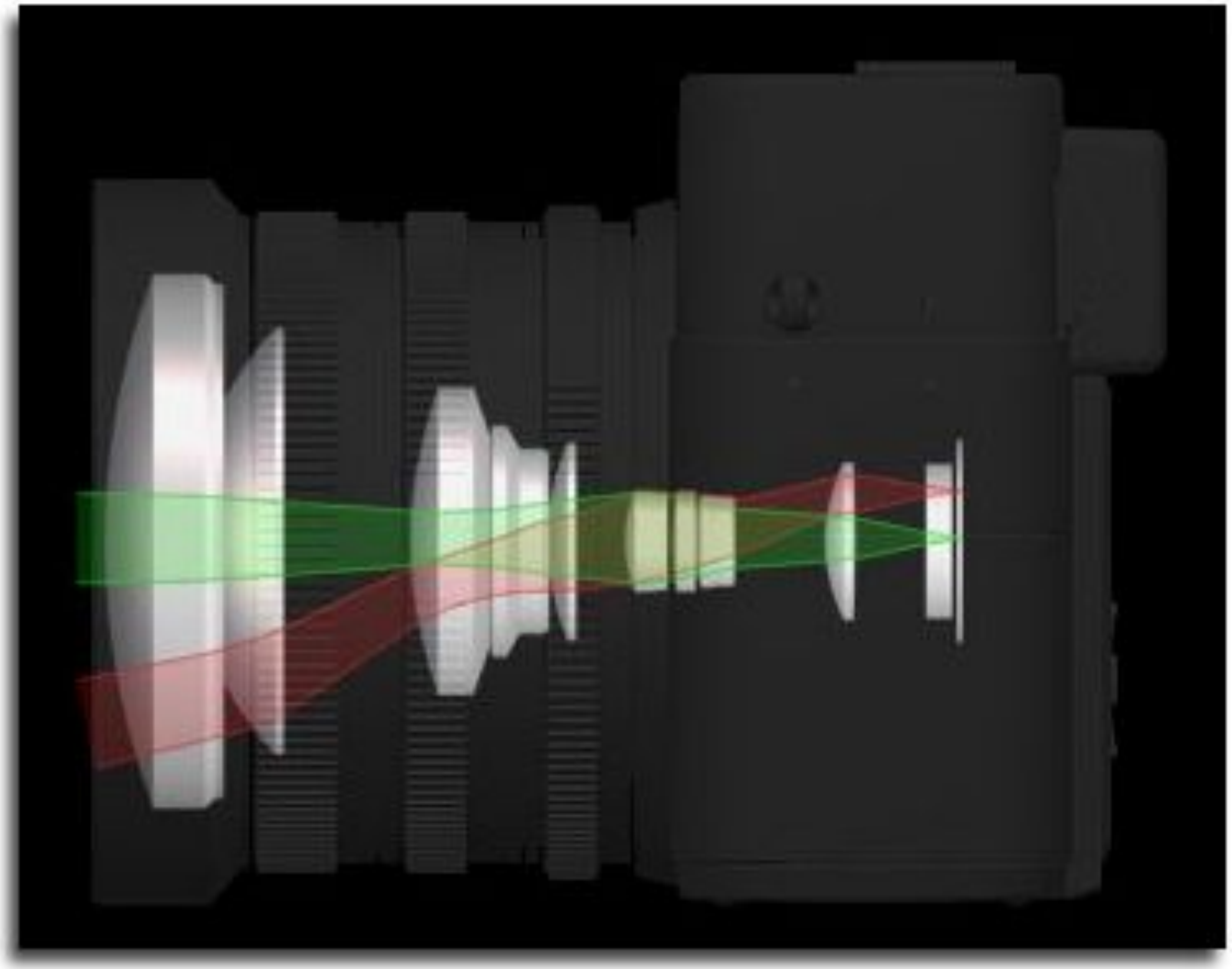


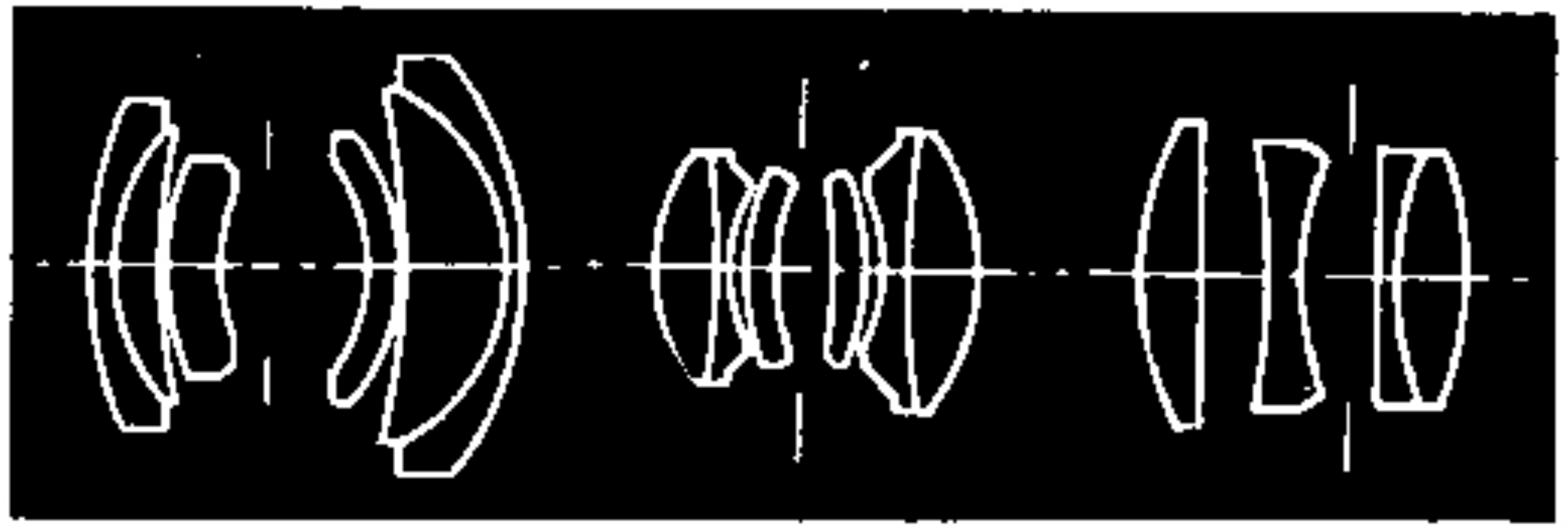
Spherical **Aberration**



Forsyth & Ponce (1st ed.) Figure 1.12a

