Image formation

CS 178, Spring 2009
(part 1 of 2)

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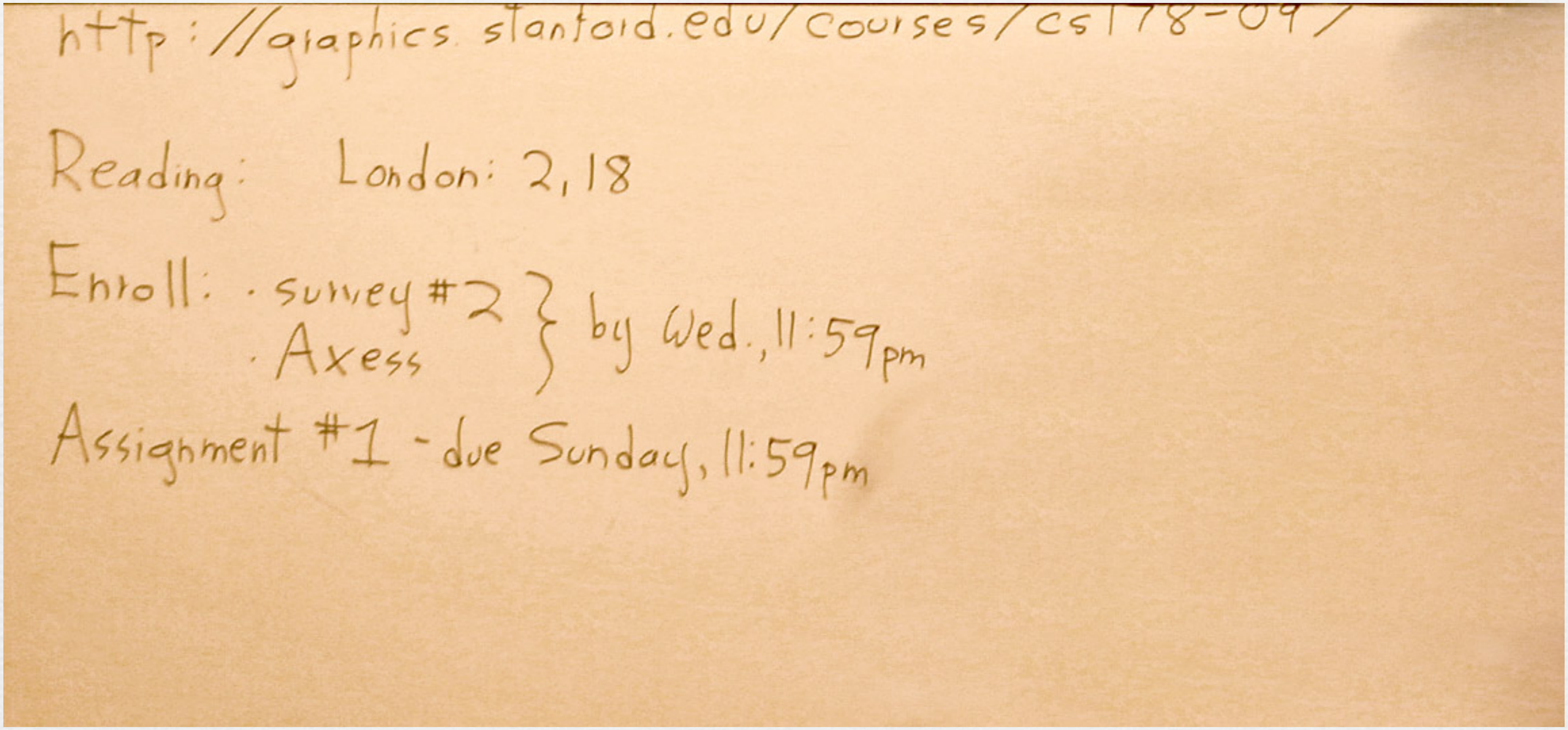
Announcements (from whiteboard)



Outline

- perspective
  - natural versus linear perspective
  - vanishing points
- image formation
  - pinhole cameras
  - lenses
- exposure
  - shutter speed
  - aperture
  - ISO
- choosing a camera

?

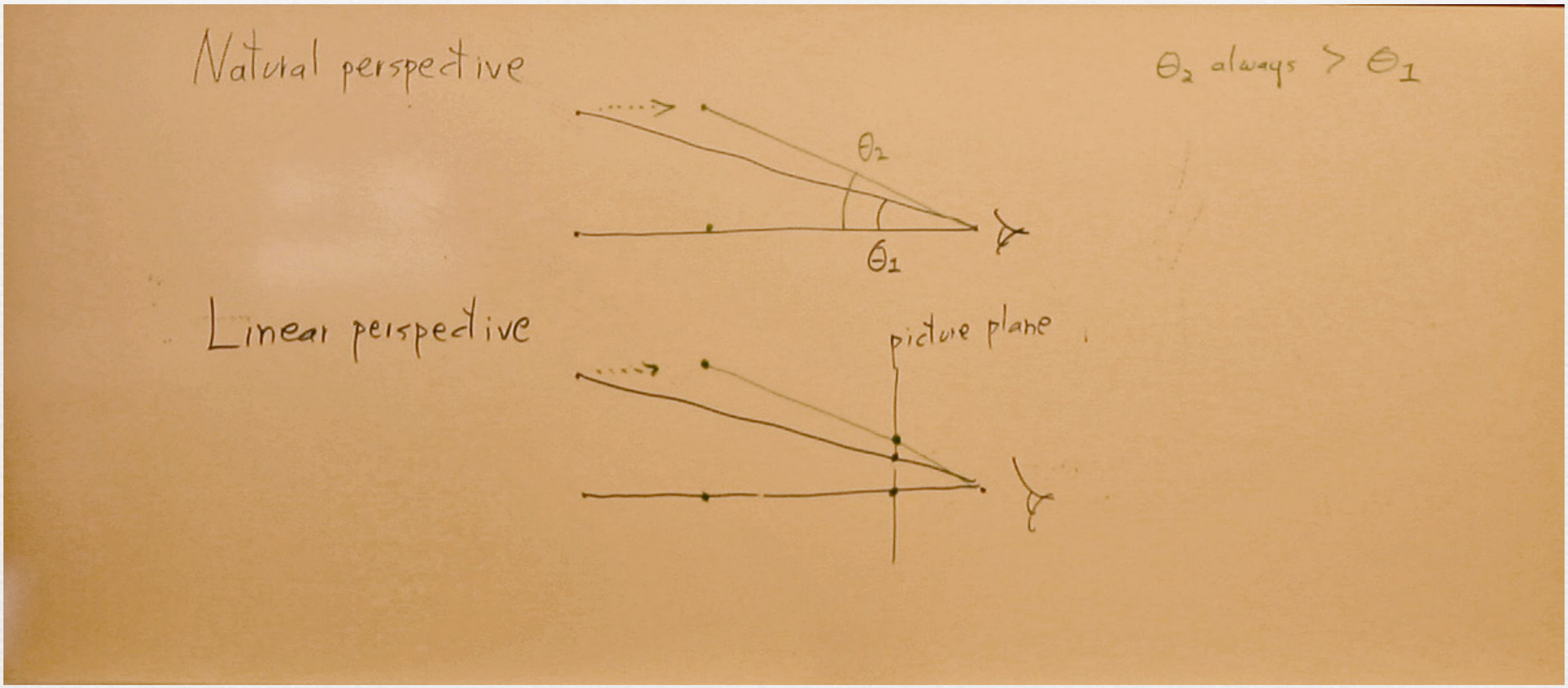
The laws of perspective

- common assumptions
  1. Light leaving an object travels in straight lines.
  2. These lines converge to a point at the eye.
- natural perspective

  3a. More distant objects subtend smaller visual angles.
- linear perspective (Filippo Brunelleschi, 1413)

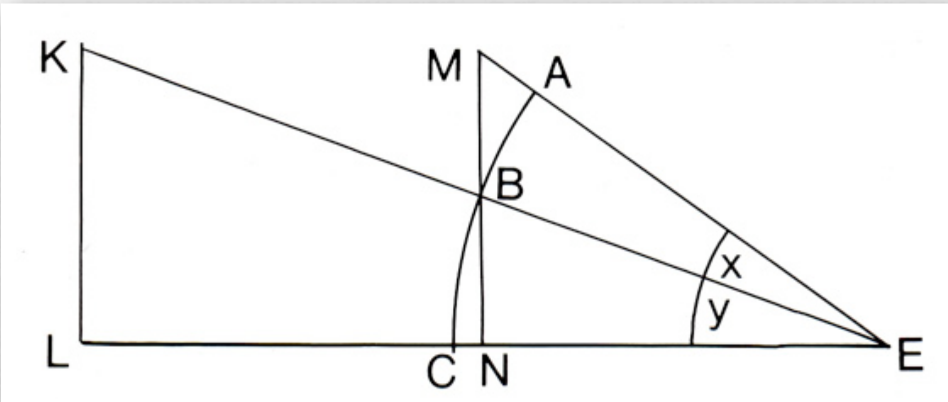
  3b. A perspective image is formed by the intersection of these lines with a "picture plane" (the canvas).

Natural vrs linear perspective (contents of whiteboard)

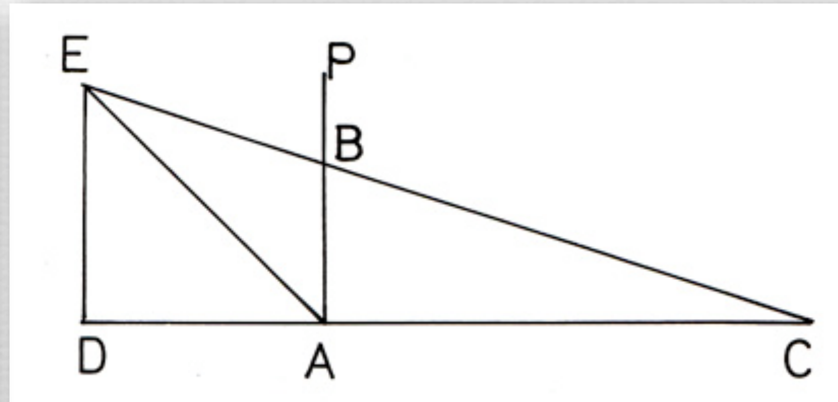


The laws of perspective

(Kemp)



(Euclid, 3rd c. B.C.)



