

**6.098 Digital and Computational
Photography**

**6.882 Advanced Computational
Photography**

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Administrivia

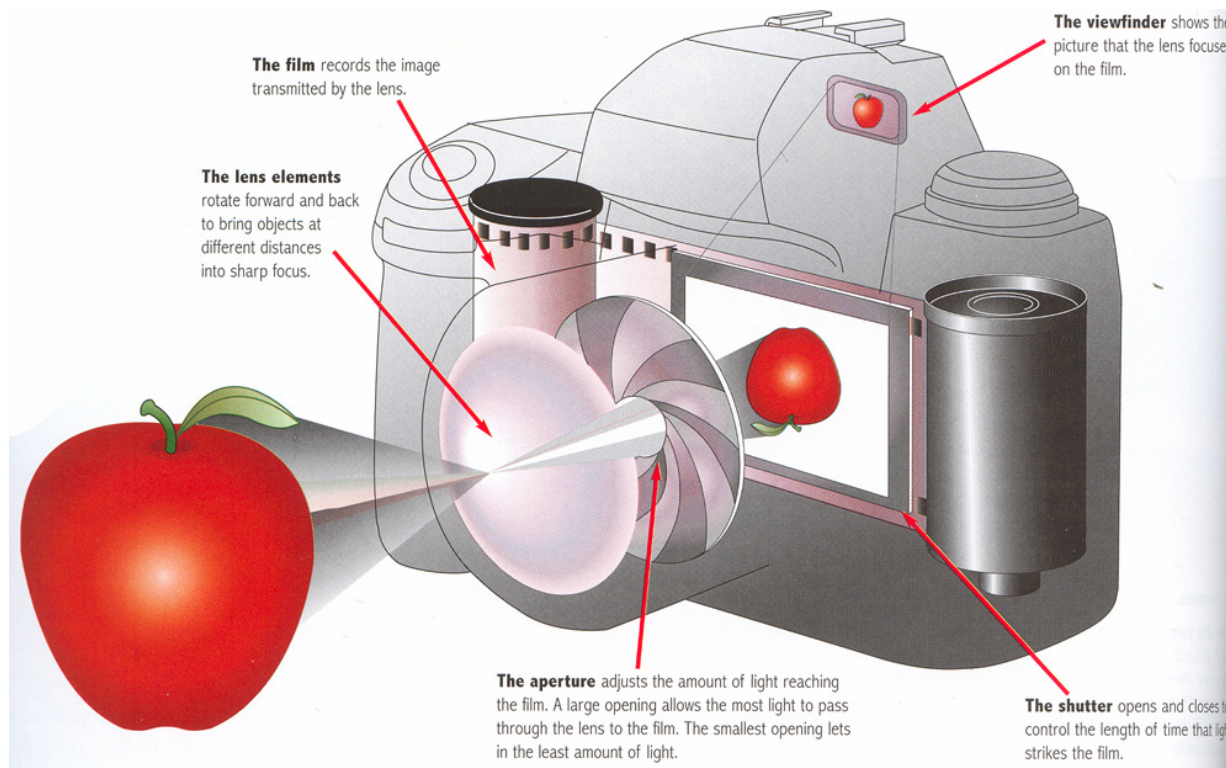
- **PSet 1 is out**
- **Due Thursday February 23**

Digital SLR initiation?

- **During Fredo's office hours Friday Feb 17 2:30-4pm in the "green-couch area" in Stata D4 south**
- **I'll have a couple of SLRs, but try to bring one if you can.**

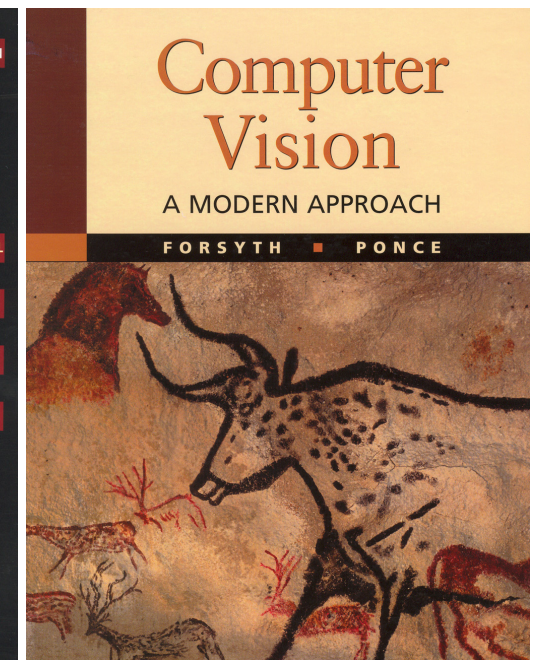
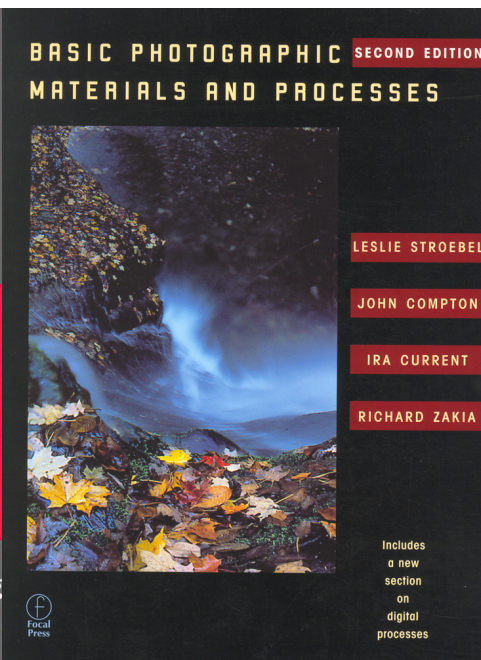
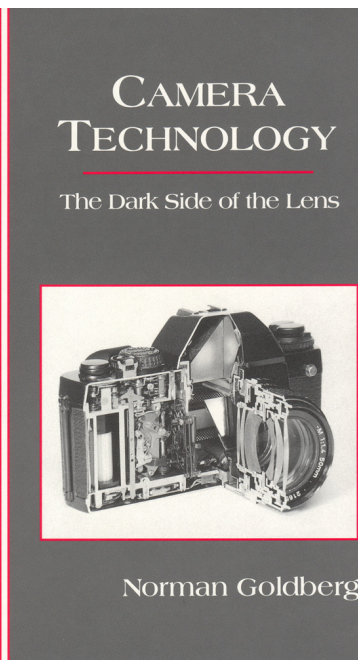
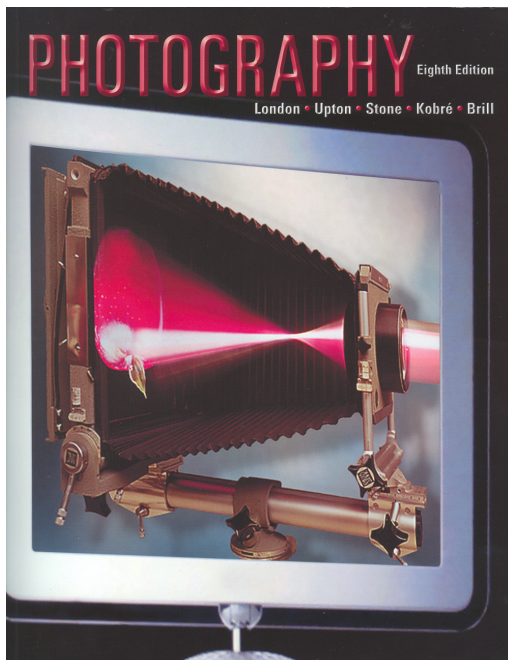
Overview

- Lens and viewpoint determine perspective
- Aperture and shutter speed determine exposure
- Aperture and other effects determine depth of field
- Film or sensor record image



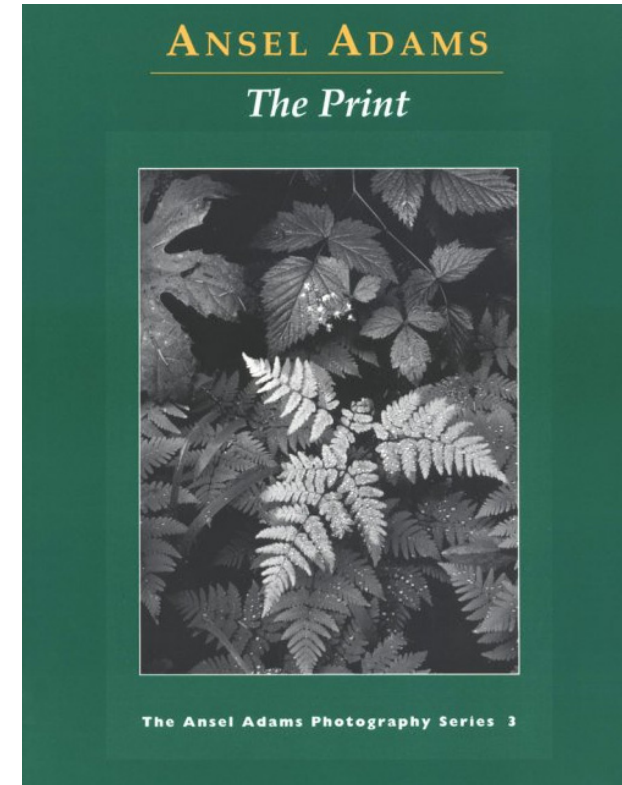
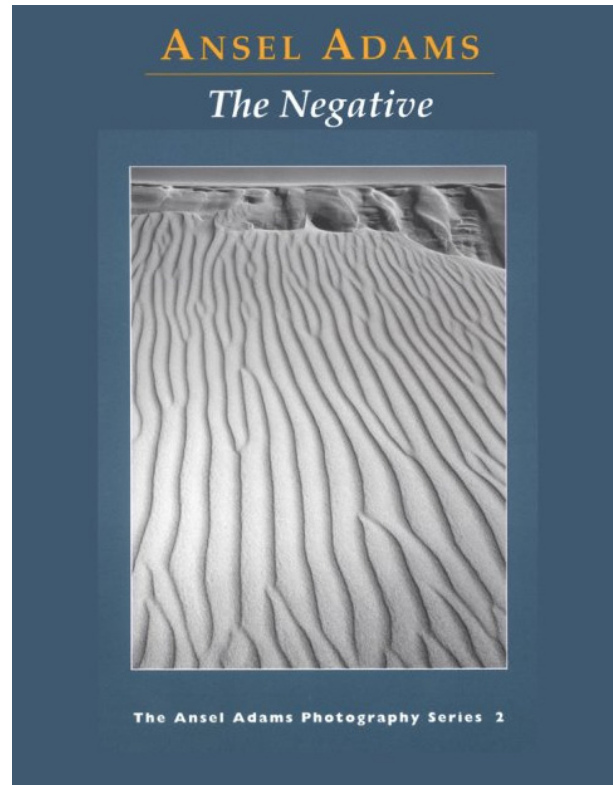
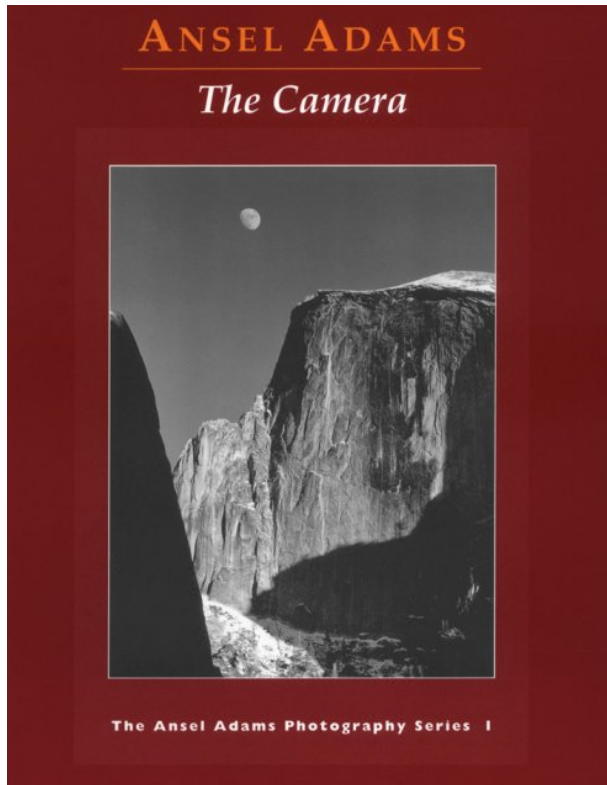
Reference

- <http://courses.csail.mit.edu/6.869/lectnotes/lect1>
- [http://en.wikipedia.org/wiki/Lens_\(optics\)](http://en.wikipedia.org/wiki/Lens_(optics))



- The slides use illustrations from these books

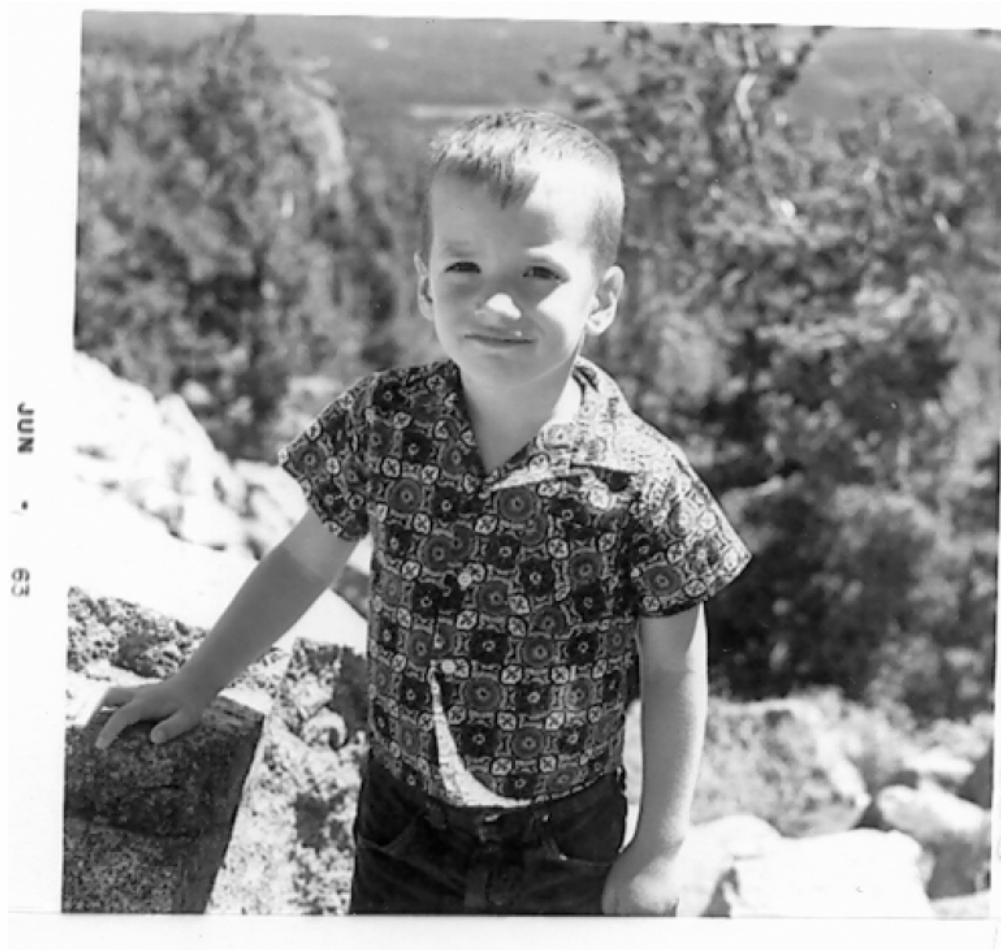
More references



Plan

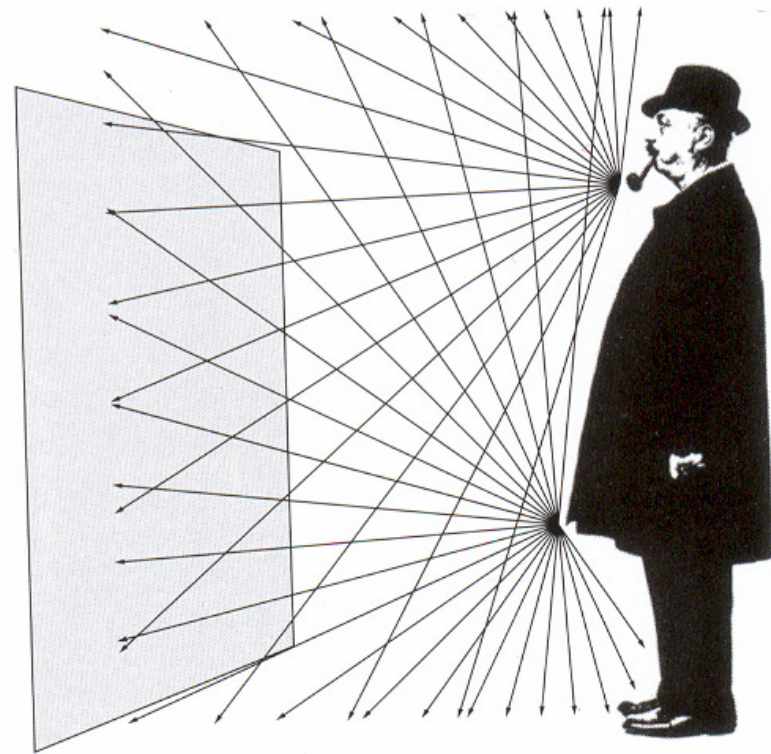
- **Pinhole optics**
- **Lenses**
- **Exposure**

7-year old's question

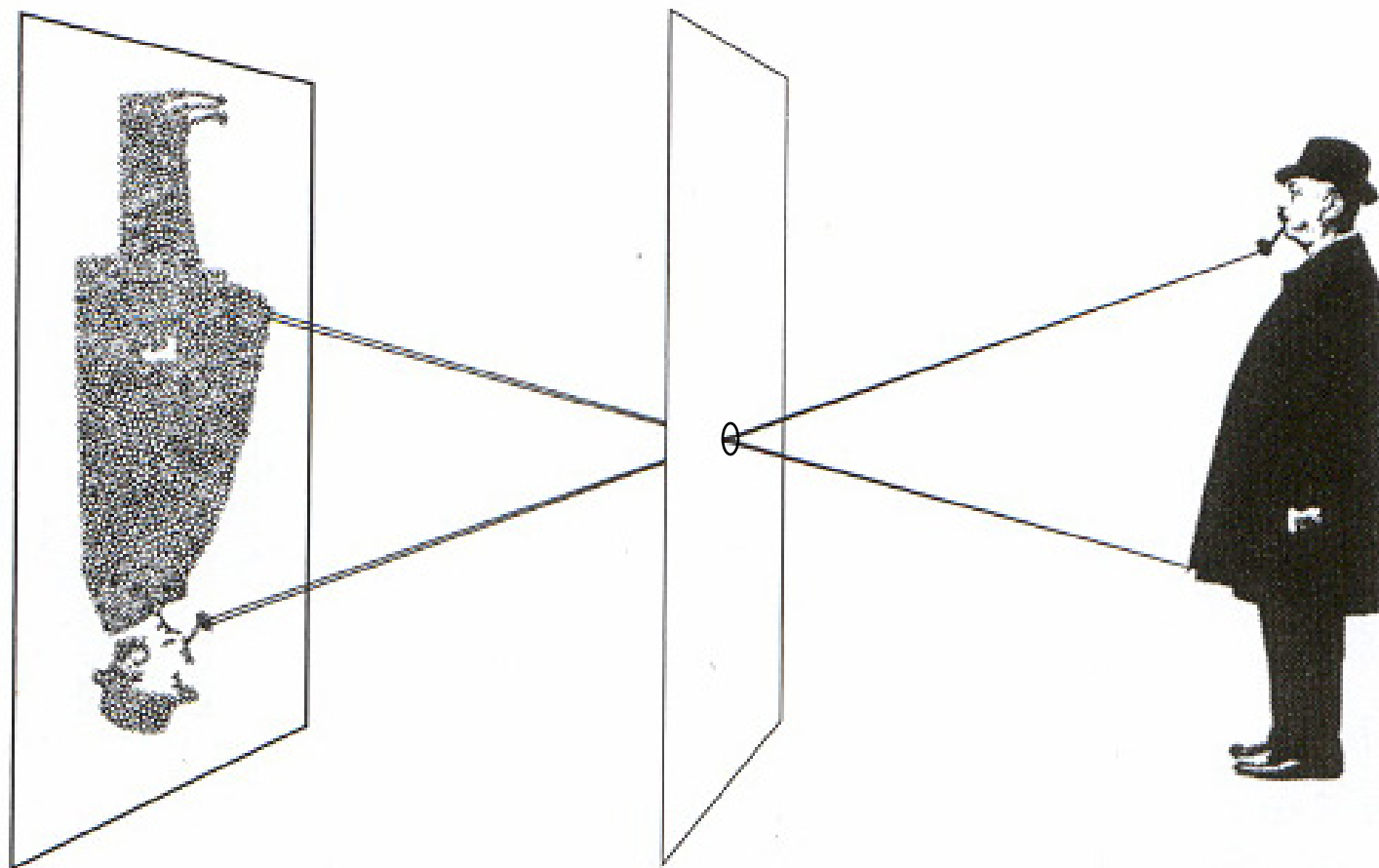


- Why is there no image on a white piece of paper?

It receives light from all directions



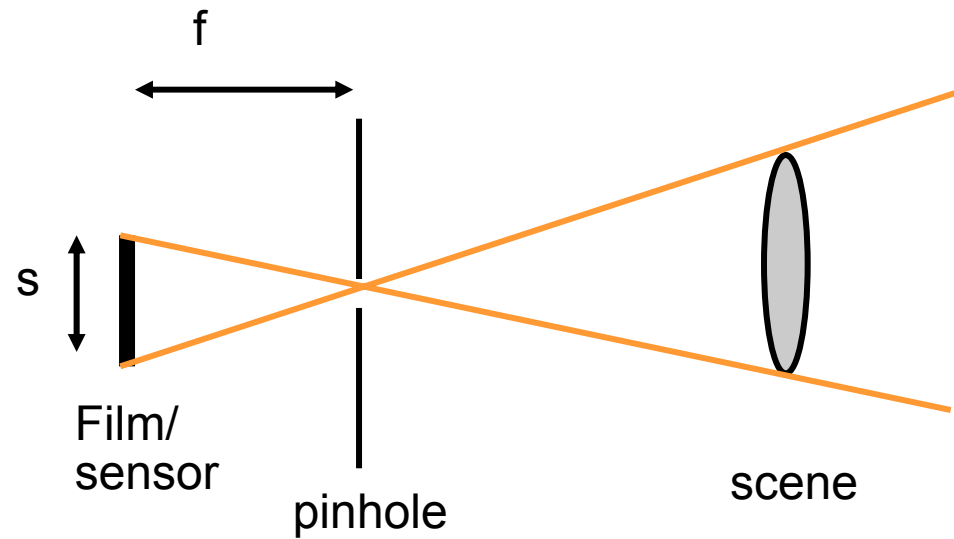
Pinhole



Demo!