Compound **Lens Systems**

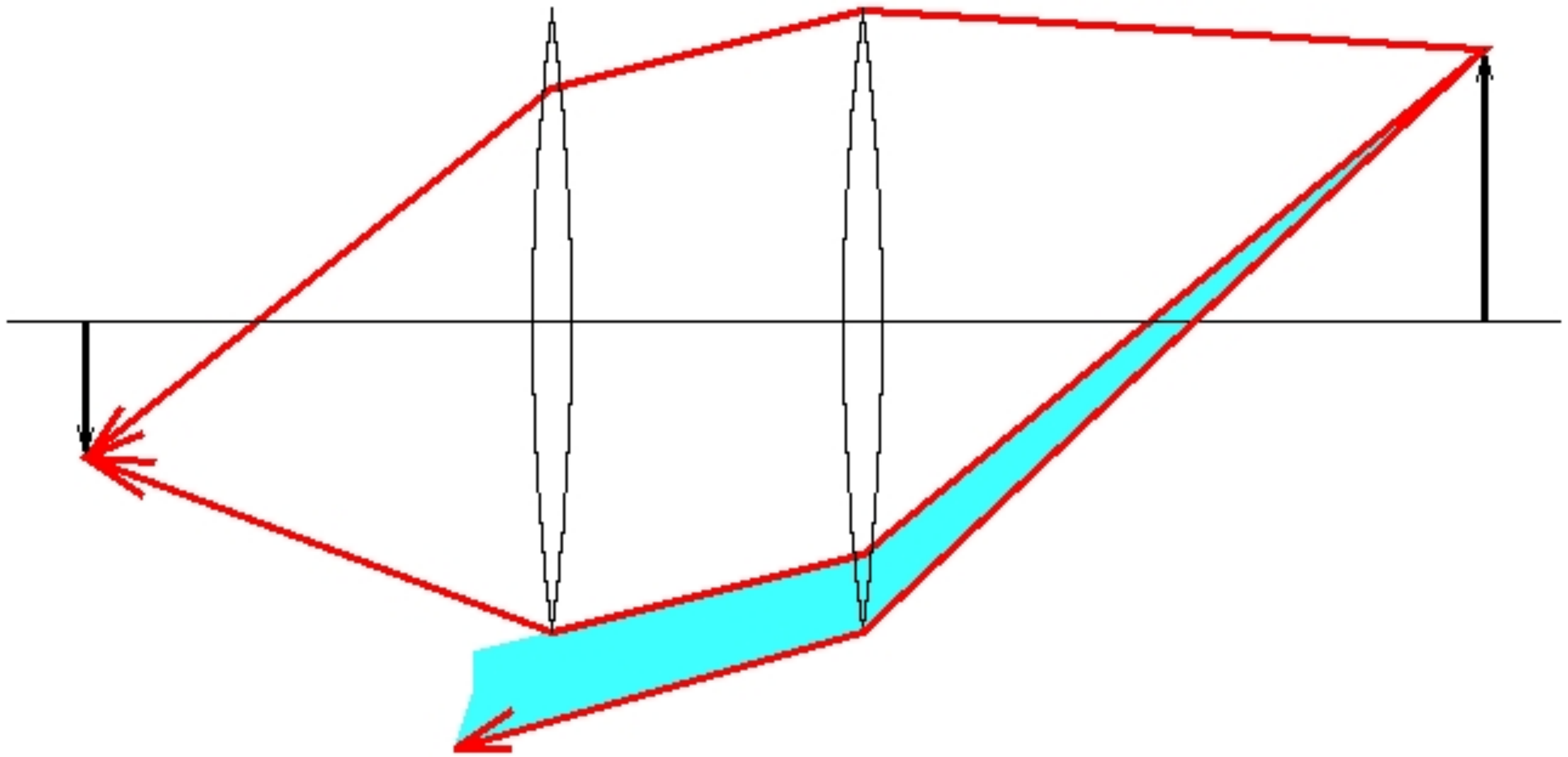




A modern camera lens may contain multiple components, including aspherical elements

