MAI4CAREU

Master programmes in Artificial Intelligence 4 Careers in Europe

Visual Computing Group

CYENS CENTRE OF EXCELLENCE

University of Cyprus – MSc Artificial Intelligence

MAI644 – COMPUTER VISION

Lecture 3: Fundamentals - Cameras

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Co-financed by the European Union
Connecting Europe Facility

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Last time

- Physics of color
- Human encoding of color
- Color spaces

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Today's Agenda - Overview of Cameras

- Pinhole Camera model
  - Aperture
  - Camera Obscura
- Cameras with lenses
  - Thin lens equation
  - Depth of field
  - Field of view
- Digital cameras
  - Bayer filters
  - Debayering

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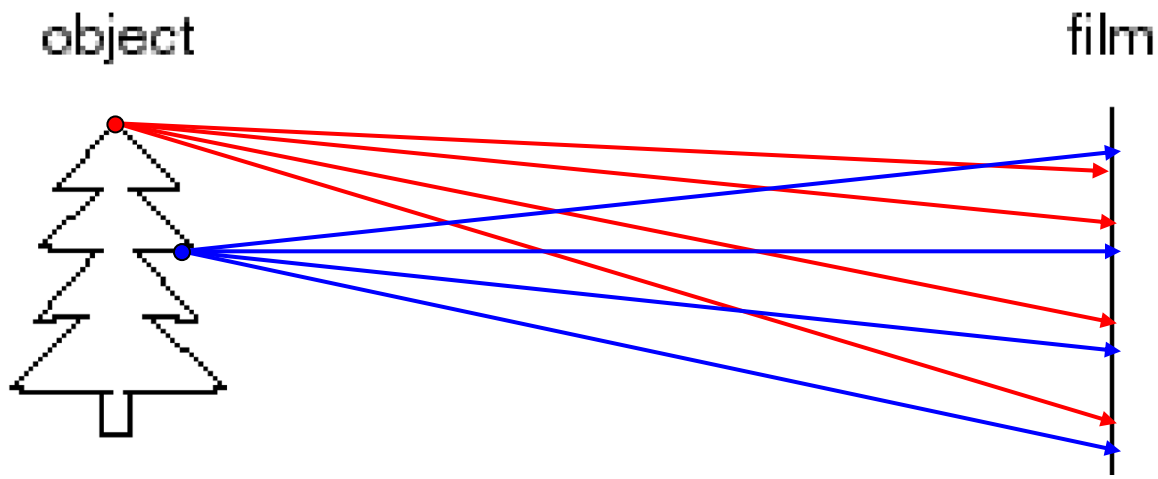
Let's design a camera



- Idea 1: put a piece of film in front of an object
- Do we get a reasonable image?

[Slide by Steve Seitz]

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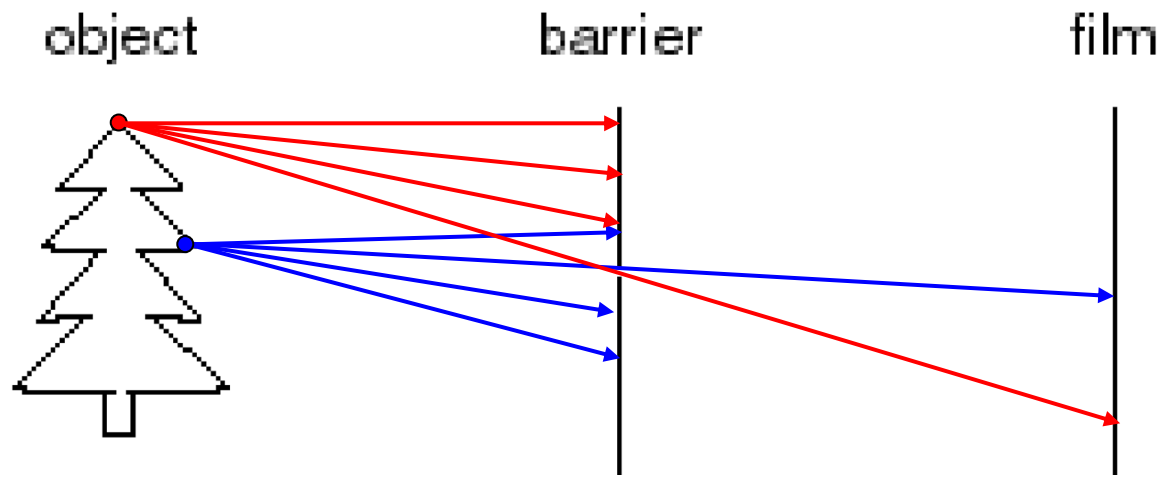
Pinhole camera



Add a barrier to block off most of the rays

- This reduces blurring
- The opening known as the **aperture**
- How does this transform the image?

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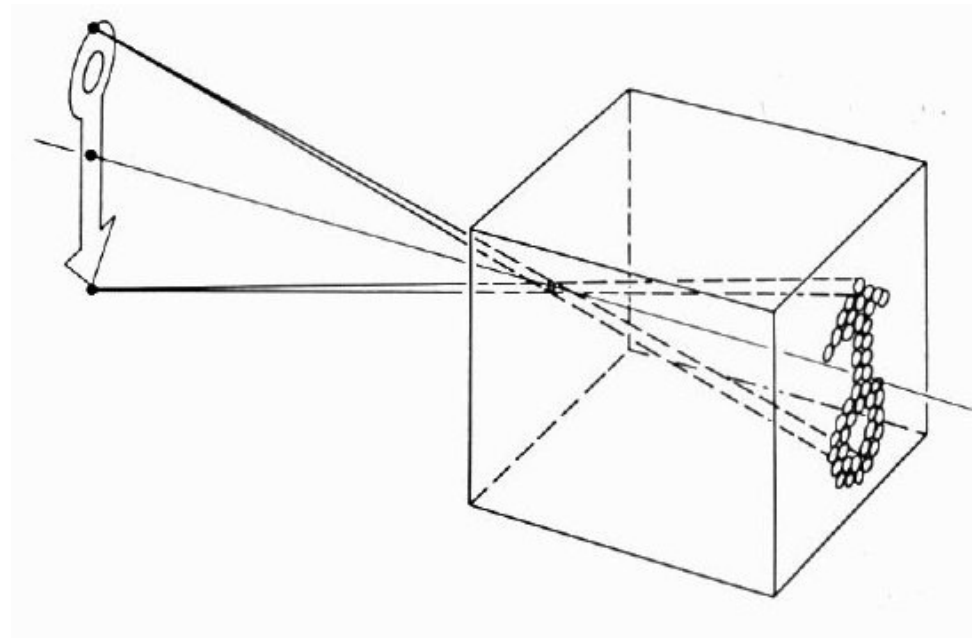
Pinhole Camera model

- Captures **pencil of rays** – all rays through a single point
- The point is called **Center of Projection**
- The image is formed on the **Image Plane**



[Slide by Steve Seitz]

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Pinhole cameras everywhere

Sun “shadows” during a solar eclipse
by Henrik von Wendt http://www.flickr.com/photos/hvw/2724969199/

[Slide by Steve Seitz]

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Pinhole cameras everywhere

Sun “shadows” during a solar eclipse
http://www.flickr.com/photos/73860948@N08/6678331997/

[Slide by Steve Seitz]

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Pinhole cameras everywhere

Tree shadow during a solar eclipse

photo credit: Nils van der Burg http://www.physicstogo.org/index.cfm [Slide by Steve Seitz]

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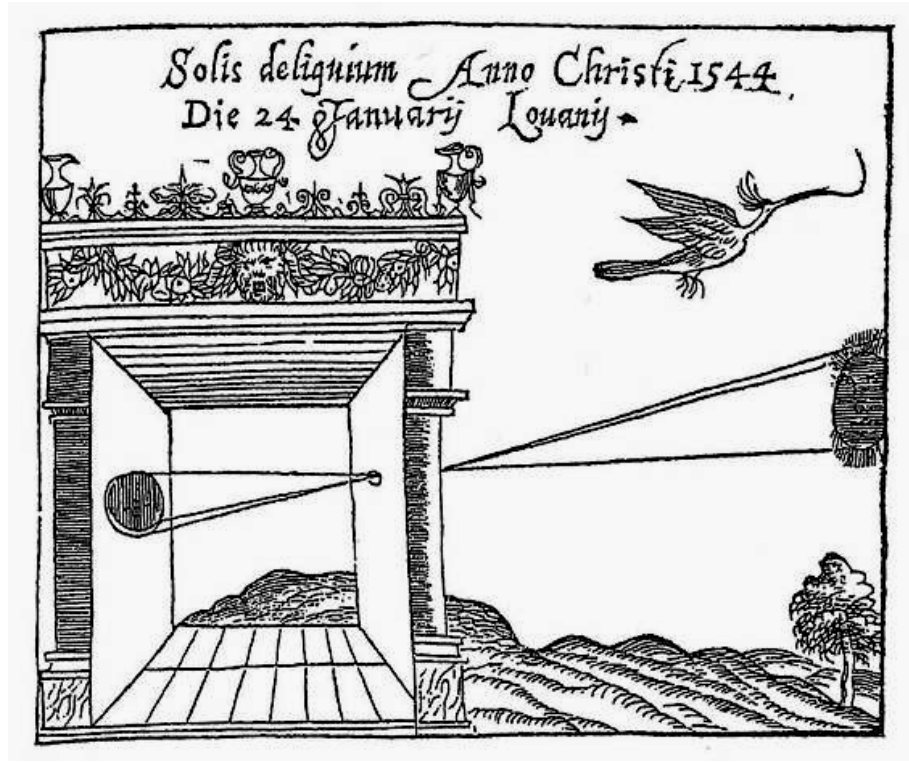
Pinhole Camera - Camera Obscura

The first camera

- Known to Aristotle



Gemma Frisius, 1558

[Slide by Steve Seitz]