(Piero della Francesca, 1474)

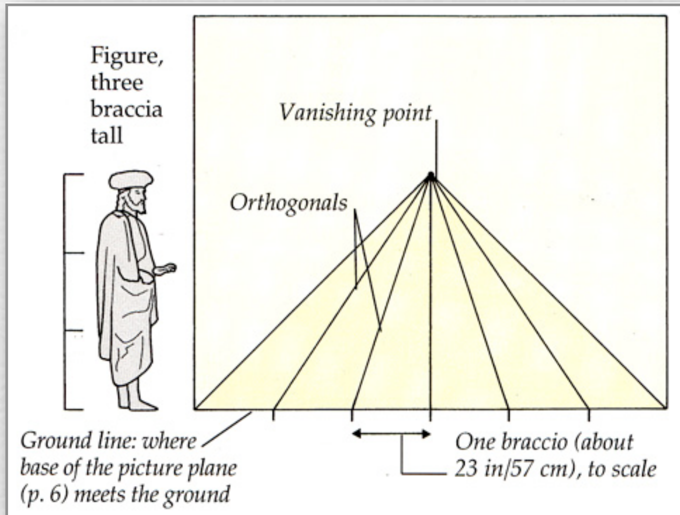
- natural perspective
  - 3a. More distant objects subtend smaller visual angles.
- linear perspective [Filippo Brunelleschi (1413)]
  - 3b. A perspective image is formed by the intersection of these lines with a "picture plane" (the canvas).

Filippo Brunelleschi,
dome of the cathedral,
Florence (1419)

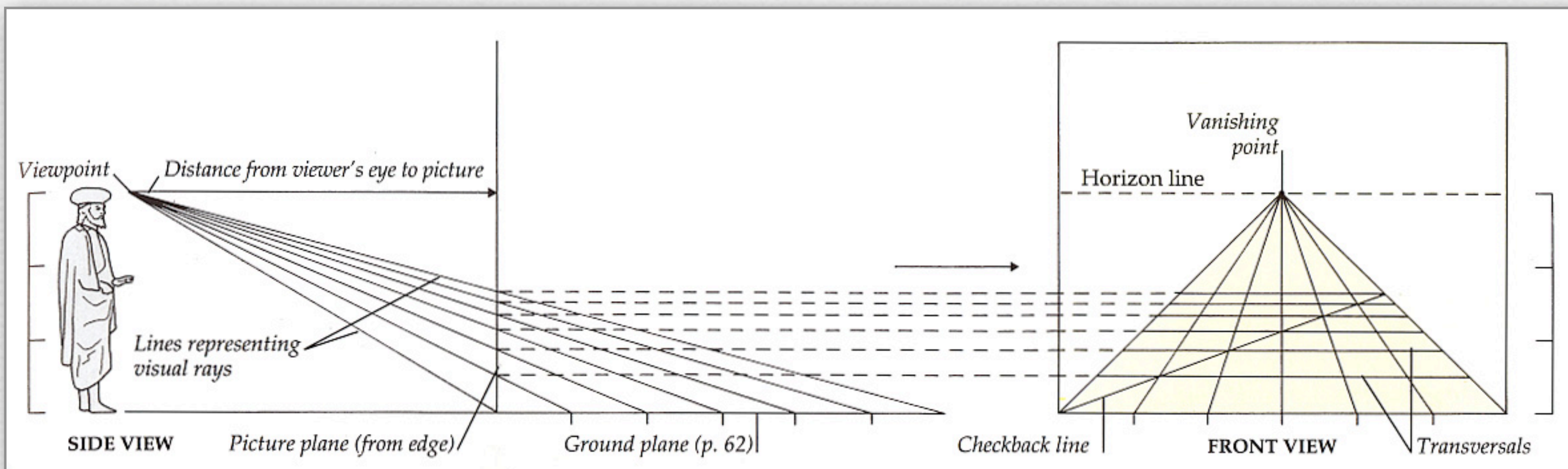
The problem of drawing pavimento

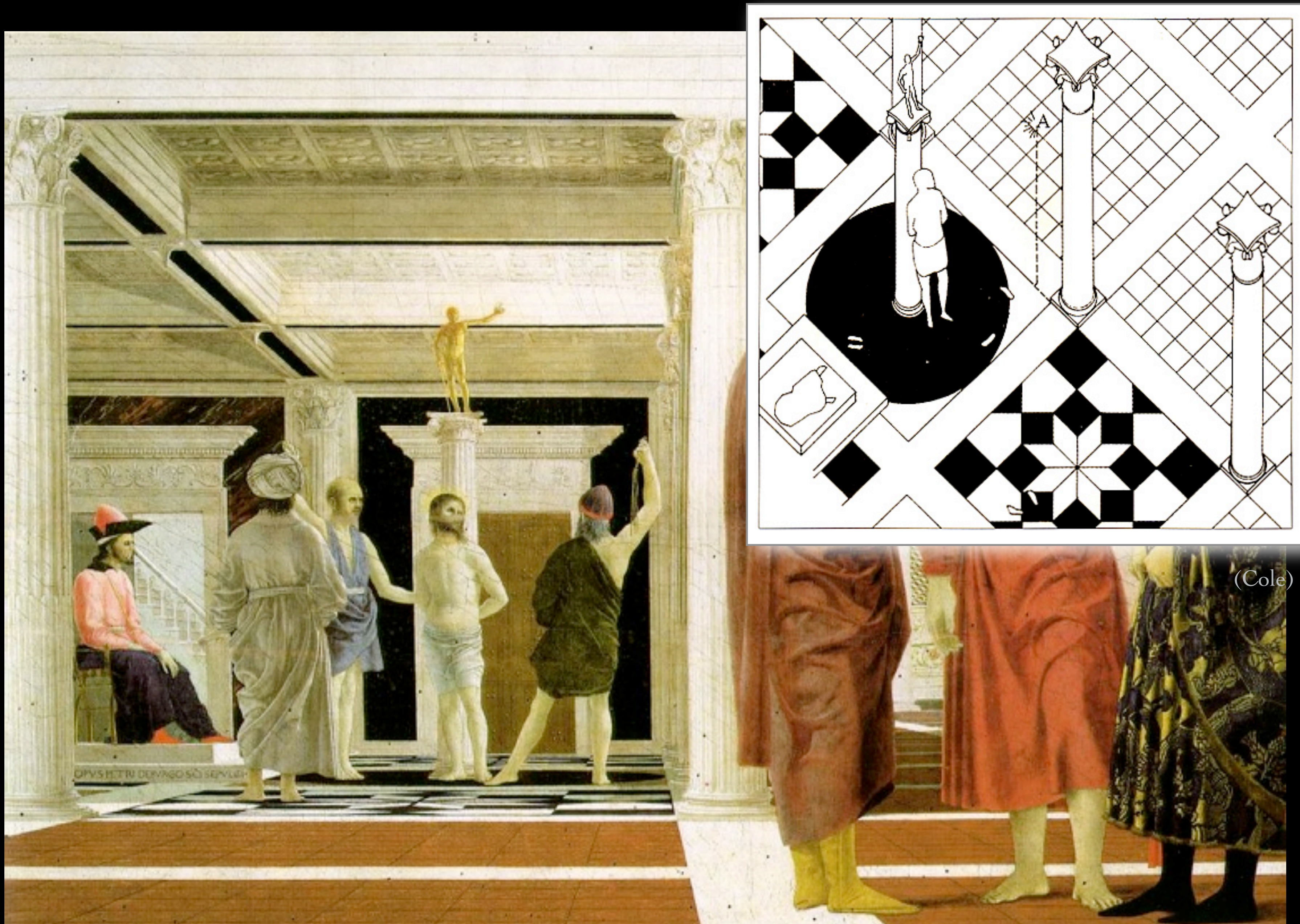
Giovanni de Paolo, Birth of St. John the Baptist (1420)

Alberti's method (1435)



(Cole)



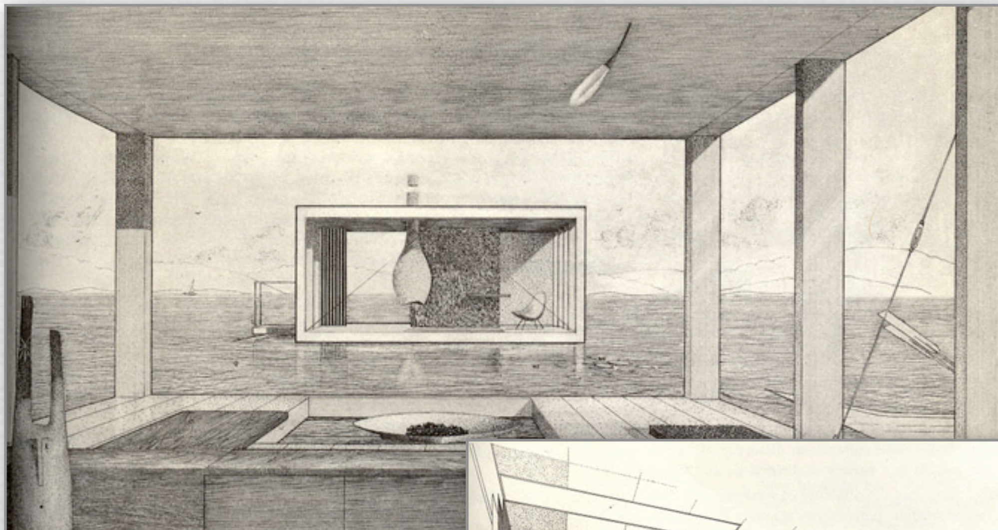


(Cole)

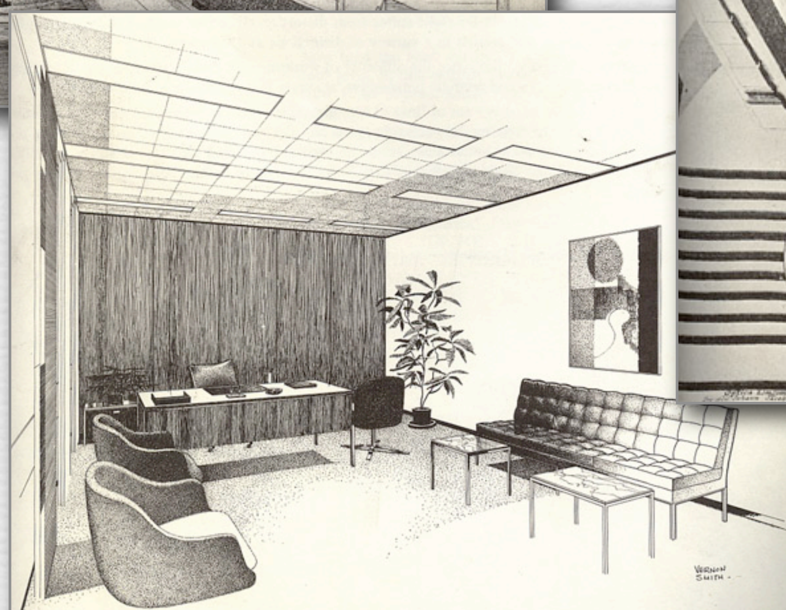
Piero della Francesca, The Flagellation (c.1460)