Vignetting

Vignetting in a two-lens system



Forsyth & Ponce (2nd ed.) Figure 1.12

The shaded part of the beam **never reaches** the second lens

Vignetting

Image Credit: Cambridge in Colour

Chromatic **Aberration**

— Index of **refraction depends on wavelength**, λ, of light

— Light of different colours follows different paths

— Therefore, not all colours can be in equal focus

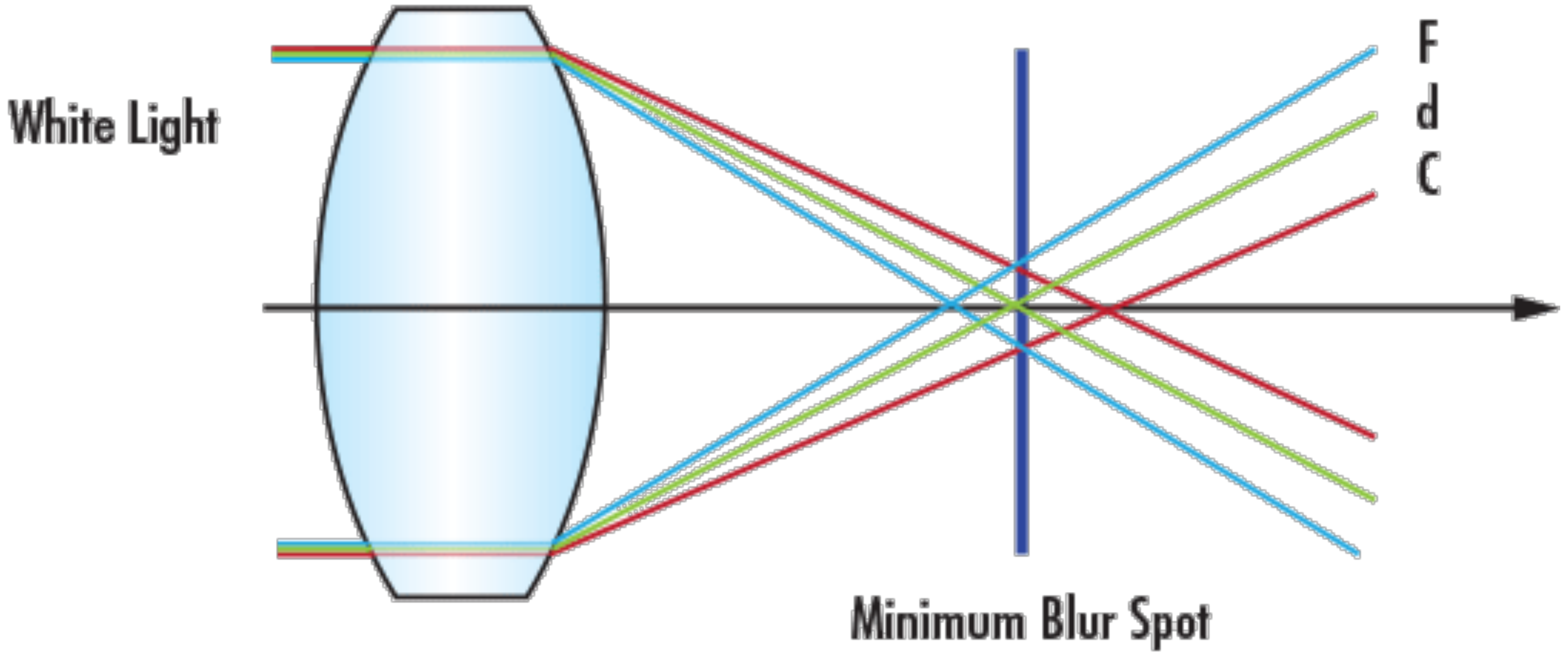


Image Credit: Trevor Darrell

Other (Possibly Significant) **Lens Effects**

Chromatic **aberration**

— Index of refraction depends on wavelength, λ, of light

— Light of different colours follows different paths

— Therefore, not all colours can be in equal focus

Scattering at the lens surface