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How to Turn a Room into a Camera Obscura

https://www.youtube.com/watch?v=hsXo4gD7iWI&ab_channel=GeorgeEastmanMuseum

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Home-made pinhole camera

Why so blurry?

http://www.debevec.org/Pinhole/

[Slide by A. Efros]

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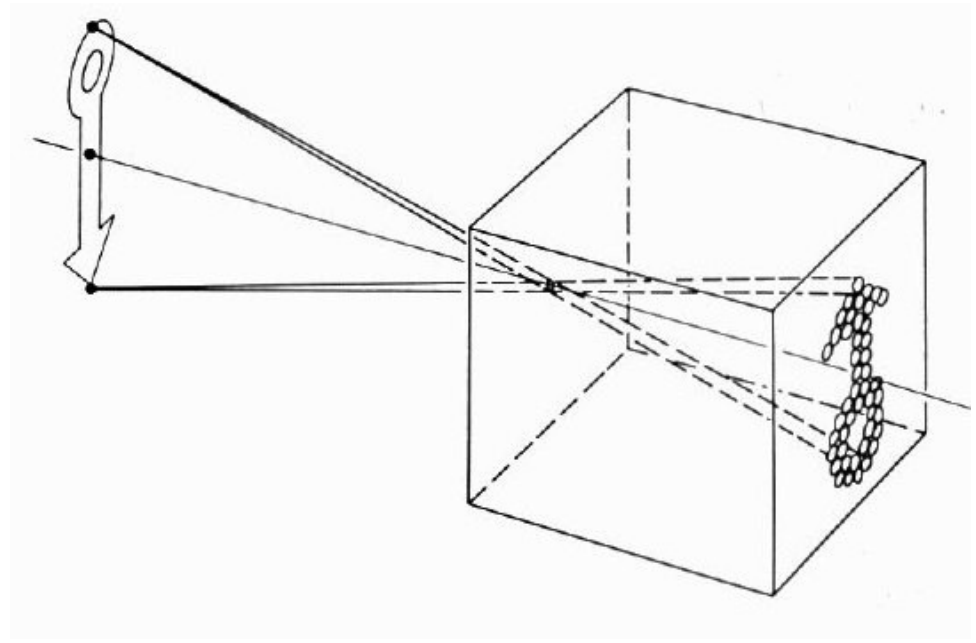
Pinhole Camera - Camera Obscura

The first camera

- Known to Aristotle
- How does the aperture size affect the image?



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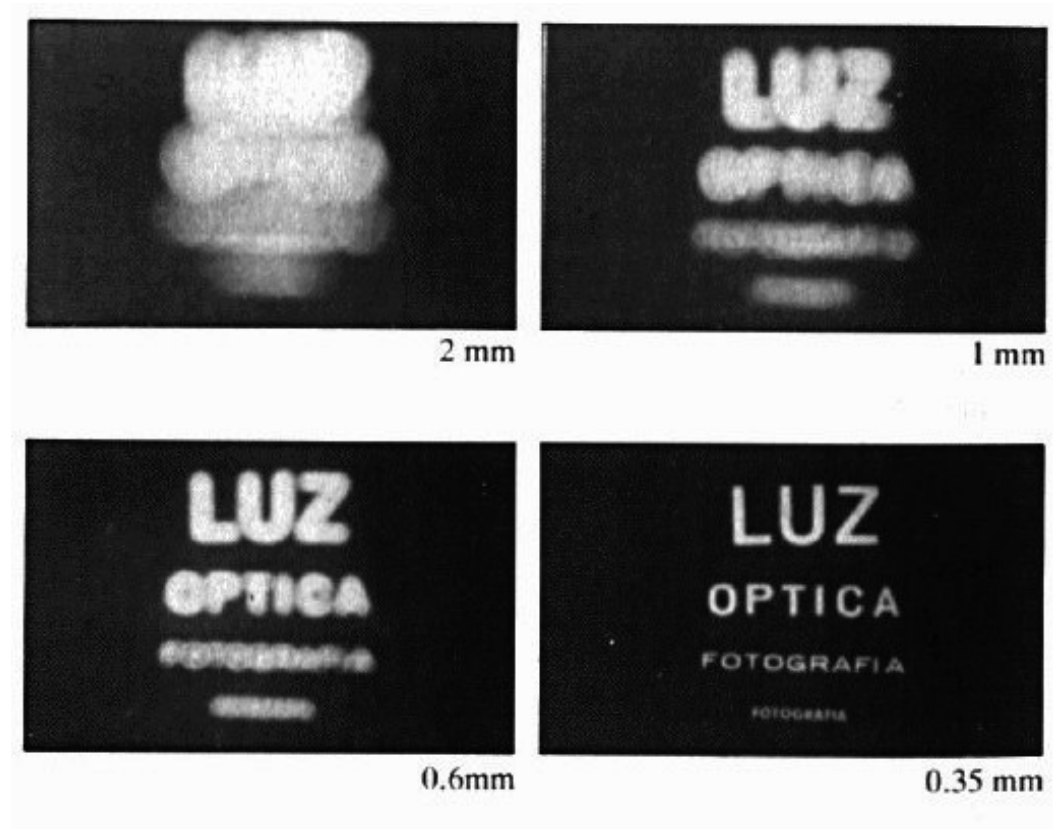
Shrinking the aperture

Why not make the aperture as small as possible?



[Slide by Steve Seitz]

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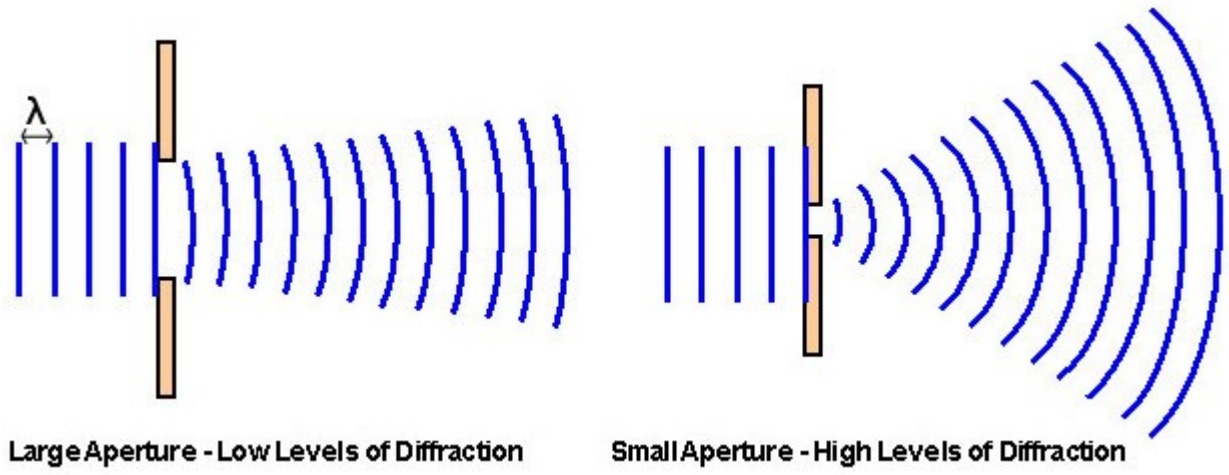
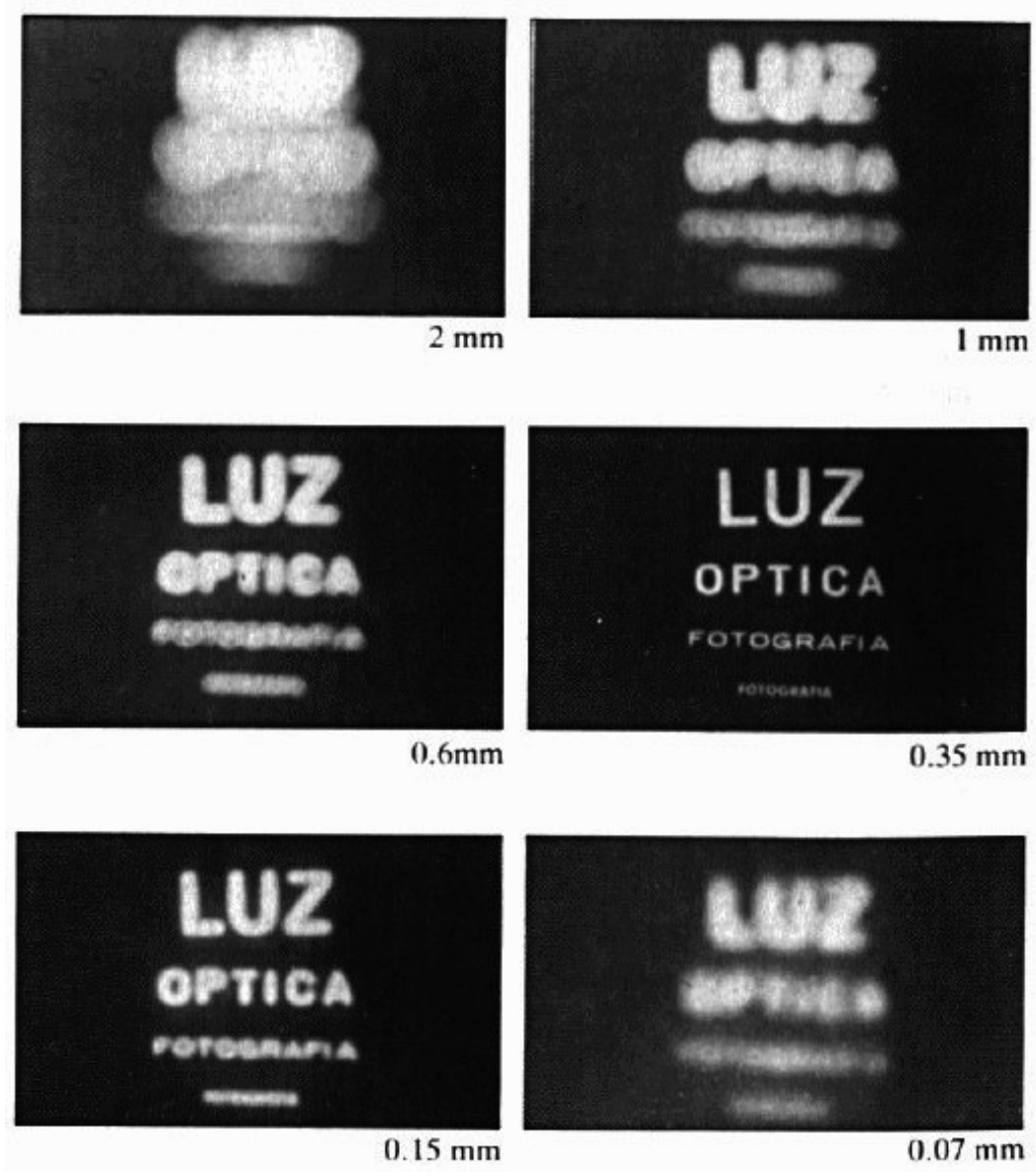
Shrinking the aperture

Why not make the aperture as small as possible?

