Lecture 1
Camera

Multimedia Systems
Spring 2020

First production camera?

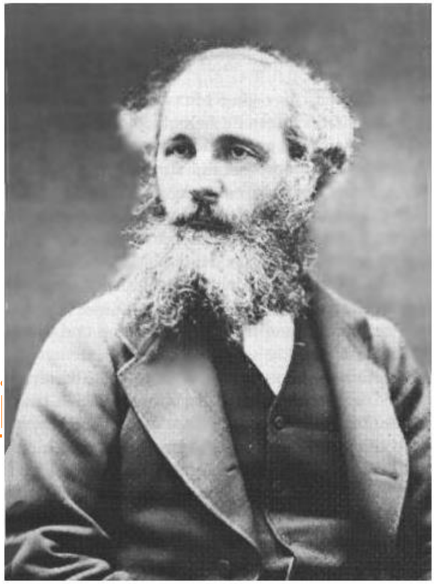
- 1839. Daguerrotype

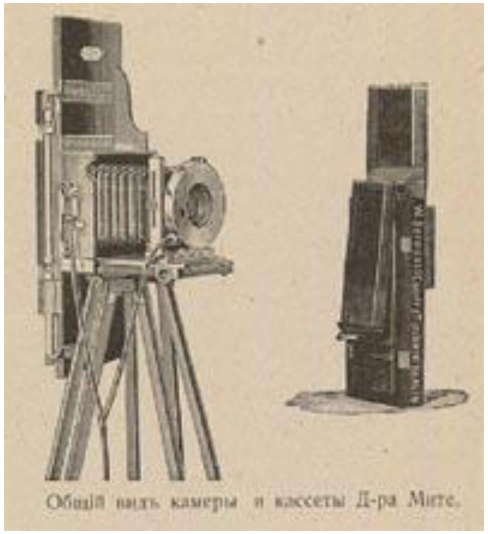
Beginning of hobby photography?

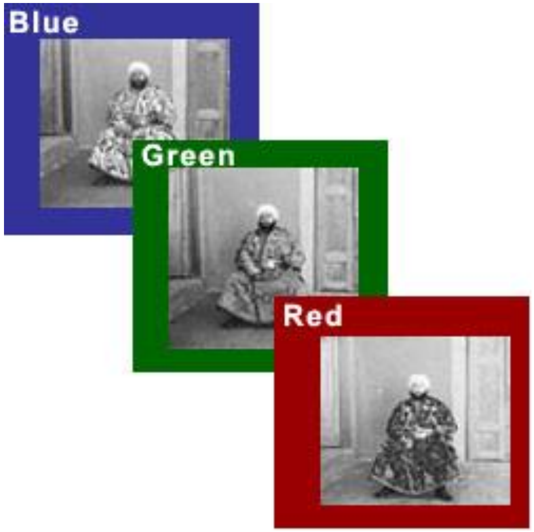
- 1900 Kodak Brownie

Quiz

- Who did the first color photography?
  - Maxwell
- When? 1861
- Oldest color photos still preserved: Prokudin-Gorskii http://www.loc.gov/exhibi