Focal length

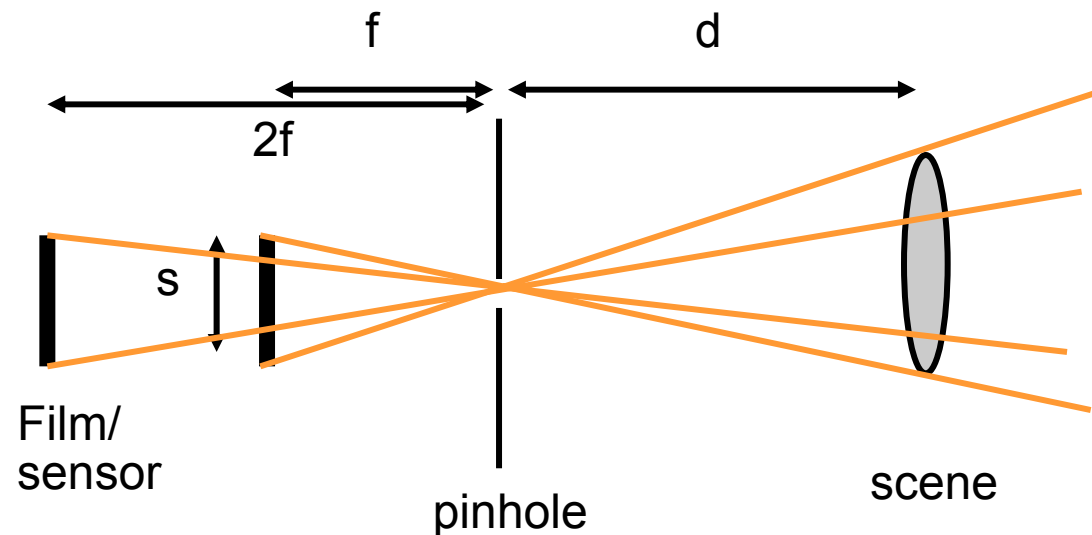


Demo!

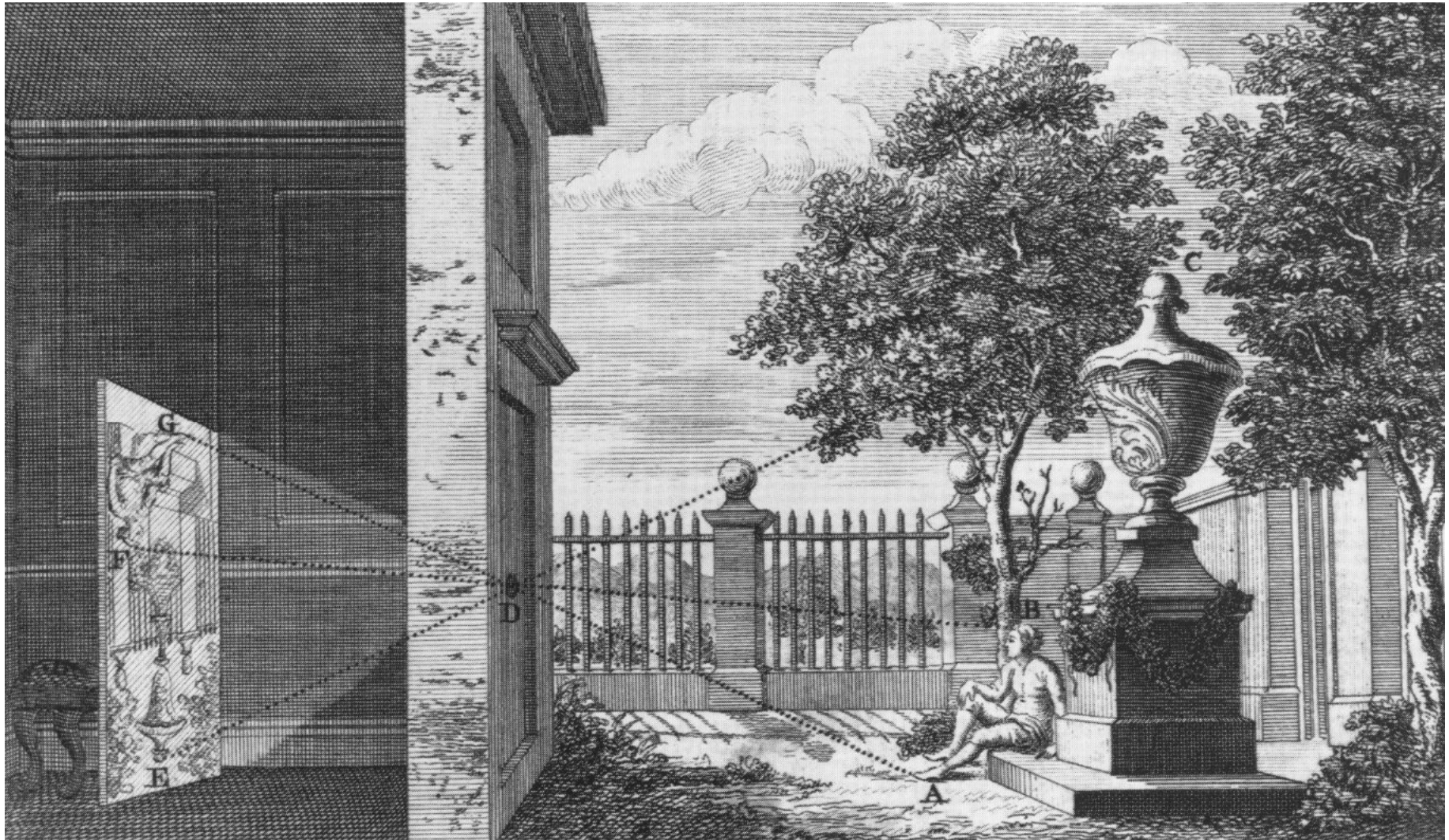


Focal length: pinhole optics

- What happens when the focal length is doubled?
 - Projected object size is doubled
 - Amount of light gathered is divided by 4

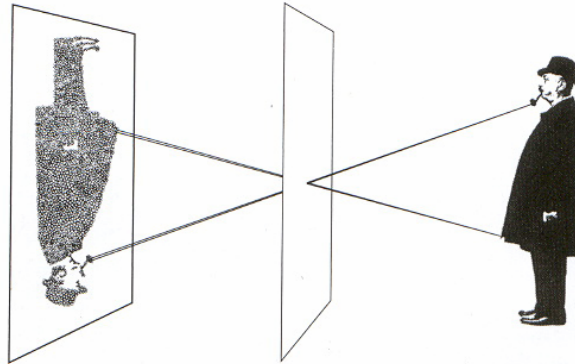


Questions?

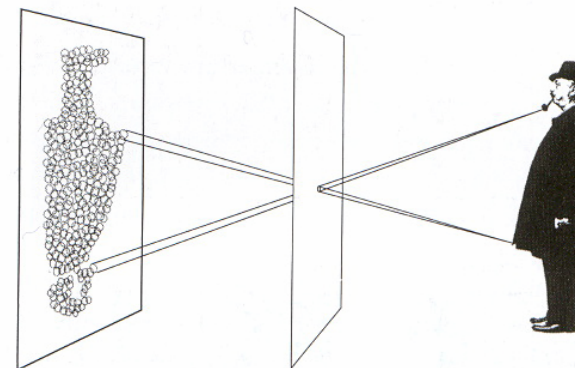


Pinhole size?

Photograph made with small pinhole

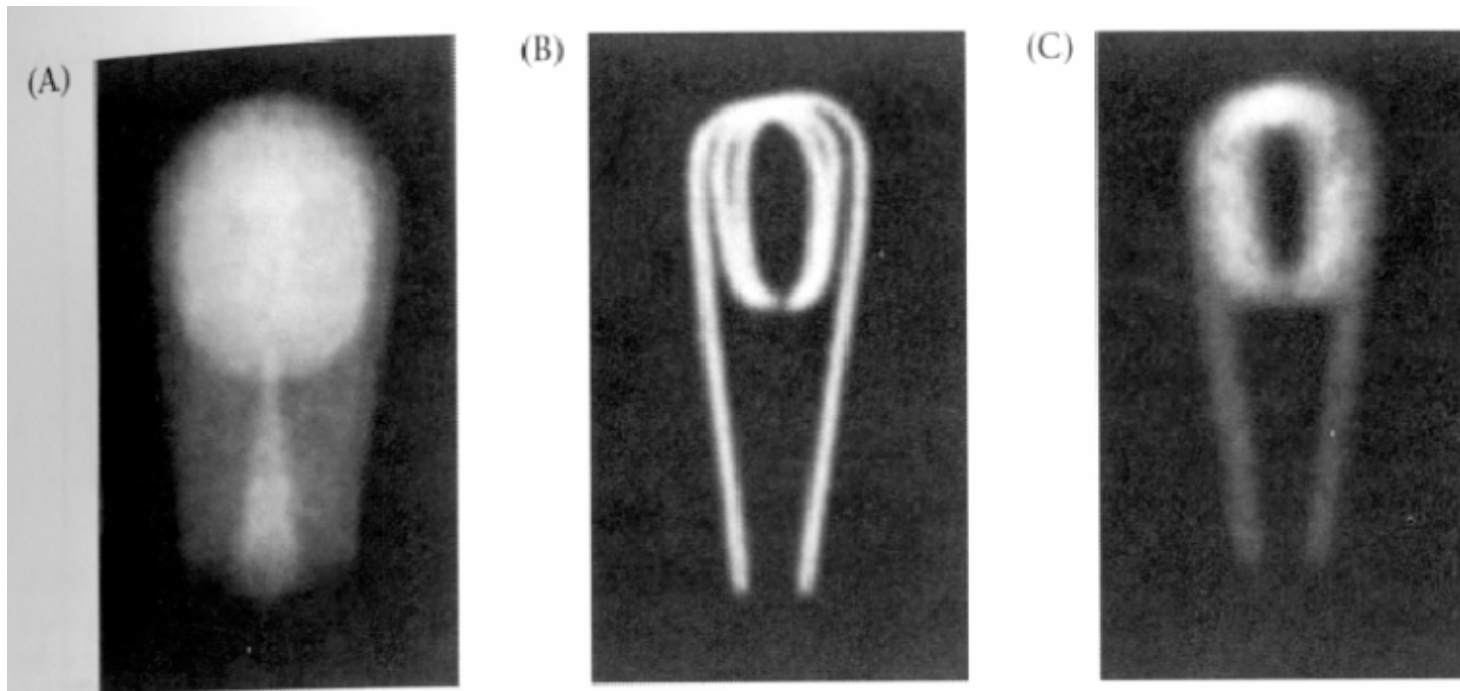


Photograph made with larger pinhole



Diffraction limit

- Optimal size for visible light:
 $\sqrt{f}/28$ (in millimeters) where f is focal length



2.18 DIFFRACTION LIMITS THE QUALITY OF PINHOLE OPTICS. These three images of a bulb filament were made using pinholes with decreasing size. (A) When the pinhole is relatively large, the image rays are not properly converged, and the image is blurred. (B) Reducing the size of the pinhole improves the focus. (C) Reducing the size of the pinhole further worsens the focus, due to diffraction. From Ruechardt, 1958.

Problem with pinhole?

- **Not enough light!**
- **Diffraction limits sharpness**

Solution: refraction!



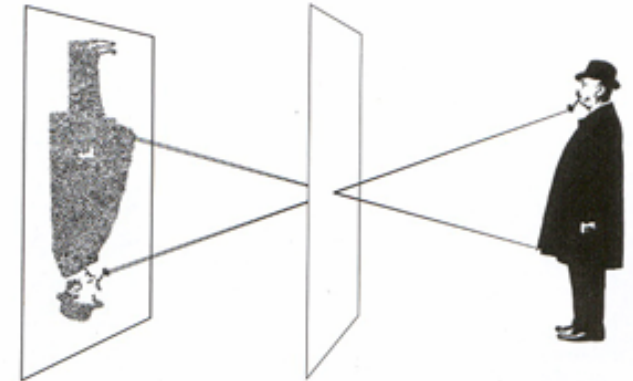
Lenses

- gather more light!
- But need to be focused

Photograph made with small pinhole



To make this picture, the lens of a camera was replaced with a thin metal disk pierced by a tiny pinhole, equivalent in size to an aperture of $f/182$. Only a few rays of light from each point on the

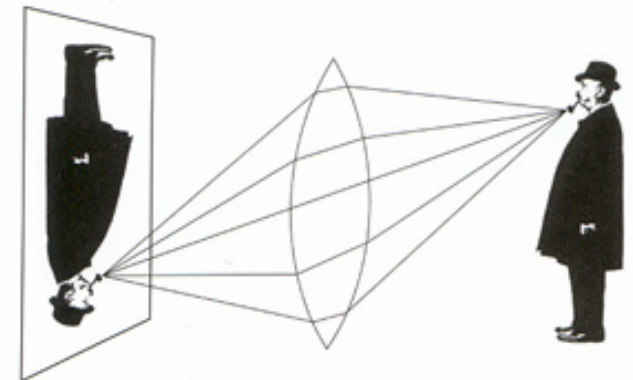


subject got through the tiny opening, producing a soft but acceptably clear photograph. Because of the small size of the pinhole, the exposure had to be 6 sec long.

Photograph made with lens



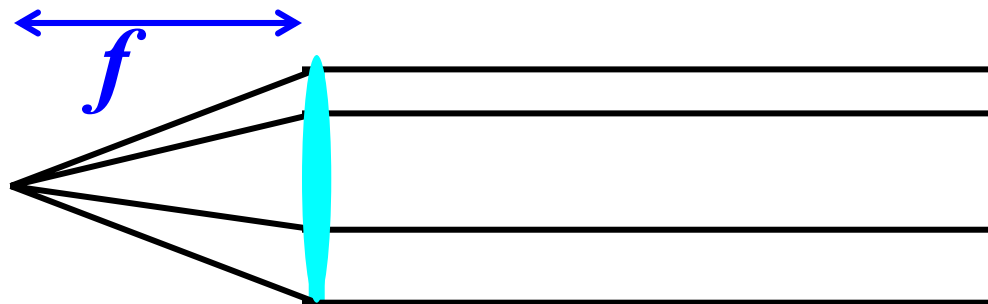
This time, using a simple convex lens with an $f/16$ aperture, the scene appeared sharper than the one taken with the smaller pinhole, and the exposure time was much shorter, only 1/100 sec.



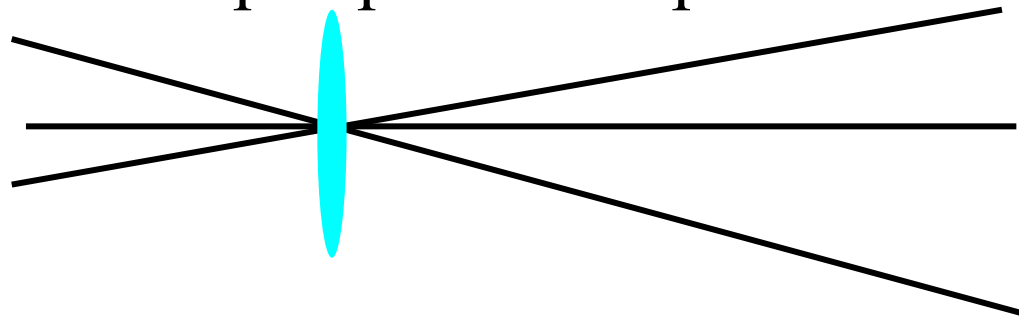
The lens opening was much bigger than the pinhole, letting in far more light, but it focused the rays from each point on the subject precisely so that they were sharp on the film.

Thin lens optics

- Simplification of geometrical optics for well-behaved lenses
- All parallel rays converge to one point on a plane located at the focal length f



- All rays going through the center are not deviated
 - Hence same perspective as pinhole

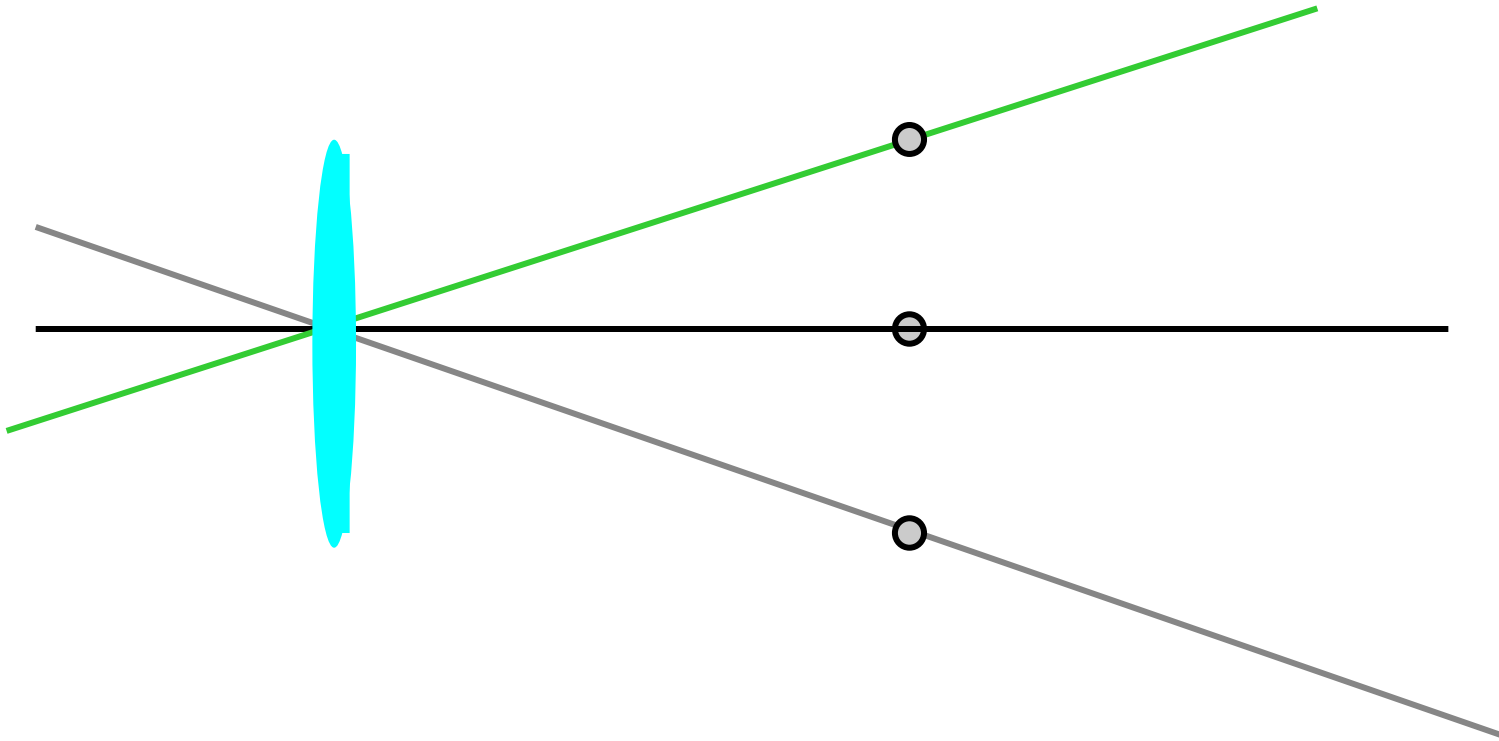


Demo!