Vanishing points

Q. How many vanishing points can there be in a perspective drawing?



1-point

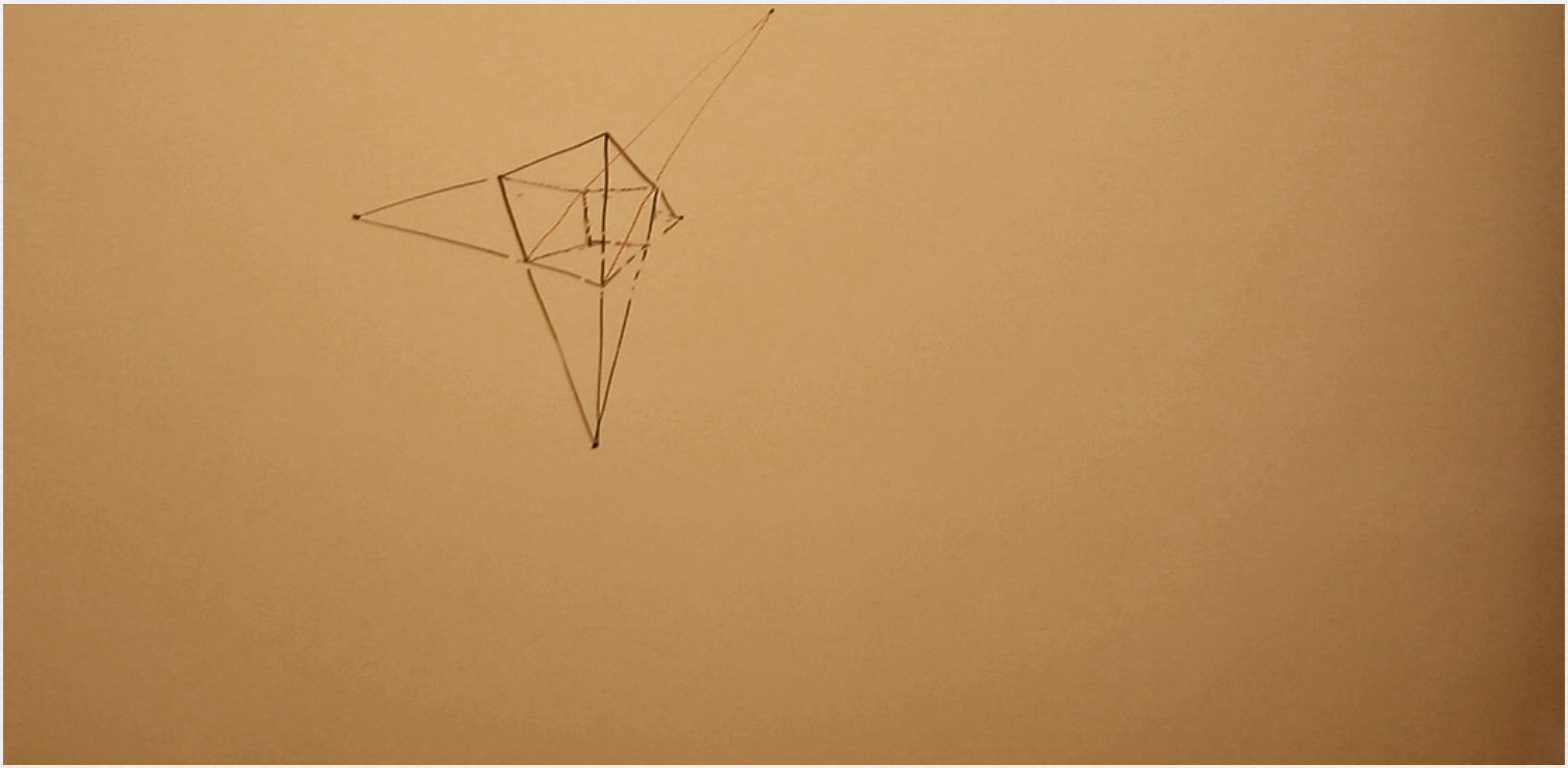


2-point

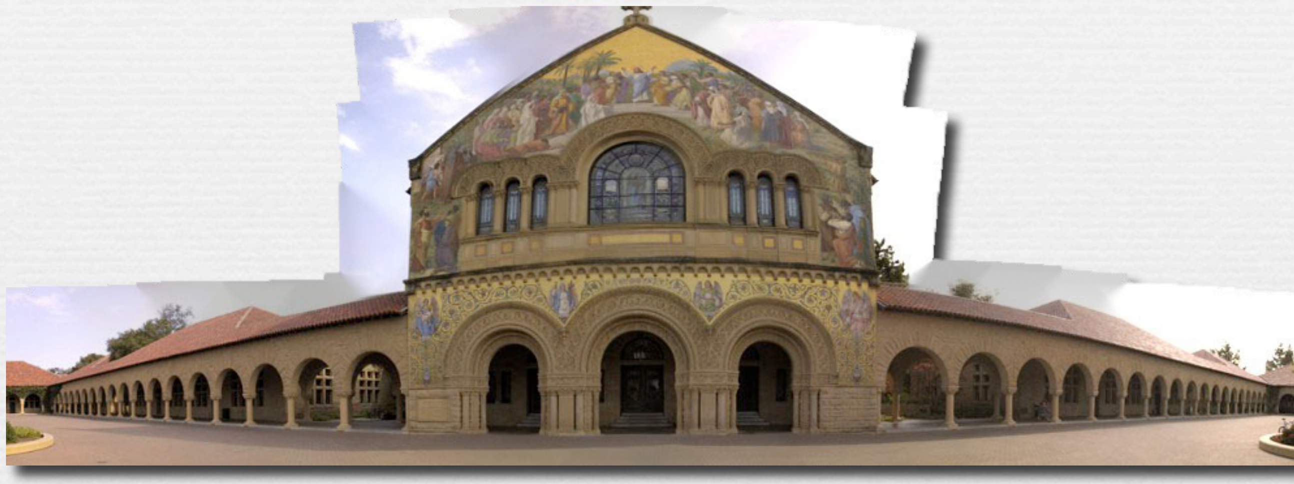
3-point

(D'Amelio)

A 4th vanishing point (contents of whiteboard)



Q. Should the distant ends of a long facade be drawn smaller than its center in a perspective drawing?



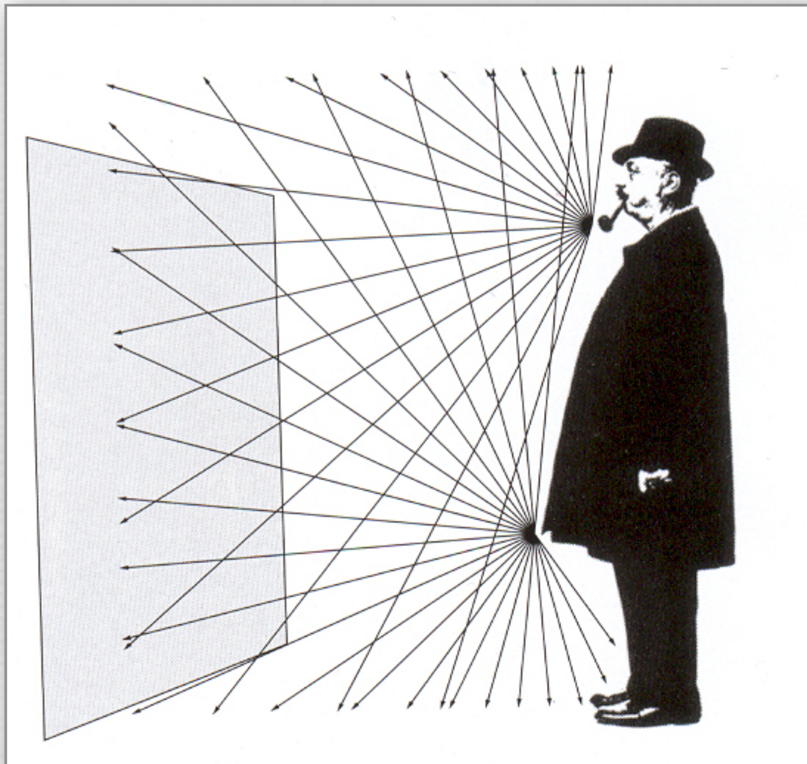
?

- no, in linear perspectives straight lines remain straight
- lines parallel to the picture plane do not converge
- they appear smaller when you view the drawing, due to natural perspective (angles subtended at eye)

Recap

- natural perspective
  - visual angle subtended by a feature in the world
- linear perspective
  - intersections of lines of sight with a picture plane
  - the correct way to make a drawing on a flat surface
- vanishing points
  - one per direction of line in the scene
  - you can eliminate them by tilting the picture plane
- distorted perspective
  - viewpoint while making the drawing versus viewpoint while viewing it (e.g. on a museum wall)