- Less light gets through
- Diffraction effects





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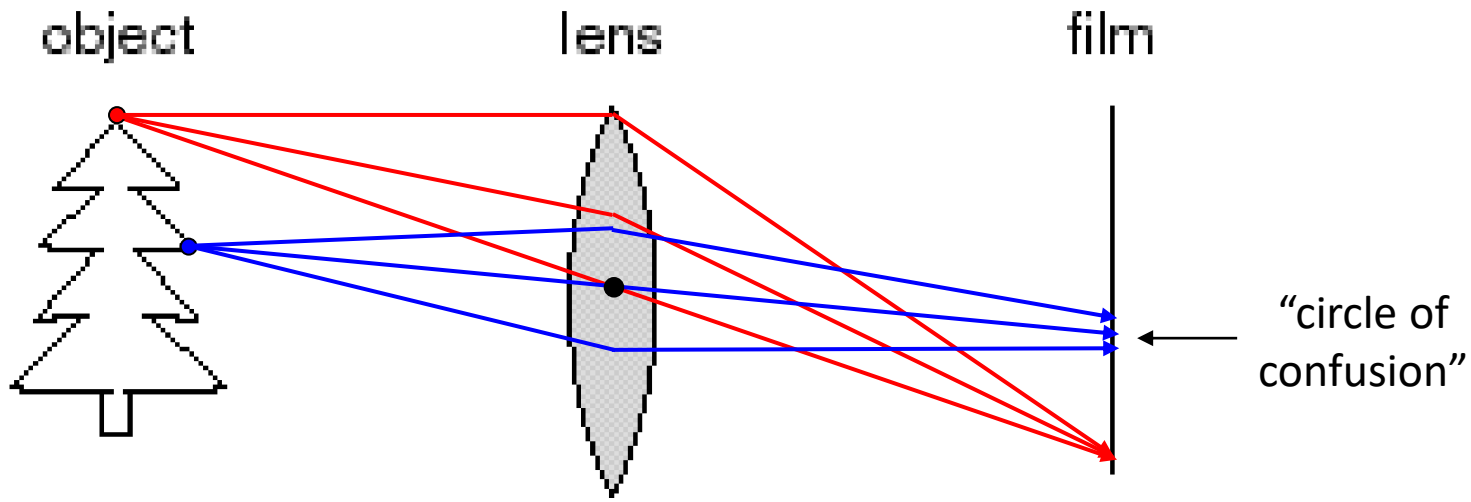
Adding a lens



A lens focuses light onto the film

- Rays passing through the center are not deviated
- There is a specific distance at which objects are “in focus”
  - other points project to a “circle of confusion” in the image

[Slide by Steve Seitz]

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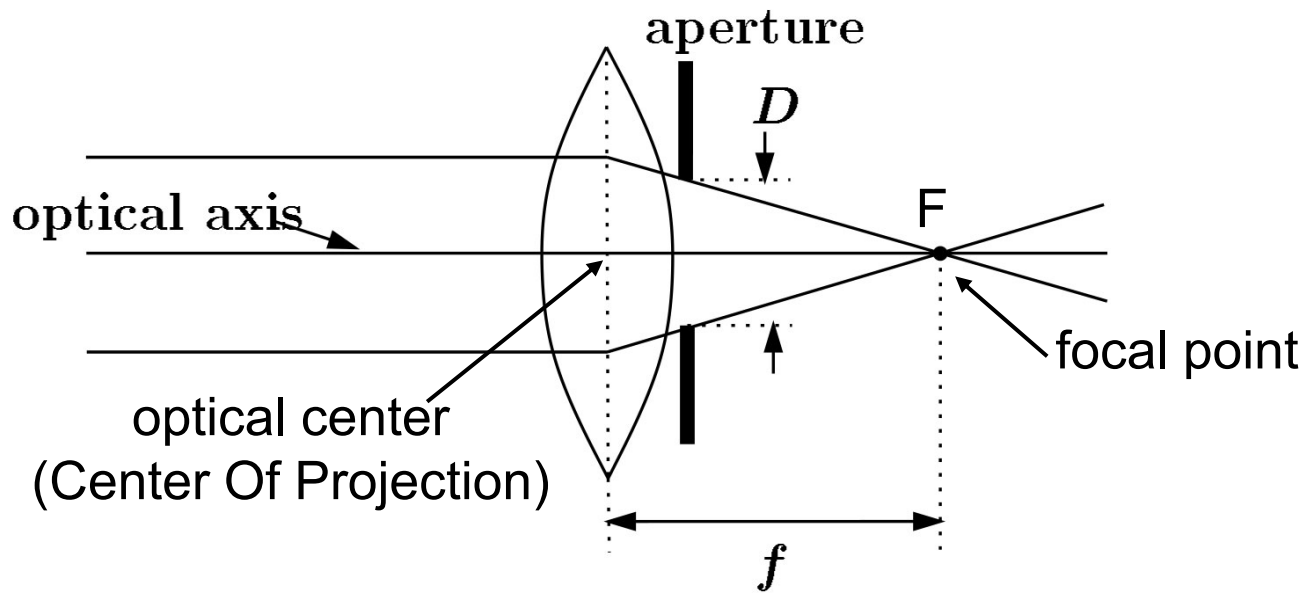
Lenses



A lens focuses rays parallel to its axis onto a single **focal point**

- Focal point is on a plane located at a distance **f** (**focal length**) beyond the plane of the lens
  - f is a function of the shape and index of refraction of the lens
- Aperture of diameter **D** restricts the range of rays
  - aperture may be on either side of the lens
- Lenses are typically spherical (easier to produce)

[Slide by Steve Seitz]

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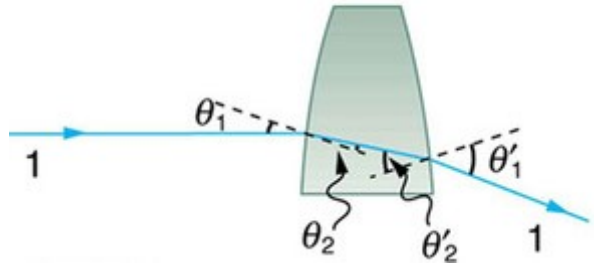
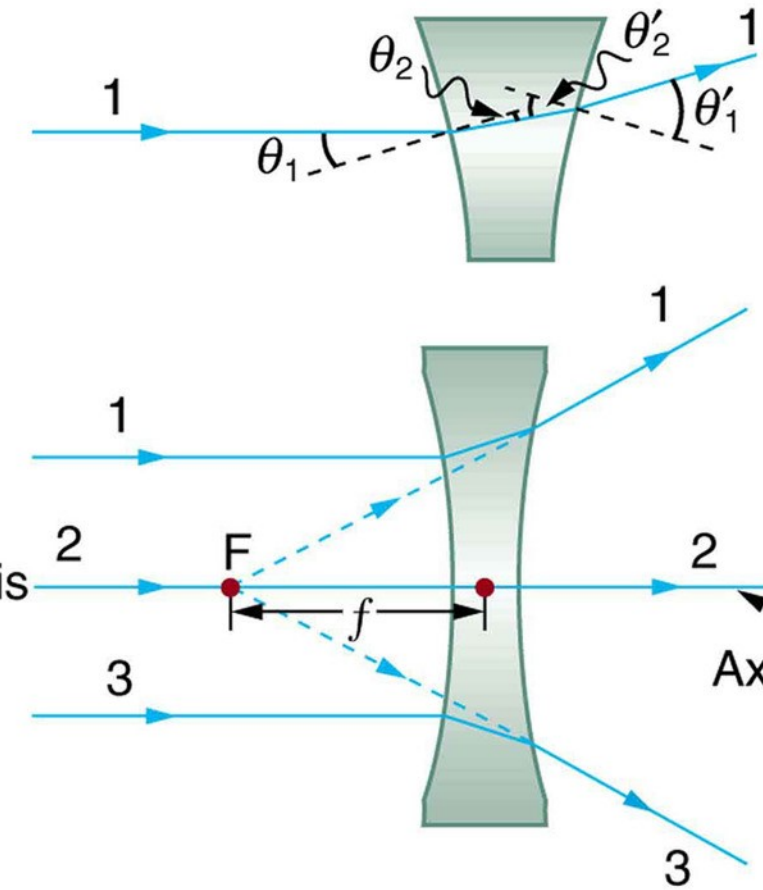
Thin lenses





[See here](#)