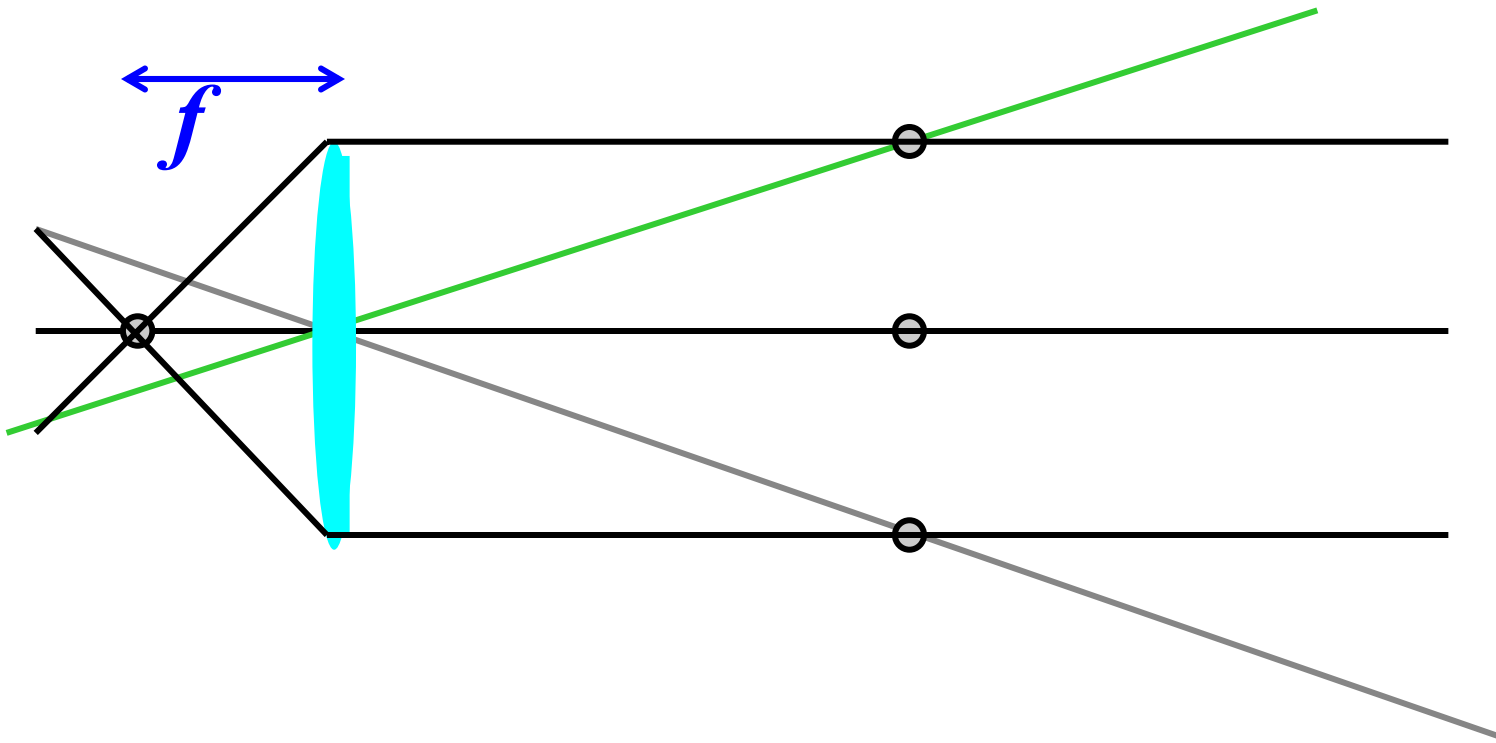
How to trace rays

- Start by rays through the center



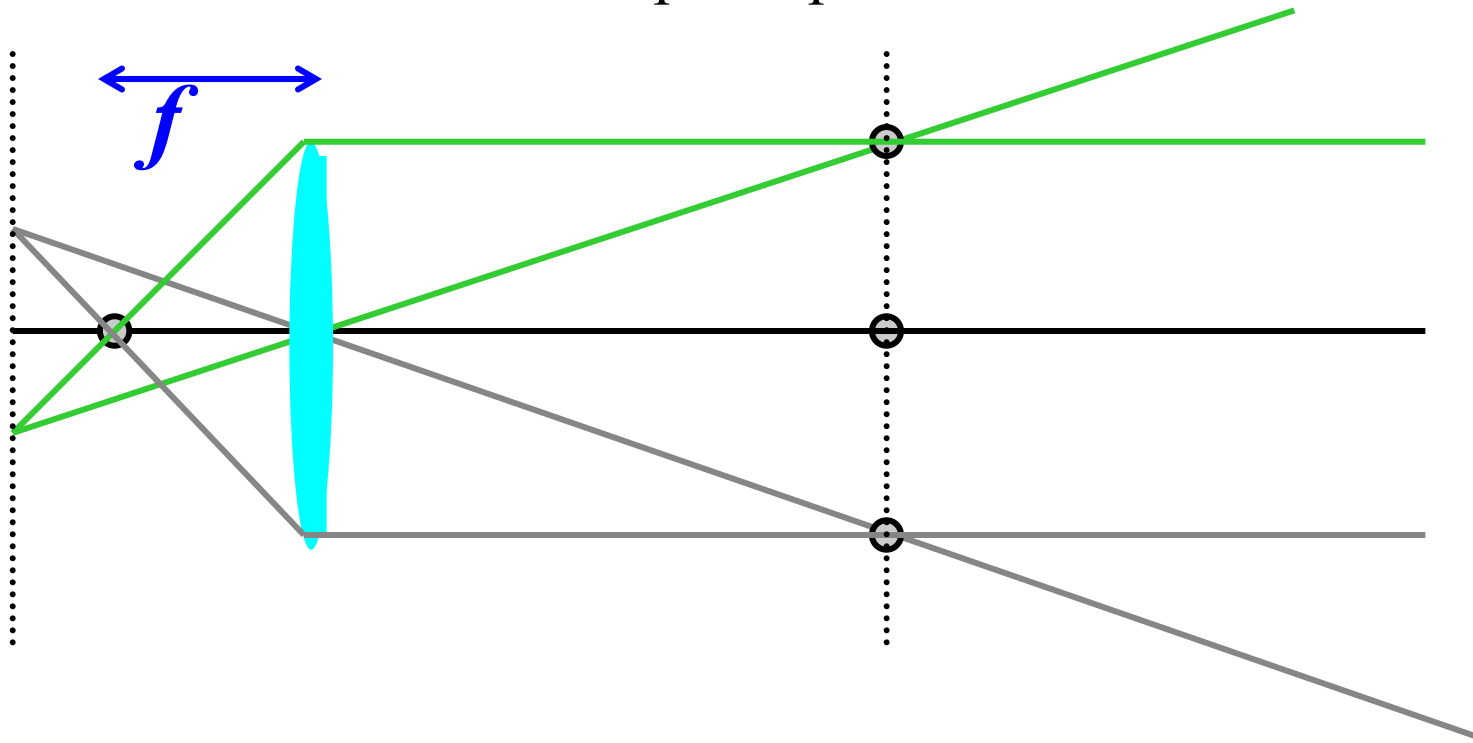
How to trace rays

- Start by rays through the center
- Choose focal length, trace parallels



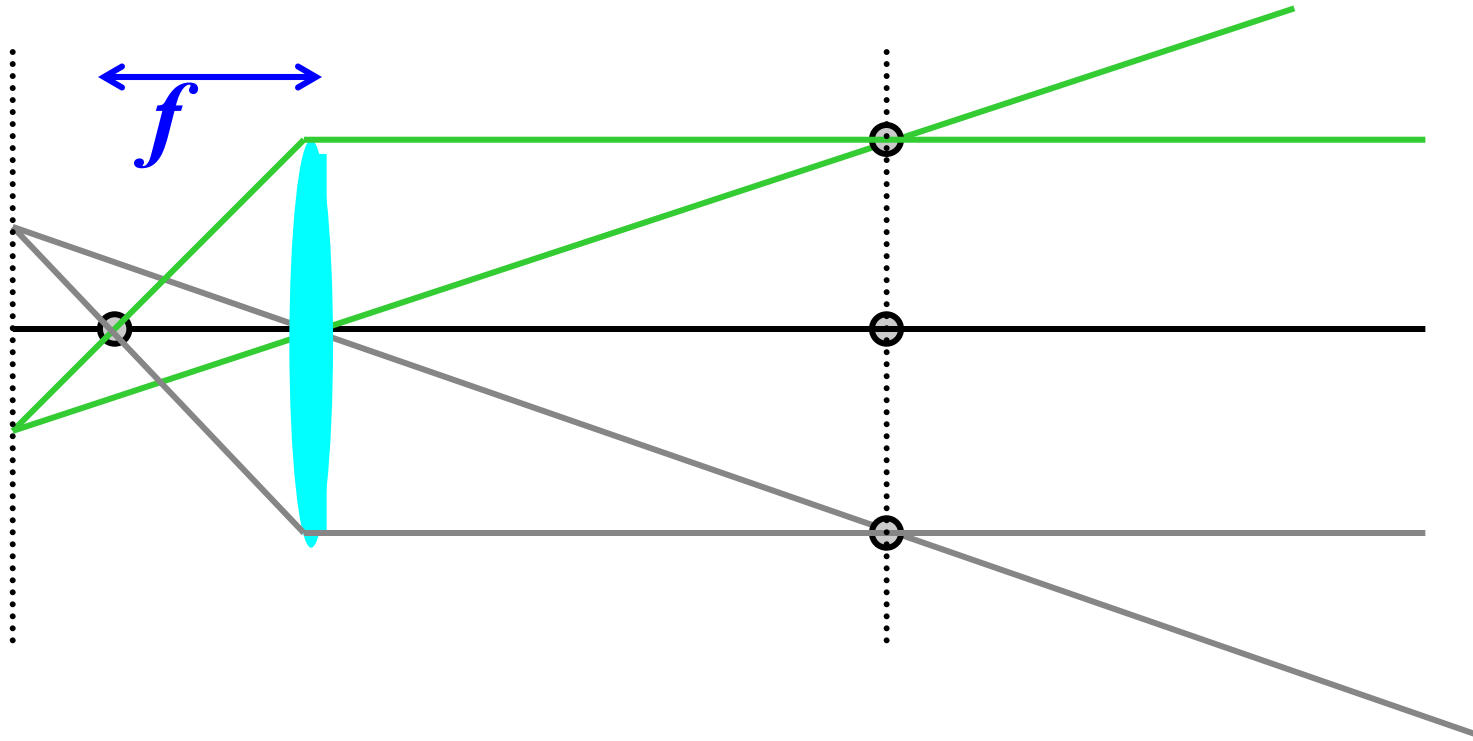
How to trace rays

- Start by rays through the center
- Choose focal length, trace parallels
- You get the focus plane for a given scene plane
 - All rays coming from points on a plane parallel to the lens are focused on another plane parallel to the lens

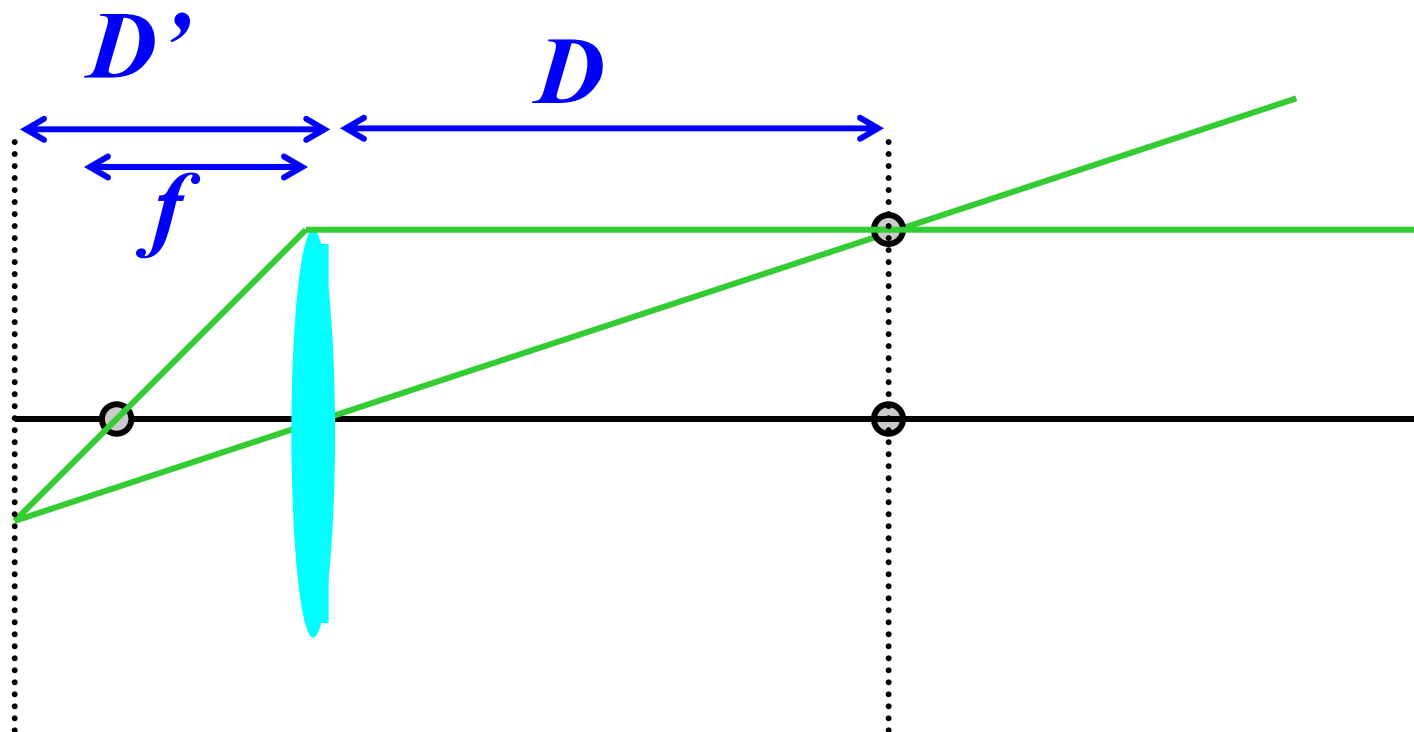


Focusing

- To focus closer than infinity
 - Move the sensor/film *further* than the focal length

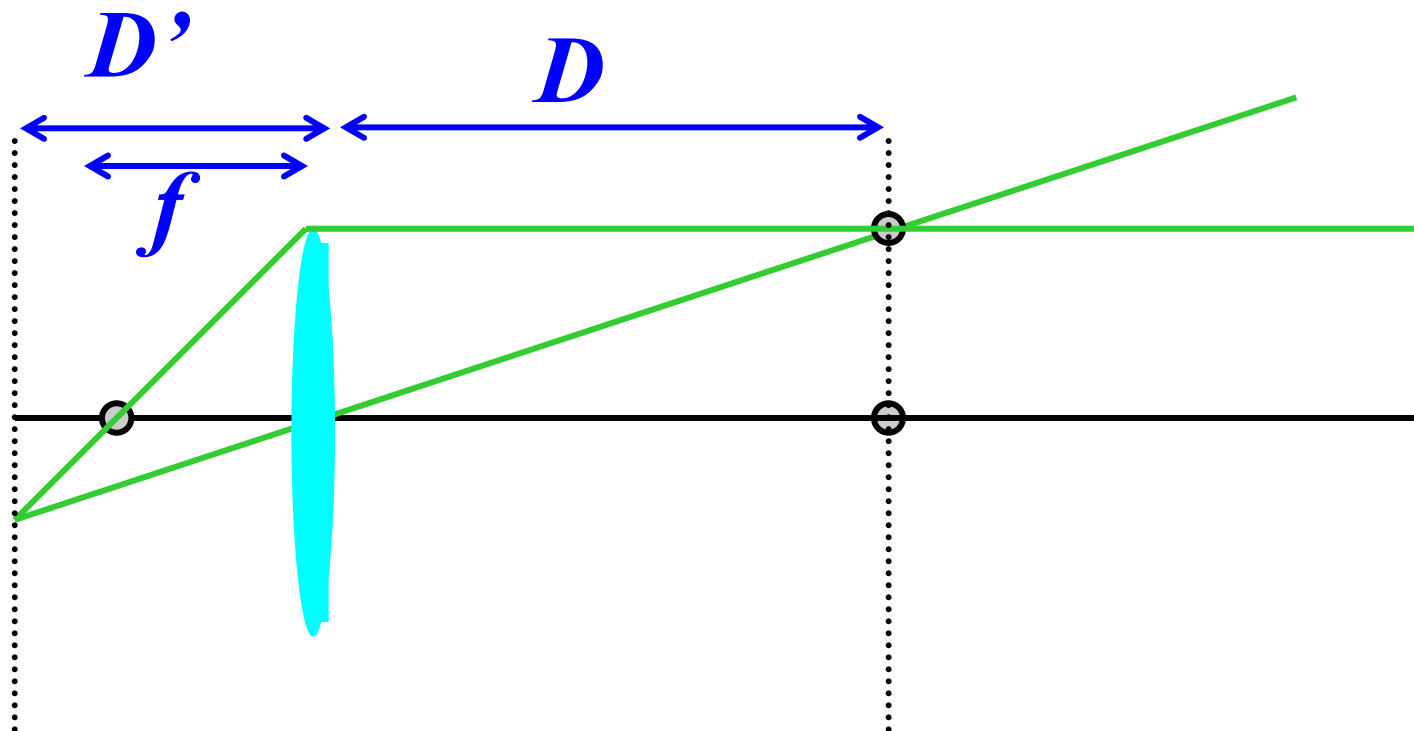


Thin lens formula



Thin lens formula

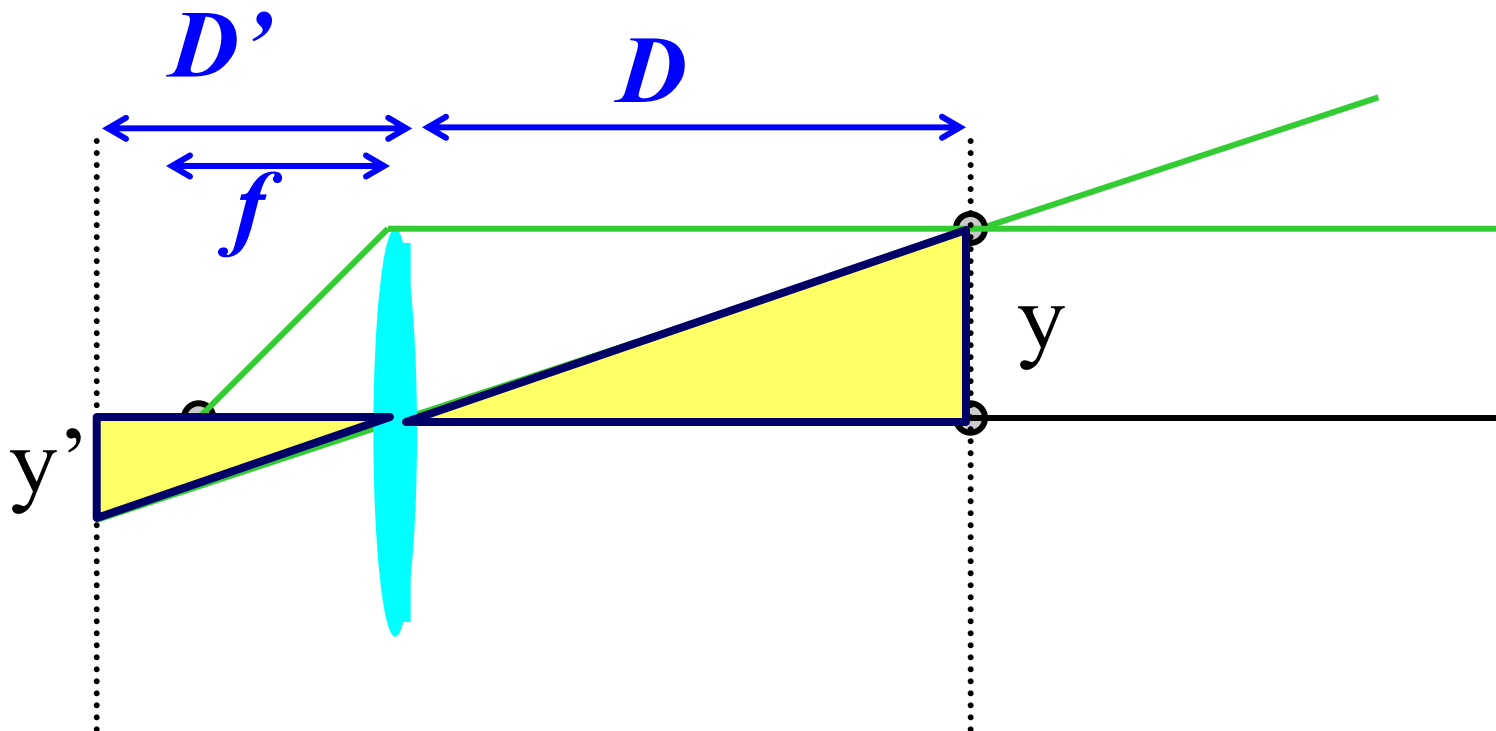
Similar triangles everywhere!



Thin lens formula

Similar triangles everywhere!

$$y'/y = D'/D$$

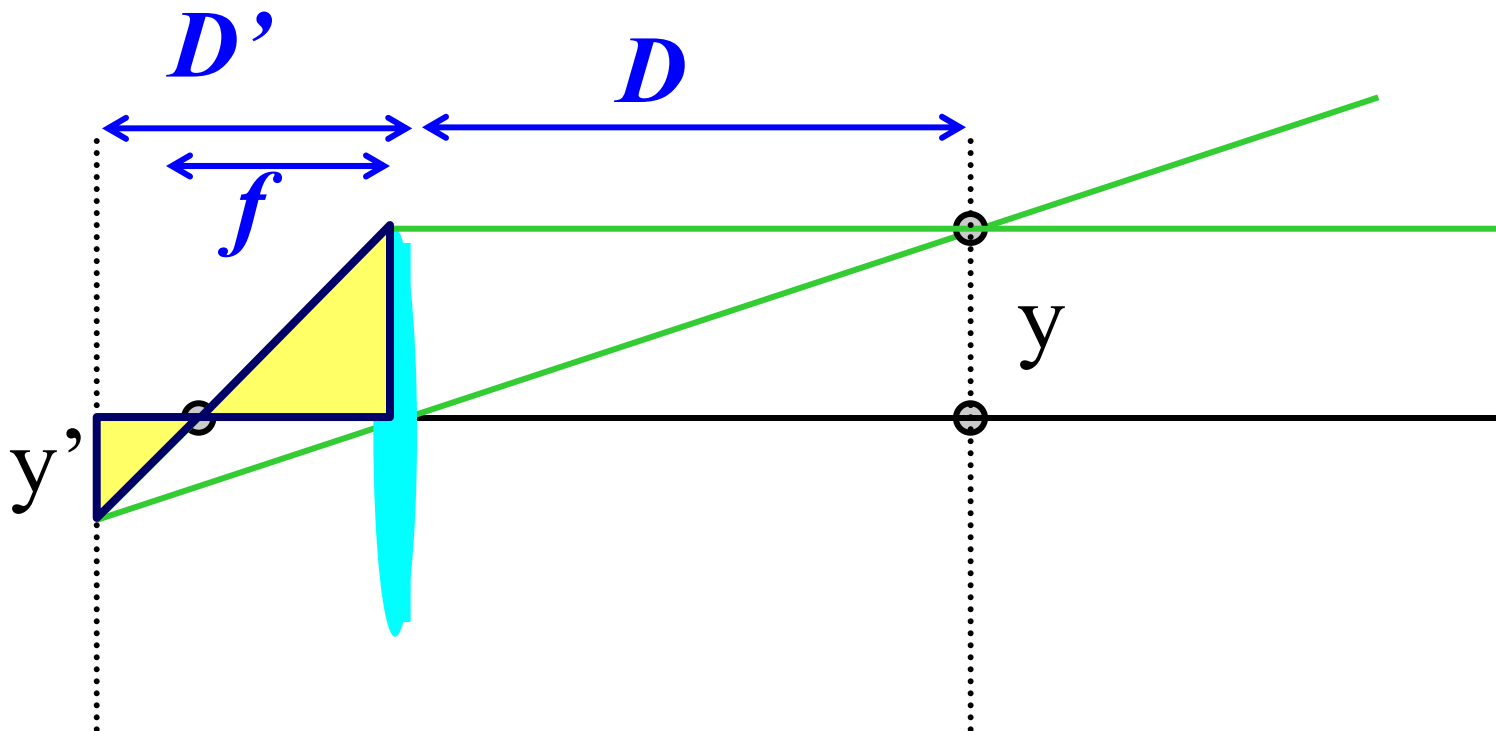


Thin lens formula

Similar triangles everywhere!