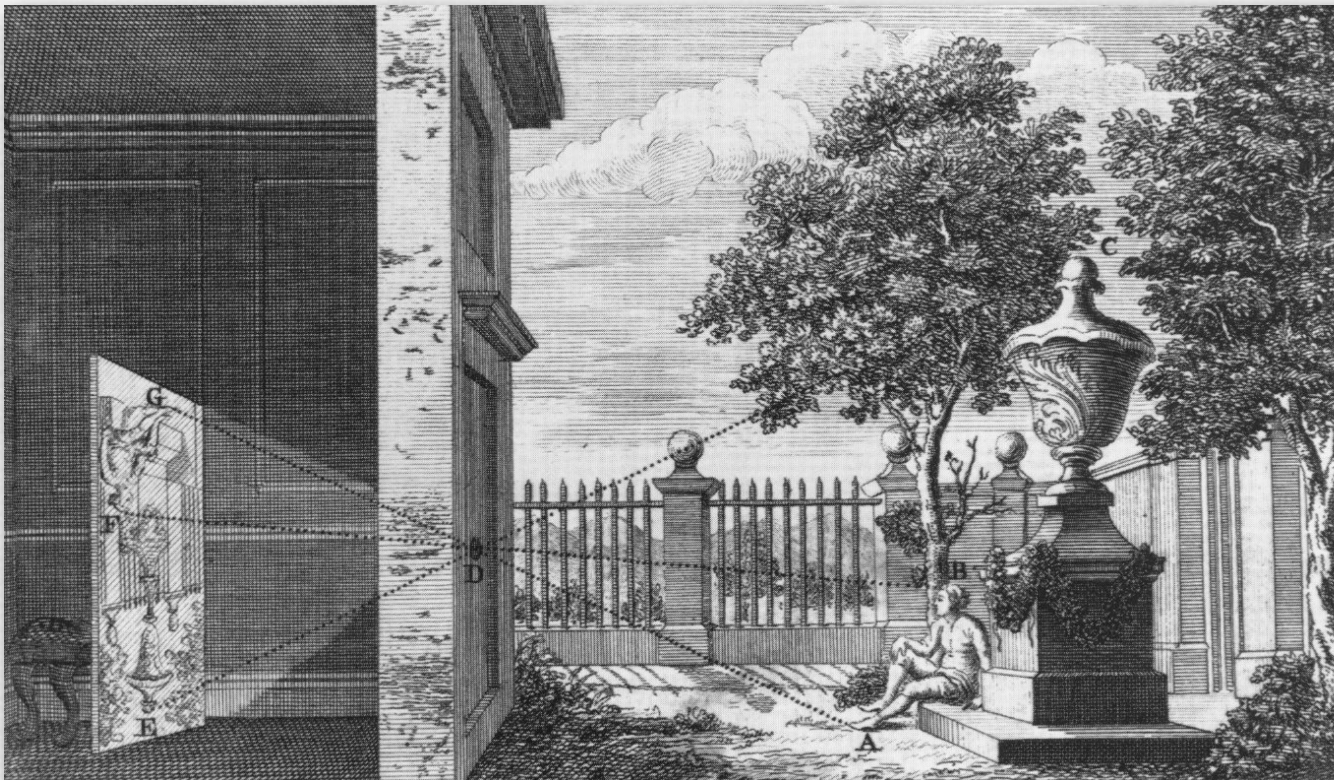
Why not use sensors without optics?



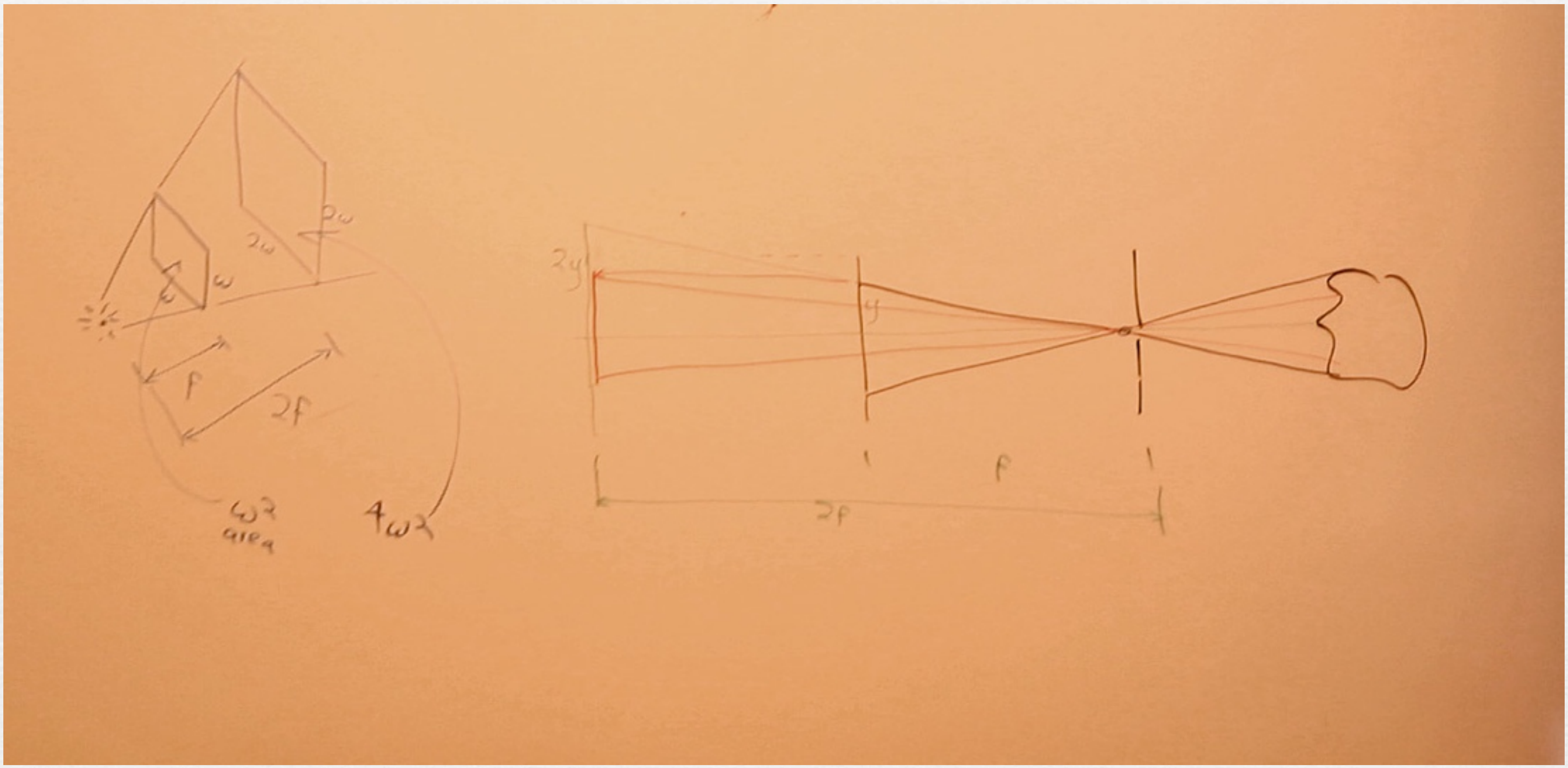
(London)

- each point on sensor would record the integral of light arriving from every point on subject
- all sensor points would record similar colors

Pinhole camera (a.k.a. *camera obscura*)



Effects of moving the sensor back (contents of whiteboard)



Effect of pinhole-to-sensor distance

Doubling the distance between the pinhole and sensor, while keeping sensor size constant...

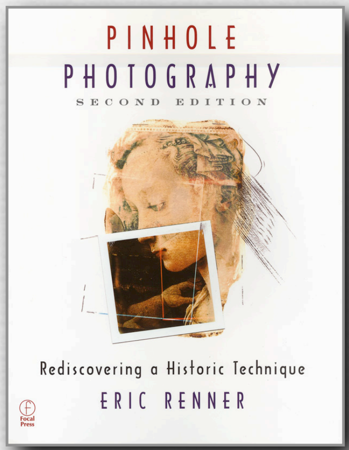
- ...doubles the magnification of the projected object
- ...decreases the angular field of view (but not by 2×!)

Q. What happens to the amount of light reaching each point on the sensor?

A. Reduced by 4×

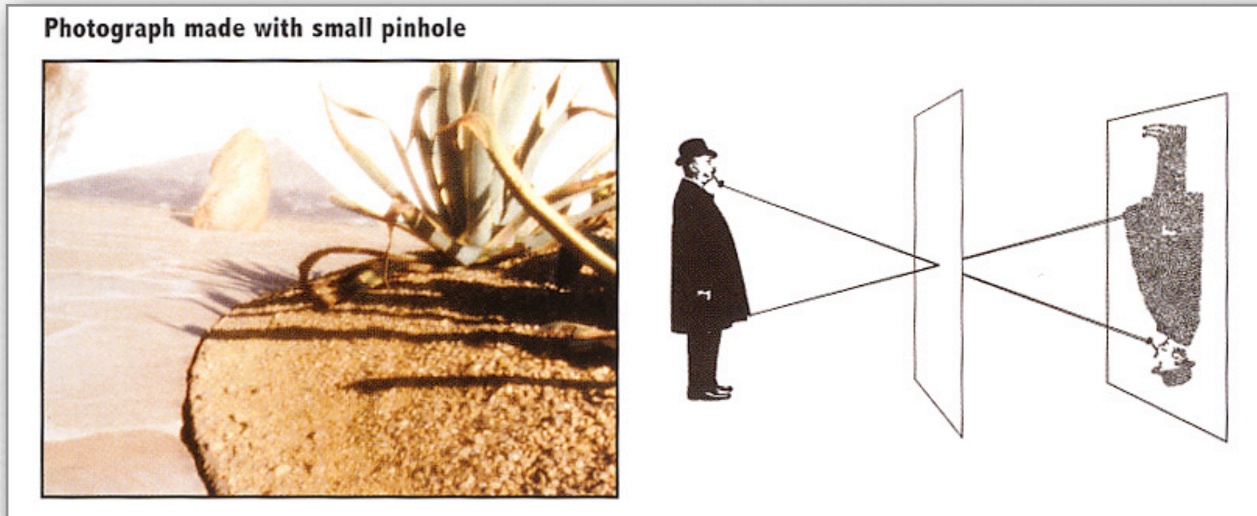
Pinhole photography

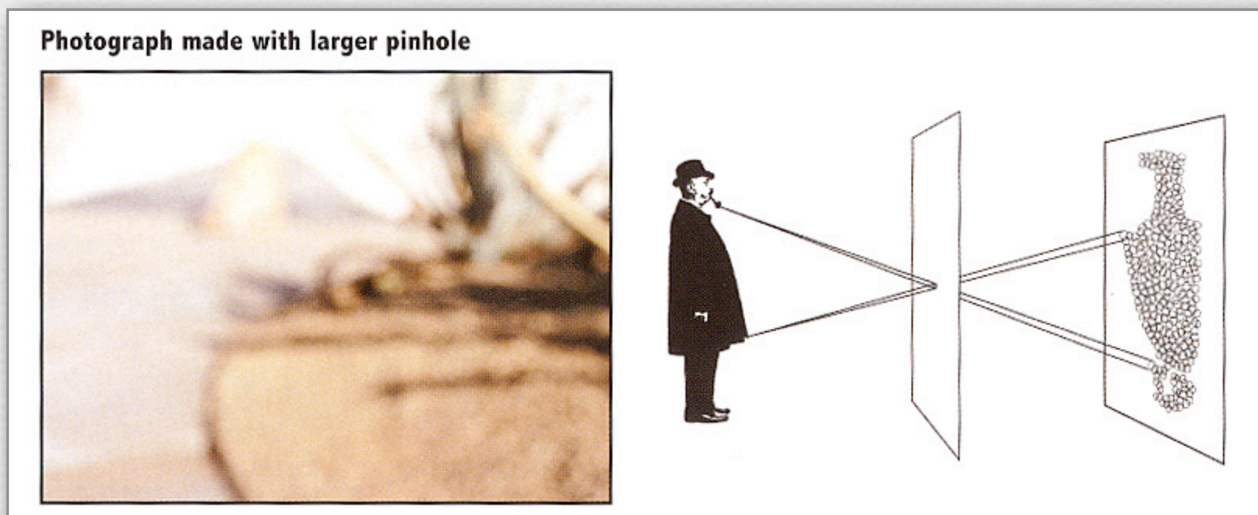
- no distortion
  - straight lines remain straight
- infinite depth of field
  - everything is in focus



