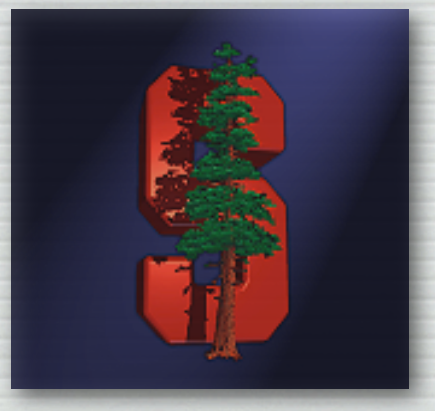
Image formation

CS 178, Spring 2009
(part 2 of 2)



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Announcements (from whiteboard)

Reminder: reading: London, 2, 18
" assignment #1 (online)

Outline: - image formation II
- history I
- extreme!

luminous exposure
~ # photons / (unit area · second)

Exposure

- $H = E \times T$
- exposure = irradiance × time

- irradiance (E)
  - controlled by aperture

- exposure time (T)
  - controlled by shutter speed

Shutter speed

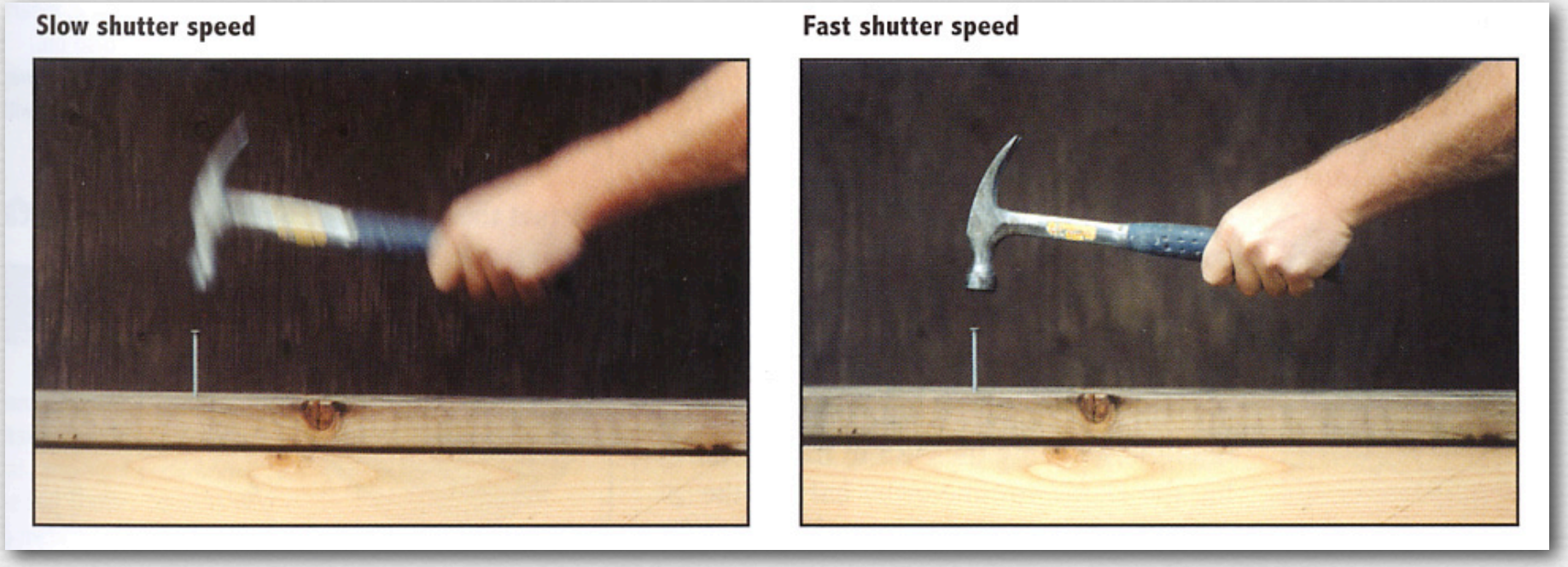
- controls how long the sensor is exposed to light
- linear effect on exposure until sensor saturates