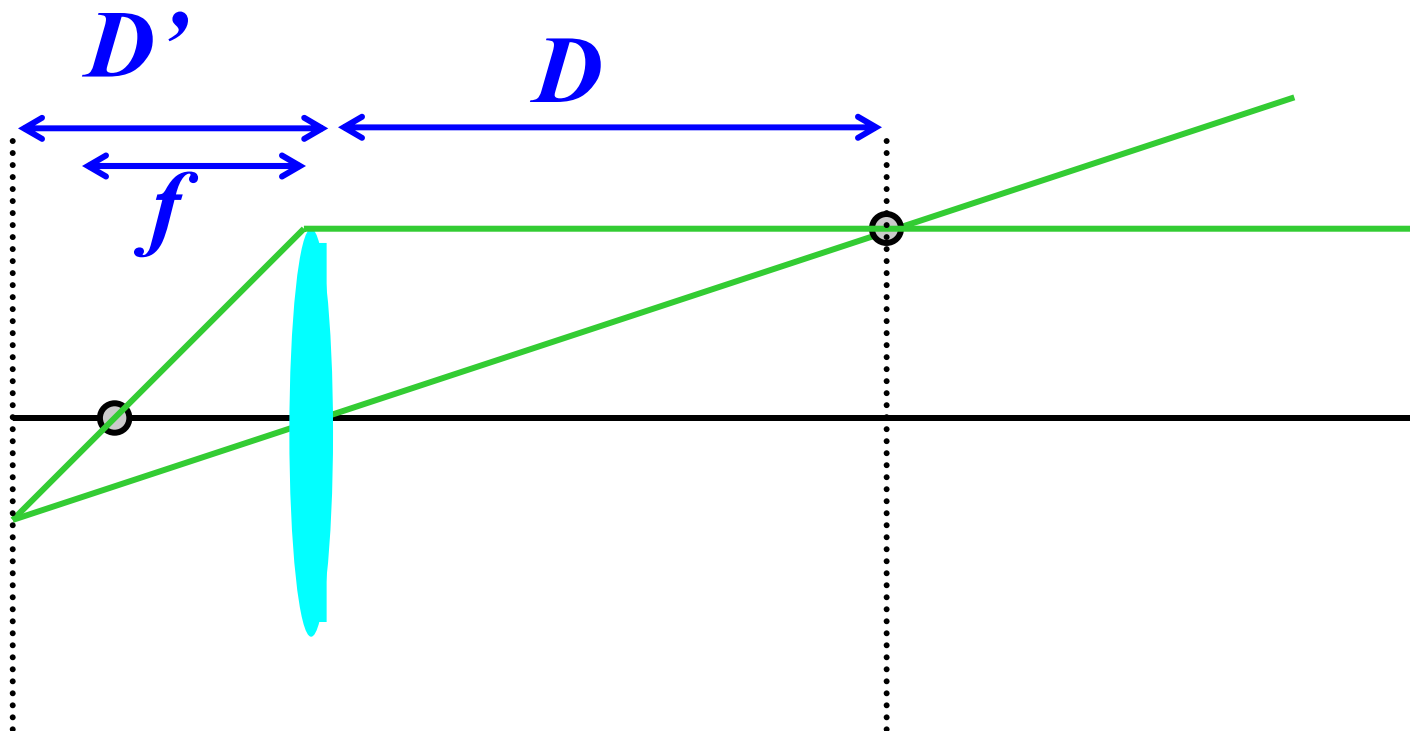
$$y'/y = D'/D$$

$$y'/y = (D' - f)/D$$



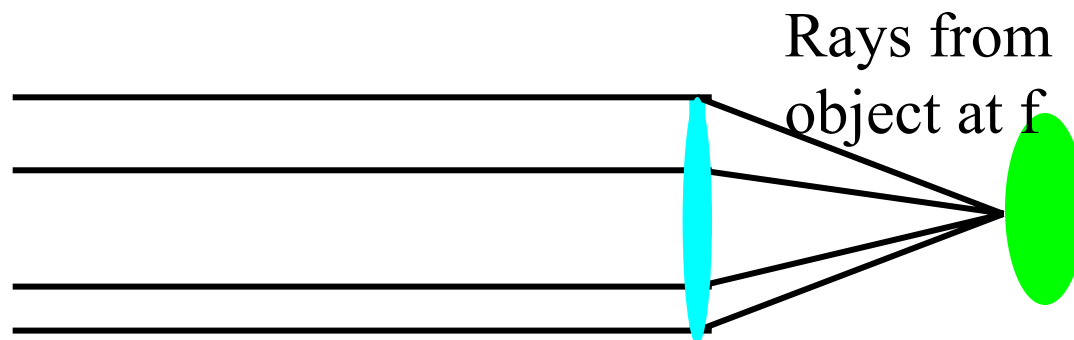
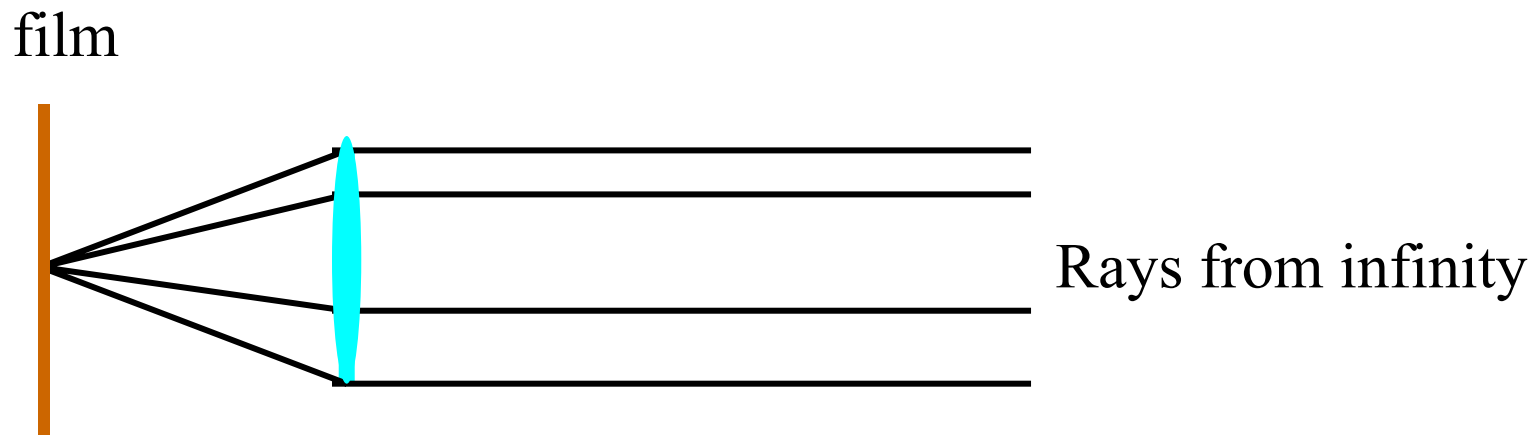
Thin lens formula

$$\frac{1}{D'} + \frac{1}{D} = \frac{1}{f}$$



Minimum focusing distance

- By symmetry, an object at the focal length requires the film to be at infinity.

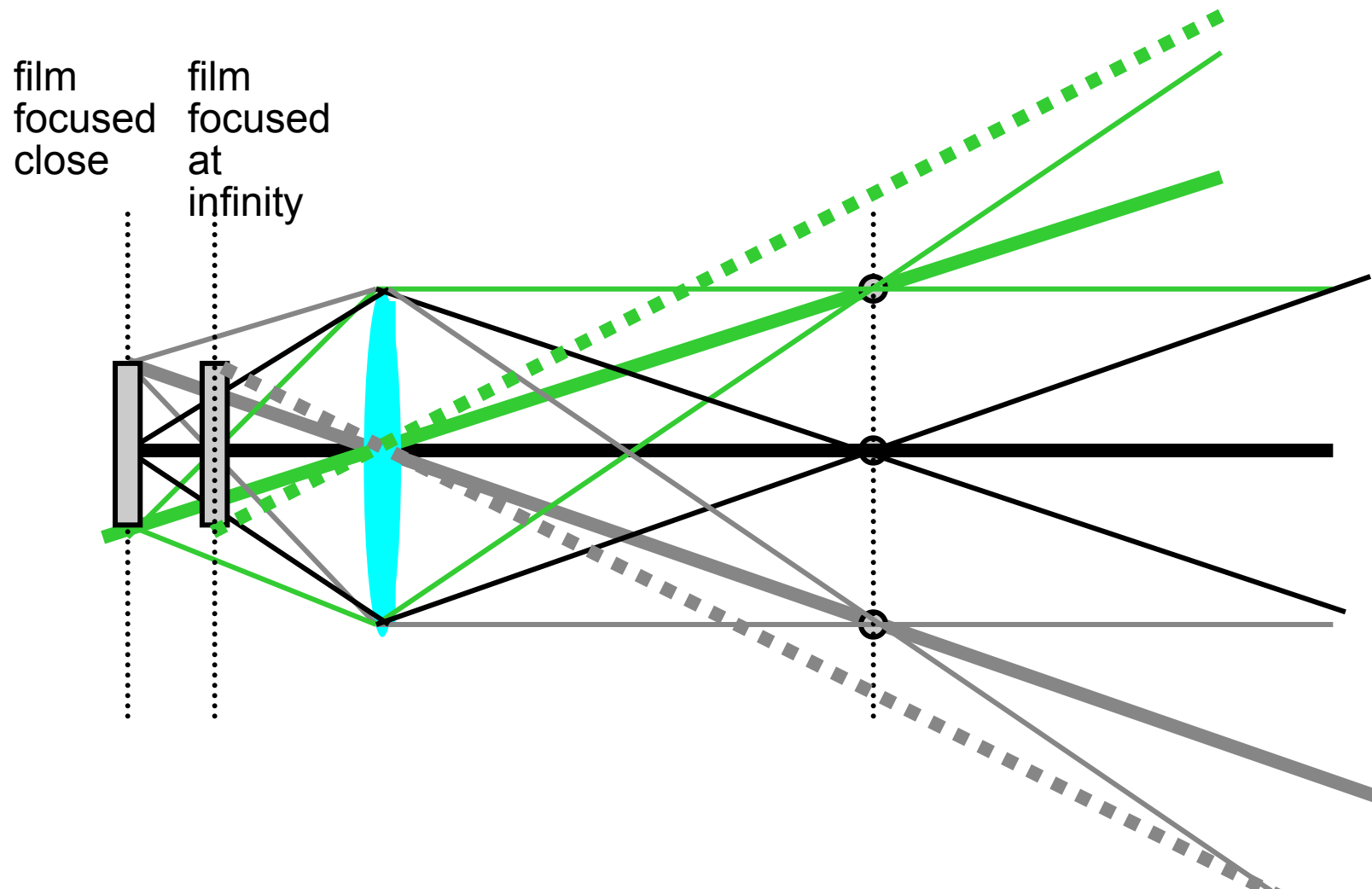


Extensions tubes

- **Allow us to put sensor/film farther**
 - focus closer

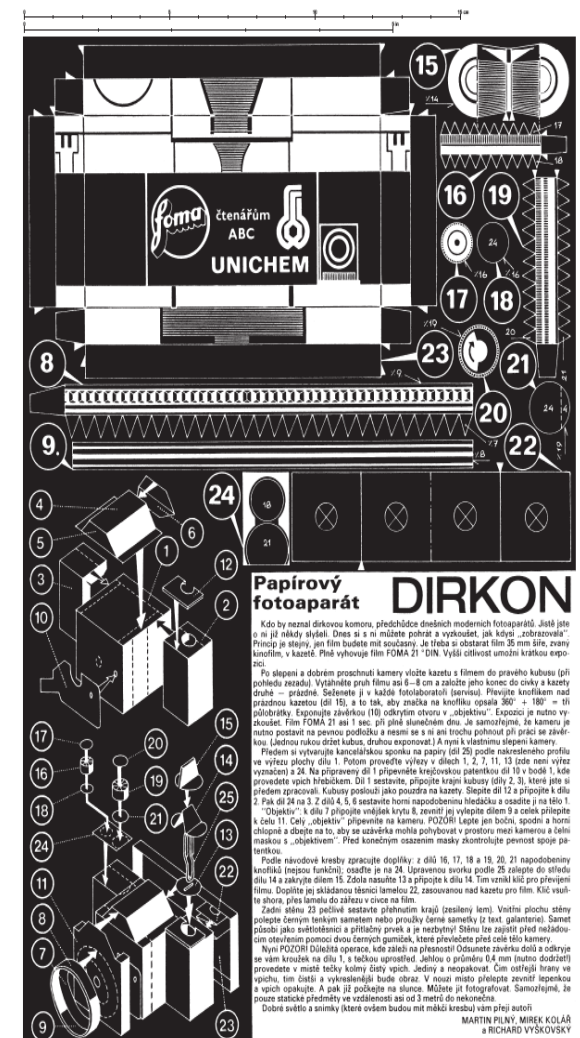
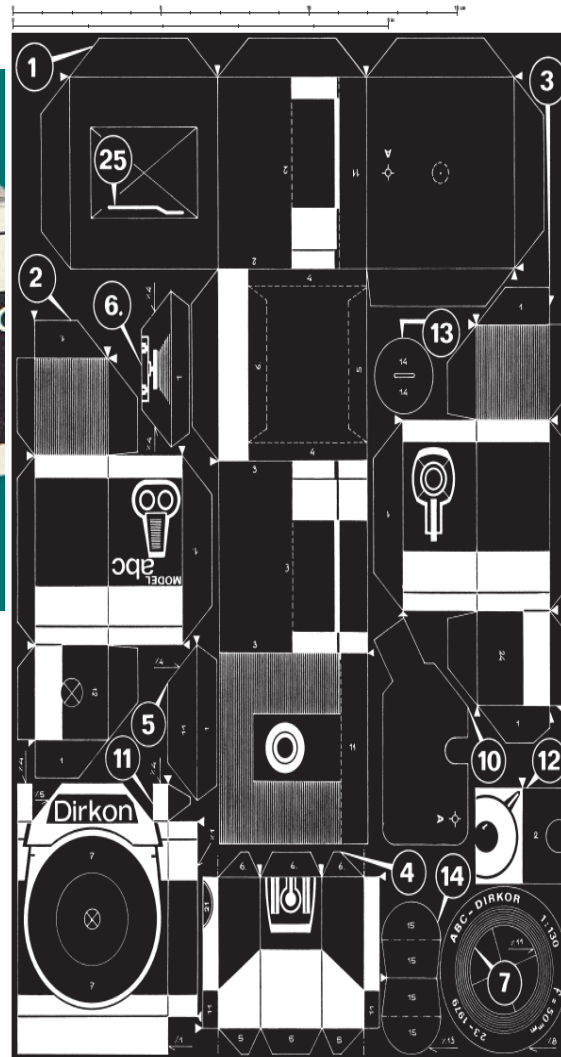
Field of view & focusing

- What happens to the field of view when one focuses closer?
 - It's reduced

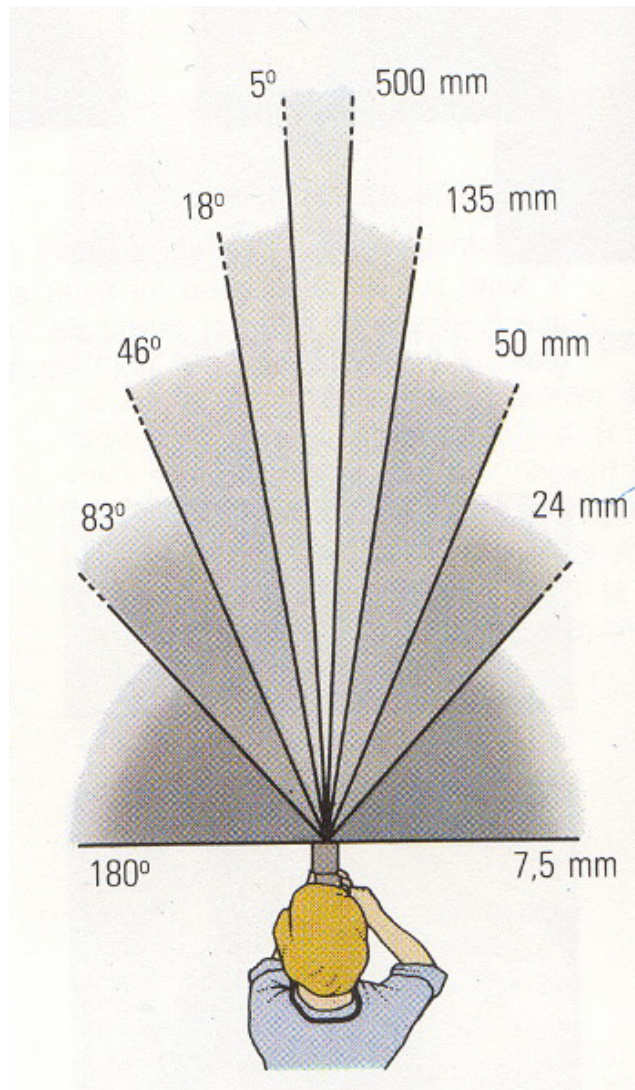


Questions?

- http://www.pinhole.cz/en/pinholecameras/dirkon_01.html



Focal length in practice



24mm



50mm

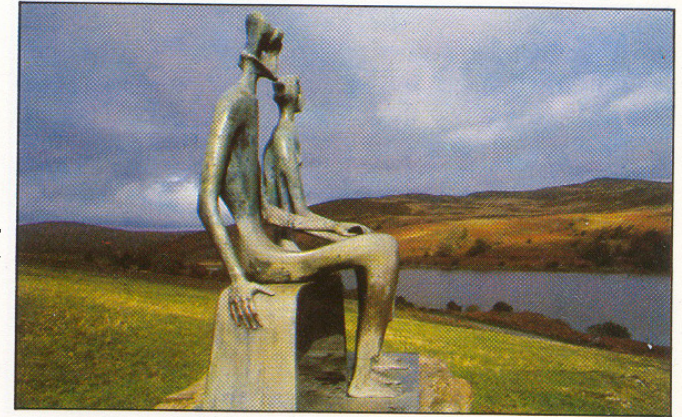
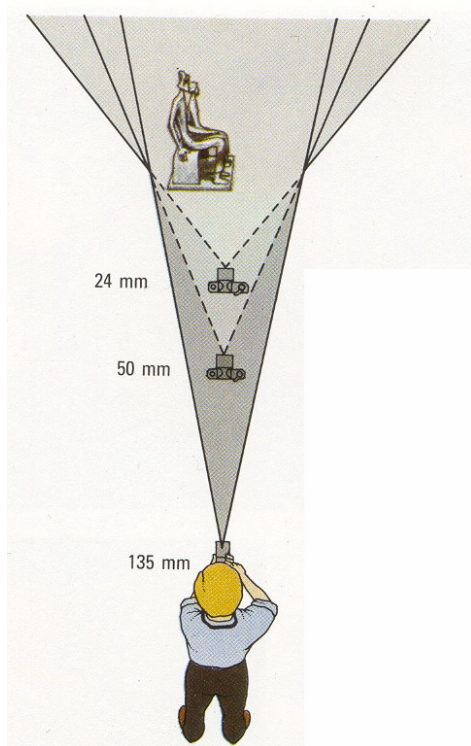


135mm

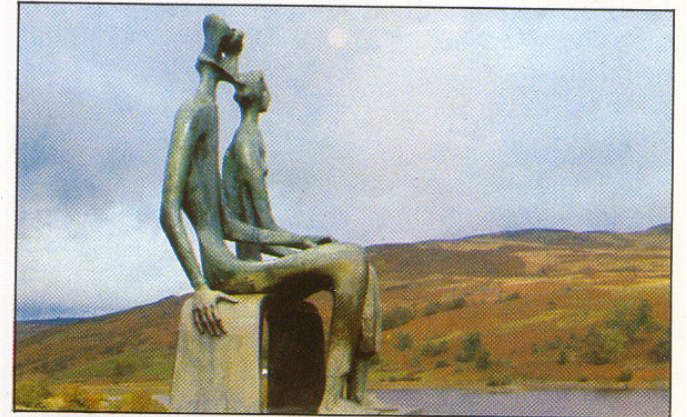


Perspective vs. viewpoint

- Telephoto makes it easier to select background (a small change in viewpoint is a big change in background).



Grand-angulaire 24 mm



Normal 50 mm



Longue focale 135 mm

Perspective vs. viewpoint

- **Martin Scorsese, Good Fellas**
- **Moves camera as you zoom in**
- **Better known as the Hitchcock Vertigo effect**



Perspective vs. viewpoint

- **Portrait: distortion with wide angle**
- **Why?**



Wide angle



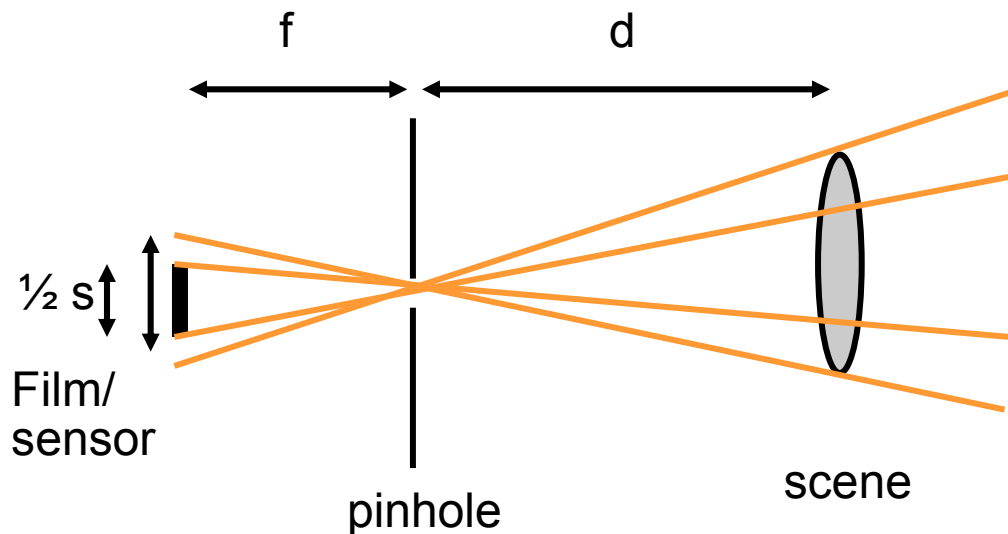
Standard



Telephoto

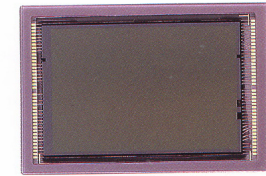
Focal length & sensor

- **What happens when the film is half the size?**
- **Application:**
 - Real film is 36x24mm
 - On the 20D, the sensor is 22.5 x 15.0 mm
 - Conversion factor on the 20D?
 - On the SD500, it is 1/1.8 " (7.18 x 5.32 mm)
 - What is the 7.7-23.1mm zoom on the SD500?