Prokudin-Gorskii

- Digital restoration

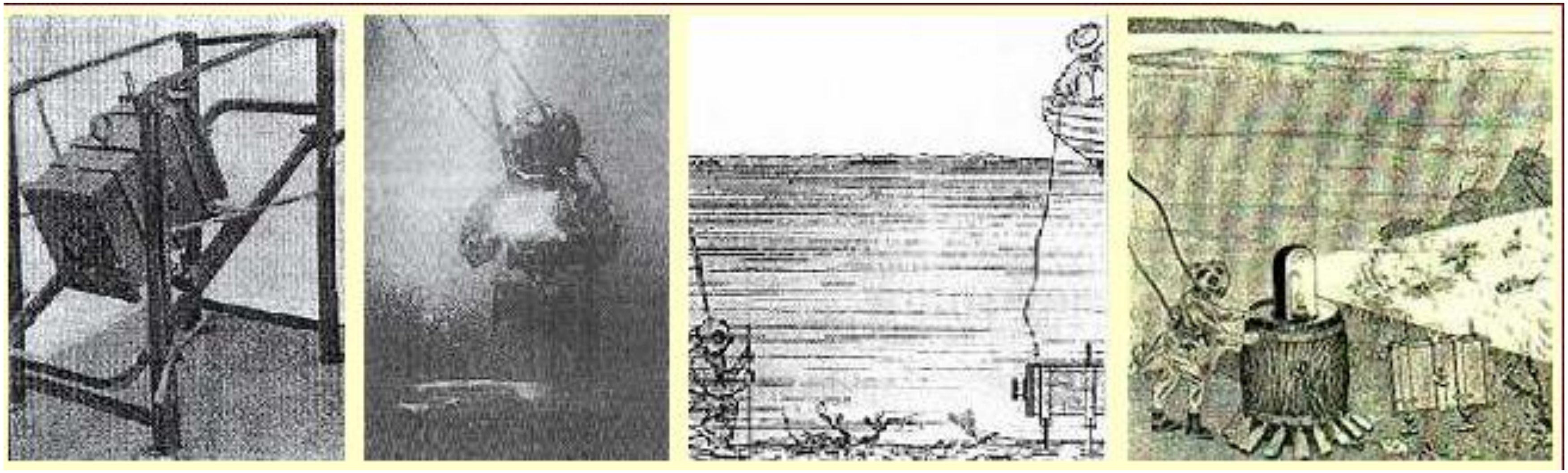
http://www.loc.gov/exhibits/empire/

Prokudin-Gorskii

Prokudin-Gorskii

Flash bulb?

- As opposed to podwer systems
- Boutan-Chauffour - 1893
- For underwater photography



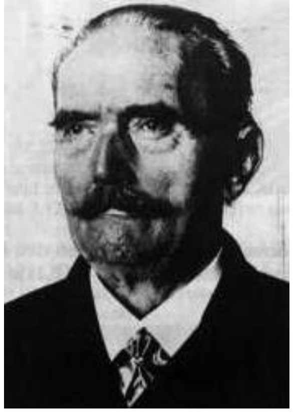
Instant photography?

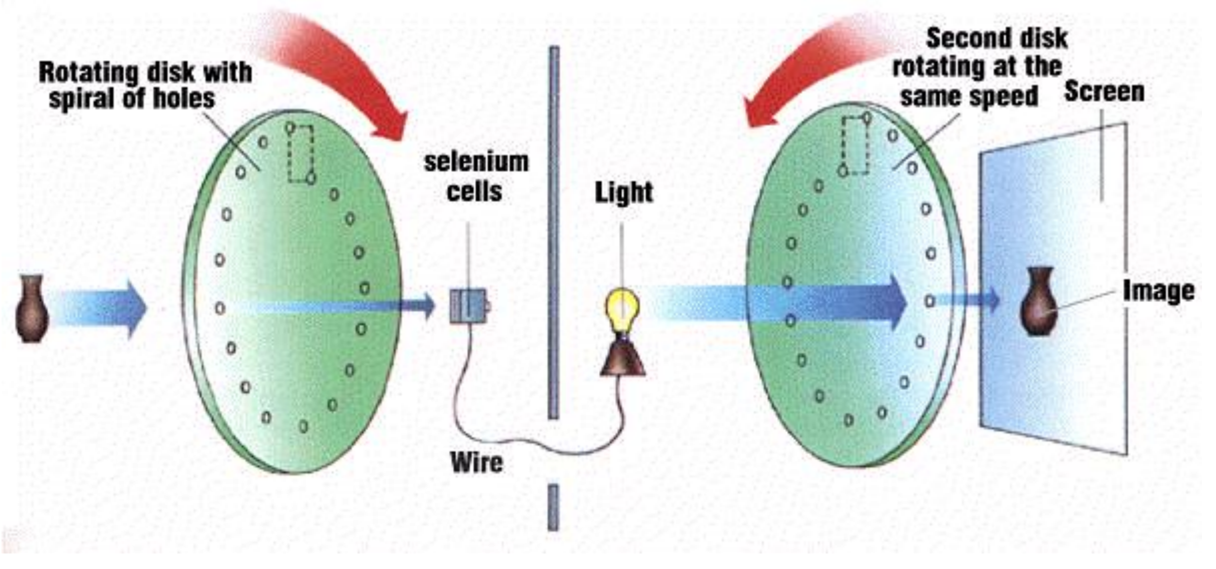
- 1947, Edwin Land (Polaroid founder)

First TV?