- denoted in fractions of a second:
  - 1/2000, 1/1000,...,1/250, 1/125, 1/60,...,15, 30, B(ulb)

- normal humans can hand-hold down to 1/60 second
  - *rule of thumb:* shortest exposure = 1 / *f*
  - e.g. 1/500 second for a 500mm lens

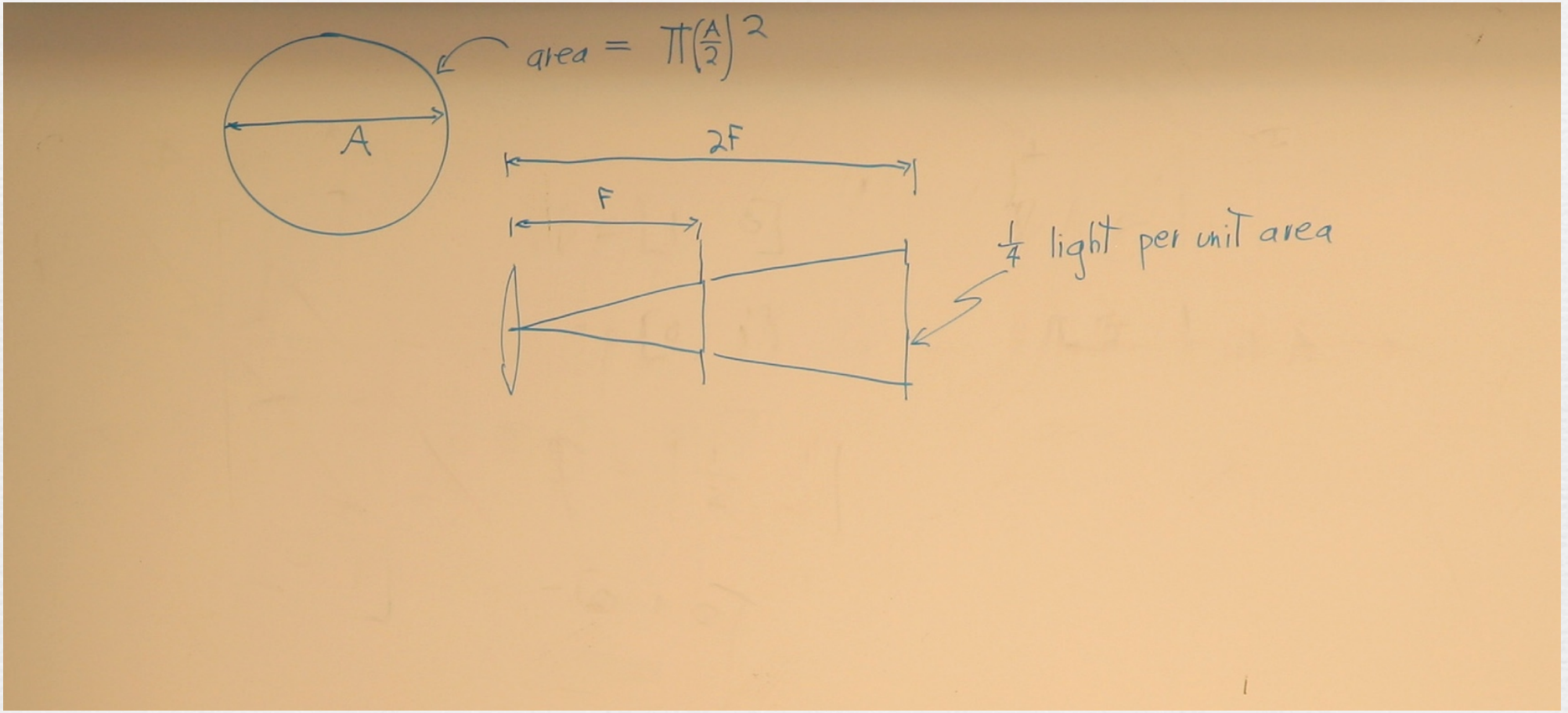
Main side-effect of shutter speed

- motion blur
- halving shutter speed doubles motion blur



(London)