Converging – Convex lens

Diverging – Concave lens

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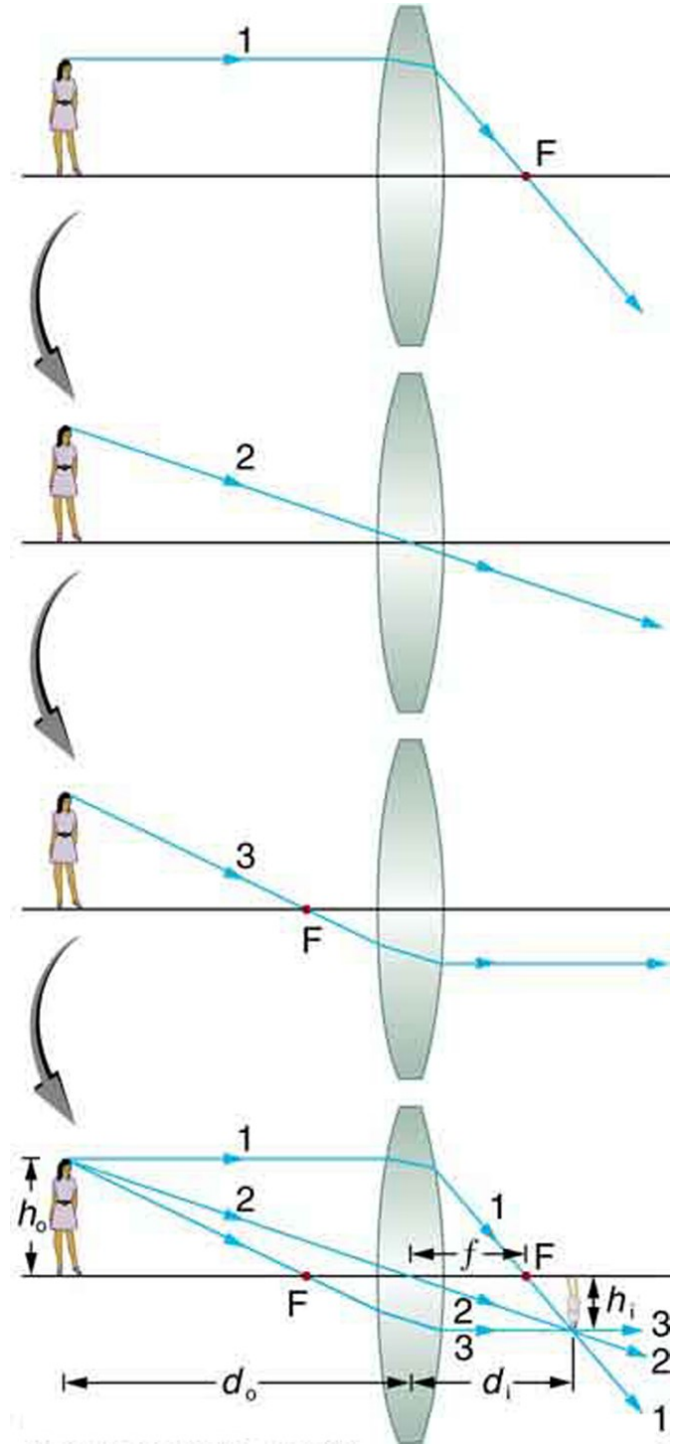
Thin lenses – ray tracing

- Five rules for image formation with thin lenses
  1. A ray entering a converging lens parallel to its axis passes through the focal point F of the lens on the other side.
  2. A ray entering a diverging lens parallel to its axis seems to come from the focal point F.
  3. A ray passing through the center of either a converging or a diverging lens does not change direction.
  4. A ray entering a converging lens through its focal point exits parallel to its axis.
  5. A ray that enters a diverging lens by heading toward the focal point on the opposite side exits parallel to the axis.



[See here]

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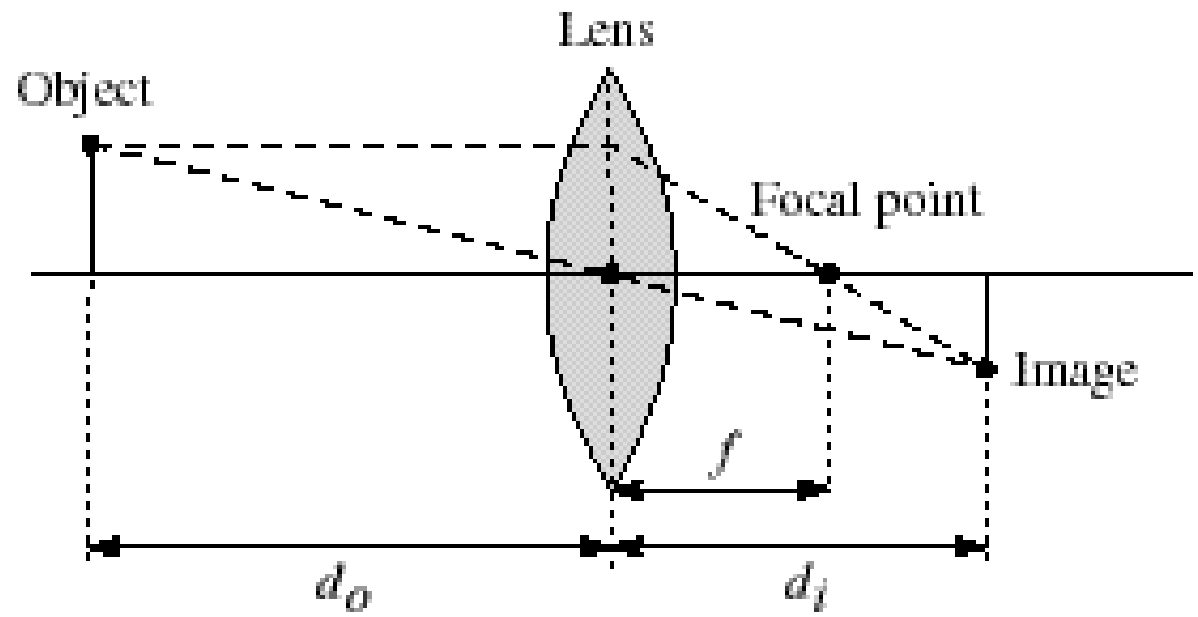
Thin lens equation



Thin lens equation: $$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

- Any object point satisfying this equation is in focus
- Thin lens applet (needs java player):
  http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html (by Fu-Kwun Hwang)

[Slide by Steve Seitz]

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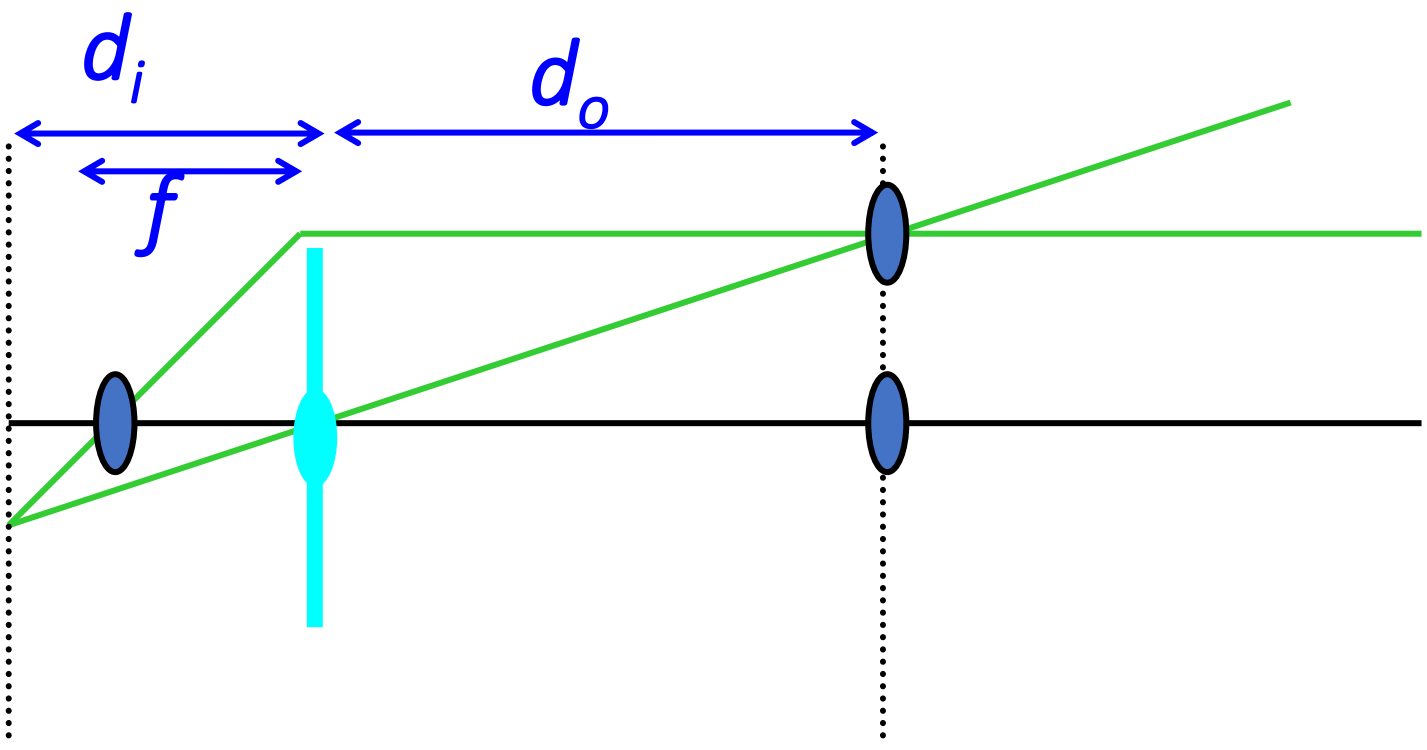
Thin lens formula



[Slide by Fredo Durand]