— Some light is reflected at each lens surface

There are other **geometric phenomena/distortions**

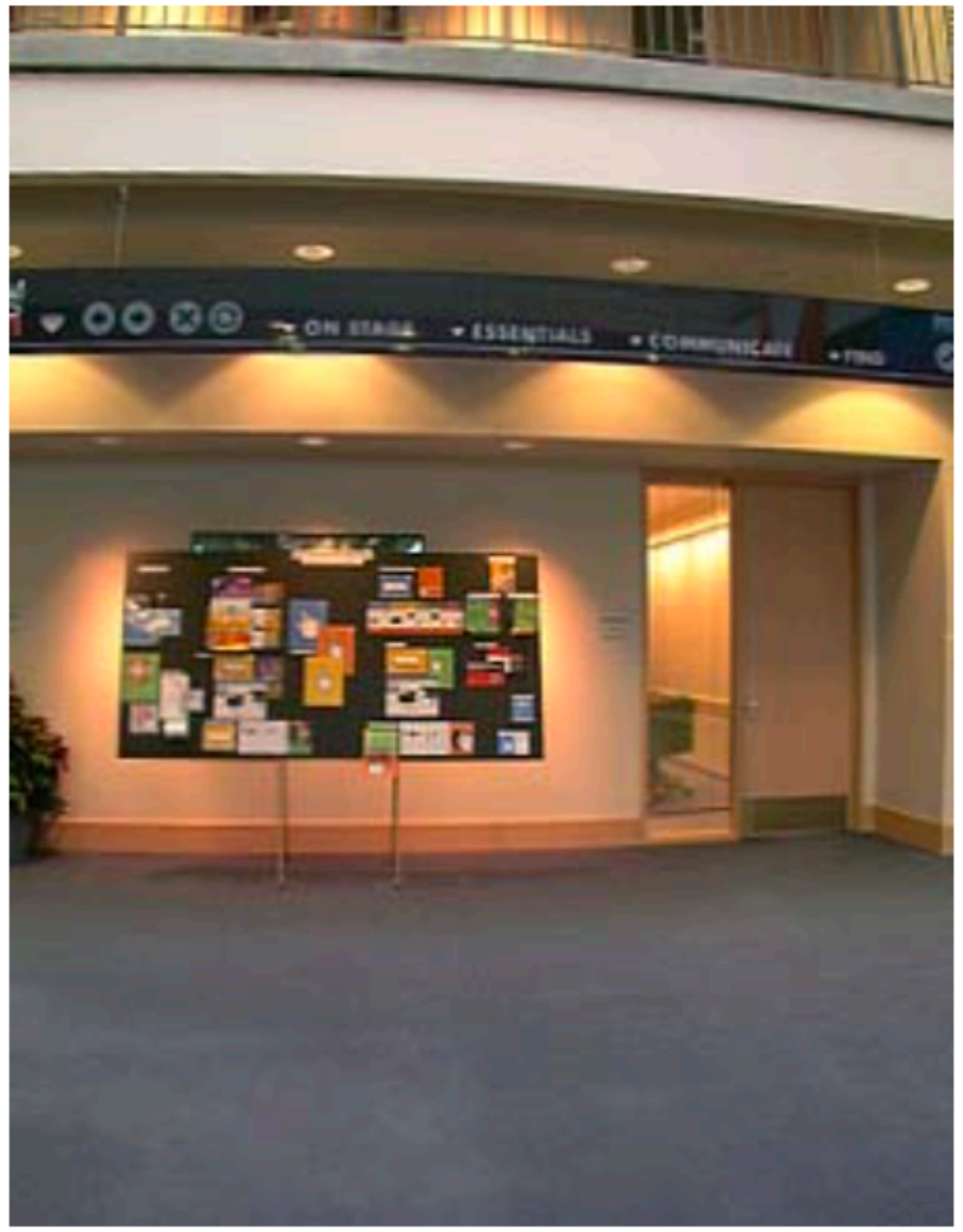
— pincushion distortion

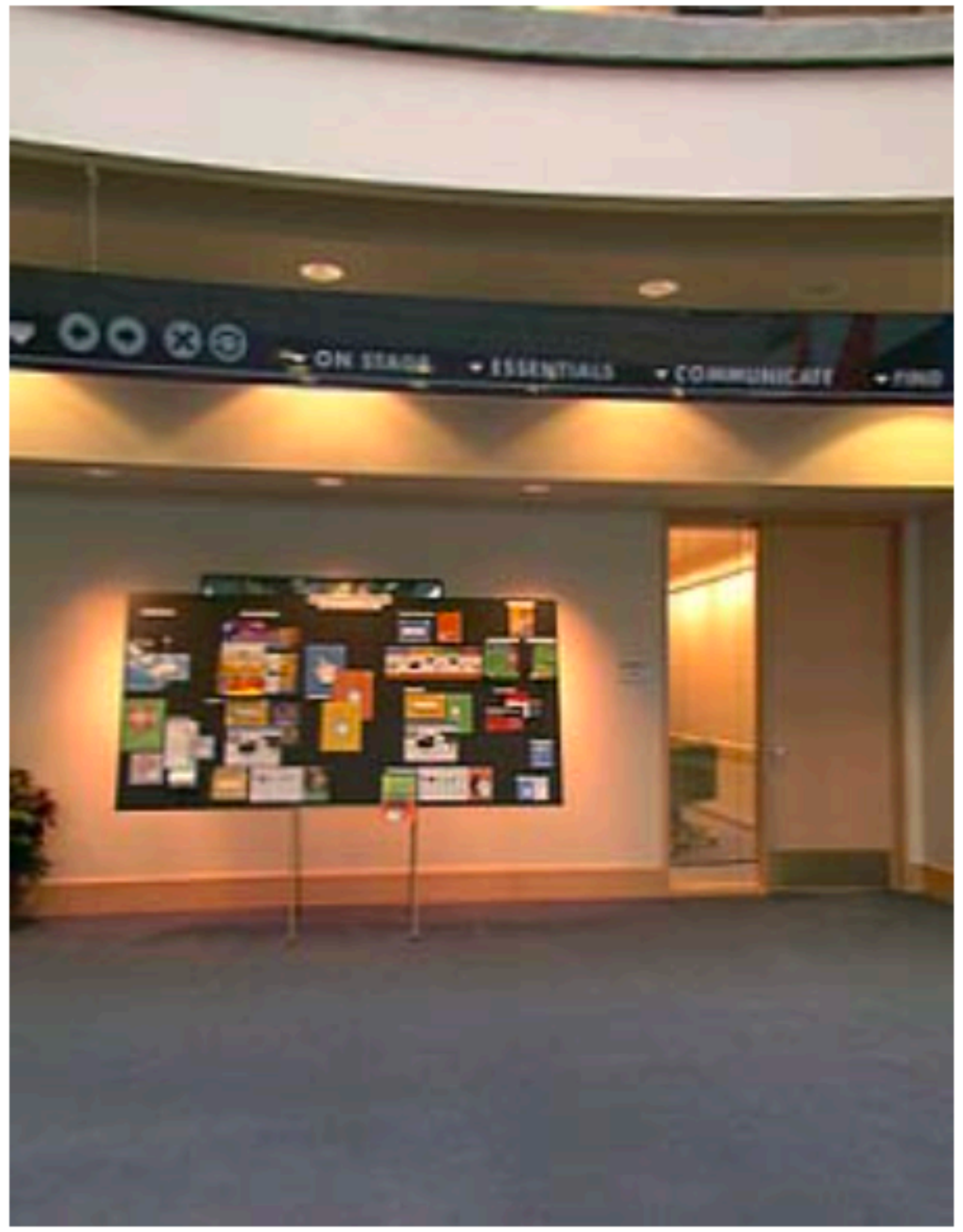
— barrel distortion

— etc

Lens **Distortion**

Fish-eye Lens





Szeliski (1st ed.) Figure 2.13

Lines in the world are no longer lines on the image, they are curves!