Aperture
(contents of whiteboard)



Aperture

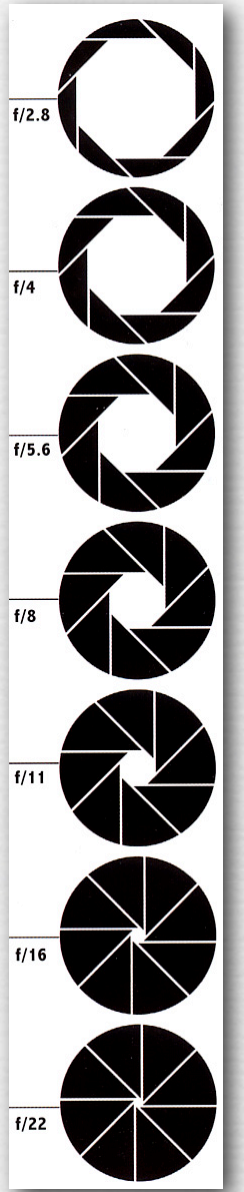
- irradiance on sensor is proportional to
  - square of aperture diameter A
  - inverse square of distance to sensor (~ focal length f)
- aperture N is thus defined relative to focal length

$$N = \frac{f}{A}$$

  - f/2.0 on a 50mm lens means the aperture is 25mm
  - f/2.0 on a 100mm lens means the aperture is 50mm

  ∴ low F-number (N) on long zooms require fat lenses

- doubling N reduces A by 2×, hence light by 4×
  - going from f/2.0 to f/4.0 cuts light by 4×
  - to cut light by 2×, increase N by √2



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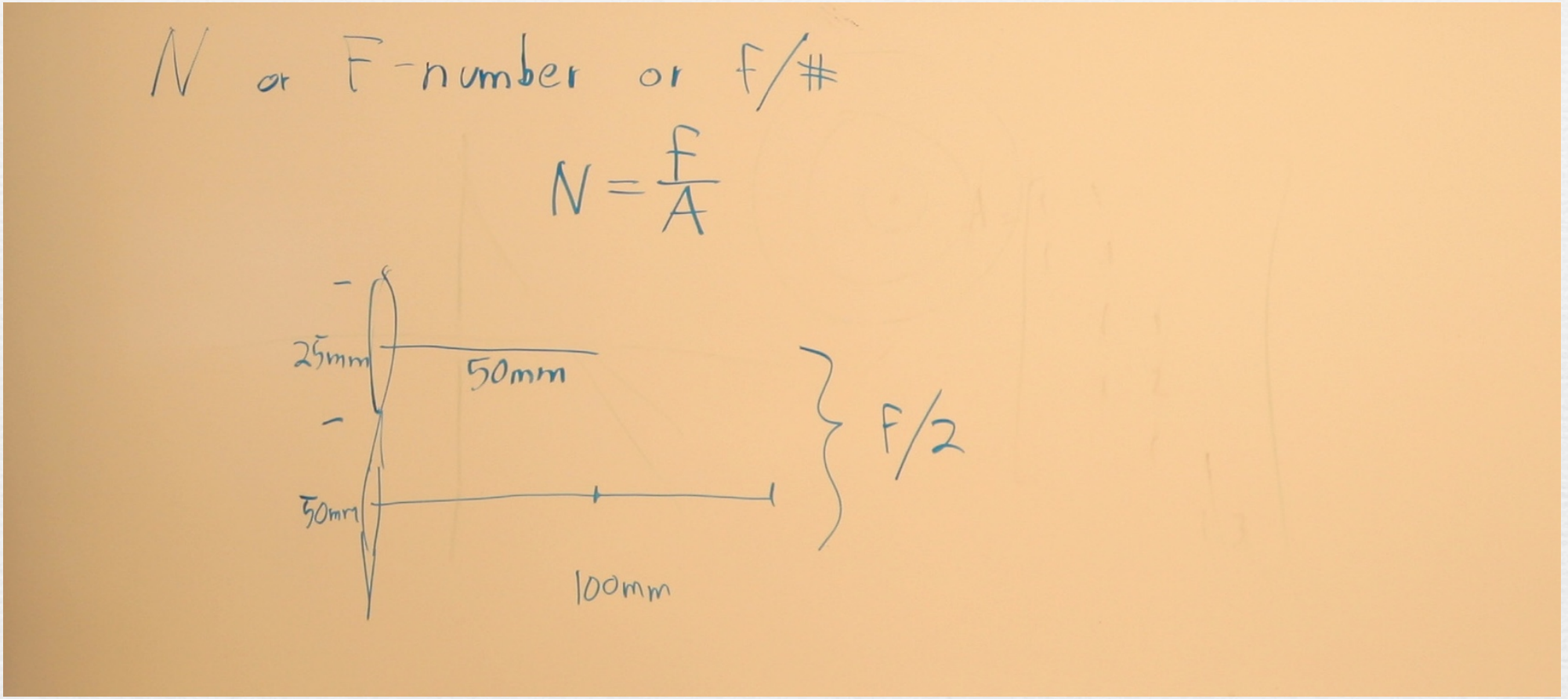
Example F-number calculation (contents of whiteboard)