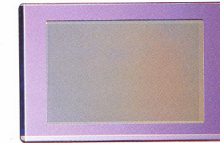


Sensor size

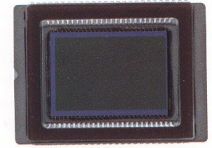
- Similar to cropping



EOS-1Ds : 35.8 x 23.8mm

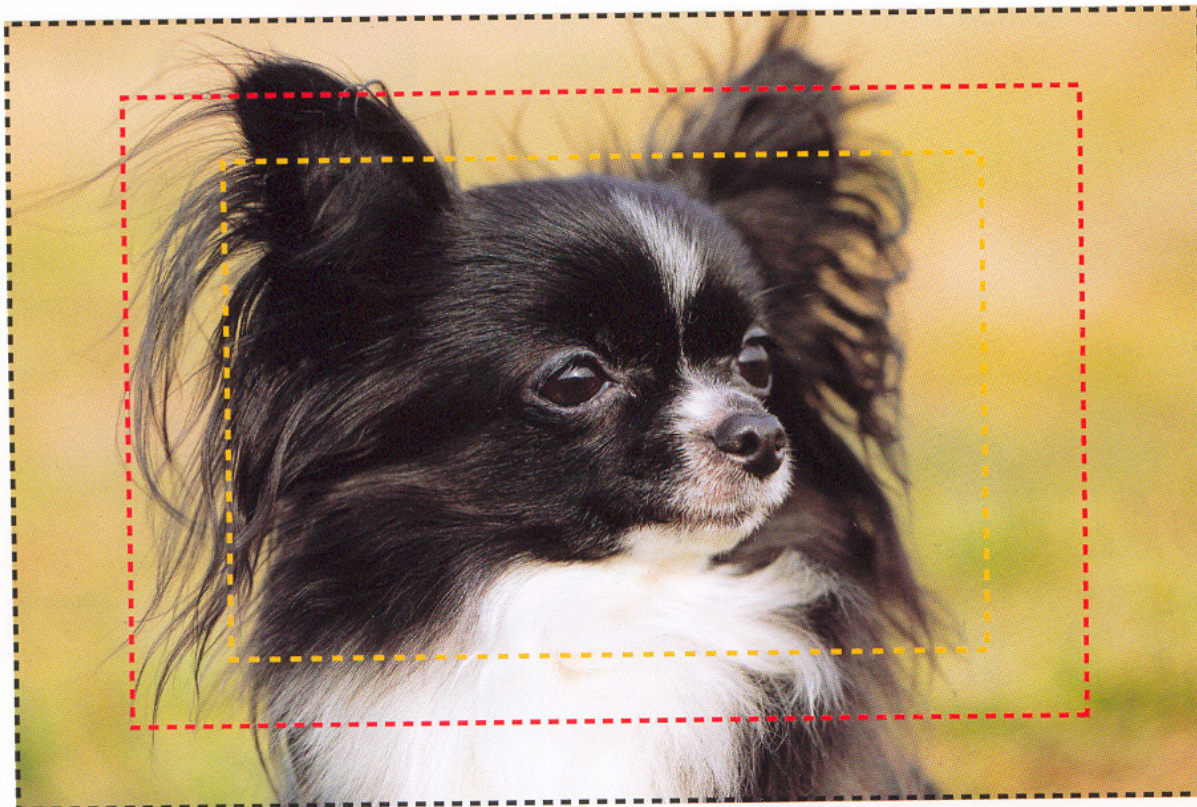


EOS-1D : 28.7 x 19.1mm



EOS 10D : 22.7 x 15.1mm

35mm full size and digital shooting range image size (picture dimensions) and lens selection



— EOS-1Ds / — EOS-1D/ — EOS 10D

source: canon red book



EOS-1D



EOS 10D

(The EOS Kiss Digital/EOS DIGITAL Rebel/EOS 300D DIGITAL SLR camera has the same image size as the EOS 10D.)

- 36x24mm (35mm format)

28.7x19.1mm (EOS 1D) = 1.26x magnification factor

APS-C sized sensors (EOS 10D, Nikon D100, Pentax *ist D, etc) = 1.5x - 1.6x

18x13.5mm (4/3" system - Olympus E-1)

8.8x6.6mm (2/3" P&S)

8.8x6.6mm (2/3")

7.2x5.3mm (1/1.8")

5.3x4mm (1/2.7")

Recap

- **Pinhole is the simplest model of image formation**
- **Lenses gather more light**
 - But get only one plane focused
 - Focus by moving sensor/film
 - Cannot focus infinitely close
- **Focal length determines field of view**
 - From wide angle to telephoto
 - Depends on sensor size

More in the lens lecture

Questions?



Exposure

- **Get the right amount of light to sensor/film**
- **Two main parameters:**
 - Shutter speed
 - Aperture (area of lens)

Shutter speed

- **Controls how long the film/sensor is exposed**
- **Pretty much linear effect on exposure**
- **Usually in fraction of a second:**
 - $1/30$, $1/60$, $1/125$, $1/250$, $1/500$
 - Get the pattern ?
- **On a normal lens, normal humans can hand-hold down to $1/60$**
 - In general, the rule of thumb says that the limit is the inverse of focal length, e.g. $1/500$ for a 500mm

Main effect of shutter speed

- Motion blur

Slow shutter speed



Fast shutter speed



Effect of shutter speed

- Freezing motion

Walking people



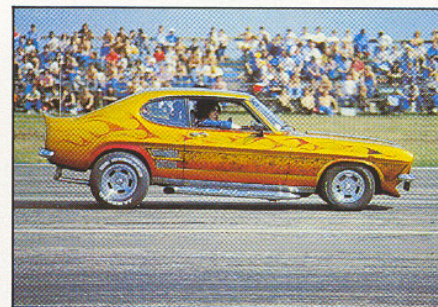
1/125

Running people



1/250

Car



1/500

Fast train



1/1000

Shutter

- Various technologies
- Goal: achieve uniform exposure across image

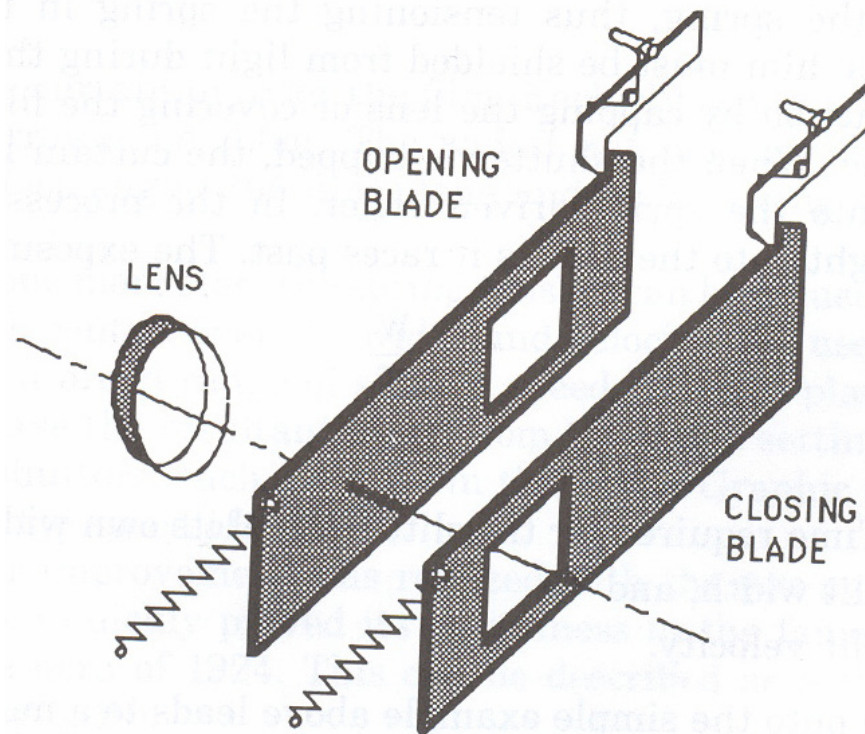


FIG. 2.8 Two-blade guillotine shutter.

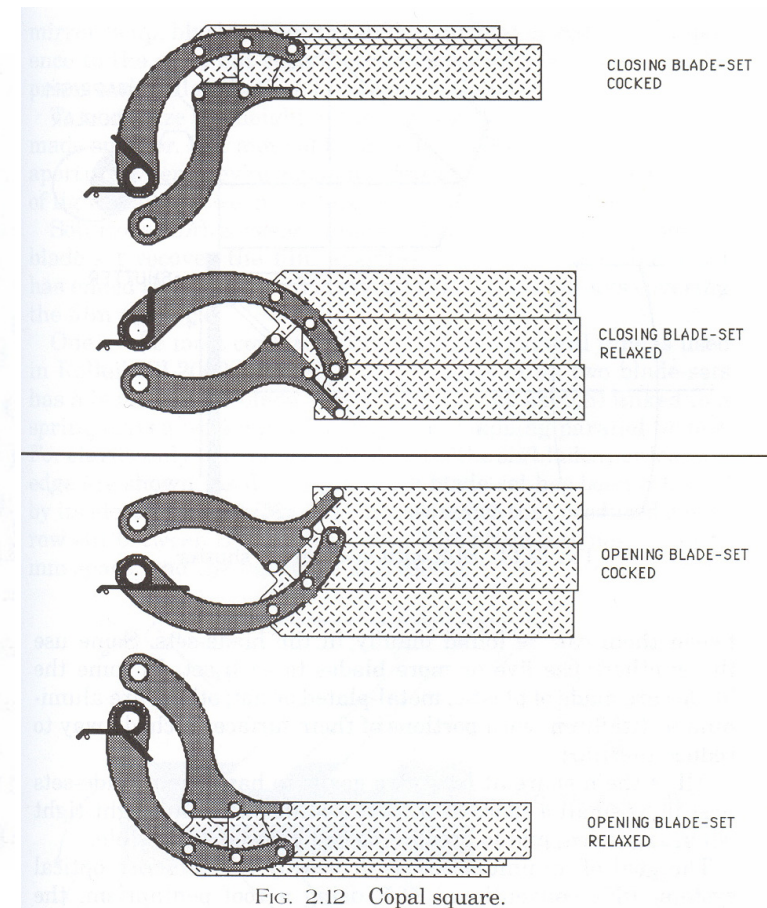


FIG. 2.12 Copal square.

Figure 6–6. Jacques Henri Lartigue, *Grand Prix of the Automobile Club of France*, 1912. This classic photograph provides an exaggerated example of the distortion that can be caused by a focal-plane shutter. The oval shape of the automobile tire is caused by the motion of the car between the time the bottom of the tire was exposed and the top. (Remember—the image is upside-down on the negative.) The same principle caused the leaning appearance of the spectators. Lartigue turned the camera to follow the automobile (panning), and thus the image of the spectators moved at the film plane during the exposure. (Courtesy International Museum of Photography at George Eastman House.)



Flash synch speed?

- Fastest shutter speed for which the shutter opens completely at some instant.
- For faster speeds, it opens and closes at the same time and exposes a slit.
- Modern high-speed flash synch uses multiple flash bursts

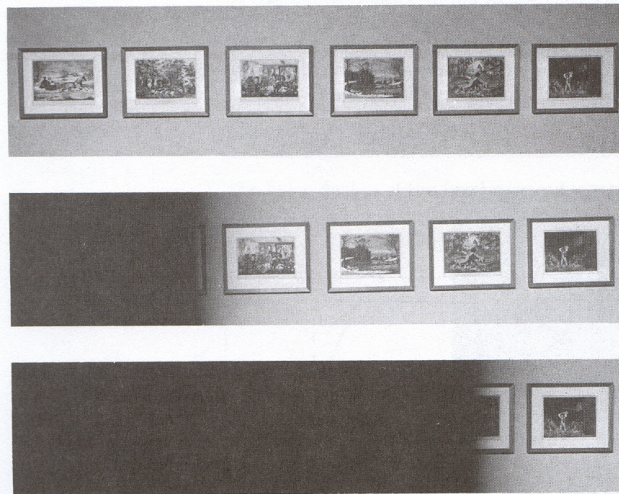


Figure 2-16 Electronic-flash illumination used with a focal-plane-shutter at shutter speeds of 1/60, 1/125, and 1/250 second (top to bottom). At the higher speeds the second curtain begins to cover the film before the first curtain has completely uncovered it. The highest shutter speeds that can be used with electronic flash have increased dramatically with newer single-lens-reflex cameras and flash units.



Your best friend

- **Use a tripod! It will always enhance sharpness**
 - Avoid camera shake



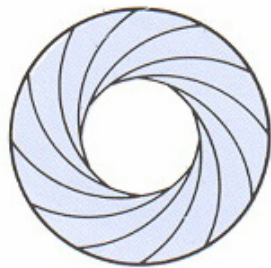
- More about shake & stabilization in lens lecture

Aperture

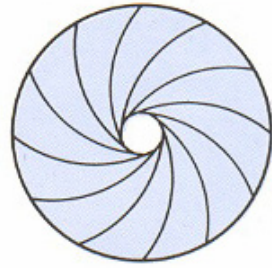
- **Diameter of the lens opening (controlled by diaphragm)**
- **Expressed as a fraction of focal length, in f-number**
 - $f/2.0$ on a 50mm means that the aperture is 25mm
 - $f/2.0$ on a 100mm means that the aperture is 50mm
- **Disconcerting: small f number = big aperture**
- **What happens to the area of the aperture when going from $f/2.0$ to $f/4.0$?**
- **Typical f numbers are $f/2.0, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, f/32$**
 - See the pattern?



Full aperture



Medium aperture



Stopped down

Aperture & physical lens size

- On telephoto, the lens size is directly dictated by the max (that is min) f number
- Other lenses, not always clear
- The aperture can be internal or not

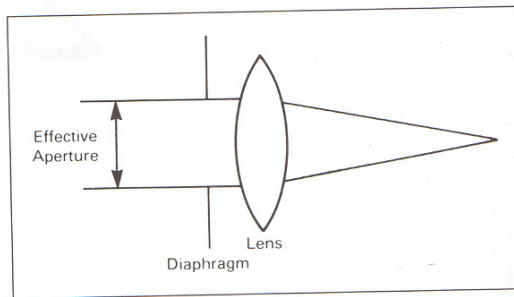


Figure 2-1 When a diaphragm is located in front of a lens, the effective aperture is the same as the aperture or diaphragm opening.

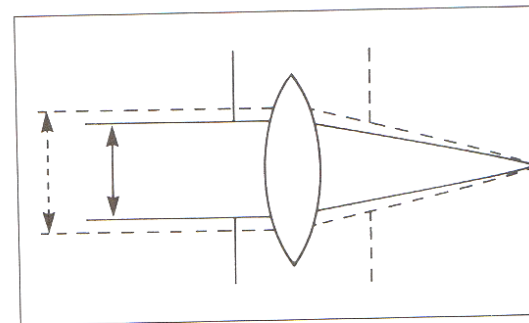


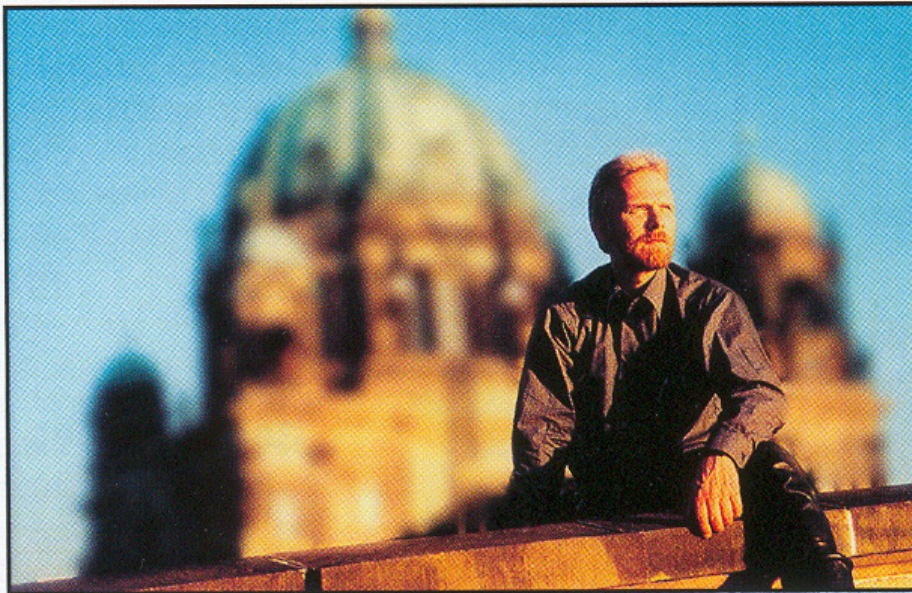
Figure 2-2 A diaphragm will transmit more light when located behind the lens than in front.

- Zoom lenses usually have a variable maximal aperture
 - Why?

Main effect of aperture

- Depth of field

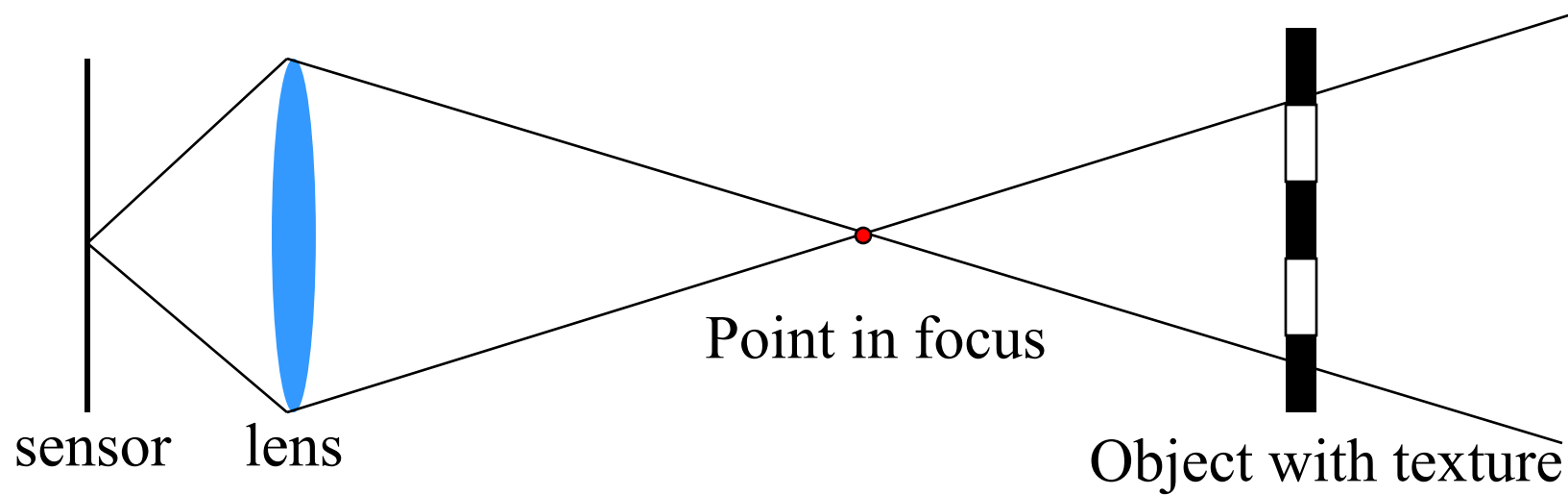
Large aperture opening



Small aperture opening

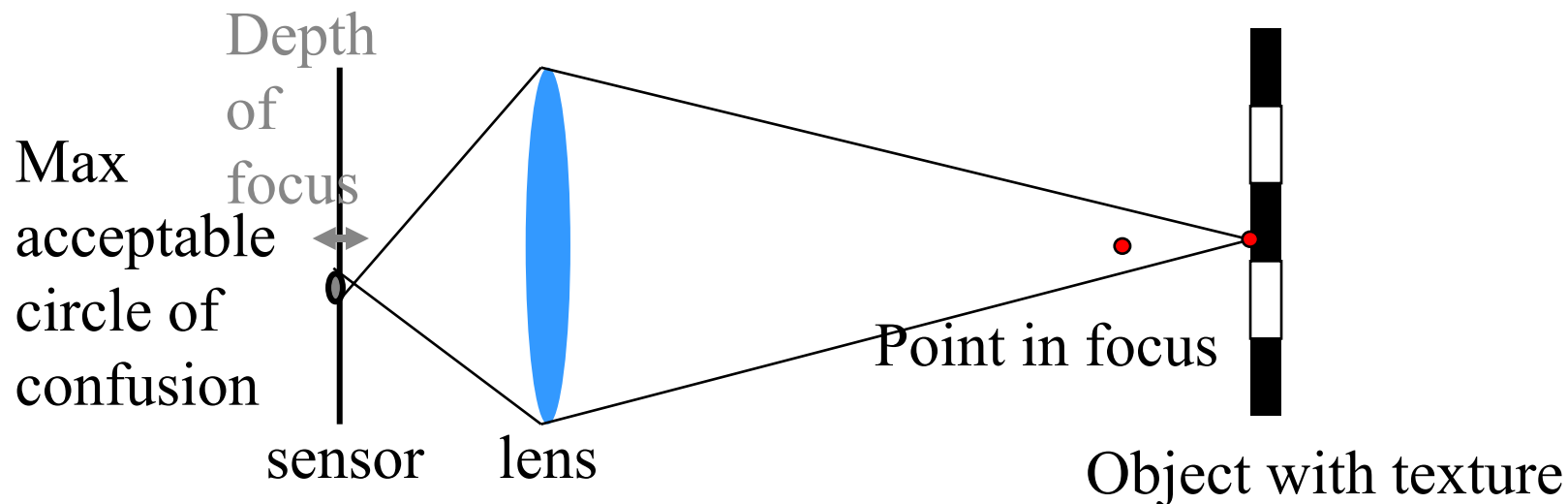
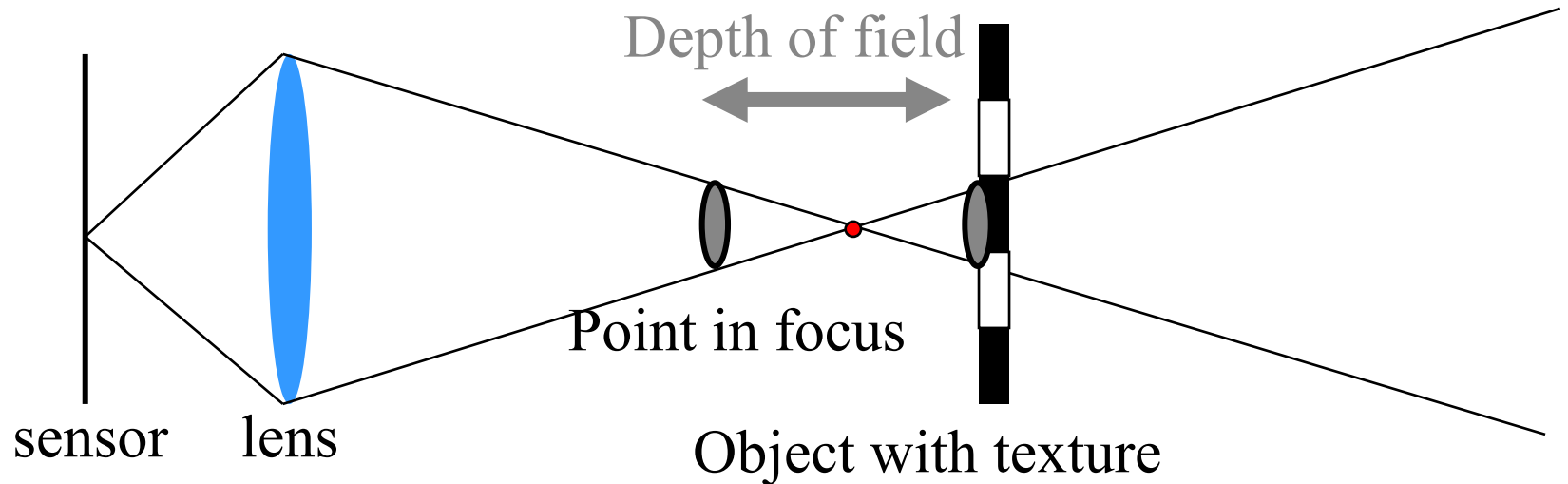