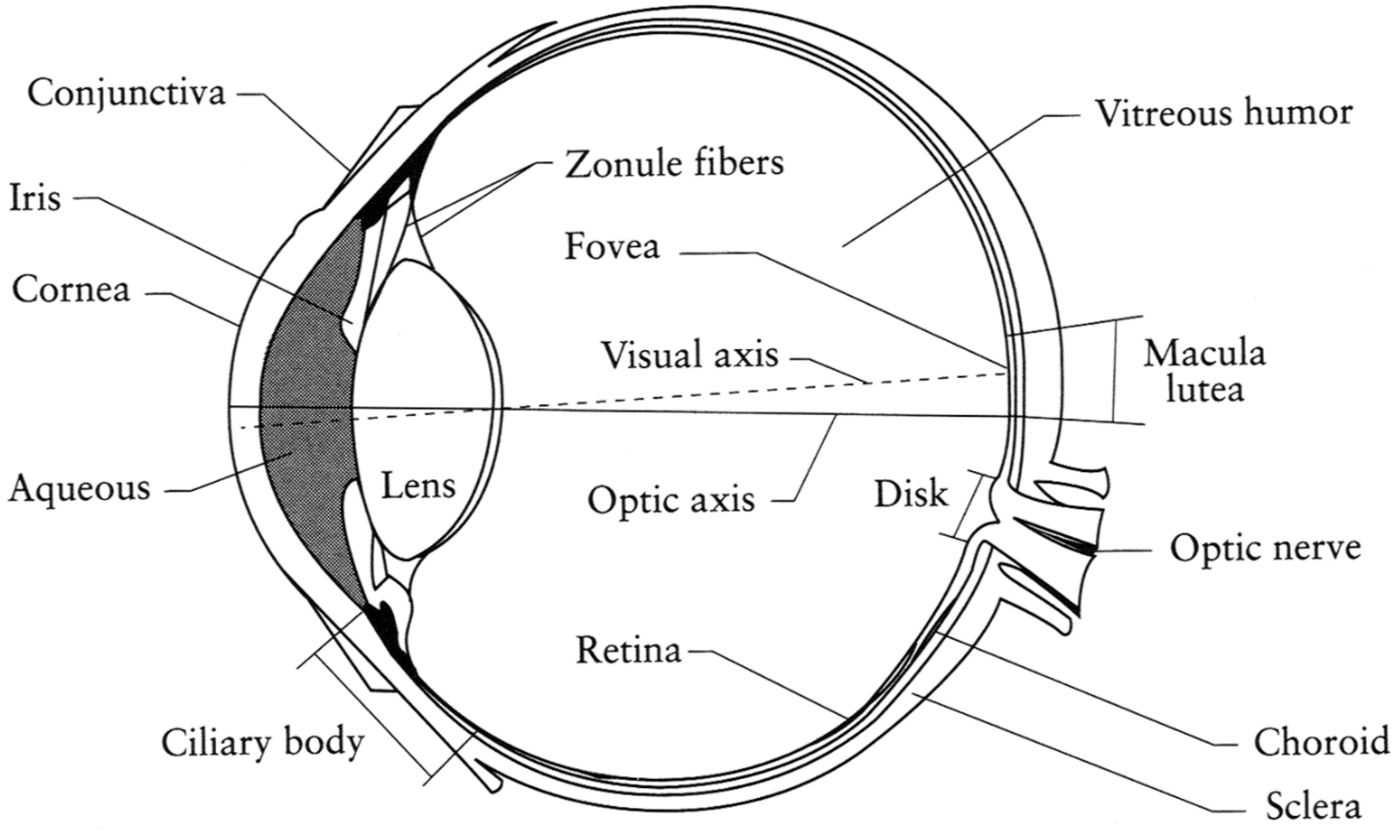
Human Eye

— The eye has an iris (like a camera)

— Focusing is done by changing shape of lens

— When the eye is properly focused, light from an object outside the eye is imaged on the retina

