6.098 Digital and Computational Photography
6.882 Advanced Computational Photography

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Administrivia

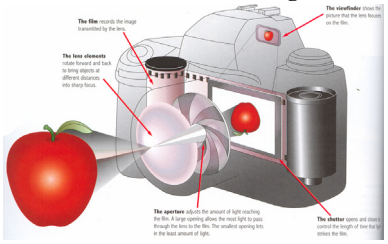
- PSet 1 is out
- Due Thursday February 23

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.

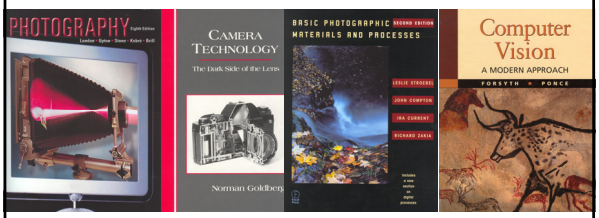
Overview

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



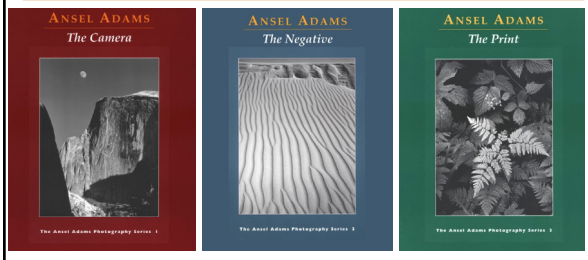
Reference

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



- The slides use illustrations from these books

More references



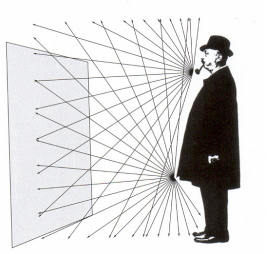
Plan

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

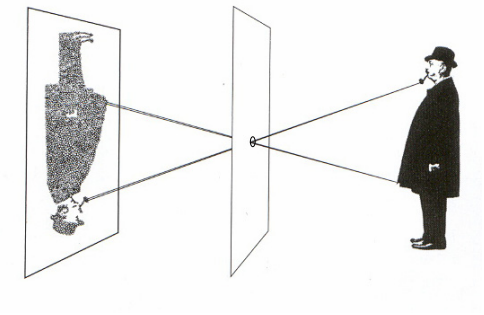
7-year old's question

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

It receives light from all directions

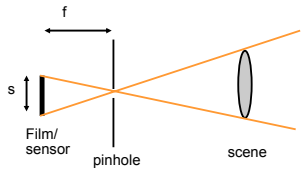


Pinhole



Demo!

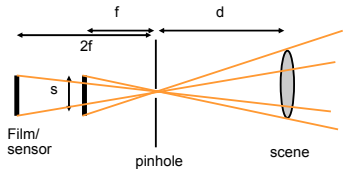
Focal length



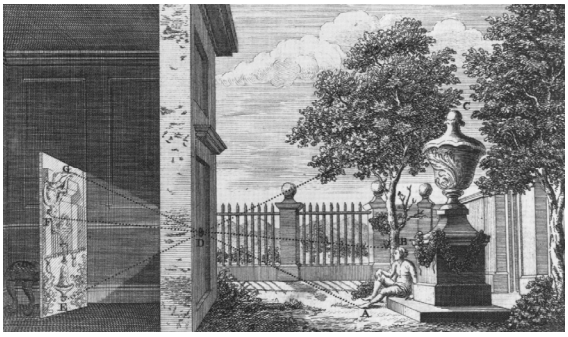
Demo!

Focal length: pinhole optics

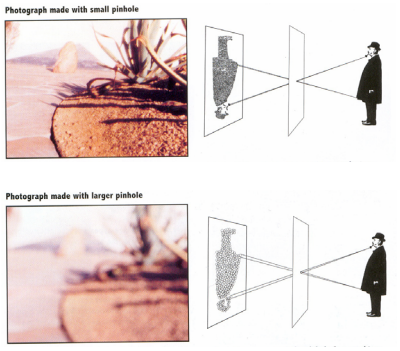
- **What happens when the focal length is doubled?**
  - Projected object size is doubled
  - Amount of light gathered is divided by 4



Questions?

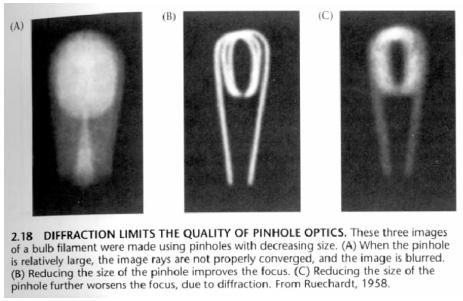


Pinhole size?