(Bami Adedoyin)

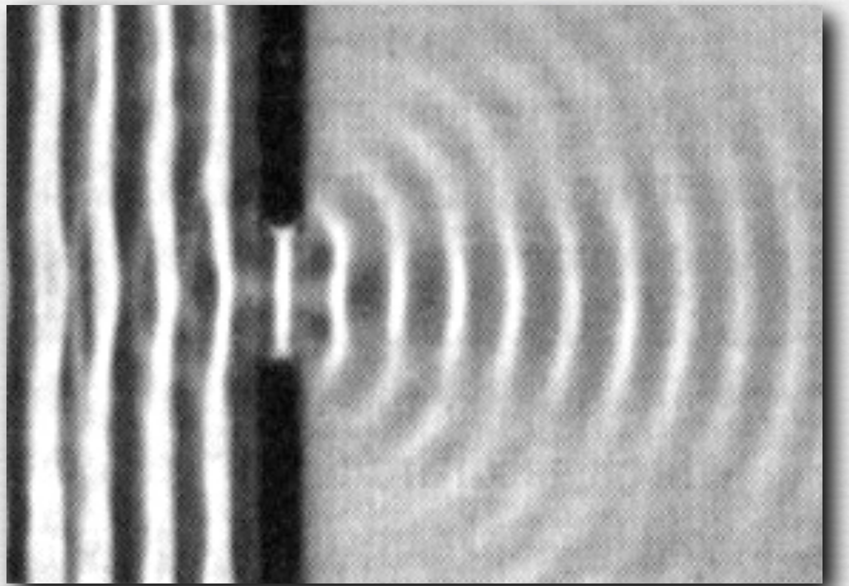
Effect of pinhole size





(London)

Diffraction limit

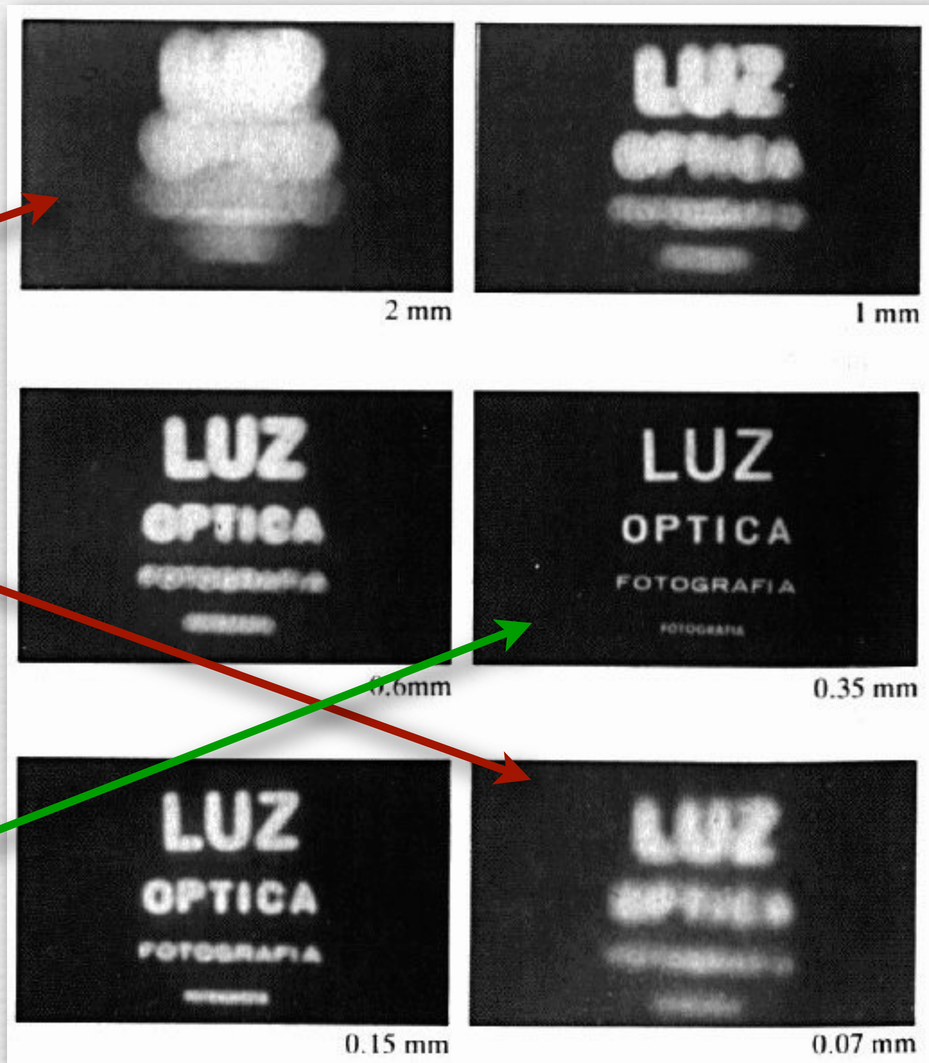


(Hecht)

- due to wave nature of light
- smaller aperture means more diffraction

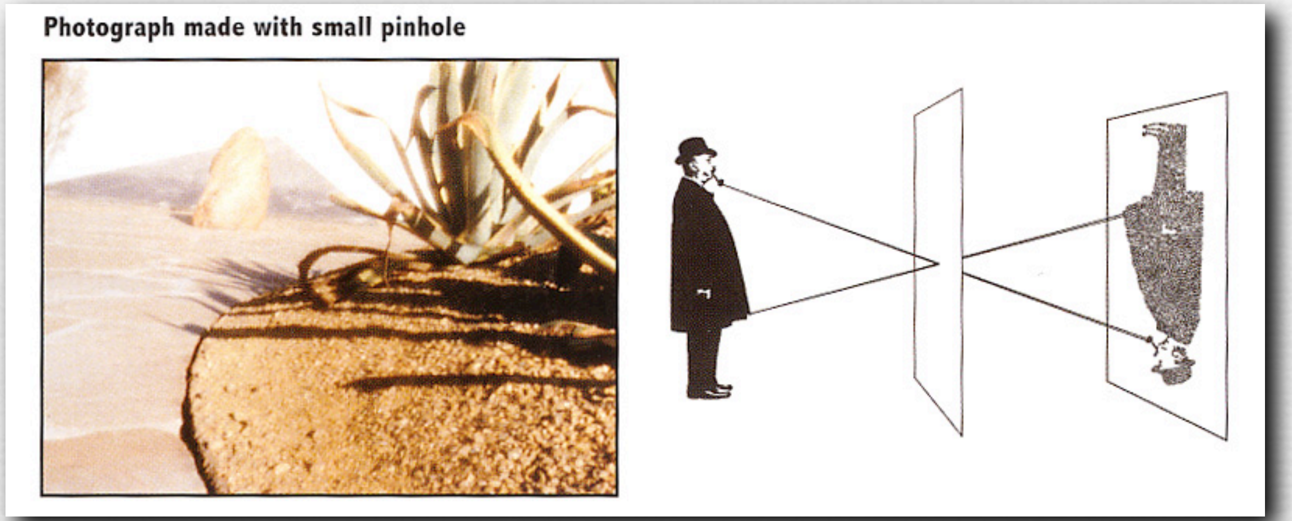
Effect of pinhole size (again)

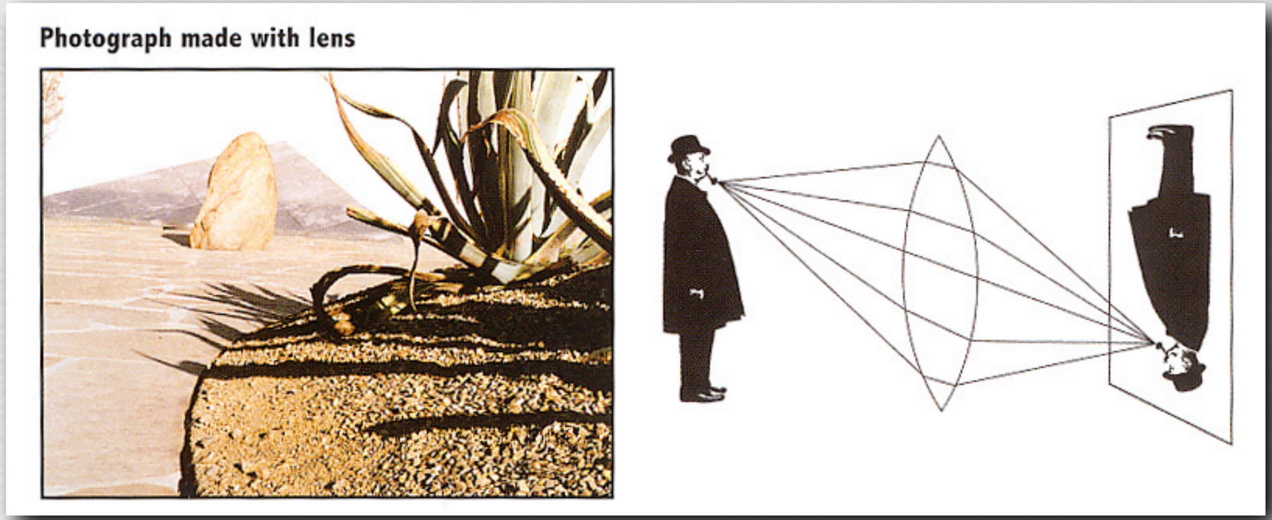
- large pinhole
  gives geometric blur
- small pinhole
  gives diffraction blur
- optimal pinhole
  gives very little light



(Hecht)