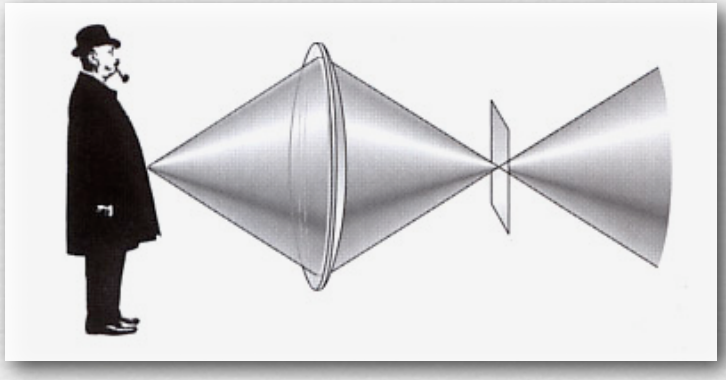
Main side-effect of aperture

- depth of field
- doubling N (two f/stops) doubles depth of field

(London)

Depth of field (briefly)

- a point in the scene is focused at a point on the sensor
- if the sensor moves too far, the point blurs too much (circle of confusion)
- this allowable depth of focus creates an allowable depth of field in the scene
- halving the aperture diameter doubles the depth of field
- this figure is not quite right...
  - we'll fix it next week