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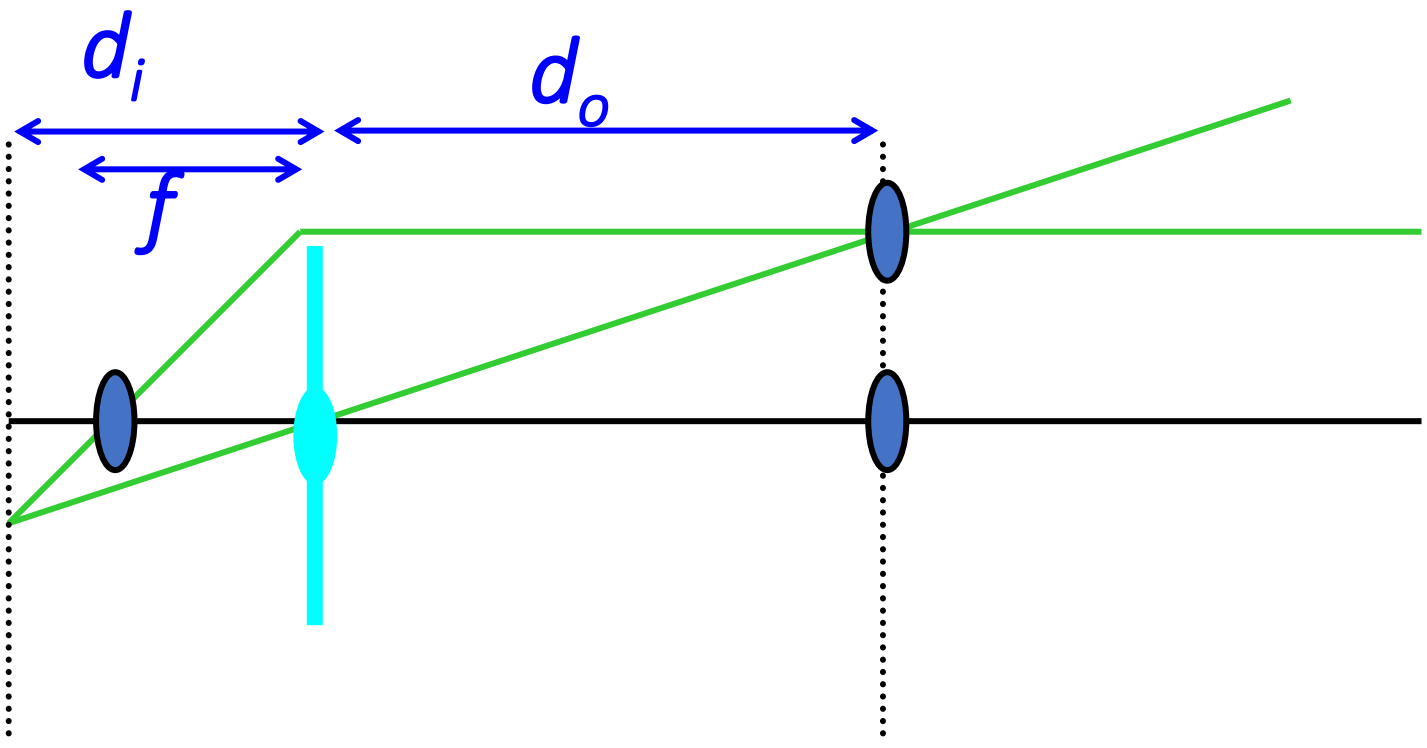
Thin lens formula

Use similar triangles!



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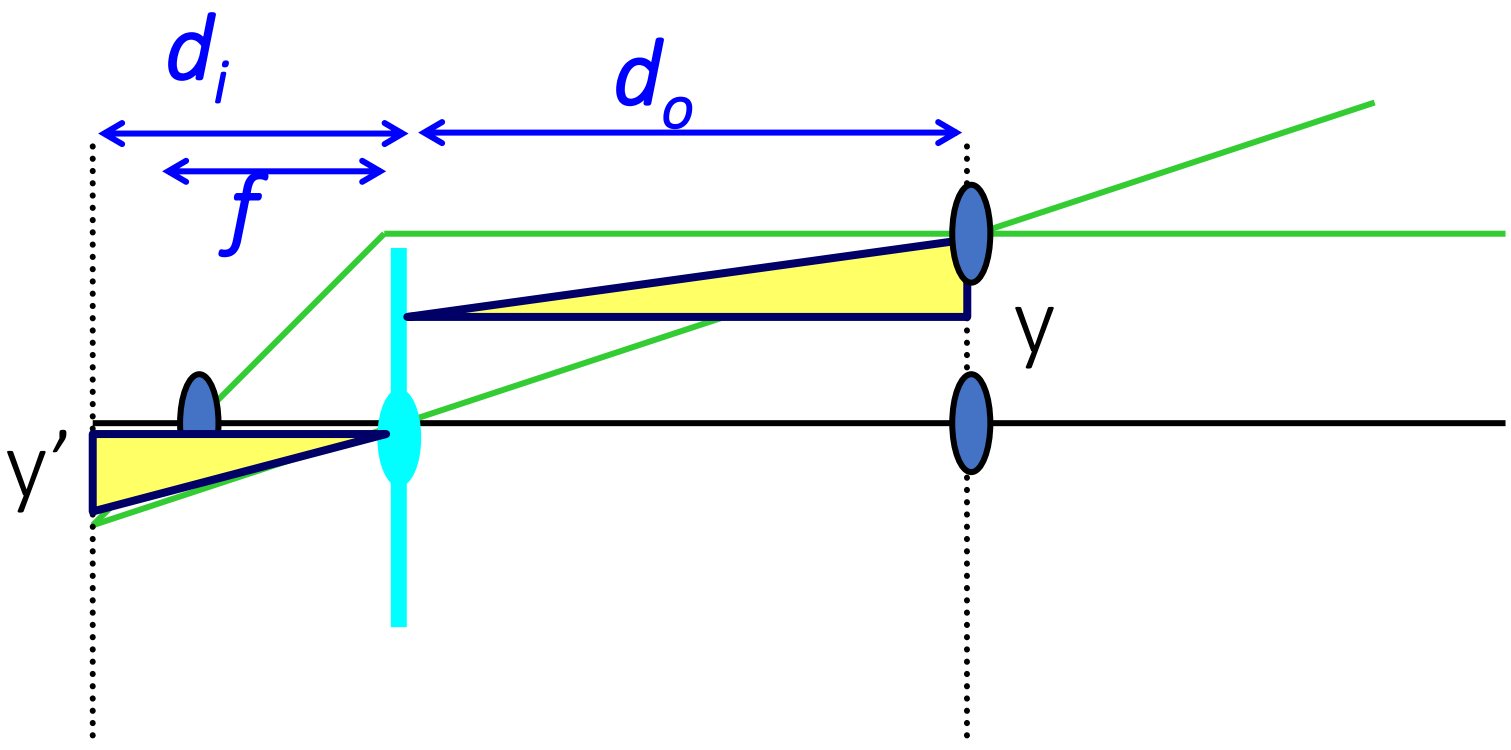
Thin lens formula

$$y'/y = d_i/d_o$$



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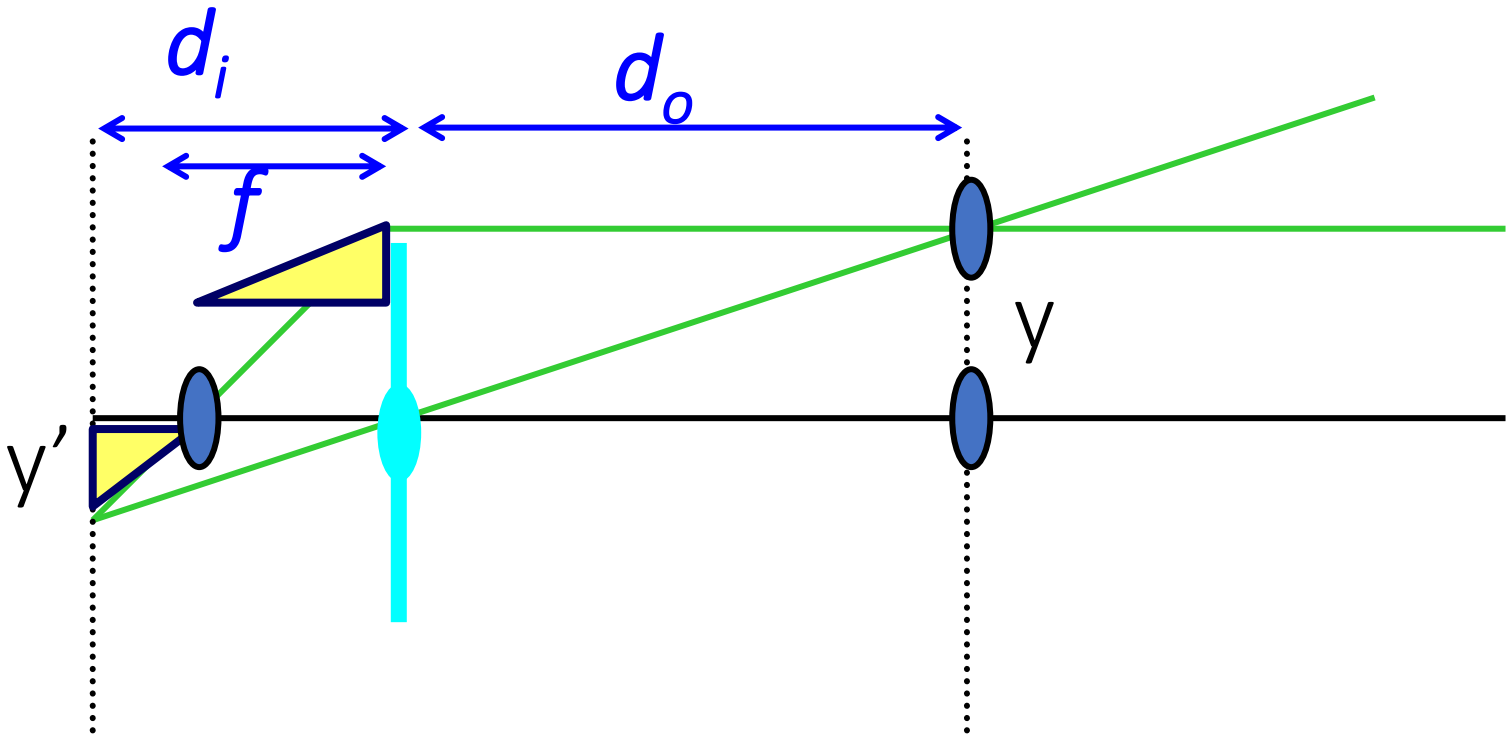
Thin lens formula