Replacing the pinhole with a lens

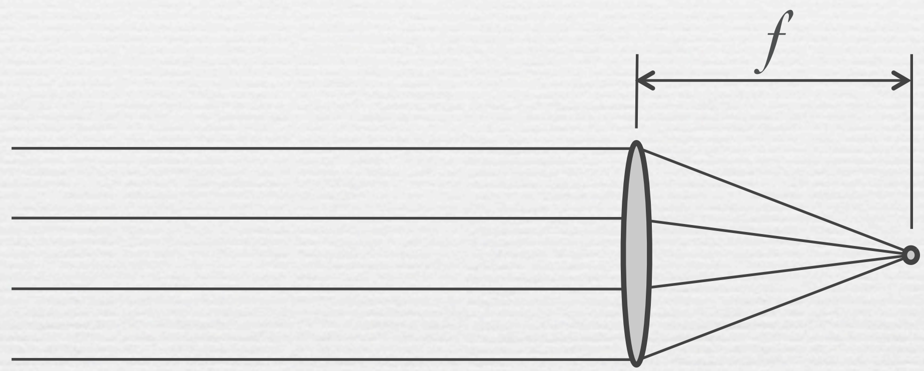




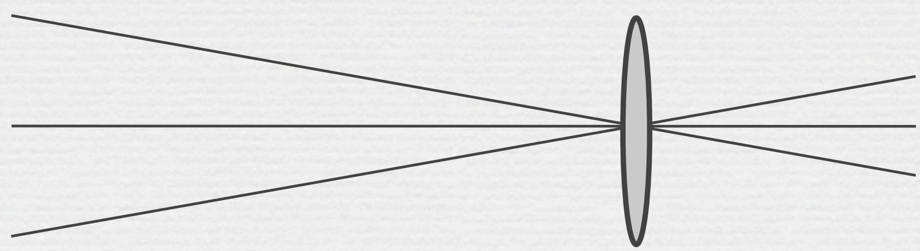
(London)

Geometrical optics

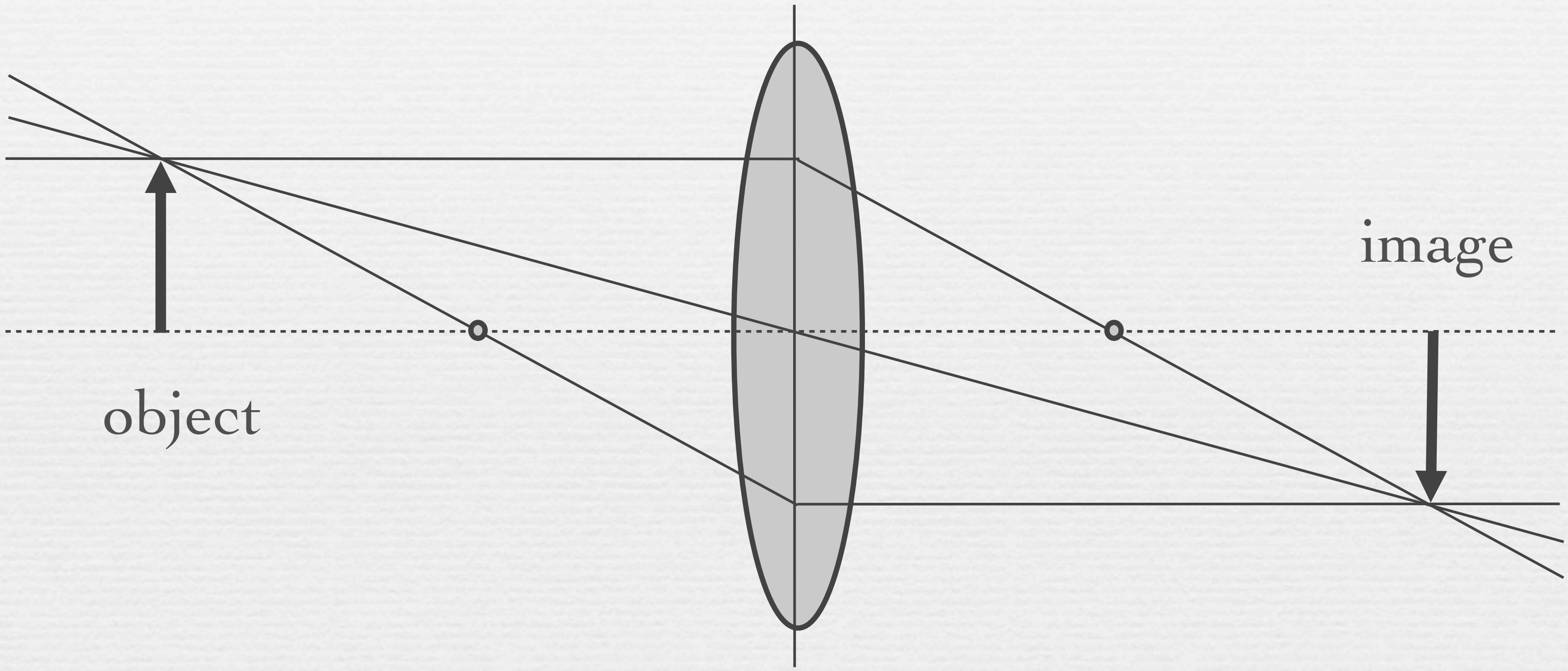
- parallel rays converge to a point located at focal length *f* from lens



- rays going through center of lens are not deviated
  - hence same perspective as pinhole



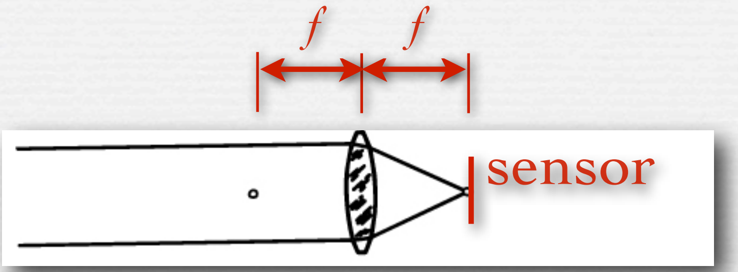
Gauss' ray tracing construction



- rays coming from points on a plane parallel to the lens are focused on another plane parallel to the lens

Changing the focus distance

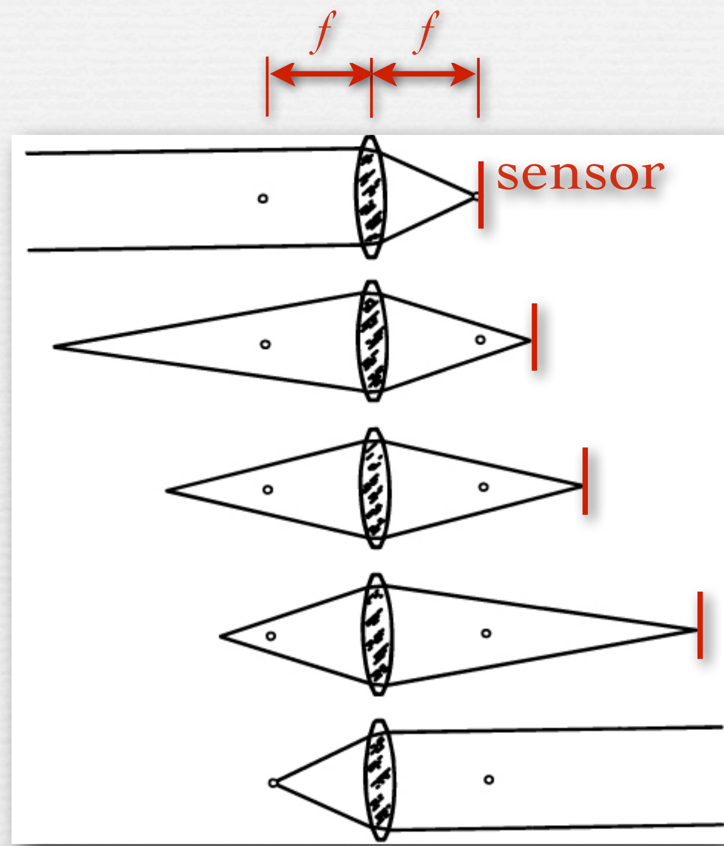
- to focus on objects
  at different distances,
  move sensor relative to lens



Changing the focus distance

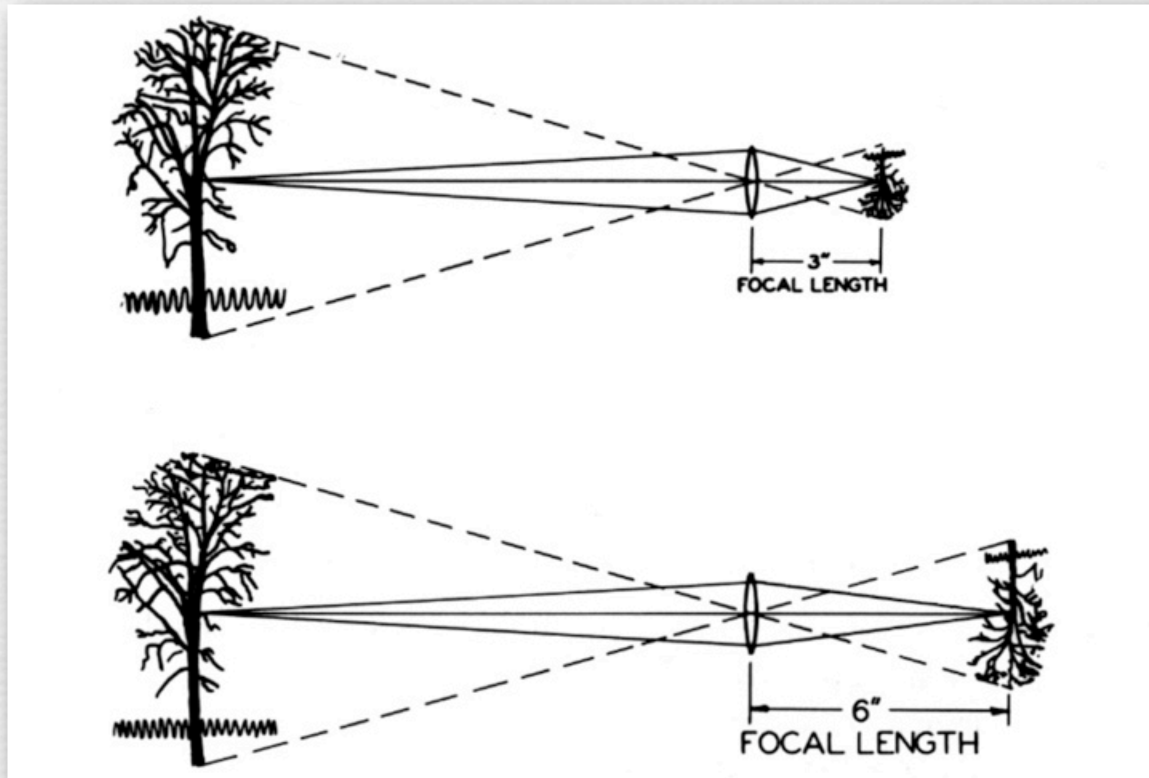
- to focus on objects at different distances, move sensor relative to lens