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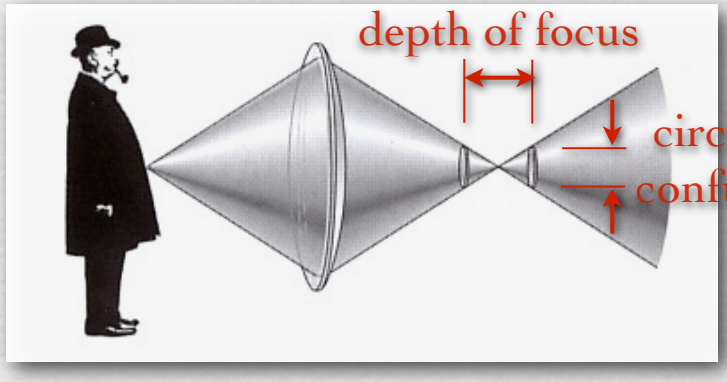
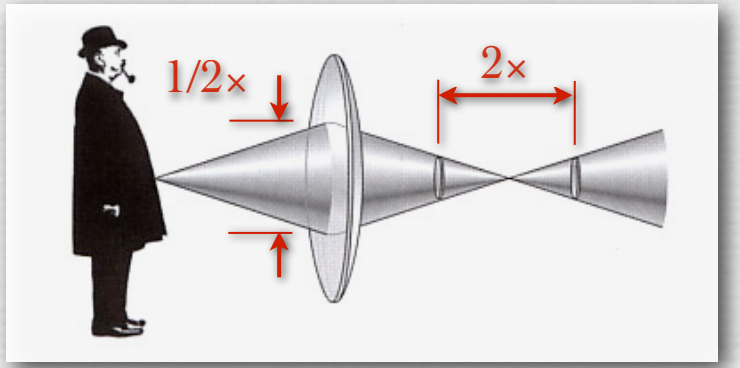
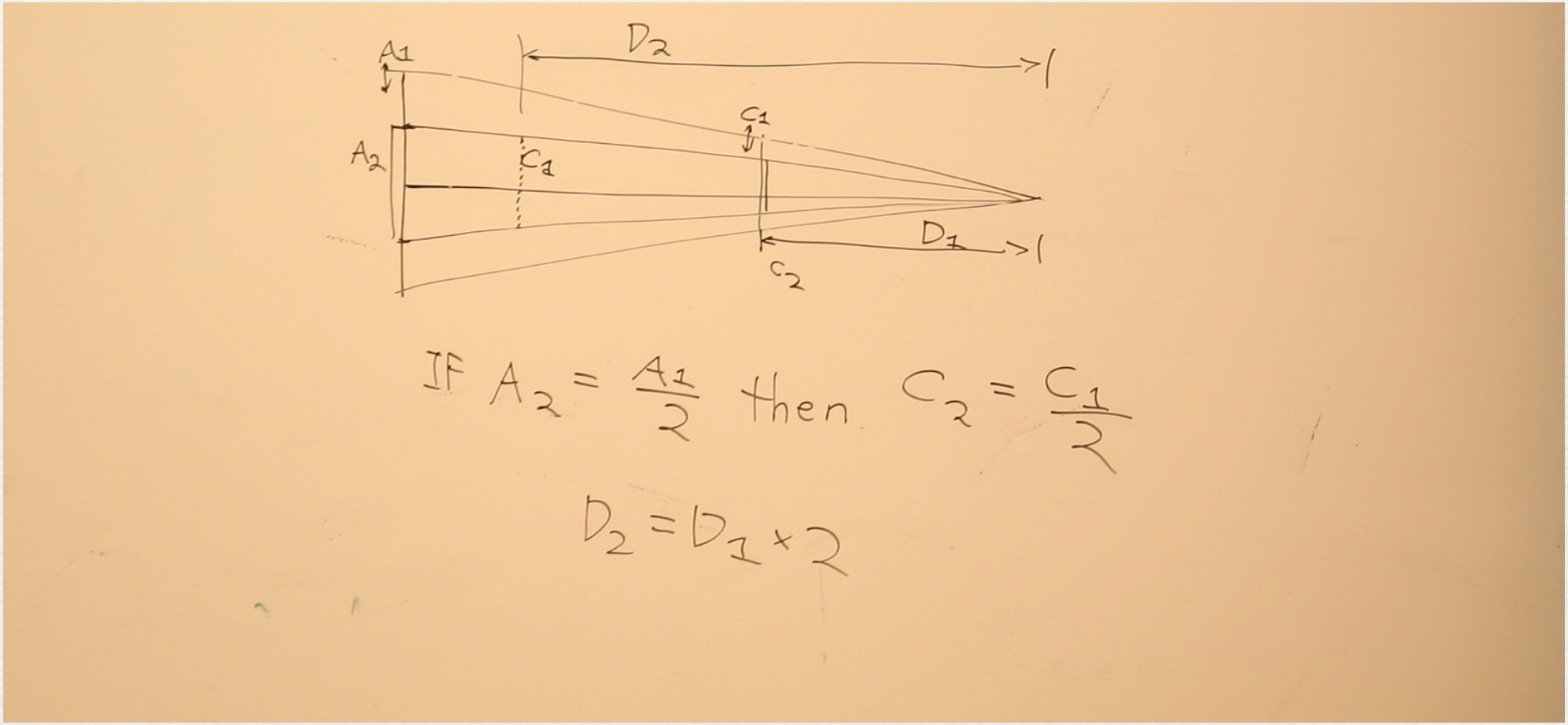
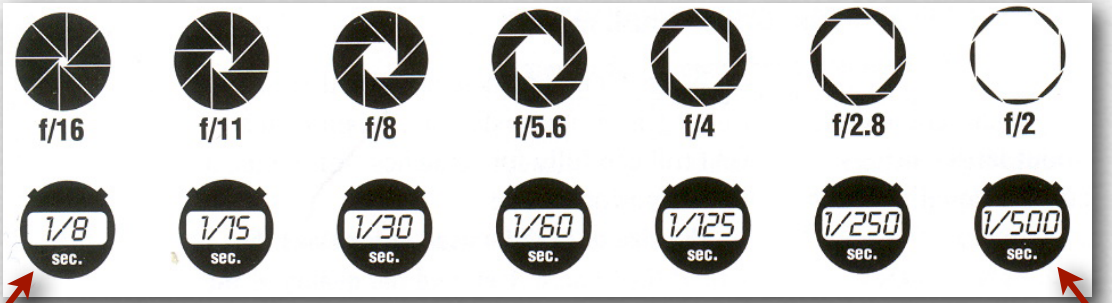