Diffraction limit

- **Optimal size for visible light:**
  sqrt(f)/28 (in millimiters) 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.

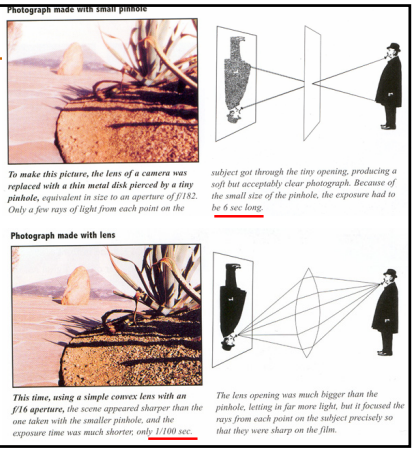
Problem with pinhole?

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

Solution: refraction!

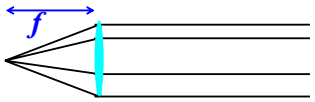
Lenses

- gather more light!
- But need to be focused

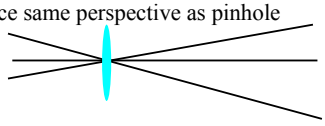


Thin lens optics

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



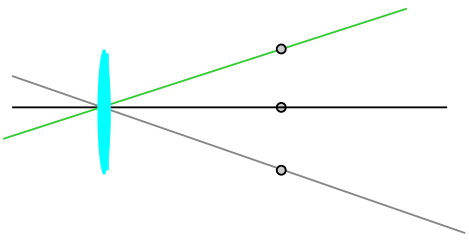
- All rays going through the center are not deviated
  - Hence same perspective as pinhole



Demo!

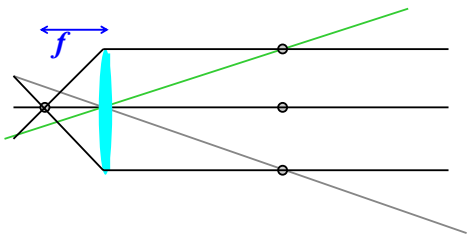
How to trace rays

- Start by rays through the center



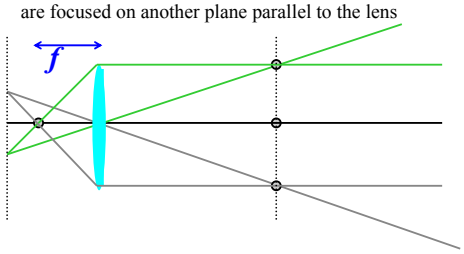
How to trace rays

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



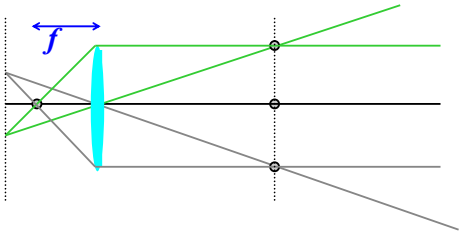
How to trace rays

- **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

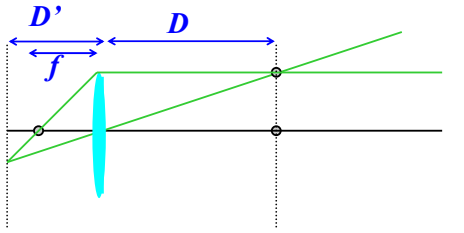


Focusing

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

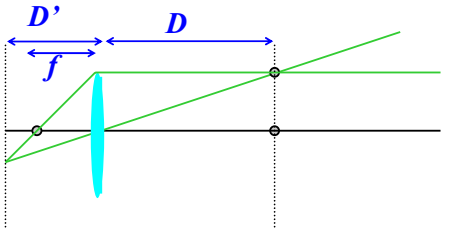


Thin lens formula



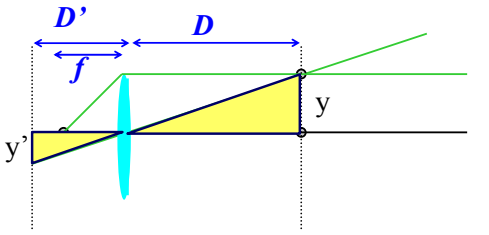
Thin lens formula

Similar triangles everywhere!