- can't focus on objects closer to lens than its focal length f



Changing the focal length

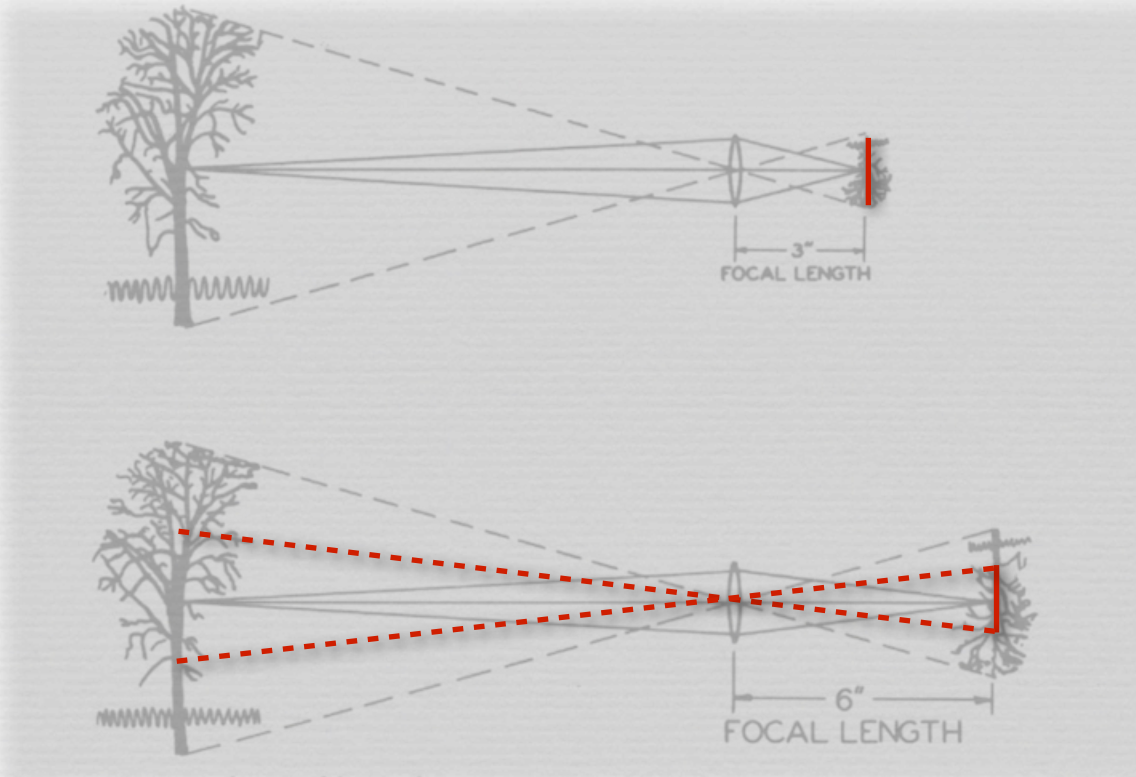
- weaker lenses have longer focal lengths
- to stay in focus, move the sensor further back



(Kingslake)

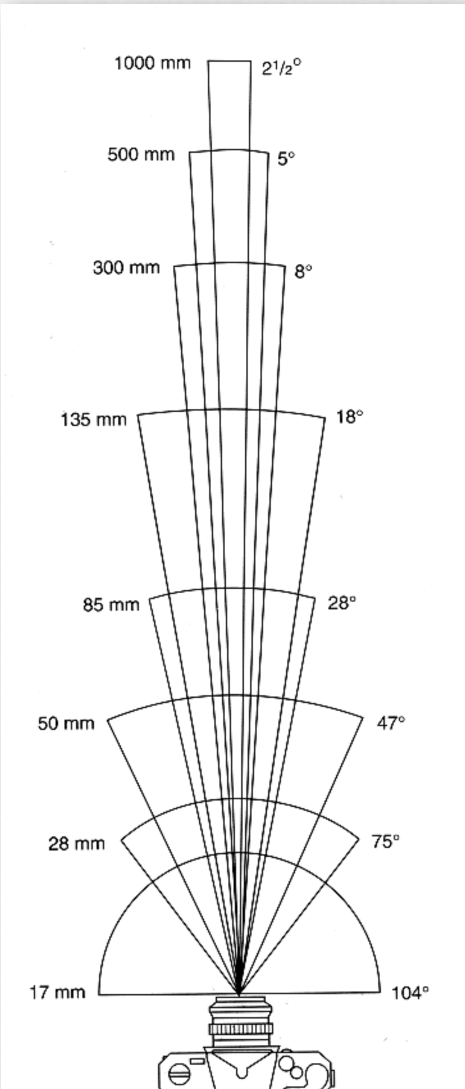
Changing the focal length

- weaker lenses have longer focal lengths
- to stay in focus, move the sensor further back
- if the sensor size is constant, the field of view becomes smaller



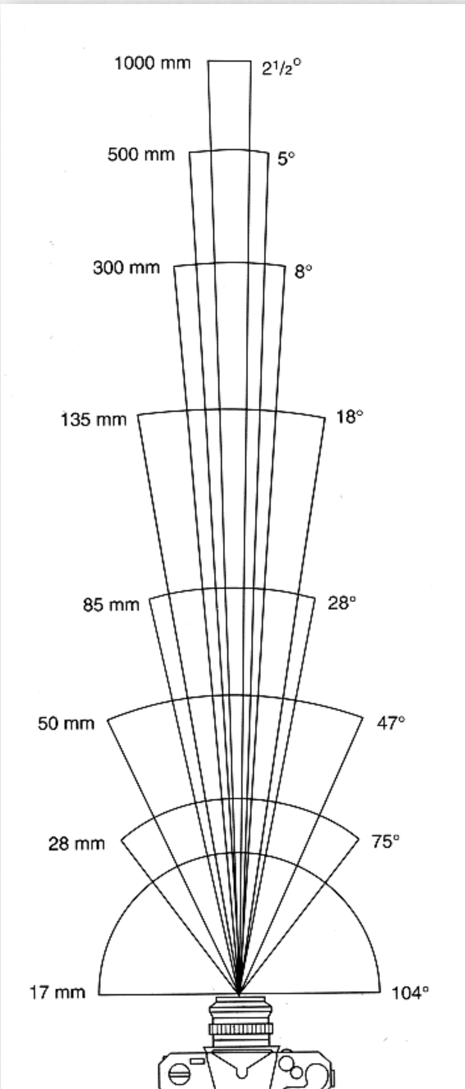
(Kingslake)

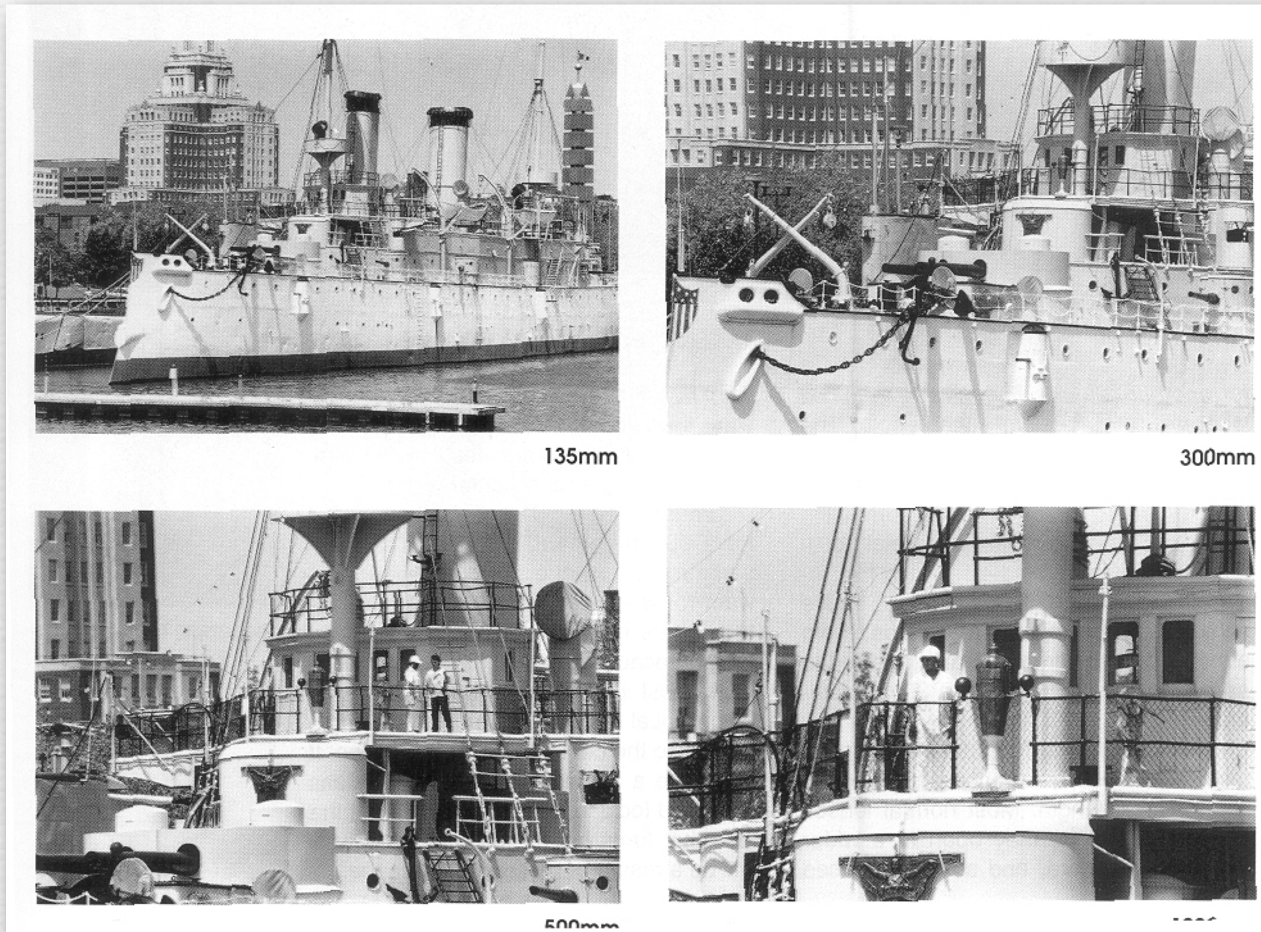
Focal length and field of view



(London)