$$y'/y = d_i/d_o$$
$$y'/y = (d_i - f)/f$$



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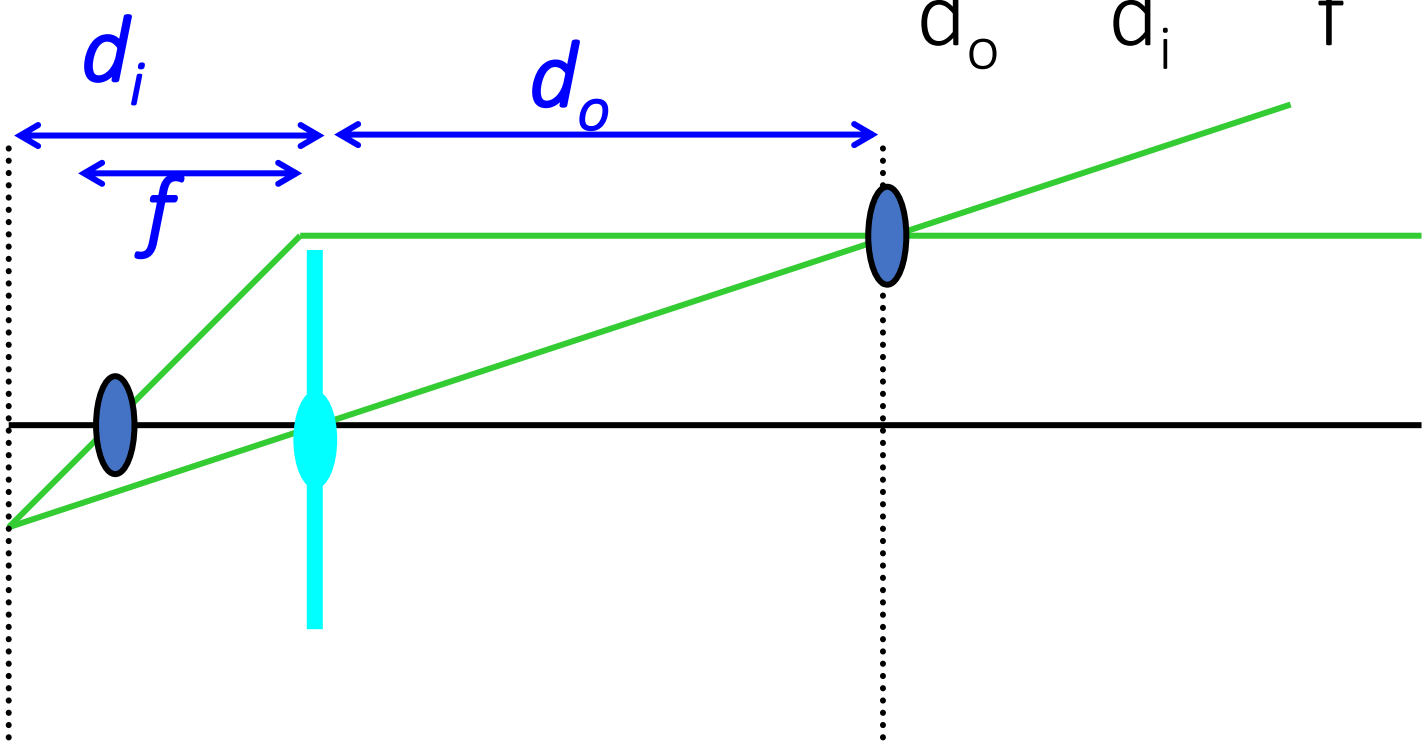
Thin lens formula

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



Any point satisfying the thin lens equation is in focus.

[Slide by Fredo Durand]

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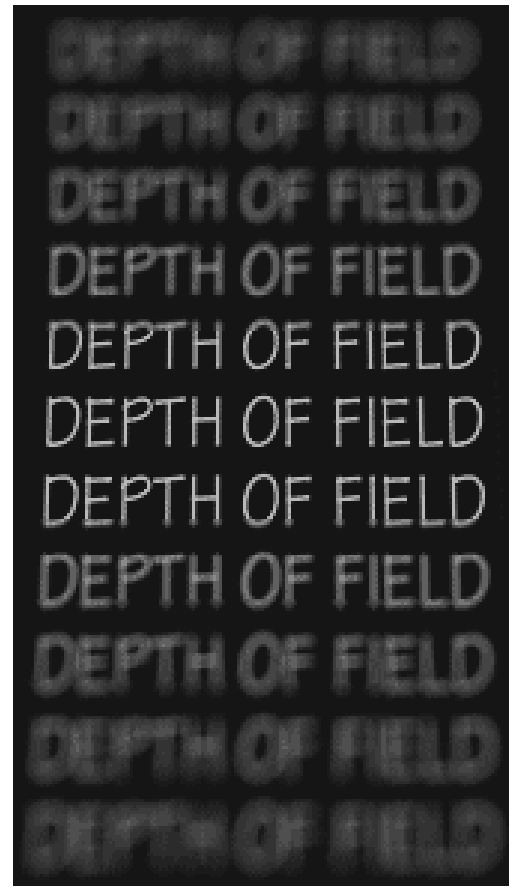
Depth of field



http://www.cambridgeincolour.com/tutorials/depth-of-field.htm

[Slide by A. Efros]

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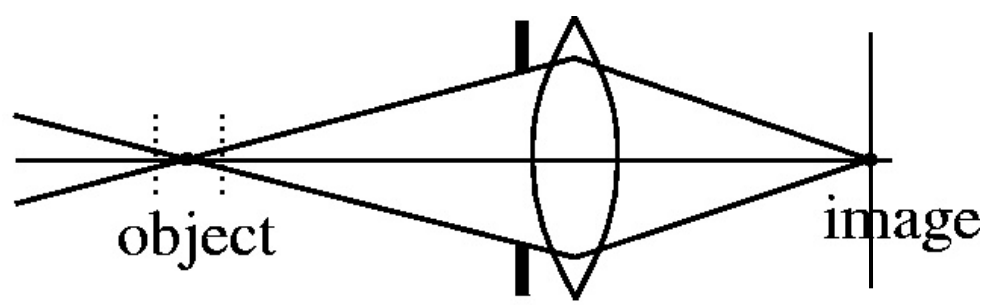
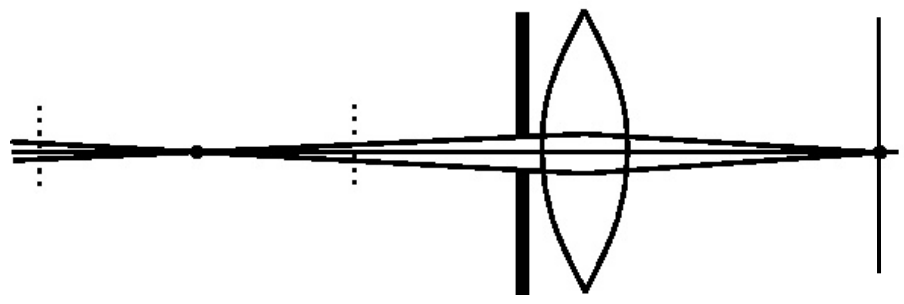
Depth of field




f / 5.6




f / 32

Changing the aperture size affects depth of field

- A smaller aperture increases the range in which the object is approximately in focus
- But small aperture reduces amount of light – need to increase exposure

Flower images from Wikipedia http://en.wikipedia.org/wiki/Depth_of_field

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Depth of field

Large aperture = small DOF

Small aperture = large DOF

[Slide by A. Efros]

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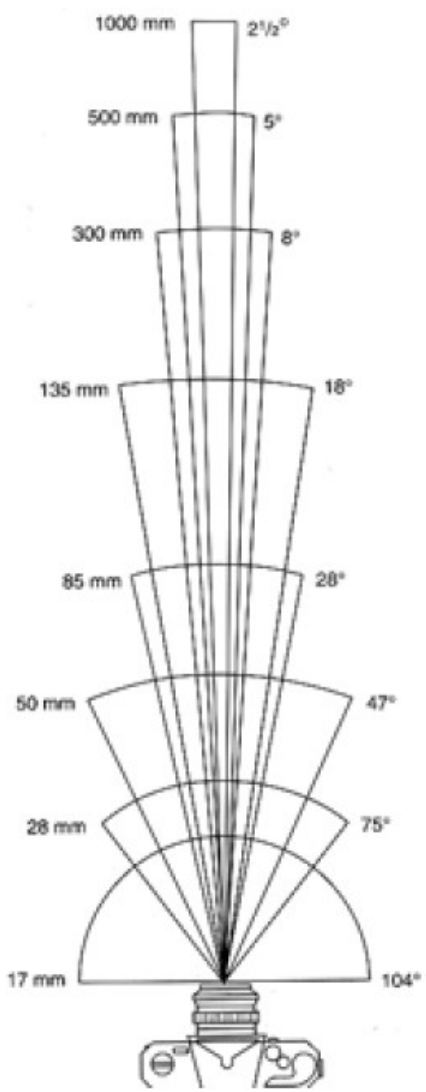
Field of view