Thin lens formula

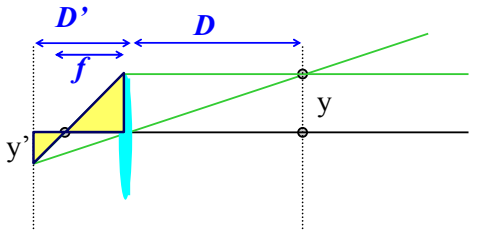
Similar triangles everywhere! $y'/y = D'/D$



Thin lens formula

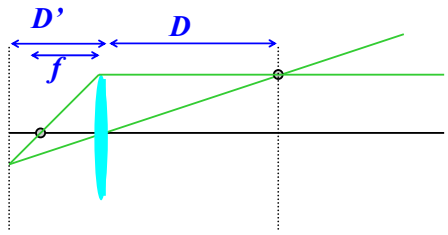
Similar triangles everywhere! $y'/y = D'/D$

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



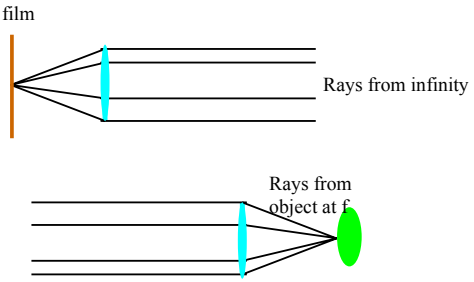
Thin lens formula

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



Minimum focusing distance

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

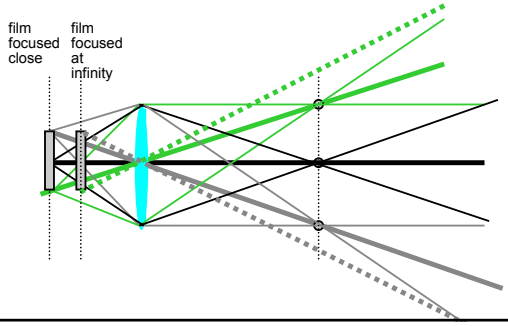


Extensions tubes

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

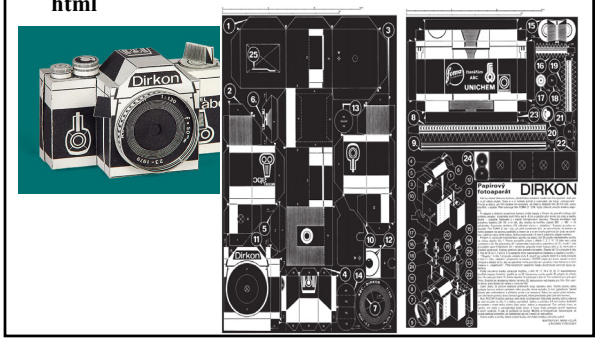
Field of view & focusing

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

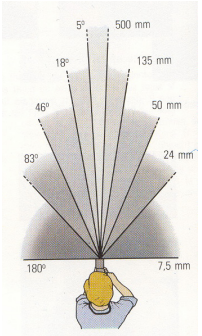


Questions?

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



Focal length in practice



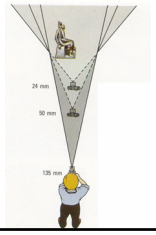
24mm

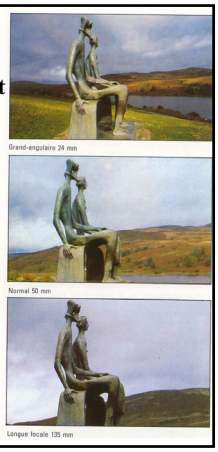
50mm

135mm

Perspective vs. viewpc

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





Perspective vs. viewpoint

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

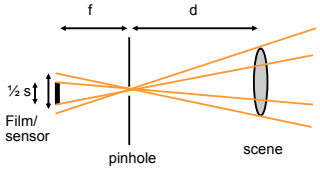
Perspective vs. viewpoint

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

Wide angle | Standard | Telephoto

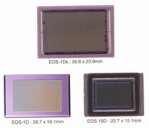
Focal length & sensor

- **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?