Focal length and field of view

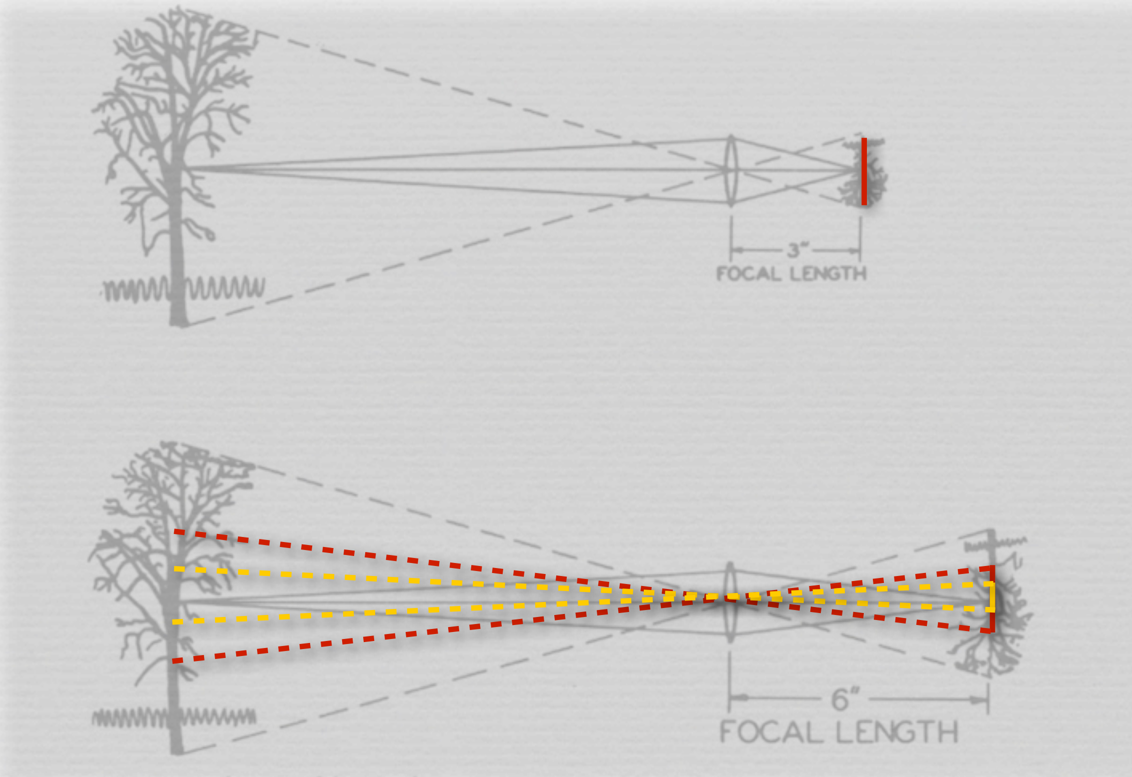




(London)

Changing the sensor size

- if the sensor size is smaller, the field of view is smaller too
- smaller sensors either have fewer pixels, or noiser pixels

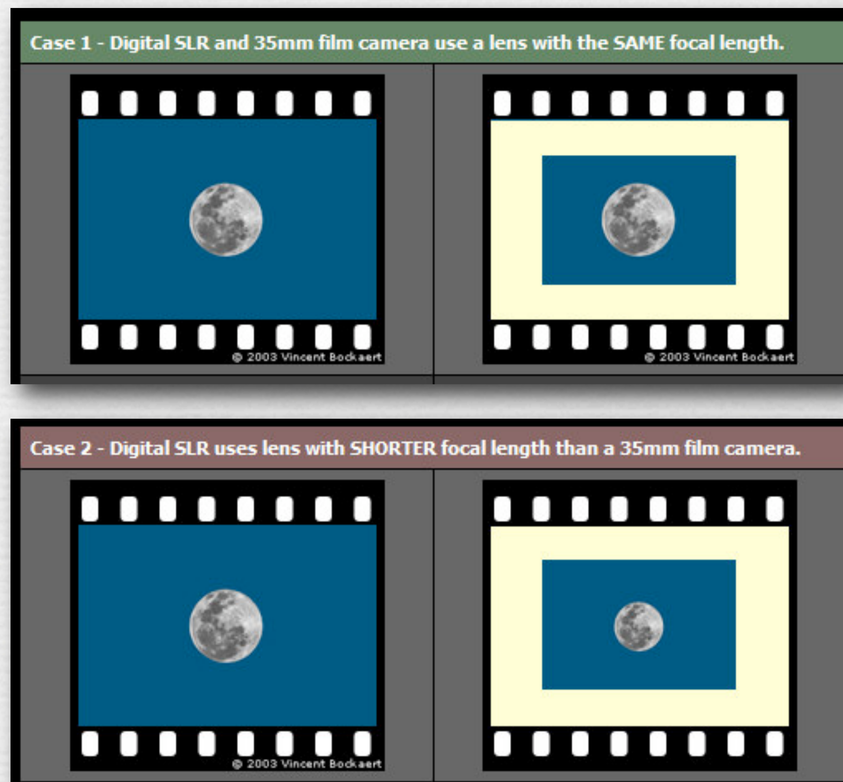


(Kingslake)

Full-frame 35mm versus APS-C

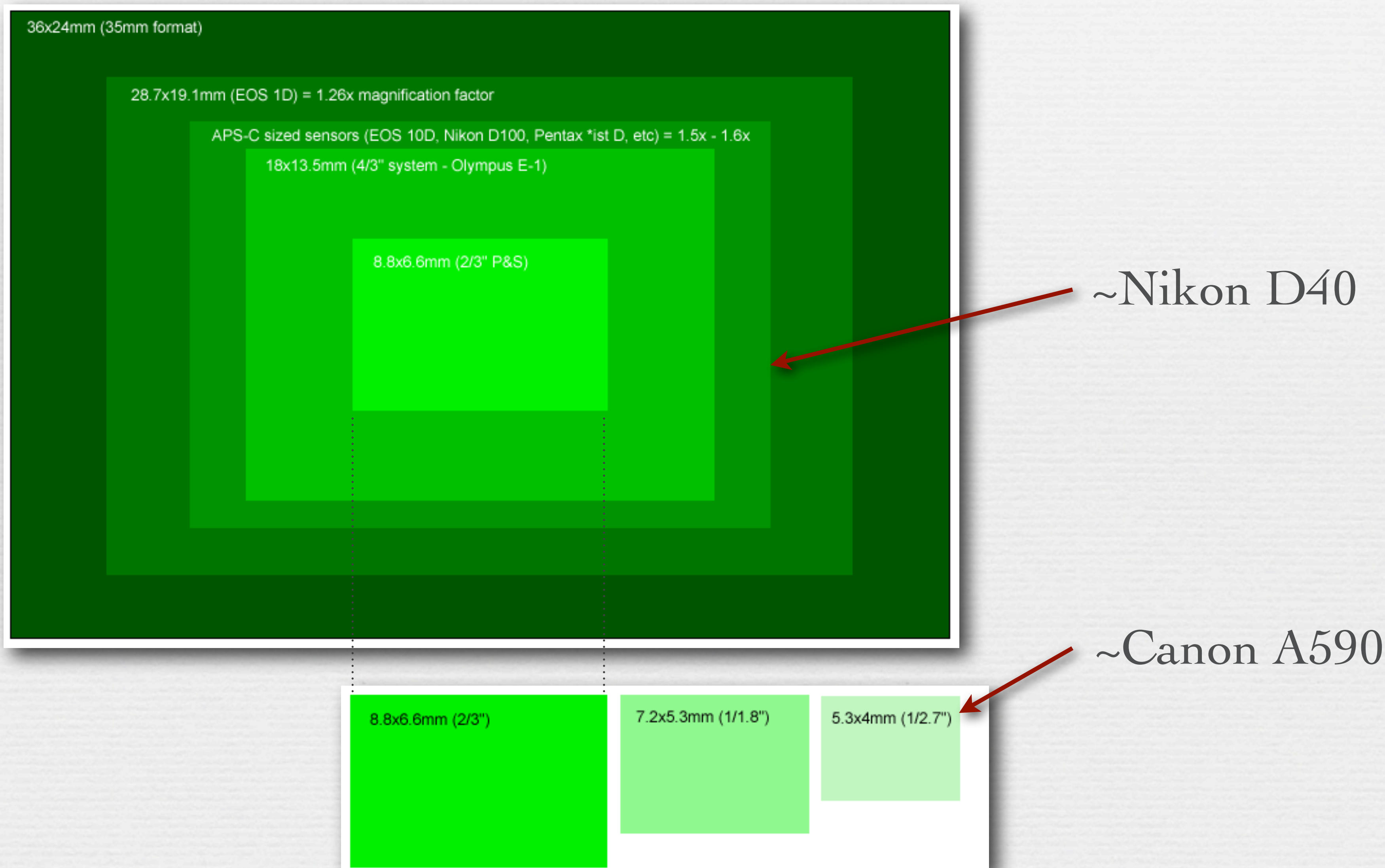
- full-frame sensor is 24 × 36mm (same as 35mm film)
- APS-C sensor is 14.8 × 22.2mm (Canon)
- conversion factor is 1.6×

(dpreview)



- object occupies the same number of pixels, but takes up more of frame
- objects occupies fewer pixels, but composition stays the same

Sensor sizes



Changing the focal length versus changing the viewpoint

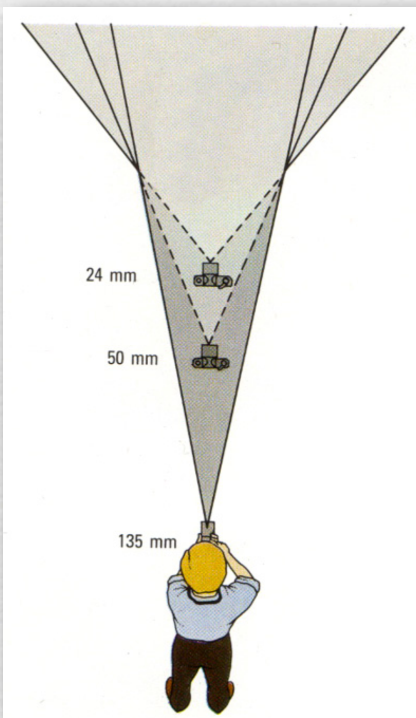
(Kingslake)

wide-angle telephoto

- changing the focal length lets us move back from a subject, while maintaining its size on the image
- but moving back changes perspective relationships

Changing the focal length versus changing the viewpoint

- moving back while changing the focal length lets you keep objects at one depth the same size
- in cinematography, this is called the dolly zoom, or "Vertigo effect", after Alfred Hitchcock's movie



Effect of focal length on portraits

- standard "portrait lens" is 85mm

wide angle

standard

telephoto

Recap

- pinhole cameras compute correct linear perspectives
  - but dark
  - diffraction limited
- lenses gather more light
  - but only one plane of scene is in focus
  - focus by moving the sensor or lens
- focal length determines field of view
  - from wide angle to telephoto
  - depends on sensor size

more in the lens lectures next week