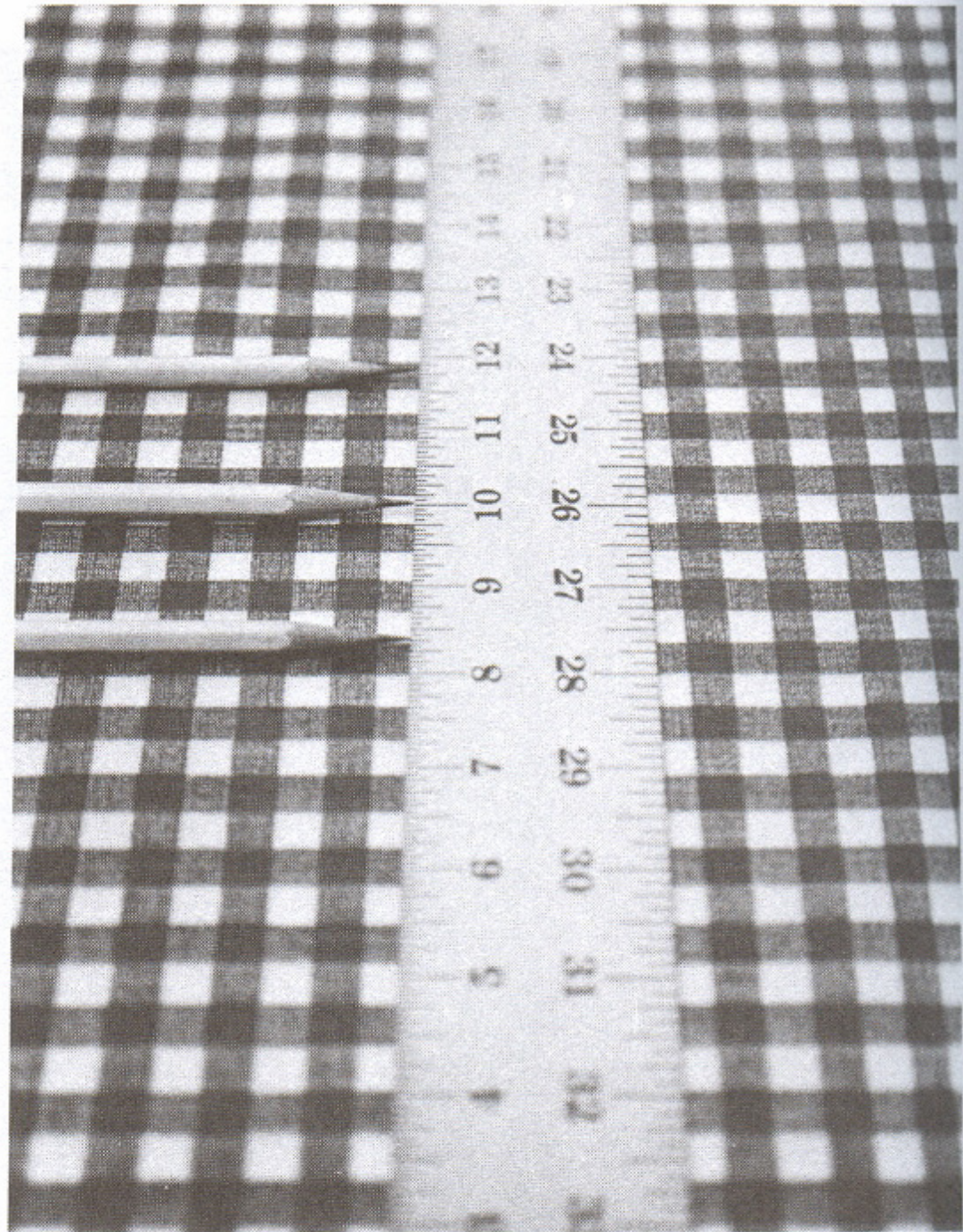
Depth of field



Depth of field

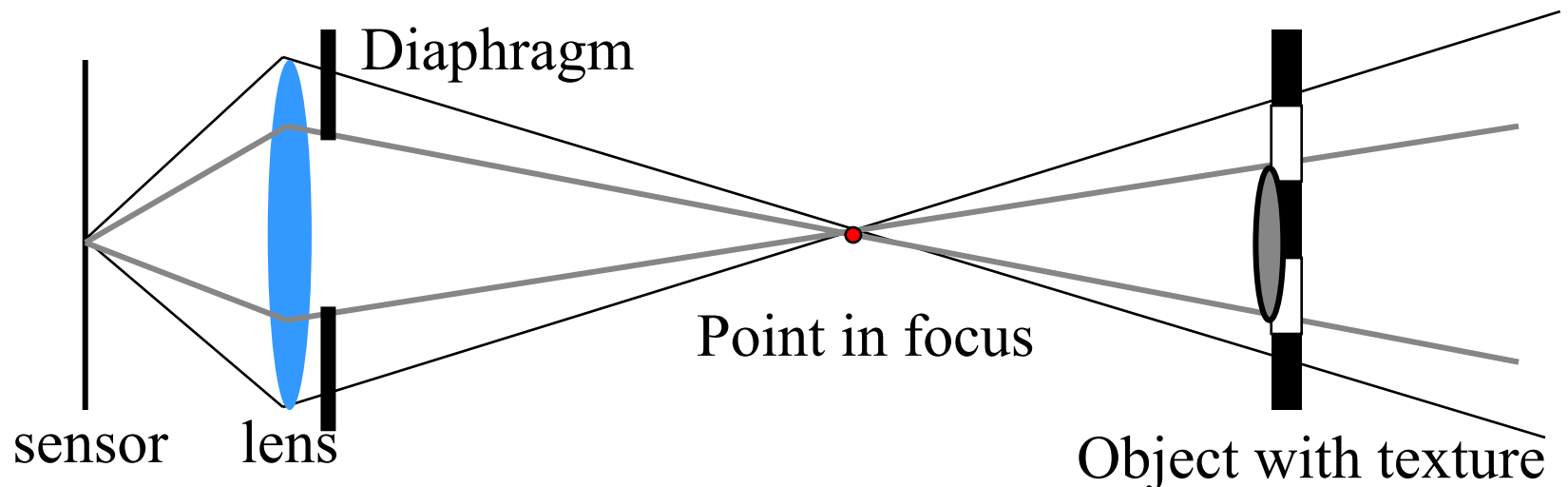
- We allow for some tolerance





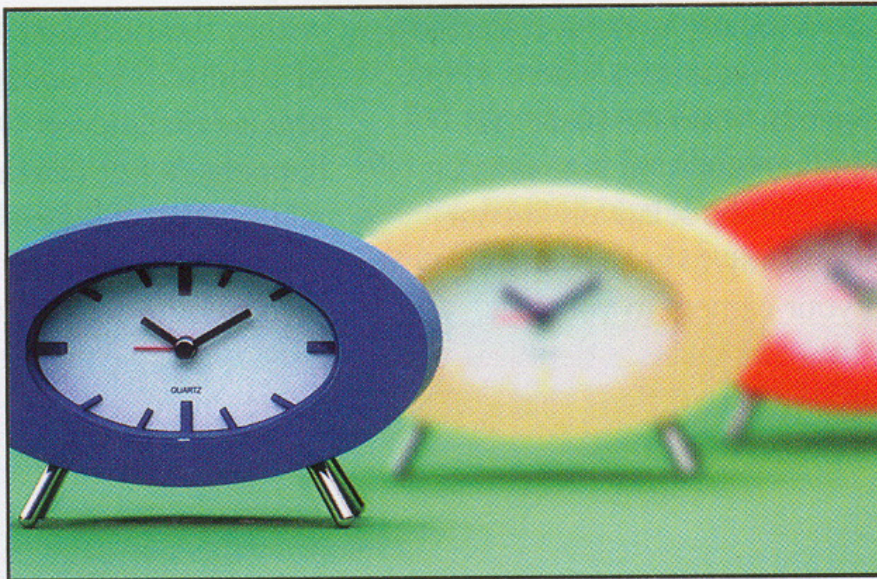
Depth of field

- **What happens when we close the aperture by two stop?**
 - Aperture diameter is divided by two
 - Depth of field is doubled



Depth of field

LESS DEPTH OF FIELD

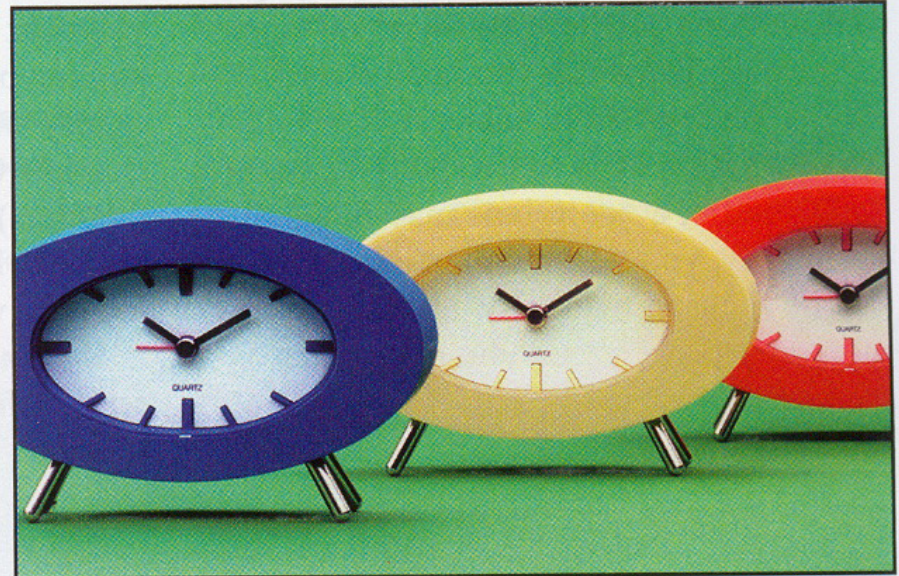


Wider aperture



$f/2$

MORE DEPTH OF FIELD



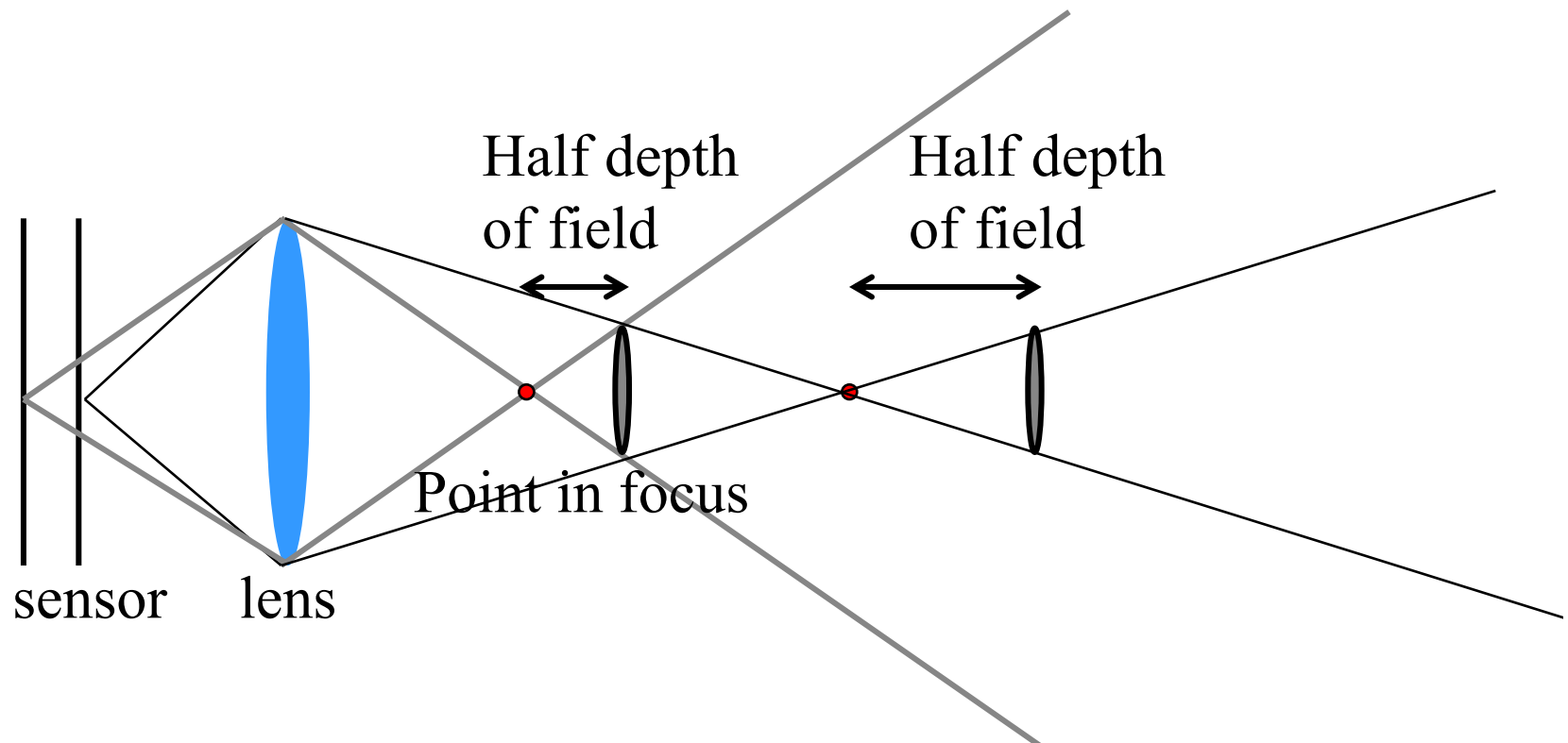
Smaller aperture



$f/16$

Depth of field & focusing distance

- What happens when we divide focusing distance by two?
 - Similar triangles $\Rightarrow$ divided by two as well

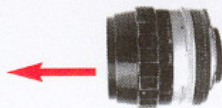


Depth of field & focusing distance

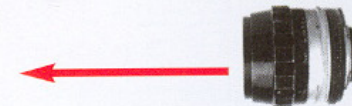
- What happens when we divide focusing distance by two?
 - Similar triangles => divided by two as well



Closer to subject 3 feet



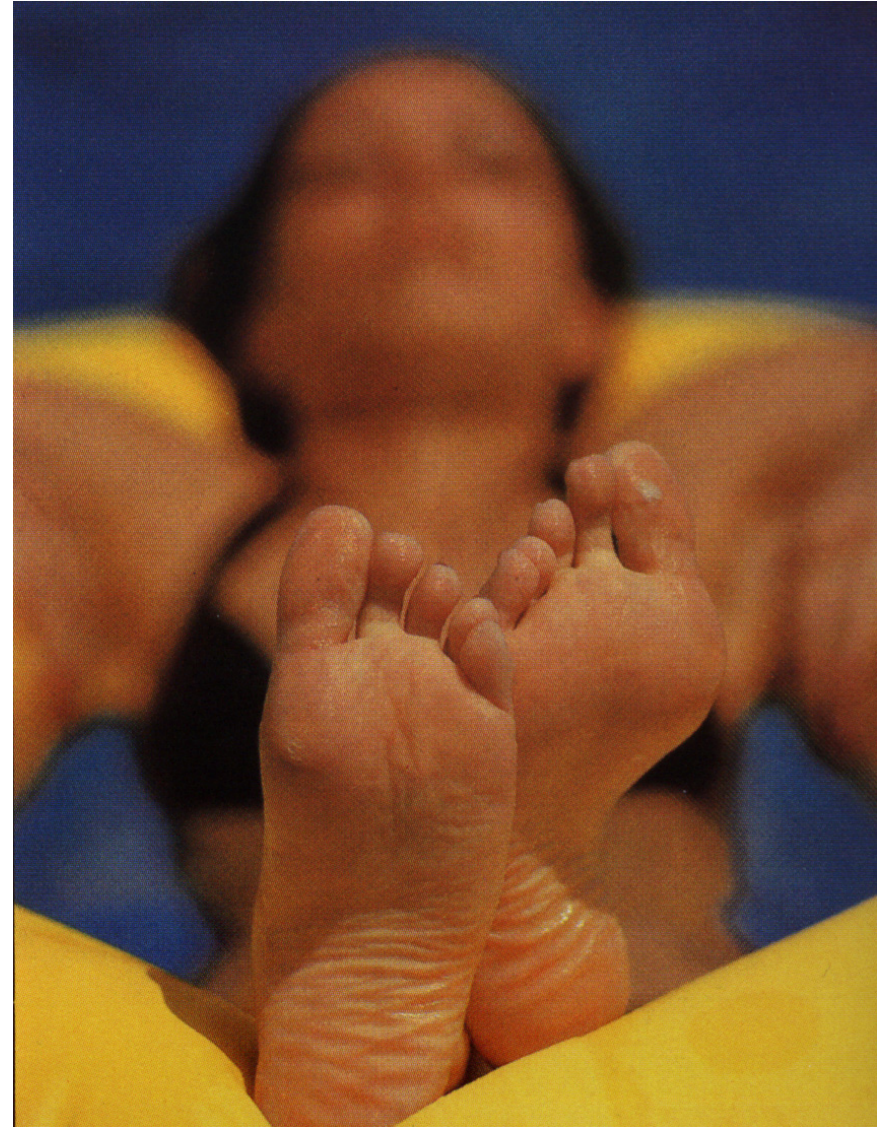
Farther from subject 10 feet



SLR viewfinder & aperture

- **By default, an SLR always shows you the biggest aperture**
- **Brighter image**
- **Shallow depth of field help judge focus**
- **Depth of field preview button:**
 - Stops down to the aperture you have chosen
 - Darker image
 - Larger depth of field

Questions?



Questions?

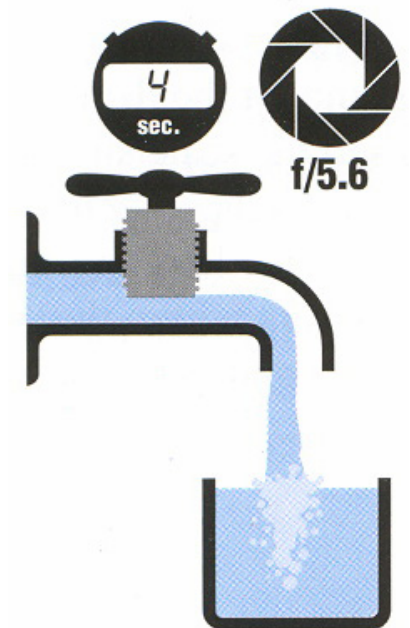
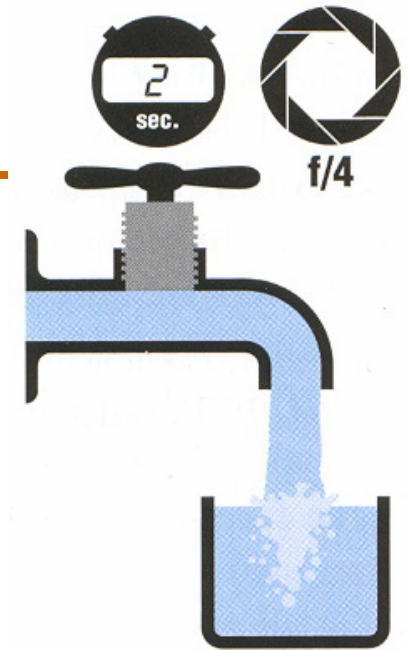


Exposure

- **Two main parameters:**
 - Aperture (in f stop)
 - Shutter speed (in fraction of a second)
- **Reciprocity**

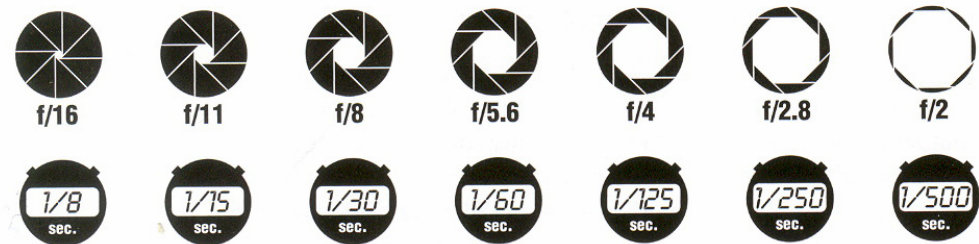
The same exposure is obtained with an exposure twice as long and an aperture *area* half as big

- Hence square root of two progression of f stops vs. power of two progression of shutter speed
- Reciprocity can fail for very long exposures

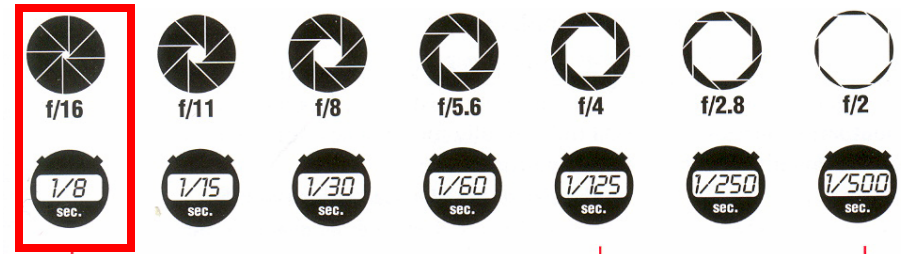


Reciprocity

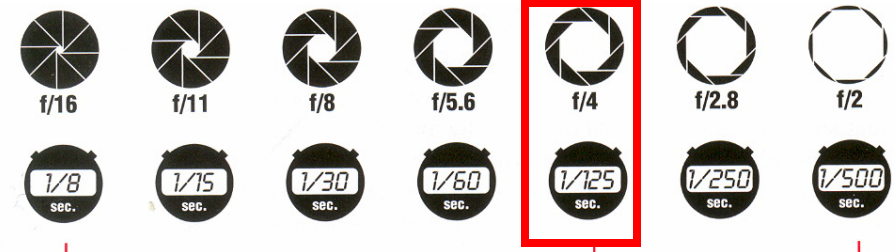
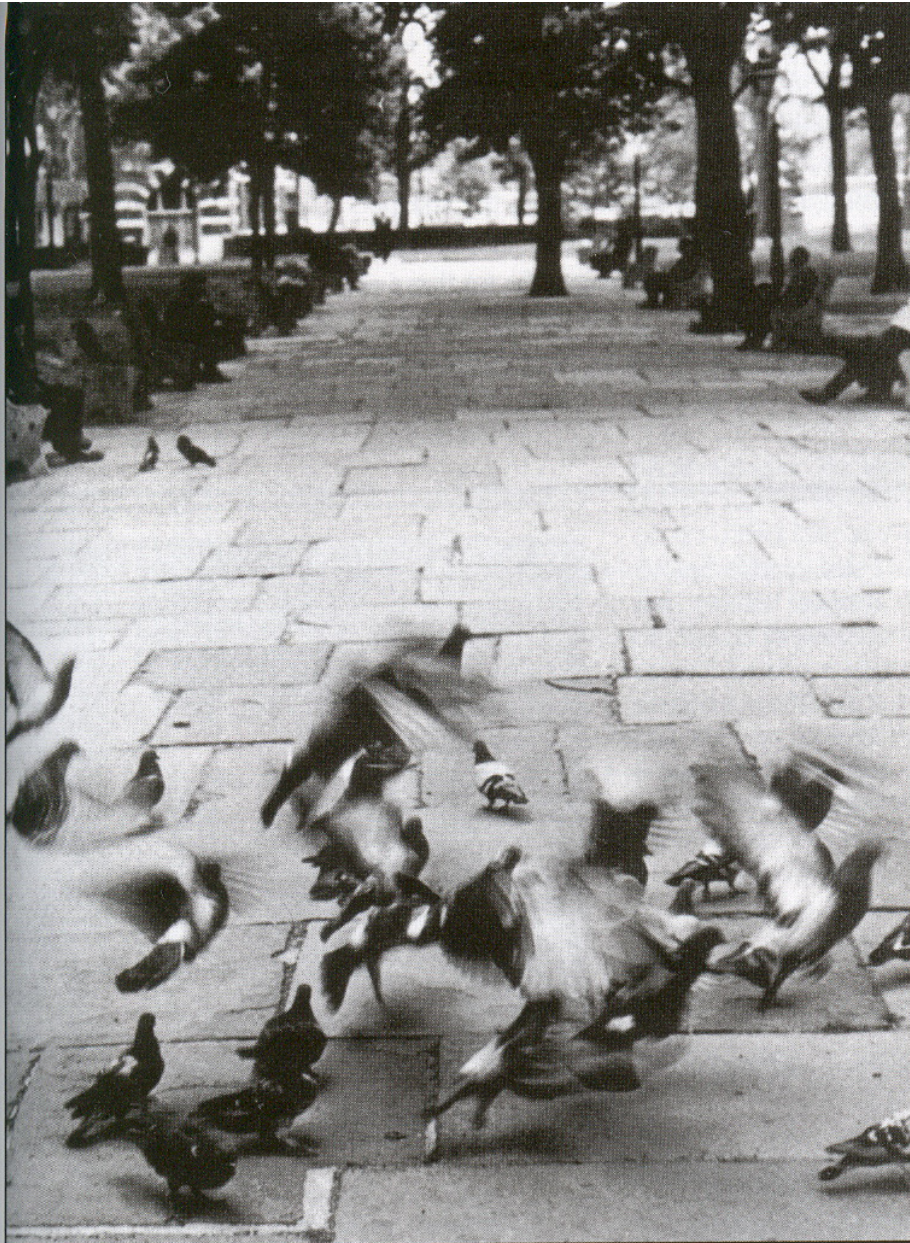
- Assume we know how much light we need
- We have the choice of an infinity of shutter speed/aperture pairs