From London and Upton

[Slide by A. Efros]

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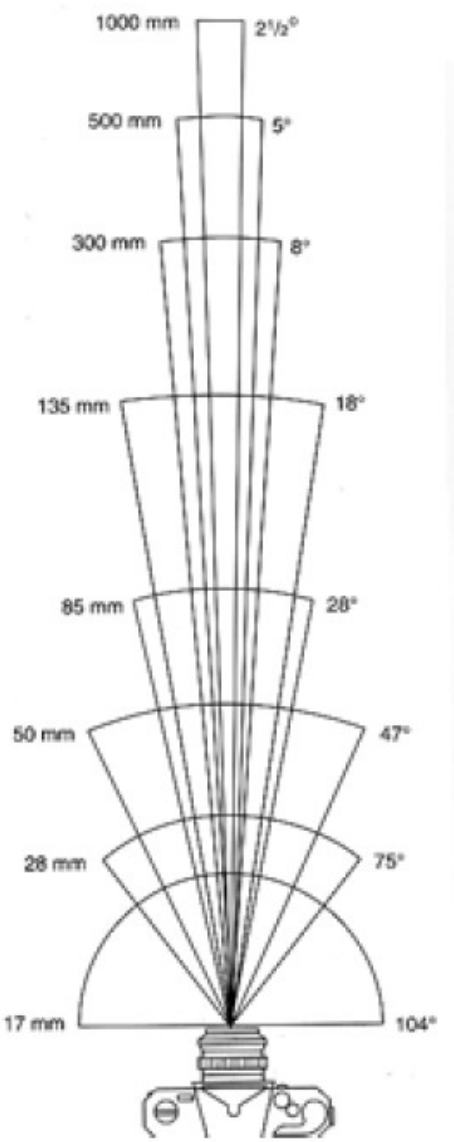
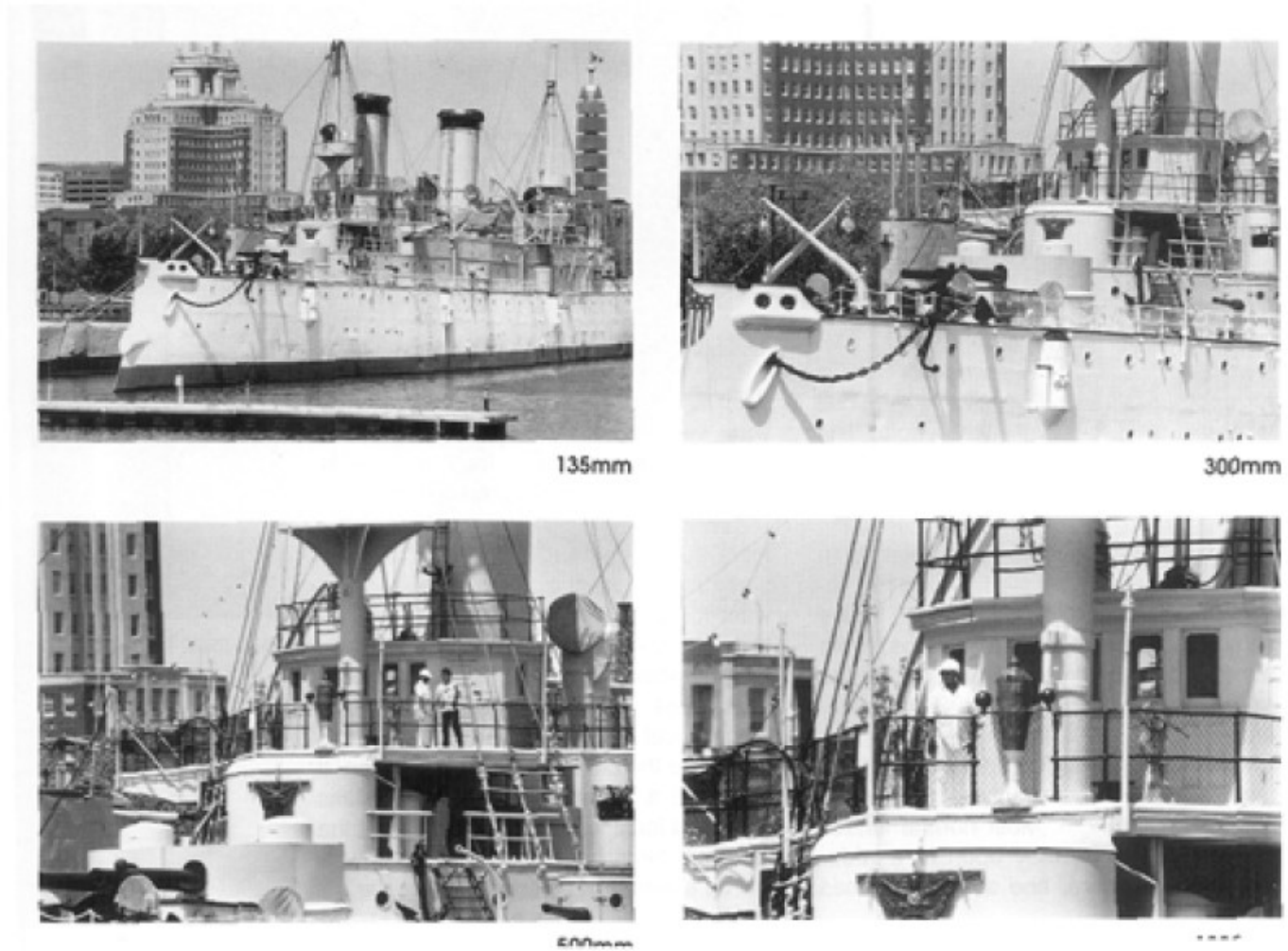
Field of view





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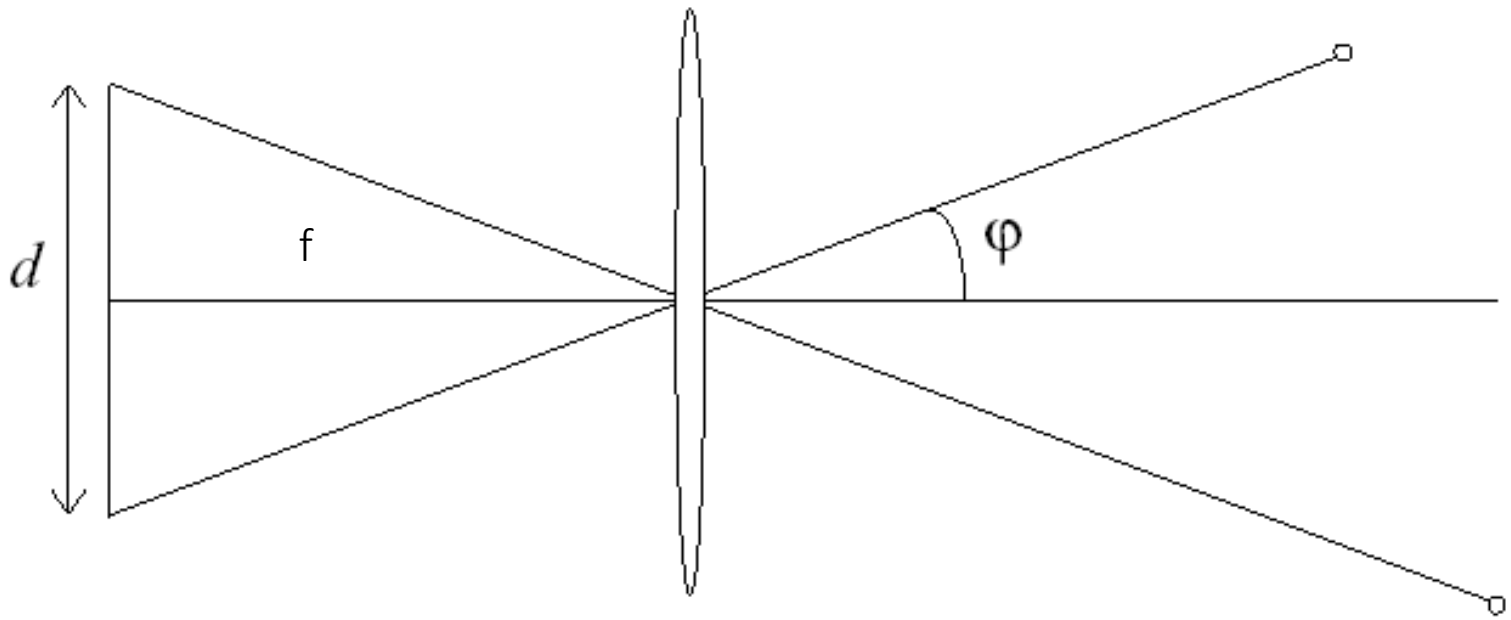
Field of view



FOV depends on focal length f and size of the camera sensor size d

$$\varphi = \tan^{-1}\left(\frac{d}{2f}\right)$$

Smaller FOV = larger Focal Length

[Slide by A. Efros]