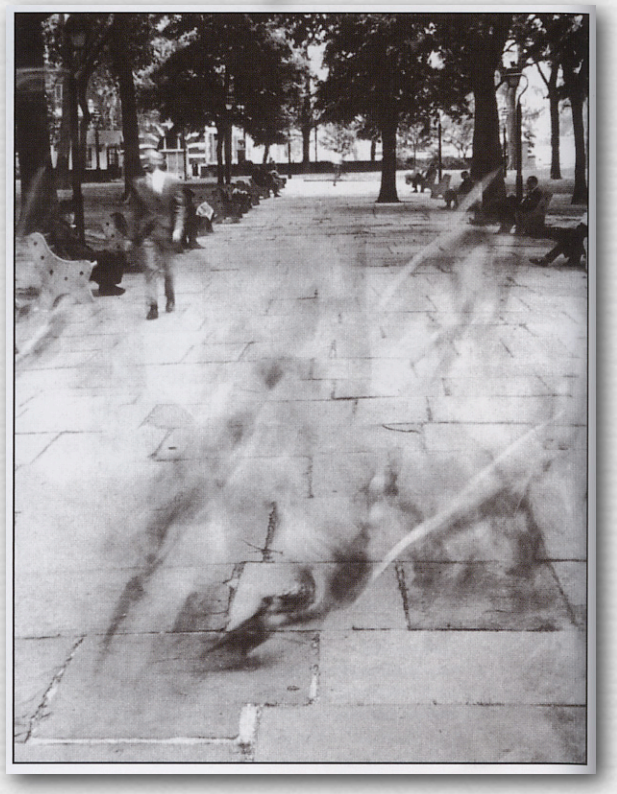


Halving the aperture diameter (contents of whiteboard)



Trading off motion blur and depth of field





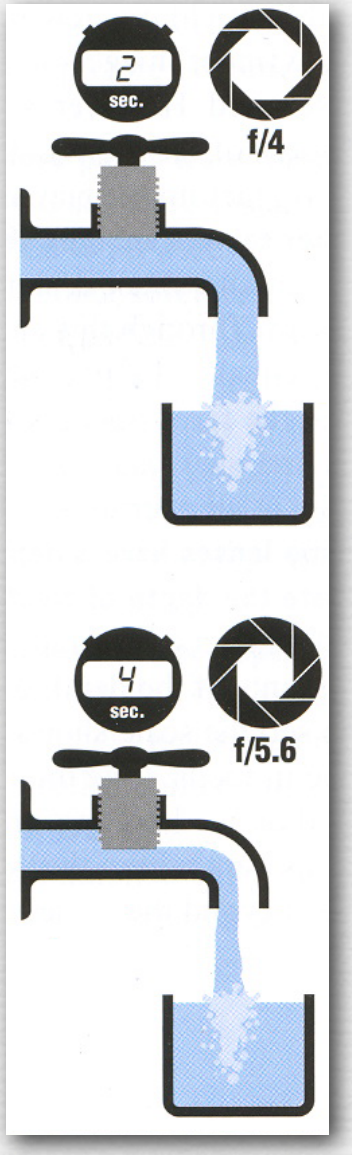
(London)