— The retina contains light receptors called rods and cones



pupil = pinhole / aperture

retina = film / digital sensor

Slide adopted from: Steve Seitz

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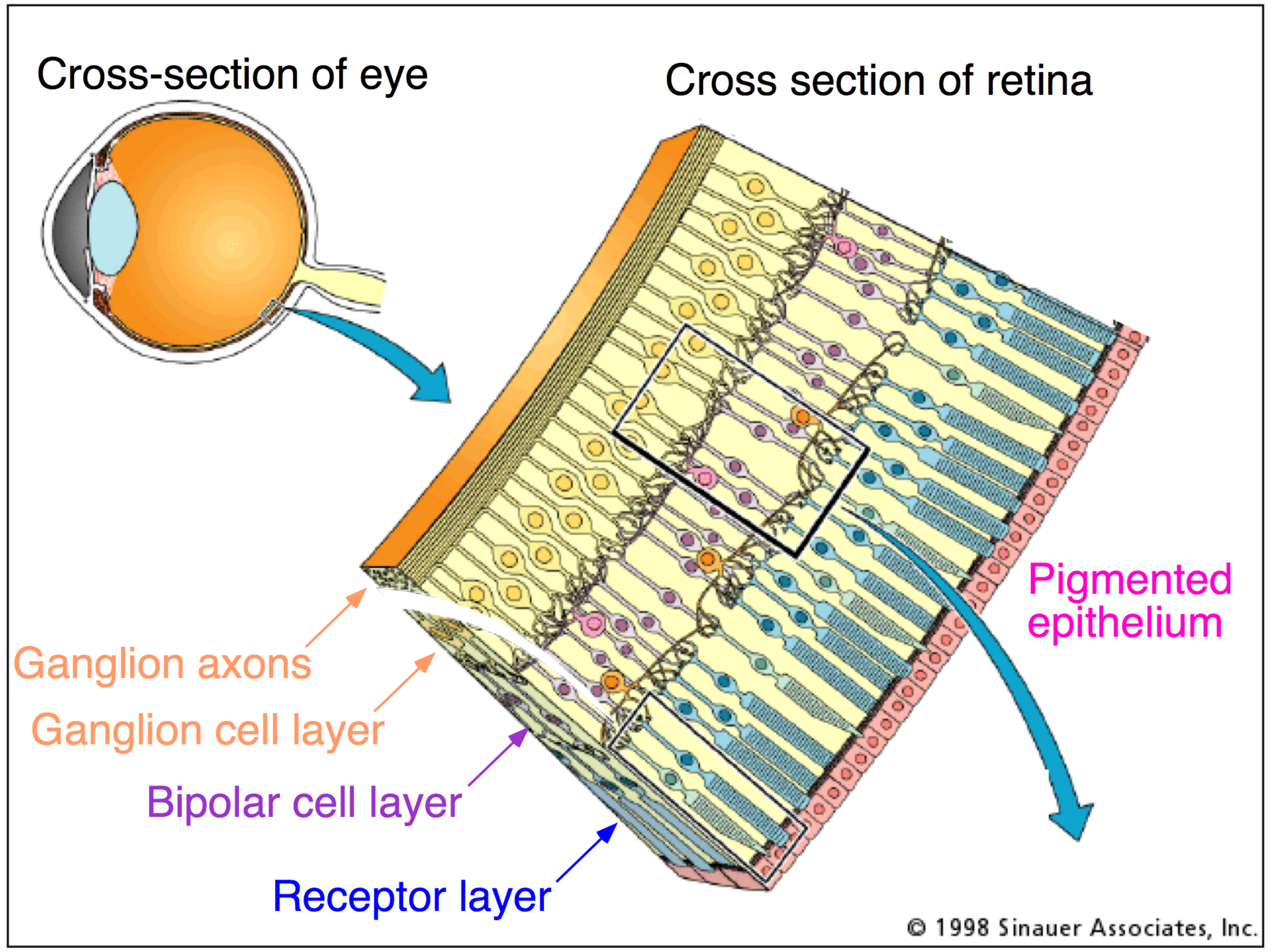

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Slide adopted from: Steve Seitz

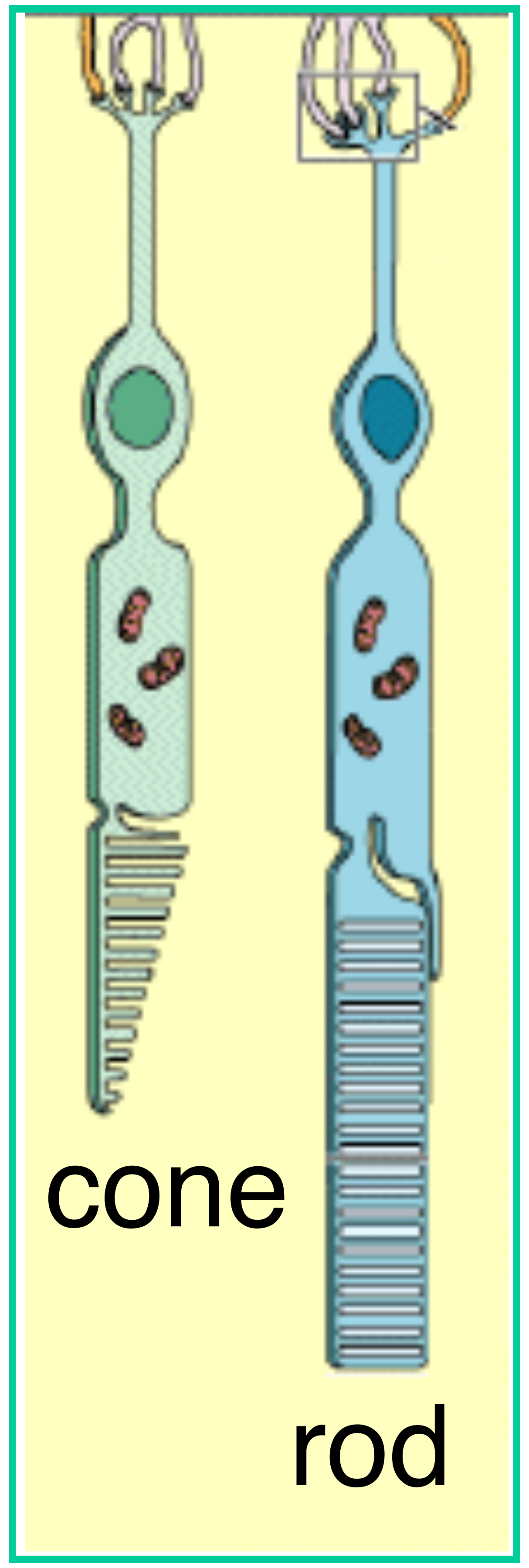
Two-types of **Light Sensitive Receptors**