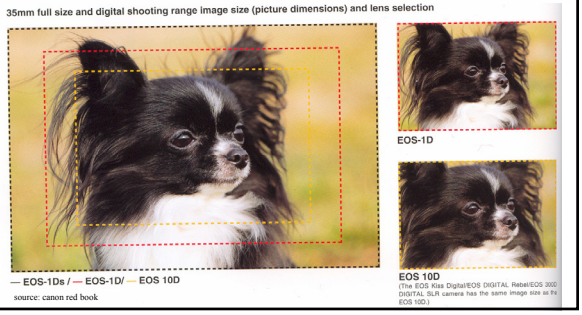


Sensor size

- **Similar to cropping**



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



http://www.photozone.de/3Technology/digital_1.htm

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

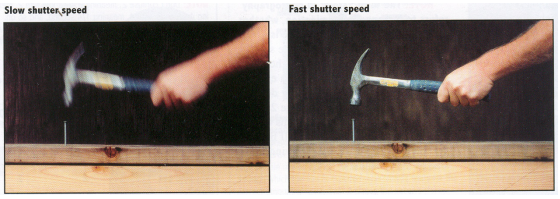
- **Get the right amount of light to sensor/film**
- **Two main parameters:**
  - Shutter speed
  - Aperture (area of lens)

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

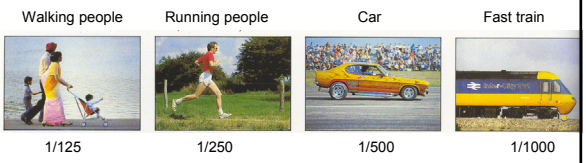
Main effect of shutter speed

- **Motion blur**



Effect of shutter speed

- **Freezing motion**



Shutter

- Various technologies
- Goal: achieve uniform exposure across image

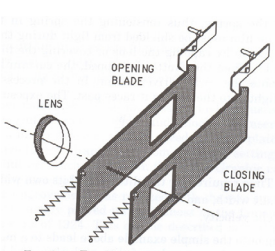


FIG. 2.8 Two-blade guillotine shutter.

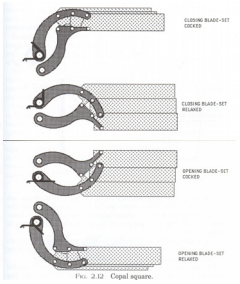


FIG. 2.12 Copal square.

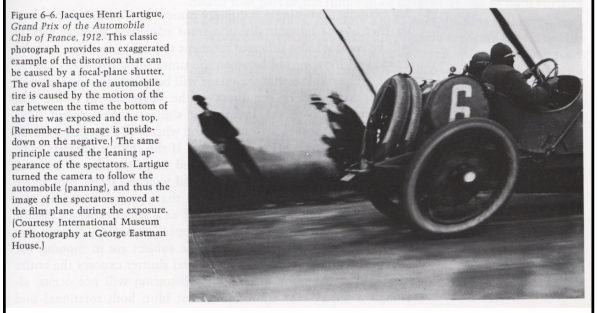
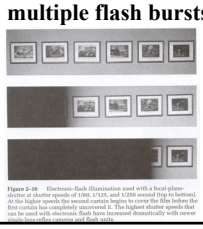
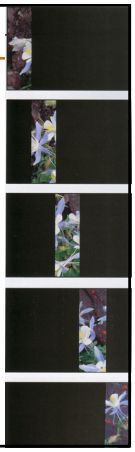


Figure 6-6. Jacques Henri Lartigue, *Grand Prix of the Automobile Club of France, 1912.* This classic photograph provides an exaggerated example of the distortion that can be caused by a focal-plane shutter. The oval shape of the automobile tire is caused by the motion of the car between the time the 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





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

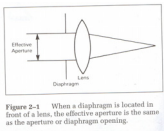


Figure 2-1 When a diaphragm is located in front of a lens, the effective aperture is the same as the aperture or diaphragm opening.

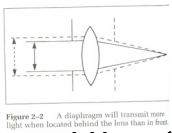
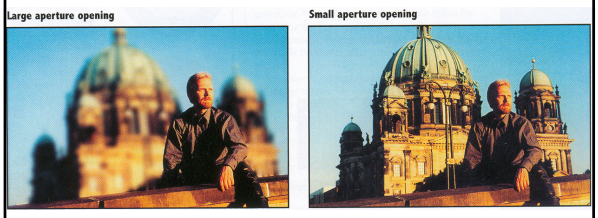


Figure 2-2 A diaphragm will transmit more light when located behind the lens than in front.

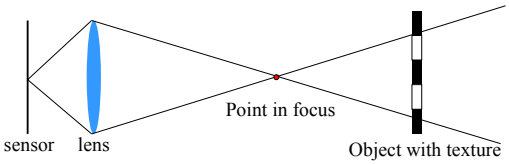
- Zoom lenses usually have a variable maximal aperture
  - Why?