Recap

- $H = E \times T$
- exposure = irradiance × time

- irradiance (E)
  - controlled by the aperture
  - lowering by one f/stop doubles H
  - lowering by two f/stops doubles depth of field
- exposure time (T)
  - controlled by the shutter speed
  - doubling exposure time doubles H
  - doubling exposure time doubles motion blur

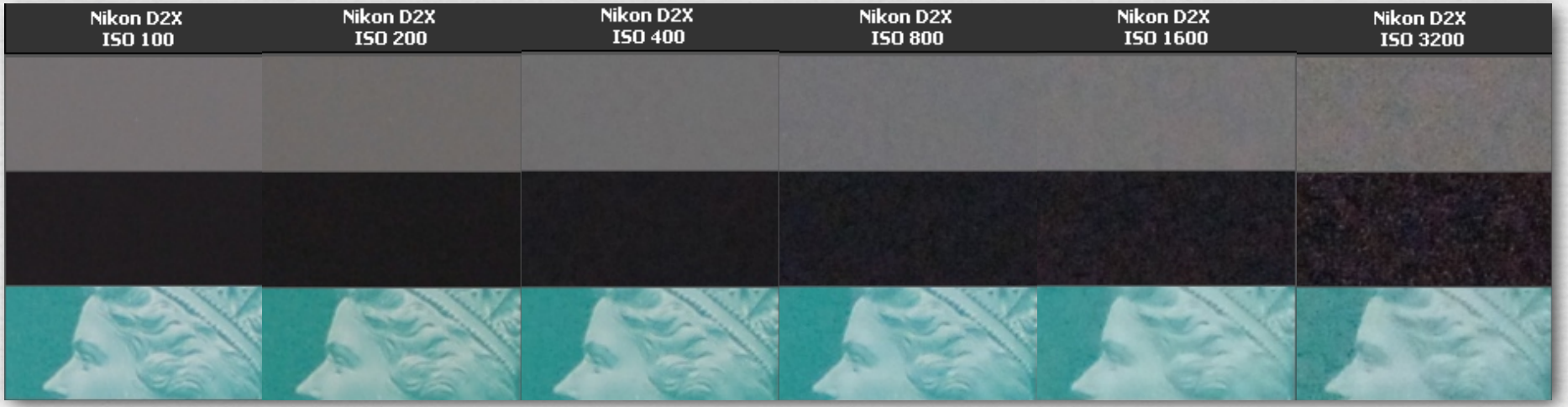
(London)



Sensitivity (ISO)

- third variable for exposure
- film: trade sensitivity for grain
- digital: trade sensitivity for noise
  - multiply signal before analog-to-digital conversion
  - linear effect (200 ISO needs half the light as 100 ISO)

more in noise lecture



(dpreview)

Slide credits

- Steve Marschner
- Fredo Durand

- Cole, A., *Perspective*, Dorling Kindersley, 1992.
- Kemp, M., *The Science of Art*, Yale University Press, 1990.
- Hecht, E., *Optics* (4th ed.), Pearson / Addison-Wesley, 2002.
- Renner, E., *Pinhole Photography* (2nd ed.), Focal Press, 2000.
- London, Stone, and Upton, *Photography* (ninth edition), Prentice Hall, 2008.
- D'Amelio, J., *Perspective Drawing Handbook*, Tudor Press, 1964.
- Dubery, F., Willats, J., *Perspective and other drawing systems*, Van Nostrand Reinhold, 1972.
- Kingslake, R. *Optics in Photography*, SPIE Press, 1992.
- http://dpreview.com