Rods

75-150 million rod-shaped receptors
not involved in color vision, gray-scale vision only
operate at night
highly sensitive, can responding to a single photon
yield relatively poor spatial detail

Cones

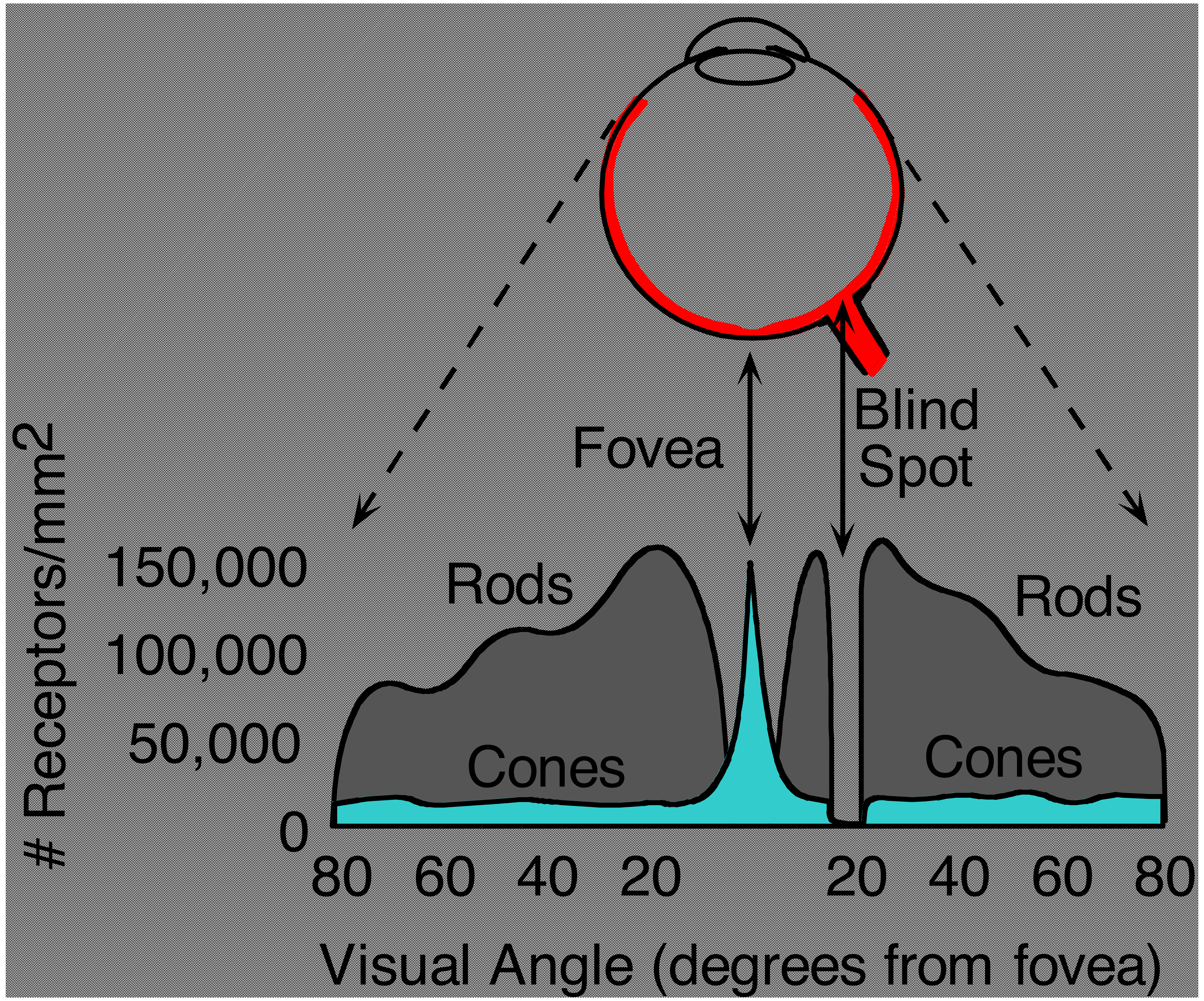
6-7 million cone-shaped receptors
color vision
operate in high light
less sensitive
yield higher resolution



Slide adopted from: James Hays

Human Eye

Density of rods and cones



Slide adopted from: James Hays

Lecture **Summary**

— We discussed a “physics-based” approach to image formation. Basic abstraction is the **pinhole camera**.

— **Lenses overcome limitations** of the pinhole model while trying to preserve it as a useful abstraction

— Projection equations: **perspective**, weak perspective, orthographic

— Thin lens equation

— Some “aberrations and **distortions**” persist (e.g. spherical aberration, vignetting)

— The **human eye** functions much like a camera