Main effect of aperture

- **Depth of field**

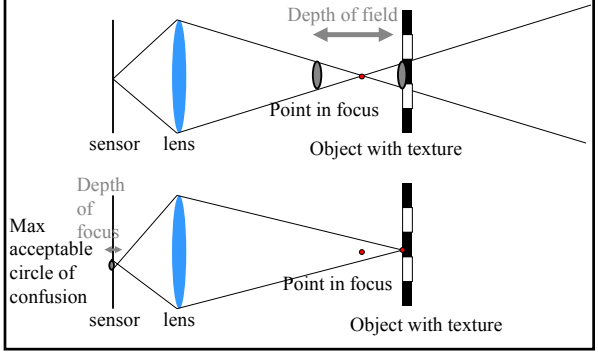


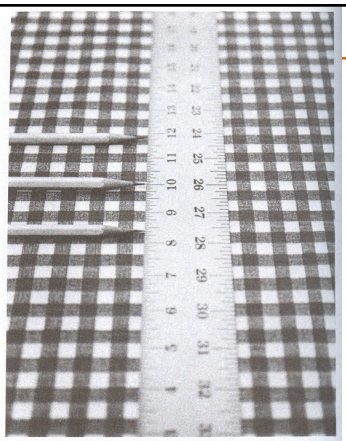
Depth of field



Depth of field

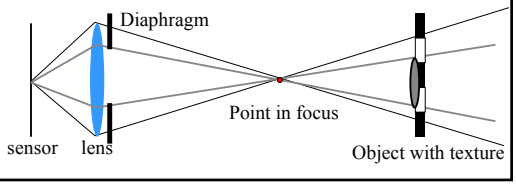
- **We allow for some tolerance**



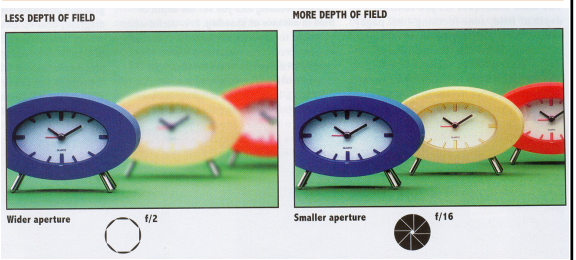


Depth of field

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

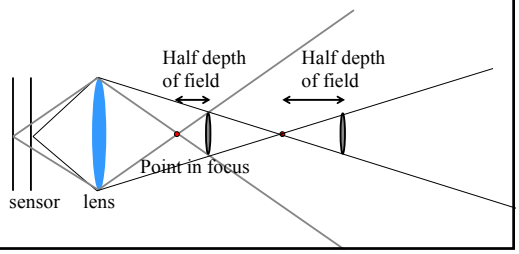


Depth of field



Depth of field & focusing distance

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



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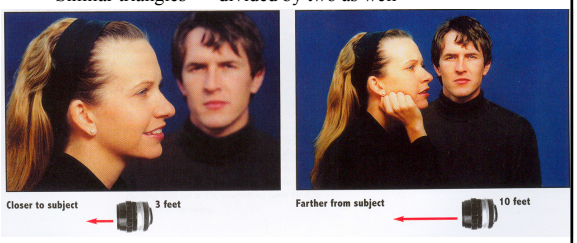
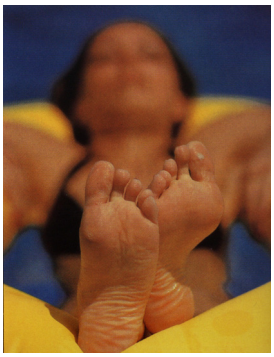


SLR viewfinder & aperture

- **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

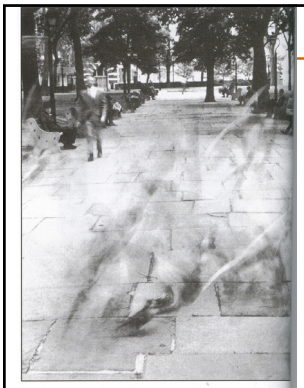
- **Two main parameters:**
  - Aperture (in f stop)
  - Shutter speed (in fraction of a second)
- **Reciprocity**

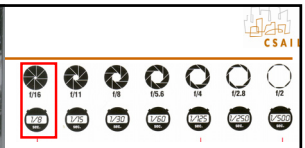
  The same exposure is obtained wit an exposure twice as long and an aperture *area* half as big
  - Hence square root of two progression of f stops vs. power of two progression of shutter speed
  - Reciprocity can fail for very long exposures

Reciprocity

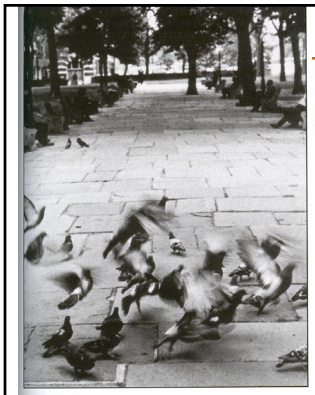
- **Assume we know how much light we need**
- **We have the choice of an infinity of shutter speed/aperture pairs**