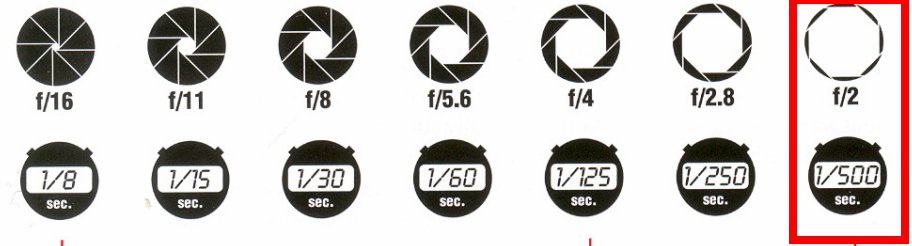
- What will guide our choice of a shutter speed?
 - Freeze motion vs. motion blur, camera shake
- What will guide our choice of an aperture?
 - Depth of field, diffraction limit
- Often we must compromise
 - Open more to enable faster speed (but shallow DoF)



Small aperture (deep depth of field), slow shutter speed (motion blurred). In this scene, a small aperture (f/16) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed (1/8 sec) was needed; it was too slow to show moving pigeons sharp. It also meant that a tripod had to be used to hold the camera steady.



Medium aperture (moderate depth of field), medium shutter speed (some motion sharp). A medium aperture ($f/4$) and shutter speed ($1/125$ sec) sacrifice some background detail to produce recognizable images of the birds. But the exposure is still too long to show the motion of the birds' wings sharply.



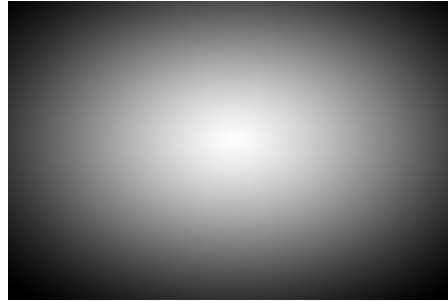
Large aperture (shallow depth of field), fast shutter speed (motion sharp). A fast shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little depth of field that the background is now out of focus.

Questions?



Metering

- **Photosensitive sensors measure scene luminance**
- **Usually TTL (through the lens)**
- **Simple version: center-weighted average**



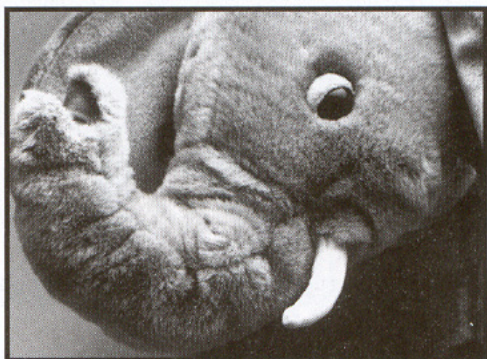
- **Assumption? Failure cases?**
 - Usually assumes that a scene is 18% gray
 - Problem with dark and bright scenes



White polar bear given exposure suggested by meter



White polar bear given 2 stops more exposure



Gray elephant given exposure suggested by meter



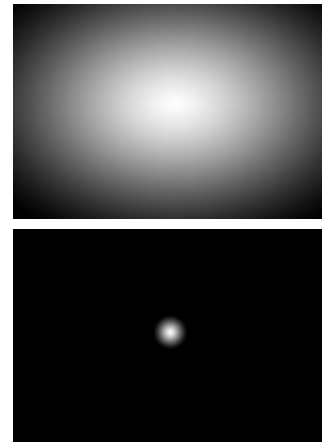
Black gorilla given exposure suggested by meter



Black gorilla given 2 stops less exposure

Metering

- **Centered average**
- **Spot**
- **Smart metering**
 - Nikon 3D matrix
 - Canon evaluative
- **Incident**
 - Measure incoming light



Next slide

Choice on Nikon



<http://www.mir.com.my//>

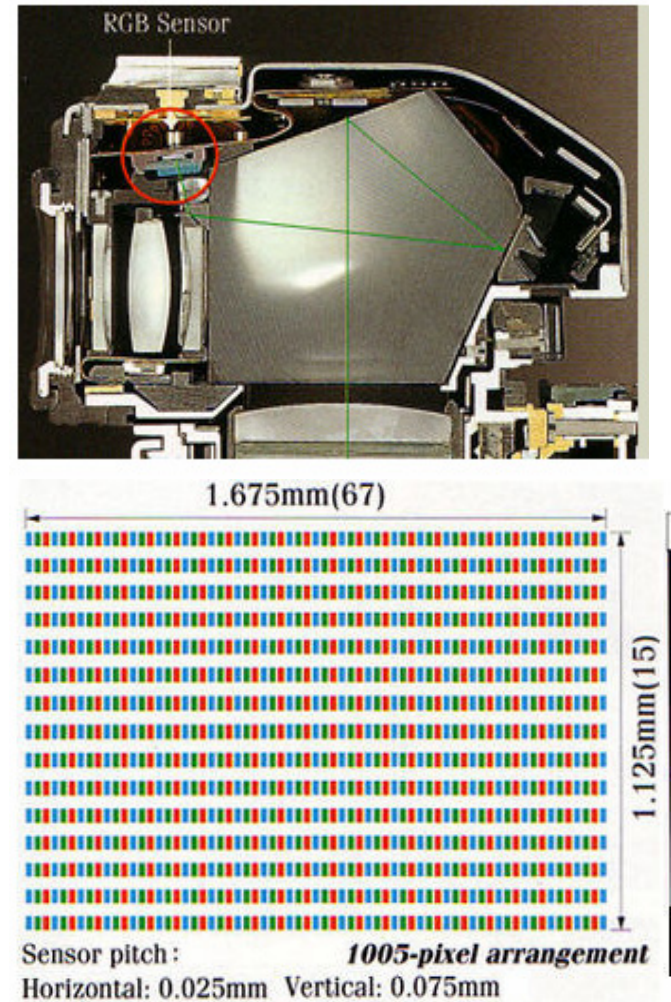


From the luminous landscape

Nikon 3D Color Matrix

<http://www.mir.com.my/rb/photography/hardwares/classics/NikonF5/metering/>

- **Learning from database of 30,000 photos**
- **Multiple captors (segments)**
- **Exposure depends on**
 - Brightness from each segments
 - Color
 - Contrast
 - Distance
 - Focus (where is the subject)



Exposure & metering

- **The camera metering system measures how bright the scene is**
- **In Aperture priority mode, the photographer sets the aperture, the camera sets the shutter speed**
- **In Shutter-speed priority mode, the photographers sets the shutter speed and the camera deduces the aperture**
 - In both cases, reciprocity is exploited
- **In Program mode, the camera decides both exposure and shutter speed (middle value more or less)**
- **In Manual, the user decides everything (but can get feedback)**

Pros and cons of various modes

- **Aperture priority (My favorite, I use it 90% of the time)**
 - Direct depth of field control
 - Cons: can require impossible shutter speed (e.g. with $f/1.4$ for a bright scene)
- **Shutter speed priority**
 - Direct motion blur control
 - Cons: can require impossible aperture (e.g. when requesting a $1/1000$ speed for a dark scene)
 - Note that aperture is somewhat more restricted
- **Program**
 - Almost no control, but no need for neurons
- **Manual**
 - Full control, but takes more time and thinking

Recap: Metering

- **Measure scene brightness**
- **Some advanced modes that take multiple sources of information**
- **Still an open problem**

Questions?

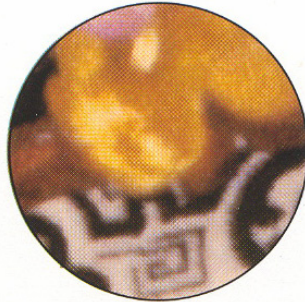


Sensitivity (ISO)

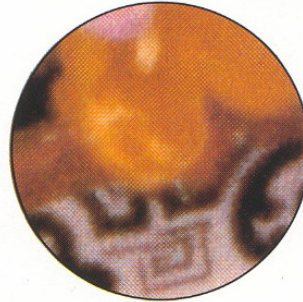
- Third variable for exposure
- Linear effect (200 ISO needs half the light as 100 ISO)
- Film photography: trade sensitivity for grain



Kodachrome 25 ASA



Ektachrome 64 ASA

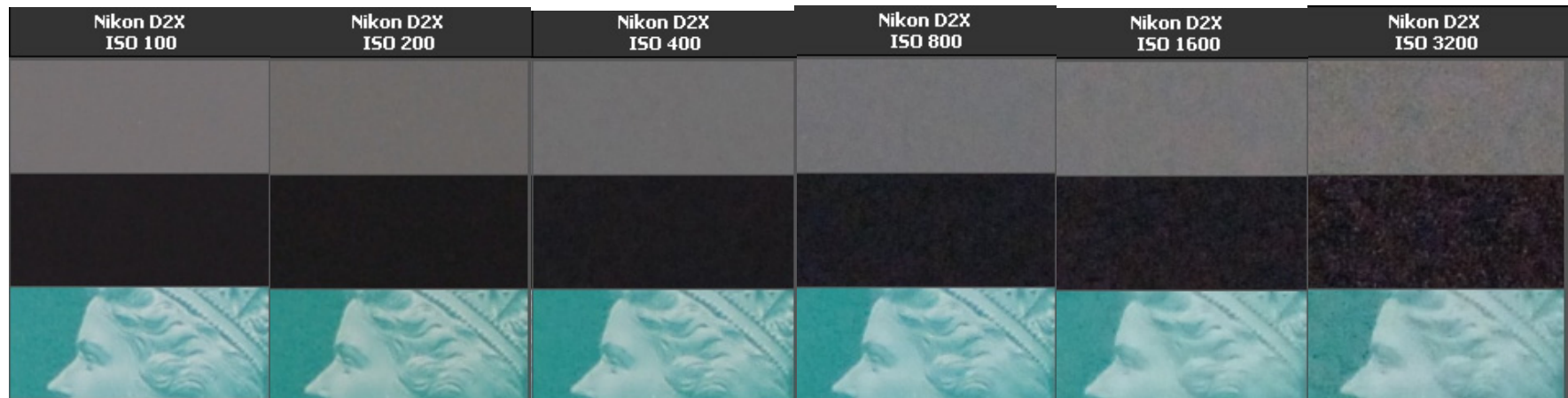


Fujichrome 100 ASA



Ektachrome 200 ASA

- Digital photography: trade sensitivity for noise

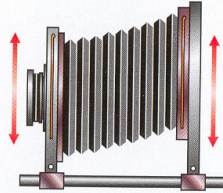


Questions?



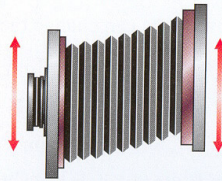
VIEW CAMERA MOVEMENTS

Side View



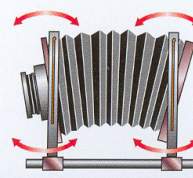
Rise and fall move the front or back of the camera in a flat plane, like opening or closing an ordinary window. Rise moves the front or back up; fall moves the front or back down.

Top View



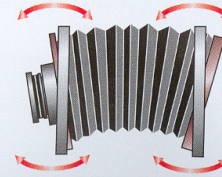
Shift (like rise and fall) also moves the front or back of the camera in a flat plane, but from side to side in a motion like moving a sliding door.

Side View

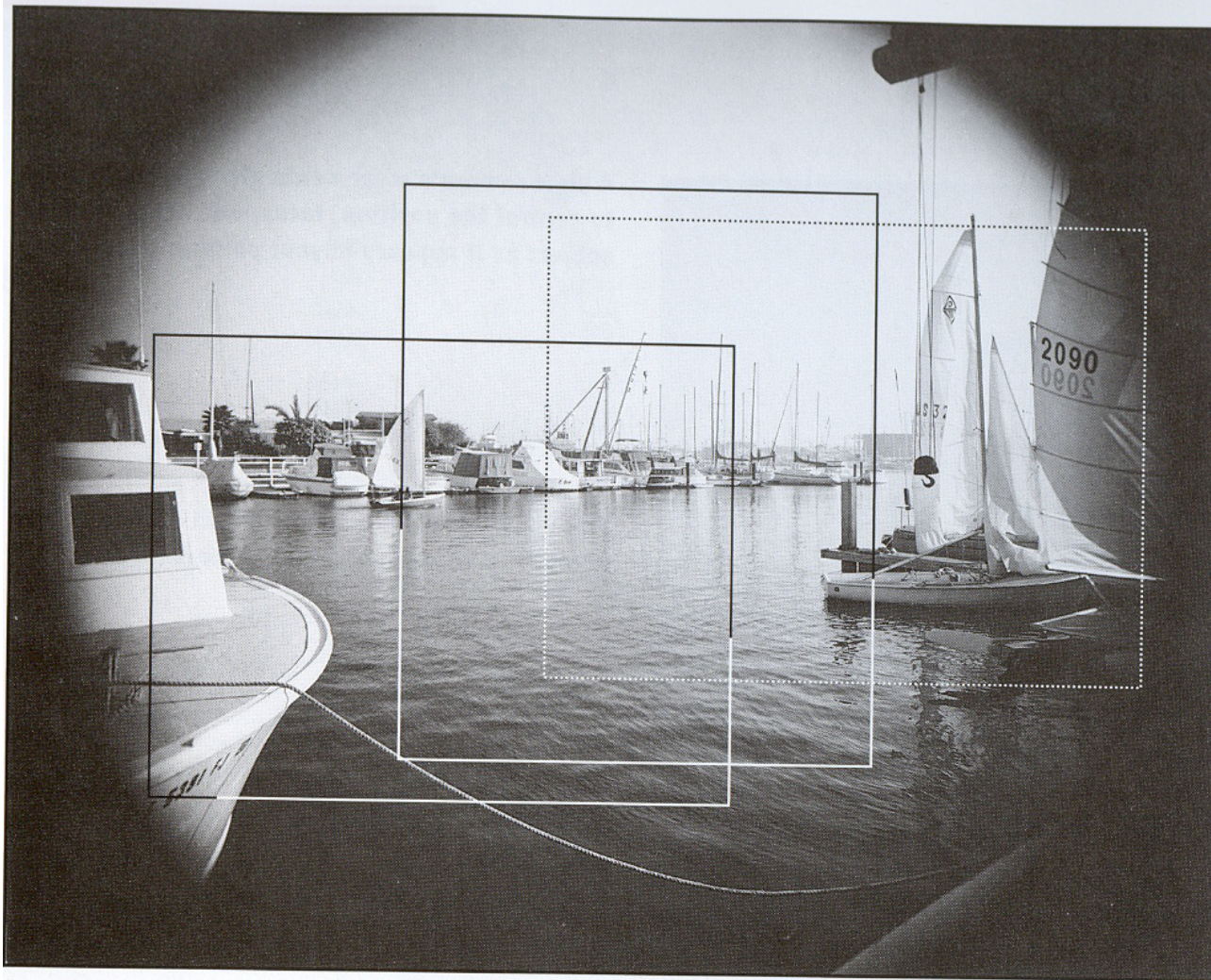


Tilt tips the front or back of the camera forward or backward around a horizontal axis. Nodding your head yes is a tilt of your face.

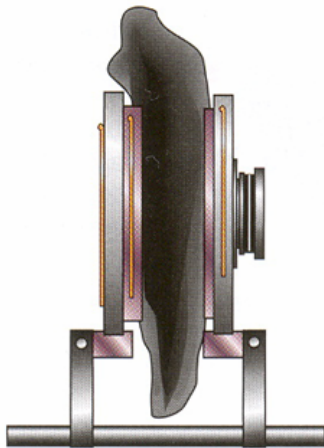
Top View



Swing twists the front or back of the camera around a vertical axis to the left or right. Shaking your head no is a swing of your face.

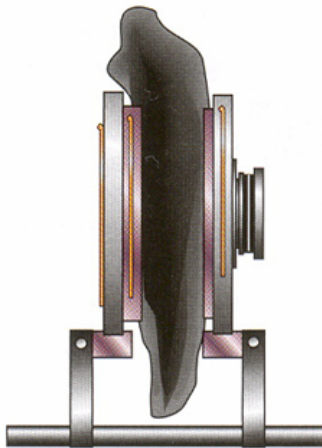


CONTROLLING CONVERGING LINES: THE KEY:

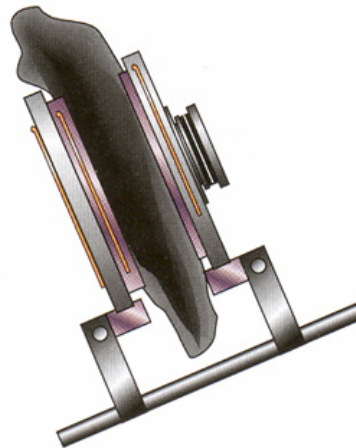


Standing at street level and shooting straight at a building produces too much street and too little building. Sometimes it is possible to move back far enough to show the entire building while keeping the camera level, but this adds even more foreground and usually something gets in the way.

CONTROLLING CONVERGING LINES: THE KEYSTONE EFFECT

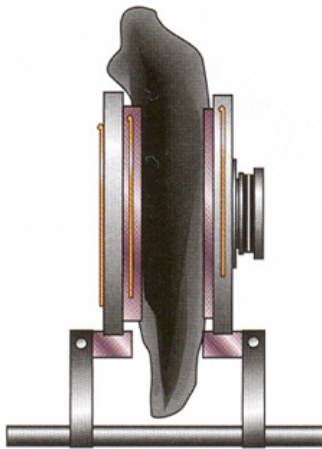
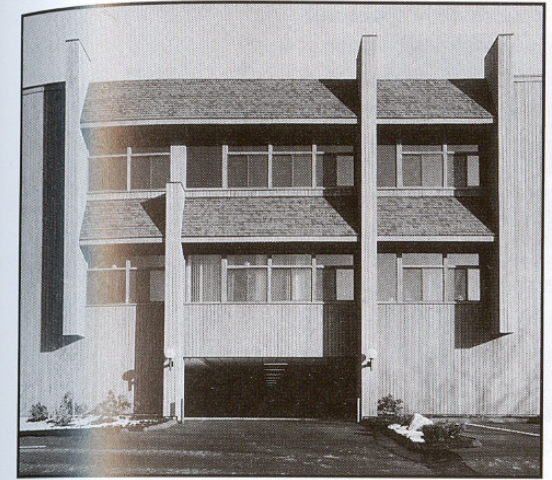
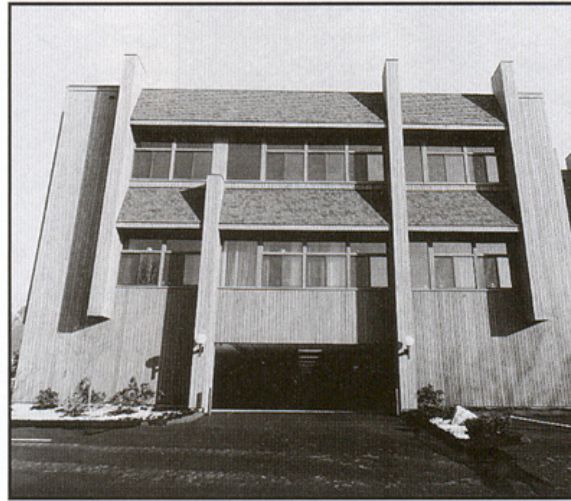


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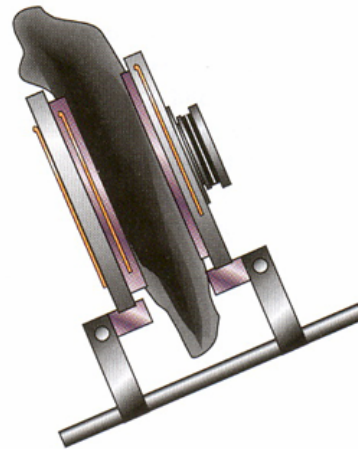


Tilting the whole camera up shows the entire building but distorts its shape. Since the top is farther from the camera than the bottom, it appears smaller; the vertical lines of the building seem to be coming closer together, or converging, near the top. This is named the keystone effect, after the wedge-shaped stone at the top of an arch. This convergence gives the illusion that the building is falling backward—an effect particularly noticeable when only one side of the building is visible.