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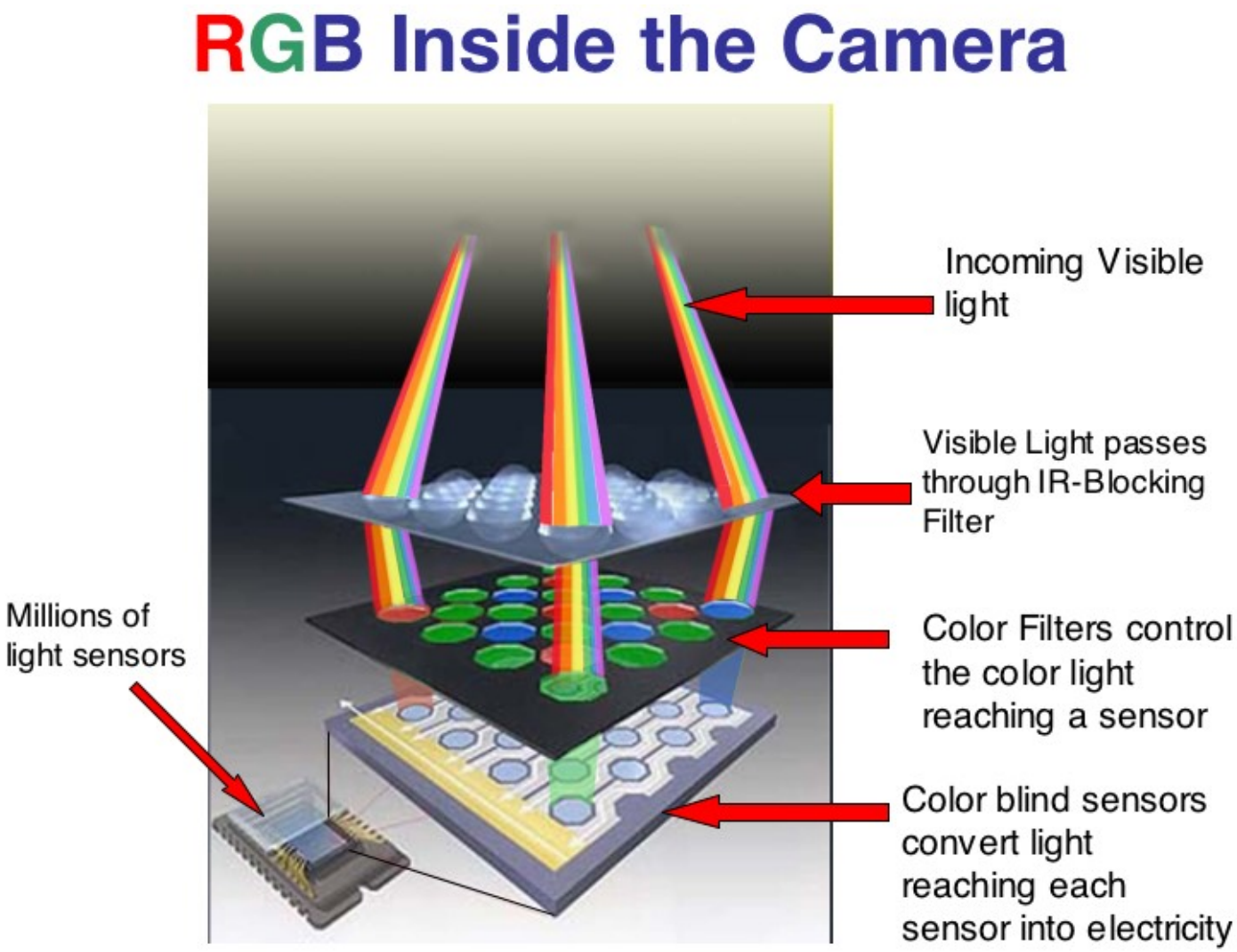
From light to pixels



https://sites.google.com/a/globalsystemsscience.org/digital-earth-watch/tools/digital-cameras/light-entering-a-camera

[Slide by Steve Seitz]

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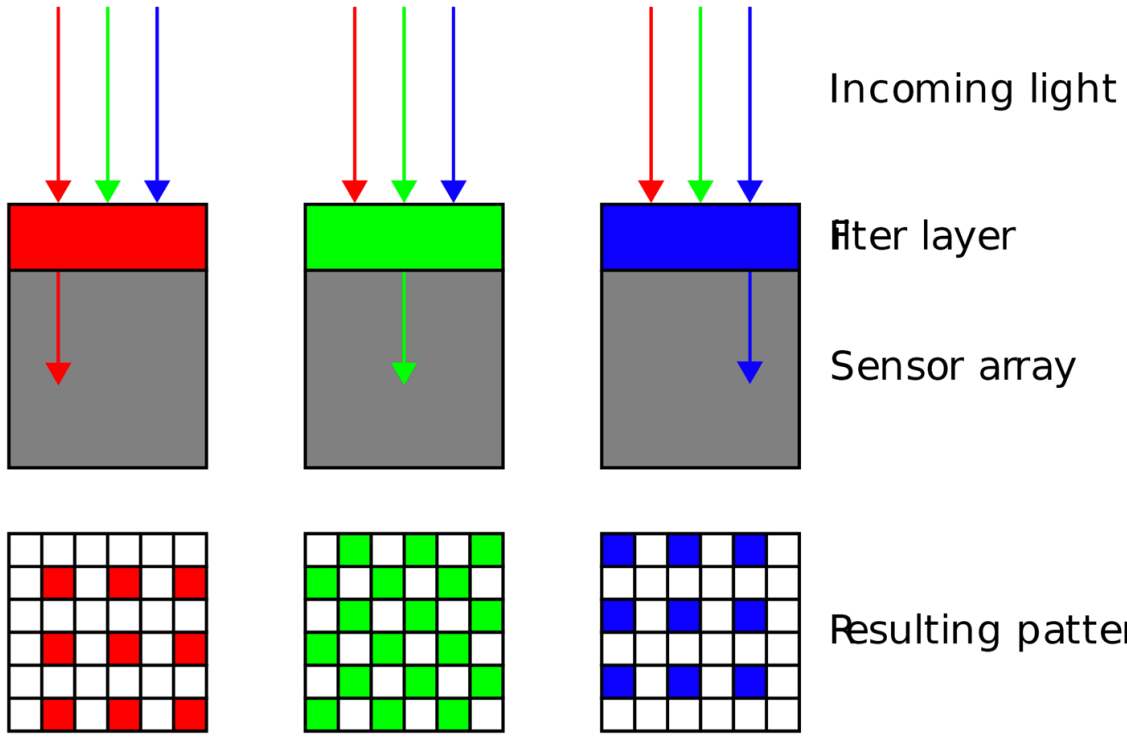
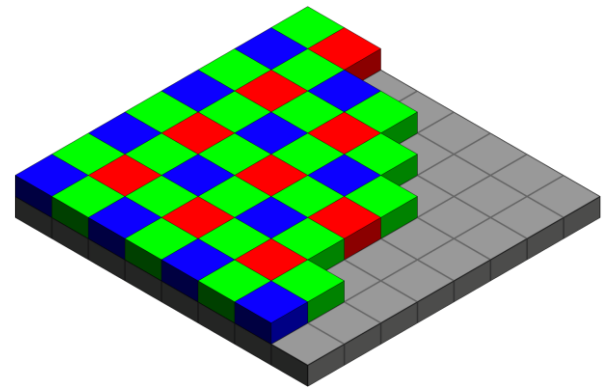
Bayer filters





https://en.wikipedia.org/wiki/Bayer_filter

¼ of pixels see red light (e.g.)

- Q: how do you get red at every pixel?
- A: Need to interpolate -- called *debayering*

[Slide by Steve Seitz]

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Today's Agenda - Overview of Cameras

- Pinhole Camera model
  - Aperture
  - Camera Obscura
- Cameras with lenses
  - Thin lens equation
  - Depth of field
  - Field of view
- Digital cameras
  - Bayer filters
  - Debayering

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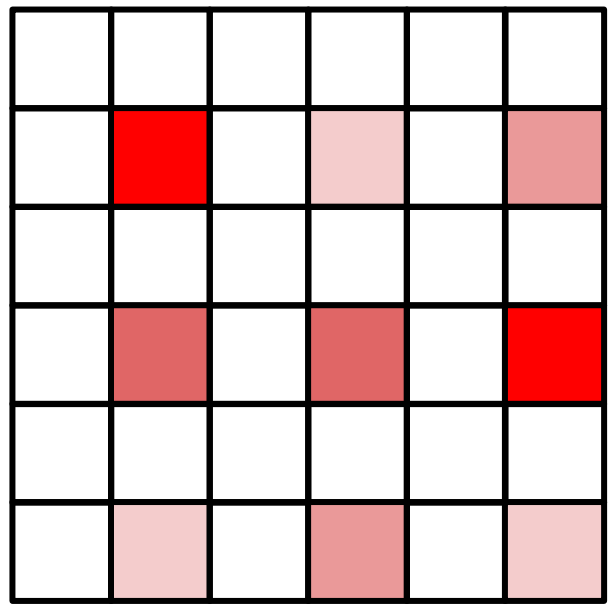
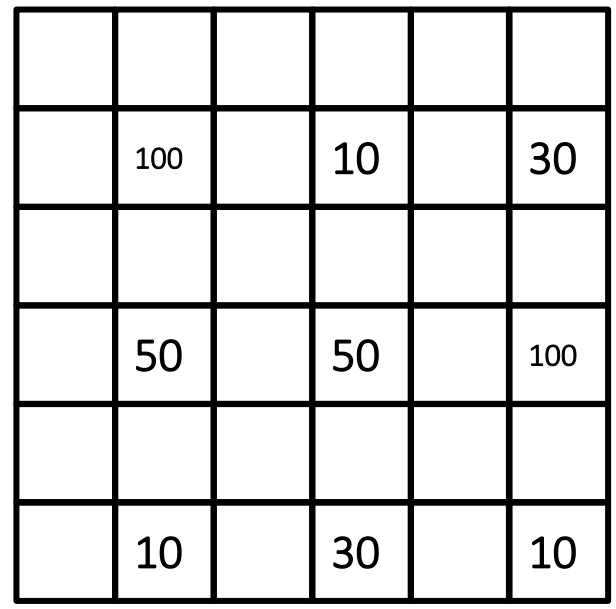
Debayering





¼ of pixels see red light (e.g.)

- Q: how do you get red at every pixel?
- A: Need to interpolate -- called *debayering*

[Slide by Steve Seitz]

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RGB images (three channel)

What we see

What we get out of the camera

[Slide by Steve Seitz]

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From now on: what to do with these RGB images

[Slide by Steve Seitz]

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Thank you.

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