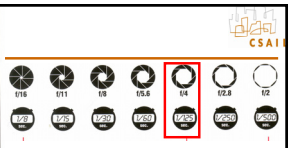
- **What will guide our choice of a shutter speed?**
  - Freeze motion vs. motion blur, camera shake
- **What will guide our choice of an aperture?**
  - Depth of field, diffraction limit
- **Often we must compromise**
  - Open more to enable faster speed (but shallow DoF)



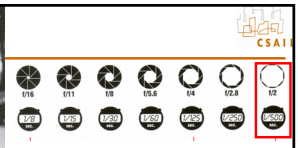


Small aperture (deep depth of field), slow shutter speed (motion blurred). *It is a scene, a small aperture (f/16) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed (1/8 sec) was needed; it was too slow to show moving pigeons so 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.*



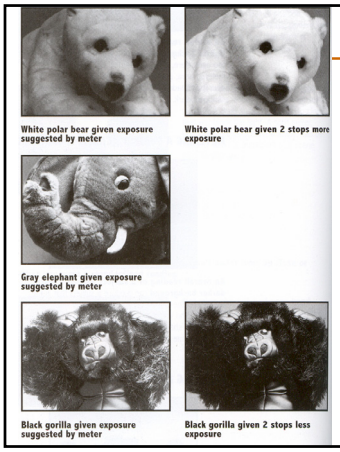
Large aperture (shallow depth of field), fast shutter speed (motion sharp). *A fast shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little depth of field that the background is now out of focus.*

Questions?

Metering

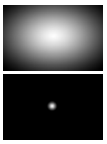
- **Photosensitive sensors measure scene luminance**
- **Usually TTL (through the lens)**
- **Simple version: center-weighted average**

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



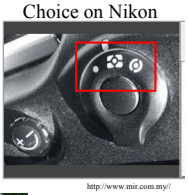
Metering

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



Next slide

Choice on Nikon



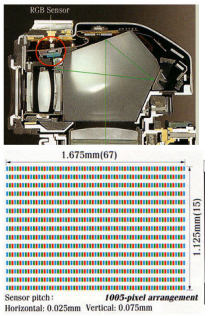
http://www.mir.com.my//

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

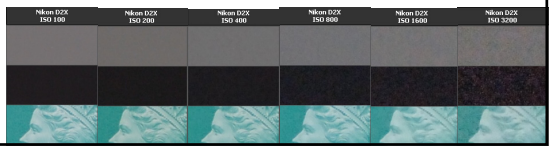
- **Measure scene brightness**
- **Some advanced modes that take multiple sources of information**
- **Still an open problem**

Questions?

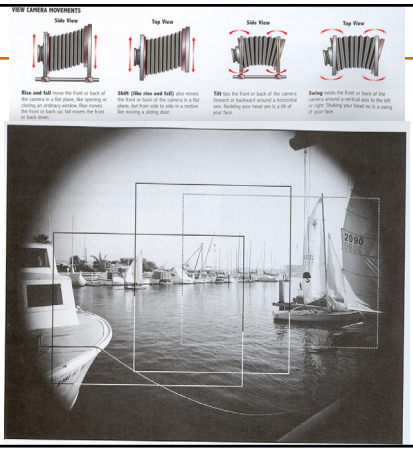
Sensitivity (ISO)

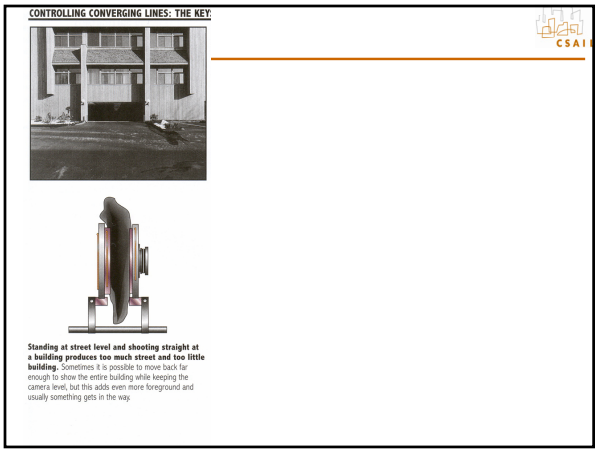
- Third variable for exposure
- Linear effect (200 ISO needs half the light as 100 ISO)
- Film photography: trade sensitivity for grain