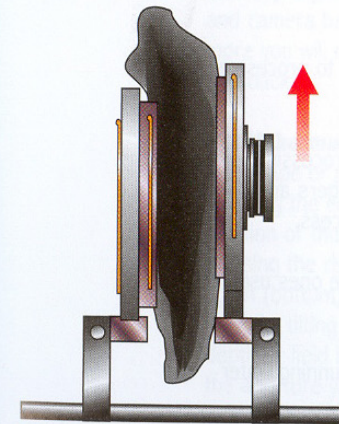
CONTROLLING CONVERGING LINES: THE KEYSTONE EFFECT



Standing at street level and shooting straight at a building produces too much street and too little building. Sometimes it is possible to move back far enough to show the entire building while keeping the camera level, but this adds even more foreground and usually something gets in the way.



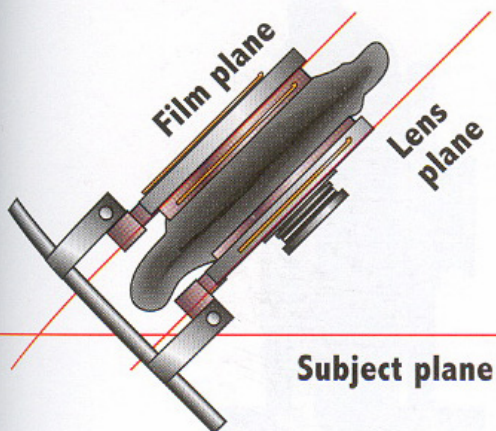
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To straighten up the converging vertical lines, keep the camera back parallel to the face of the building. To keep the face of the building in focus, make sure the lens is parallel to the camera back. One way to do this is to level the camera and then use the rising front or falling back movements or both.

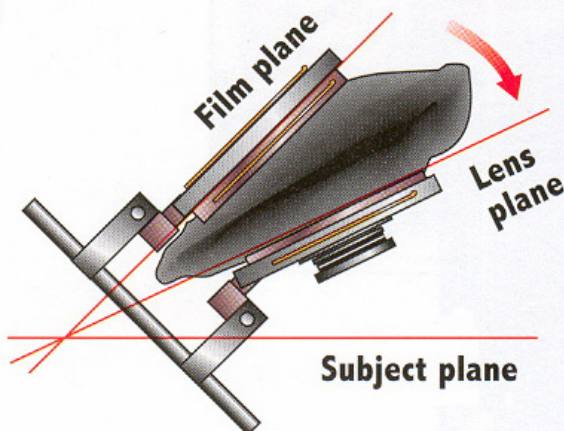
Another solution is to point the camera upward toward the top of the building, then use the tilting movements—first to tilt the back to a vertical position (which squares the shape of the building), then to tilt the lens so it is parallel to the camera back (which brings the face of the building into focus). The lens and film will end up in the same positions with both methods.

ADJUSTING THE PLANE OF FOCUS TO MAKE THE ENTIRE SCENE SHARP



The book is partly out of focus because the lens plane and the film plane are not parallel to the subject plane.

Instead of a regular accordion bellows, the diagrams show a bag bellows that can bring camera front and back closer together for use with a short focal-length lens.

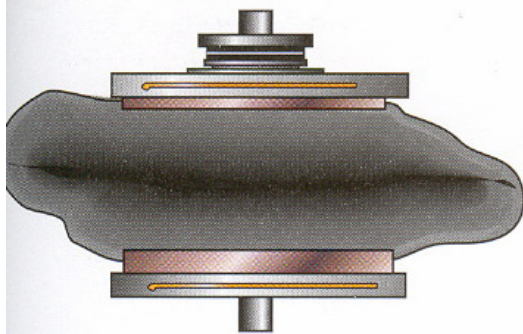


Tilting the front of the camera forward brings the entire page into sharp focus. The camera diagram illustrates the Scheimpflug principle, explained at right.

- Useful for landscape to get depth of field from foreground to infinity

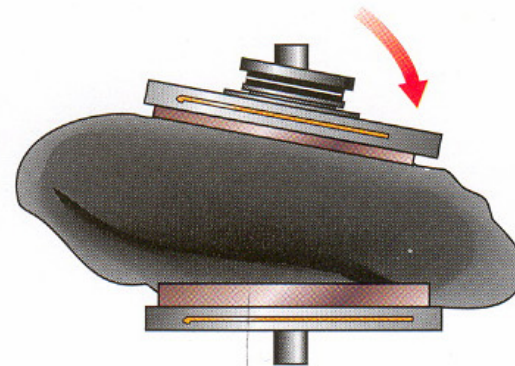


ADJUSTING THE PLANE OF FOCUS TO MAKE ONLY PART OF THE SCENE SHARP

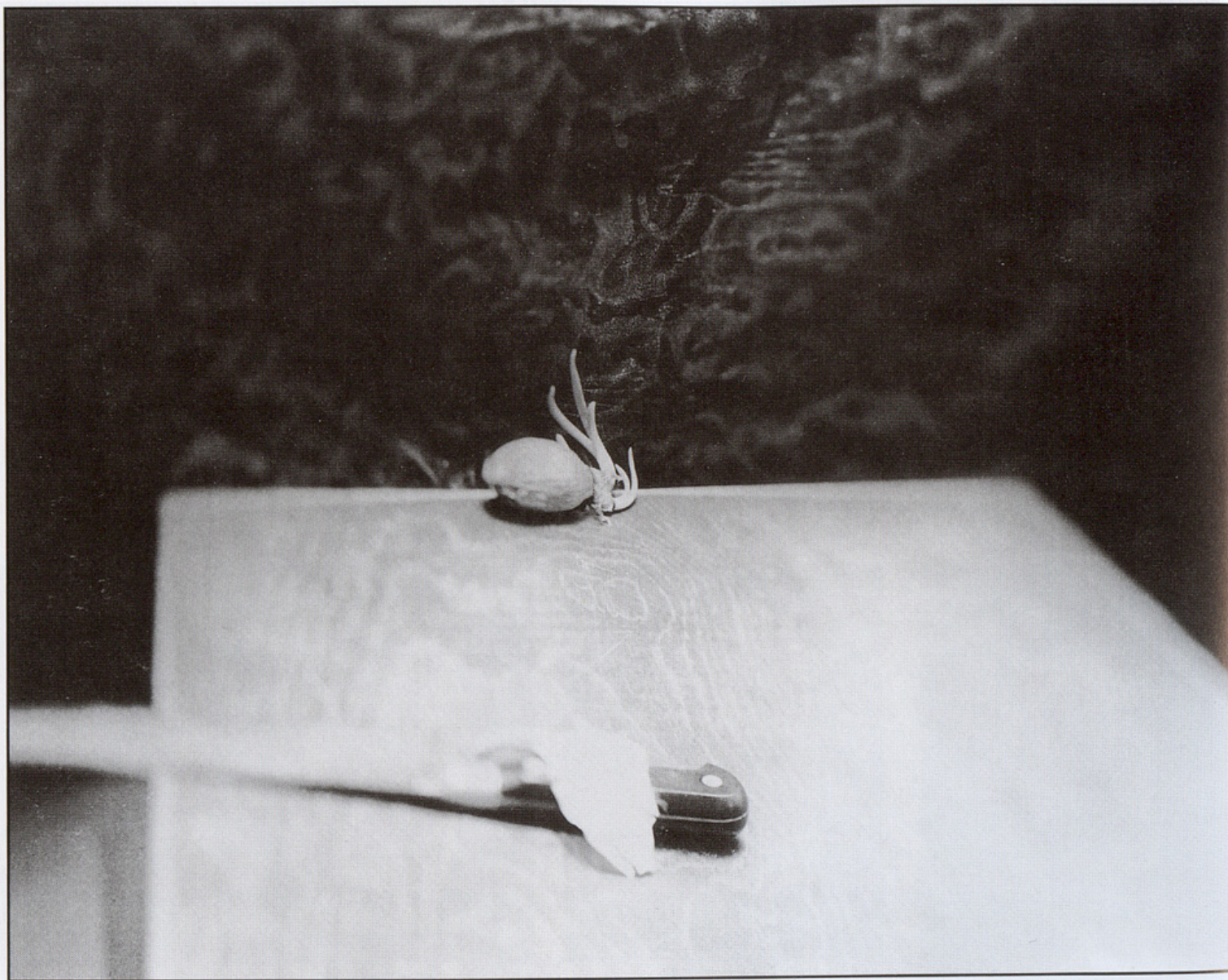


Top view

Here the photographer wanted just the spilled beans sharp, not those in the foreground and background jars.



A swing of the camera front to the right moves the plane of focus to angle along the receding pile of beans. The photographer opened up the lens to its maximum of $f/5.6$, which throws the other jars out of focus and directs attention to the beans.

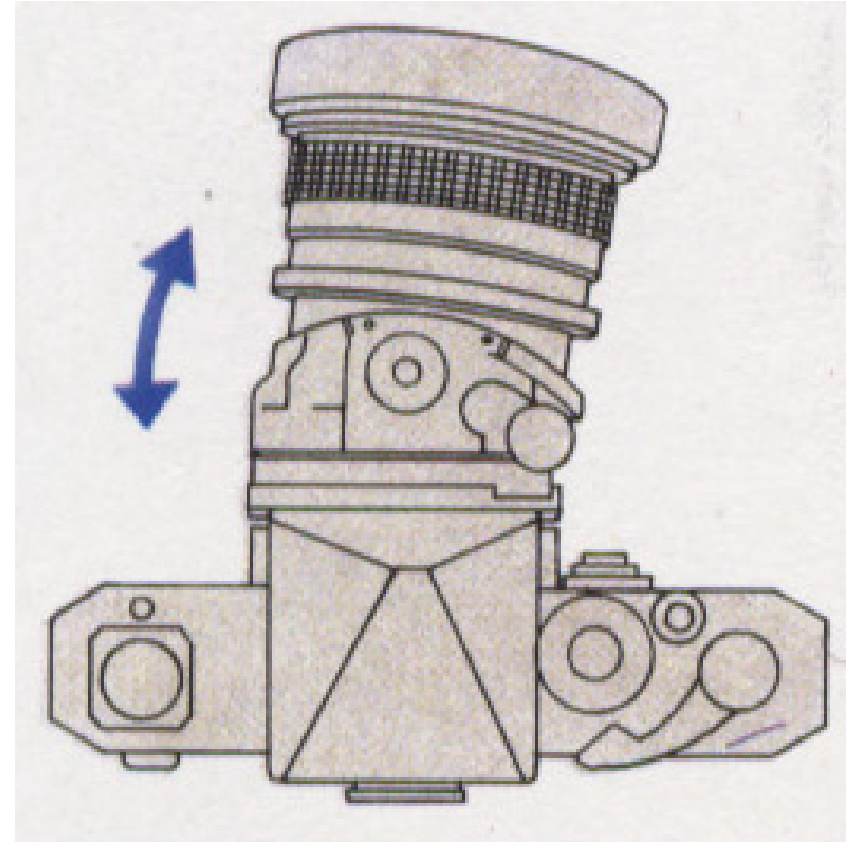
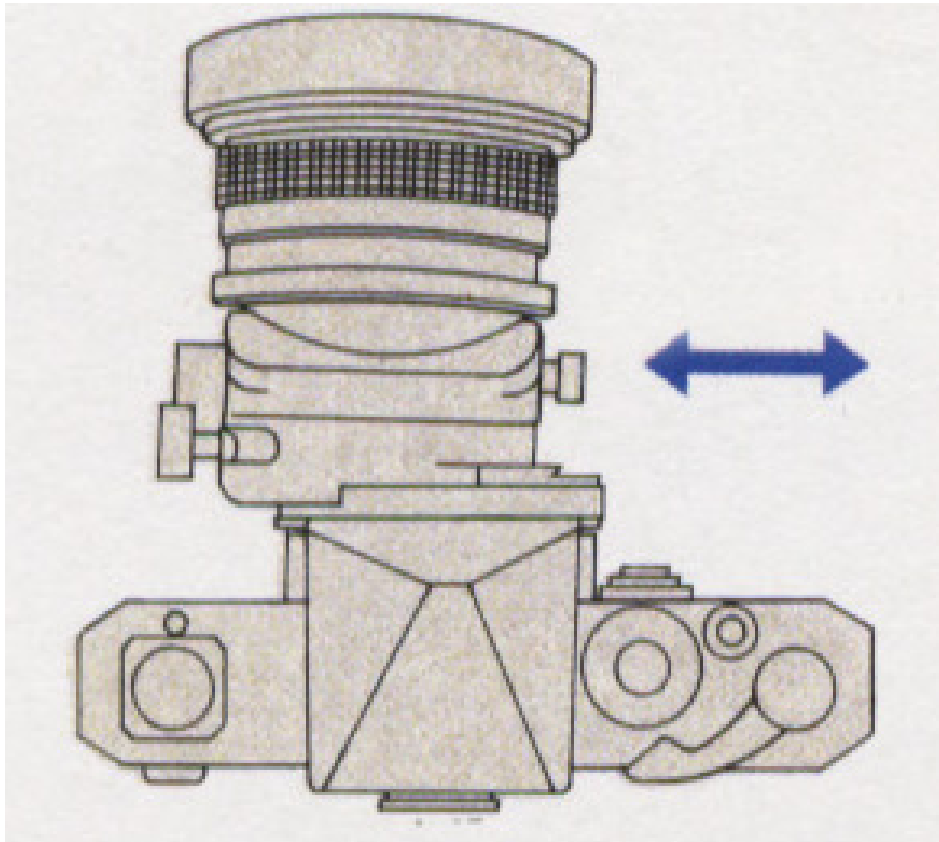


IAN GROOVER Untitled, 1985

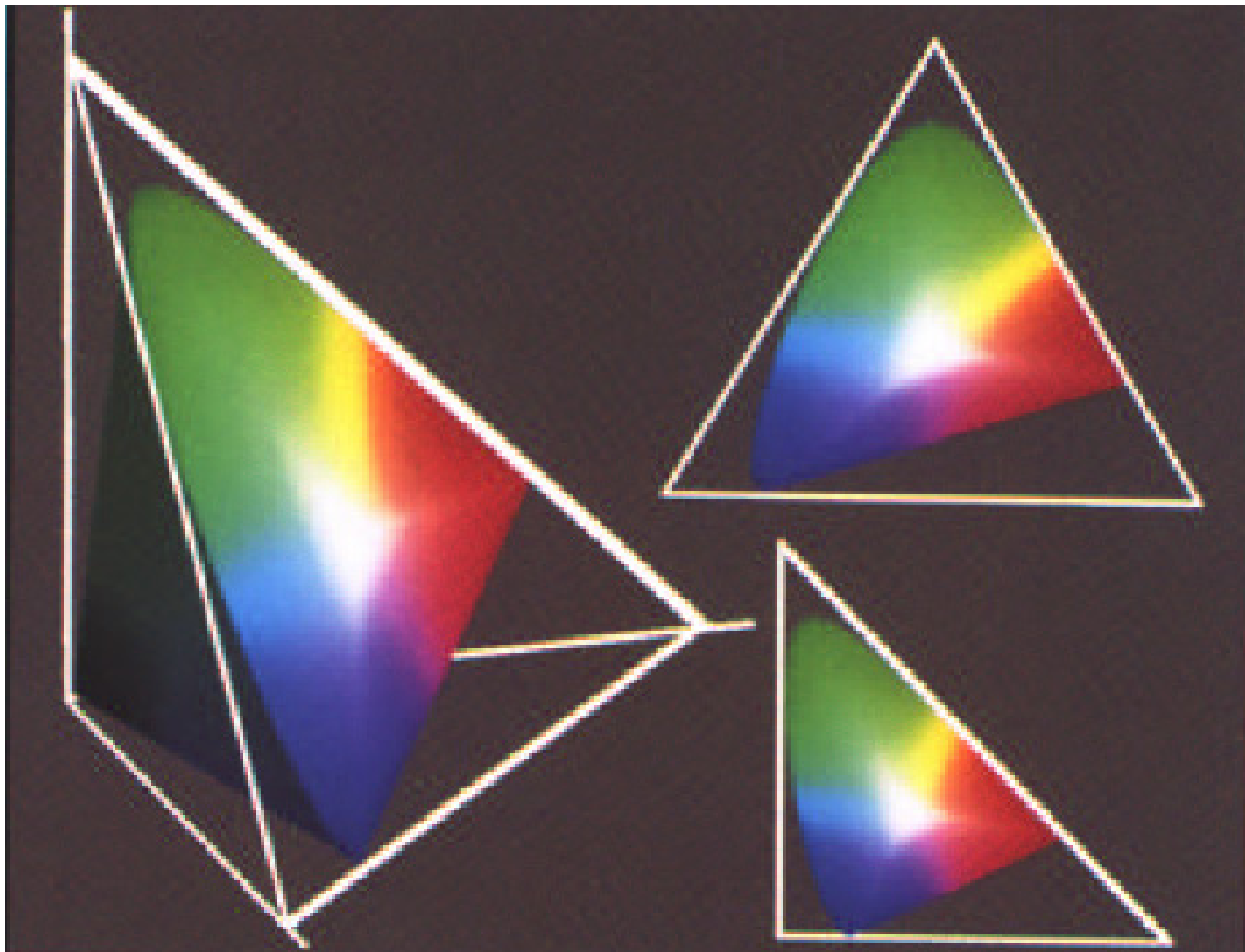
Swinging the camera front to the left or right manipulates the plane of focus. In this austere still life, the plane of focus is almost at a right angle to the film plane. The objects are commonplace, but the scene is subject to interpretation.

Tilt-shift lens

- 35mm SLR version



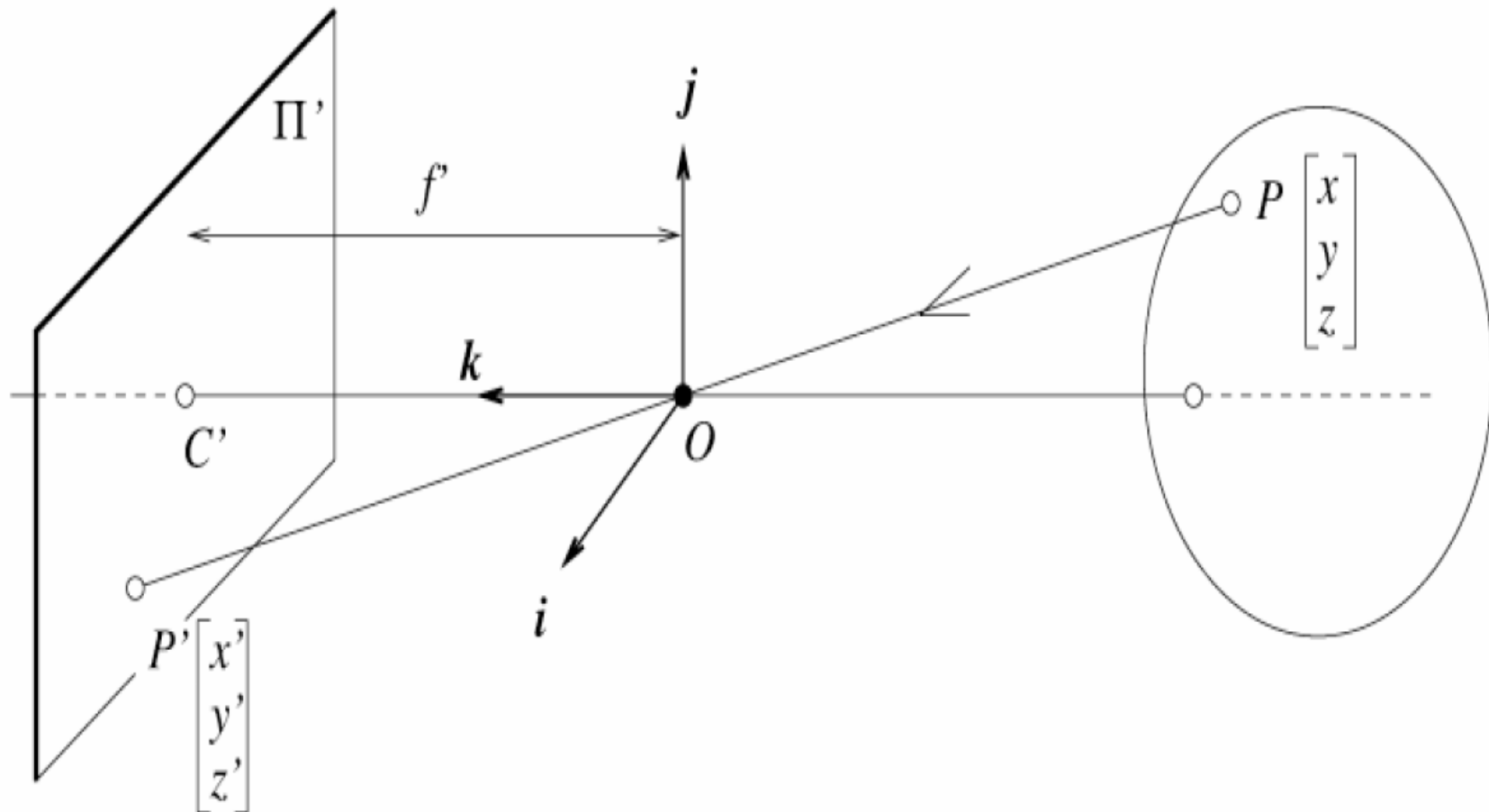
Next time: color



Appendix

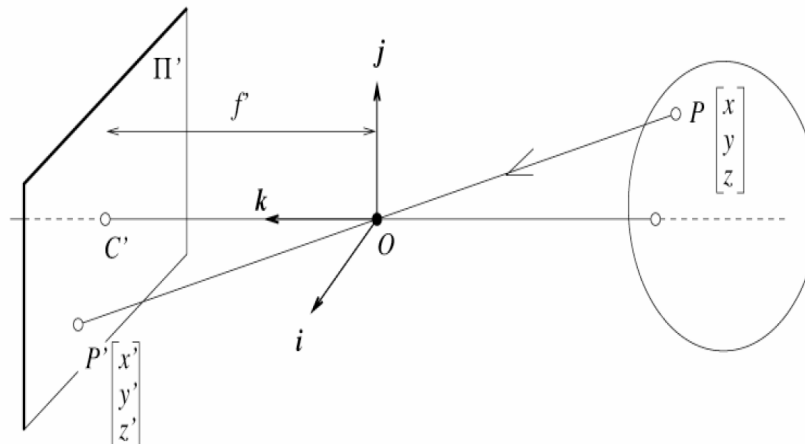


Equation of projection



Equation of projection

- Cartesian coordinates:
 - We have, by similar triangles, that
 $(x, y, z) \rightarrow (f x/z, f y/z, -f)$
 - Ignore the third coordinate, and get
 $(x, y, z) \rightarrow (f x/z, f y/z)$



Effect of projection

- **Points go to points**
- **Lines go to lines**
- **Planes go to a half plane**
- **Parallel lines go to converging lines**
- **Polygons go to polygons**
- **Degenerate cases:**
 - Line through the pinhole go to points
 - Planes through the pinhole go to a line
 - Parallels parallel to the image plane stay parallel
 - Planes parallel to the image plane goes to full planes

Next time: color