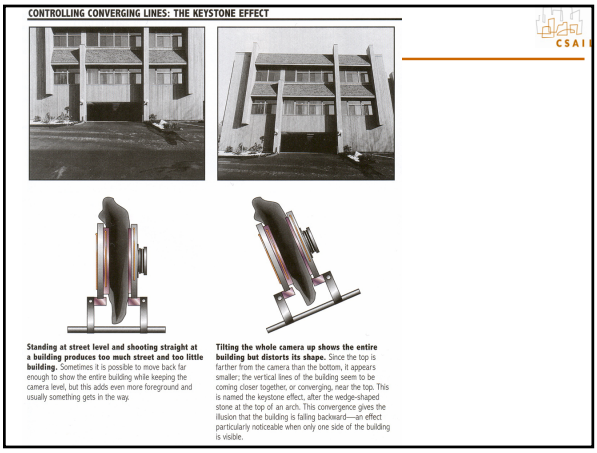
- Digital photography: trade sensitivity for noise

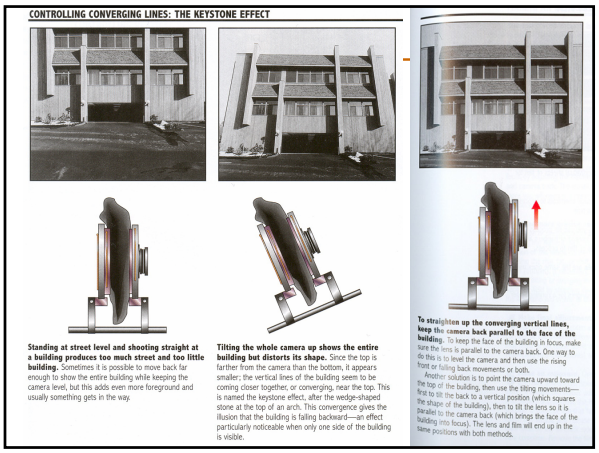


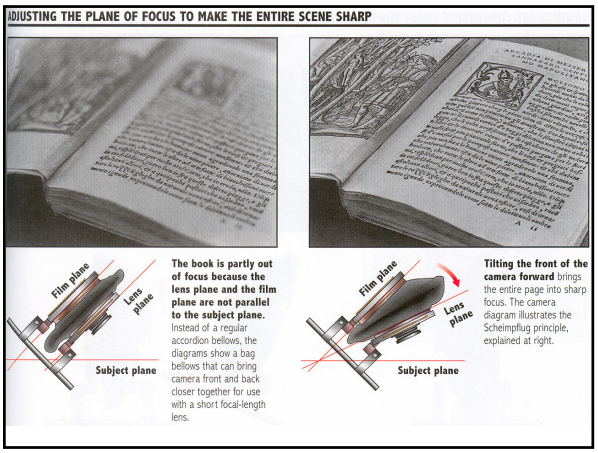
Questions?

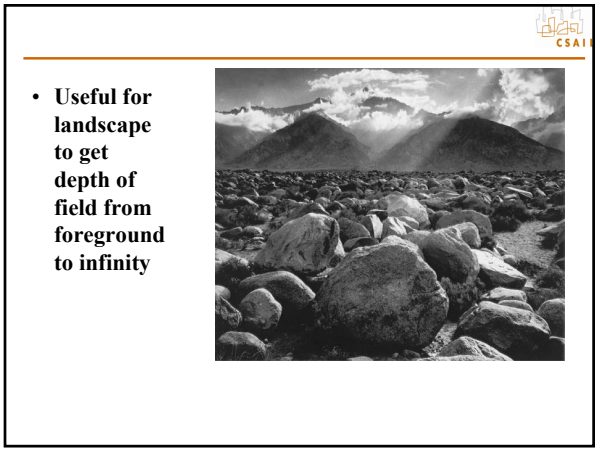


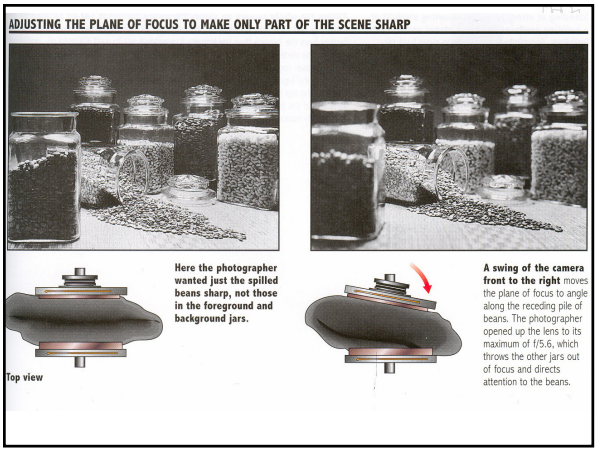


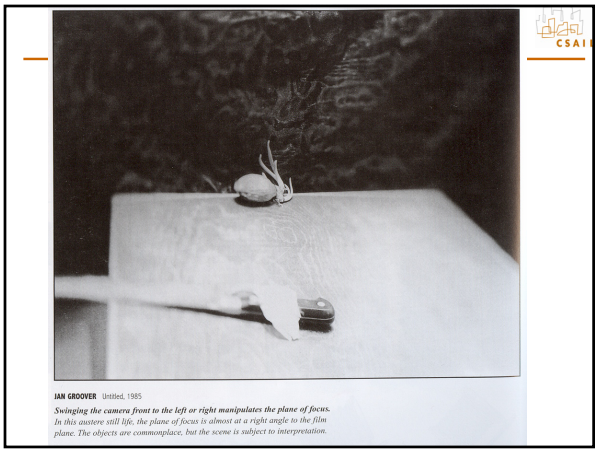


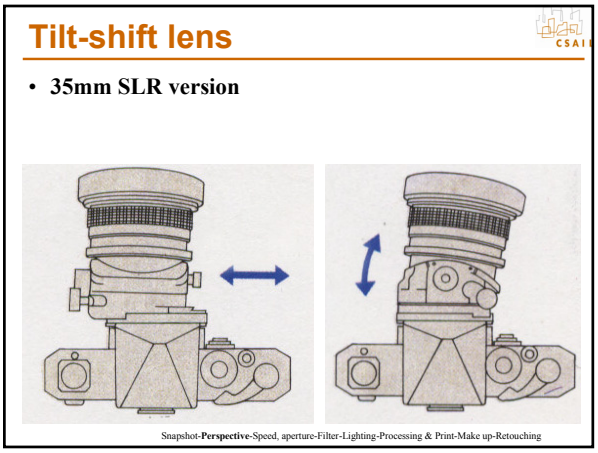

CONTROLLING CONVERGING LINES: THE KEYSTONE EFFECT
Standing at street level and shooting straight at a building produces too much street and too little building. Sometimes it is possible to move back far enough to show the entire building while keeping the camera level, but this adds even more foreground and usually something gets in the way.
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.
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
Film plane
Lens plane
Subject plane
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.
Film plane
Lens plane
Subject plane
Tilting the front of the camera forward brings the entire page into sharp focus. The camera diagram illustrates the Scheimpflug principle, explained at right.

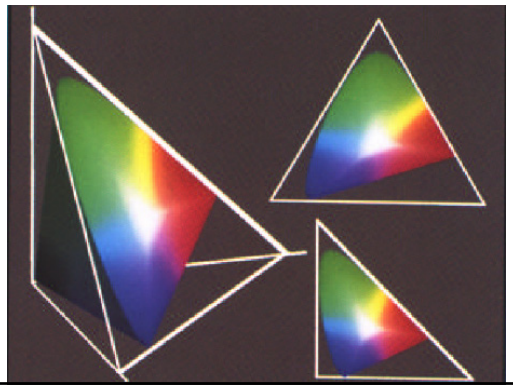

CSAI
• Useful for landscape to get depth of field from foreground to infinity


ADJUSTING THE PLANE OF FOCUS TO MAKE ONLY PART OF THE SCENE SHARP
Here the photographer wanted just the spilled beans sharp, not those in the foreground and background jars.
Top view
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.


CSAI
JAN 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.

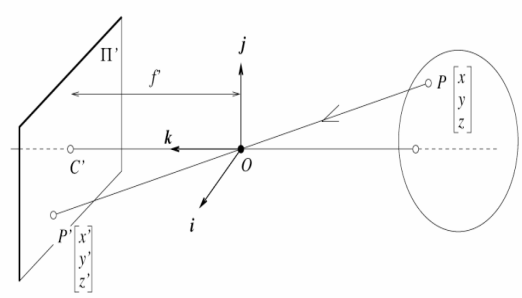

Tilt-shift lens
CSAI
• 35mm SLR version
Snapshot-Perspective-Speed, aperture-Filter-Lighting-Processing & Print-Make up-Retouching

Next time: color



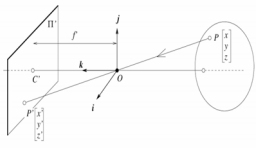
Appendix

Equation of projection



Equation of projection

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