Transmission of moving images

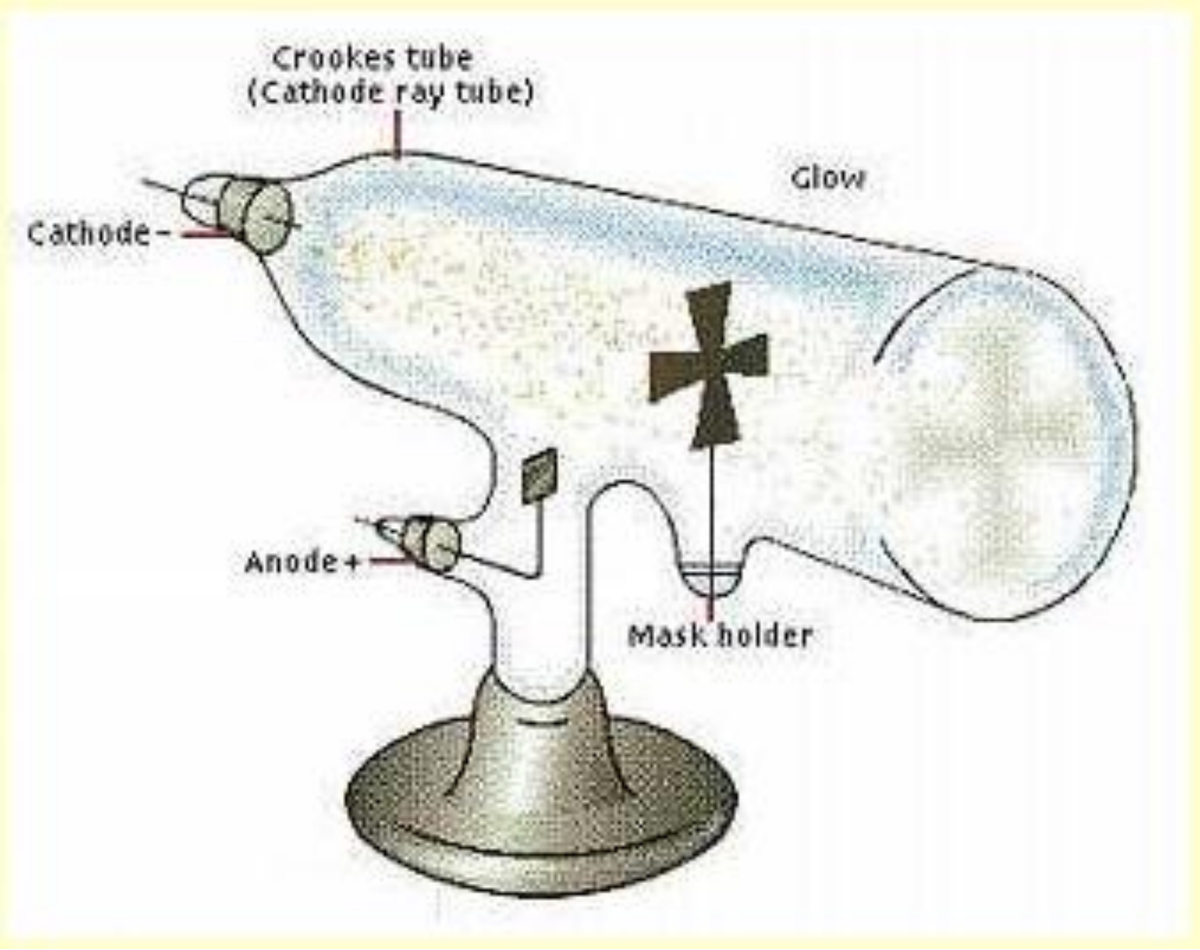
- 1884 - Paul Nipkow
  - Using rotating disk with raster spiral
  - But amplification problems





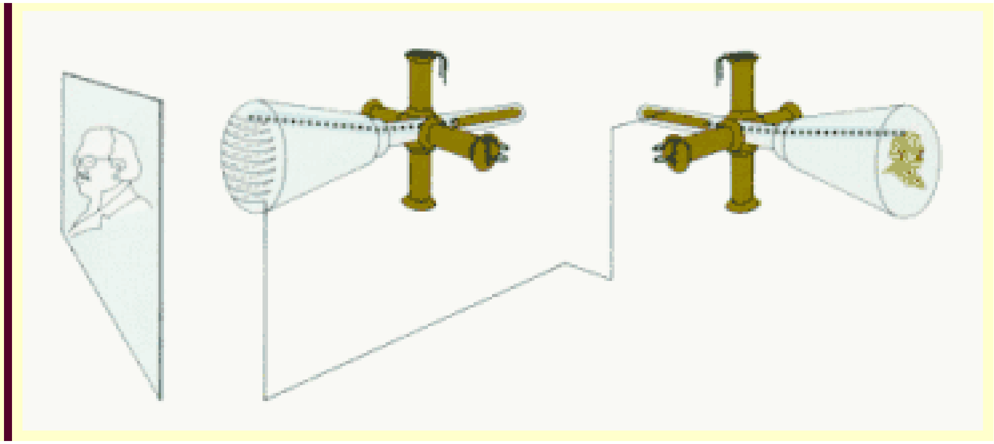
CRT?

- 1897
- Karl Braun



Electronic photography?

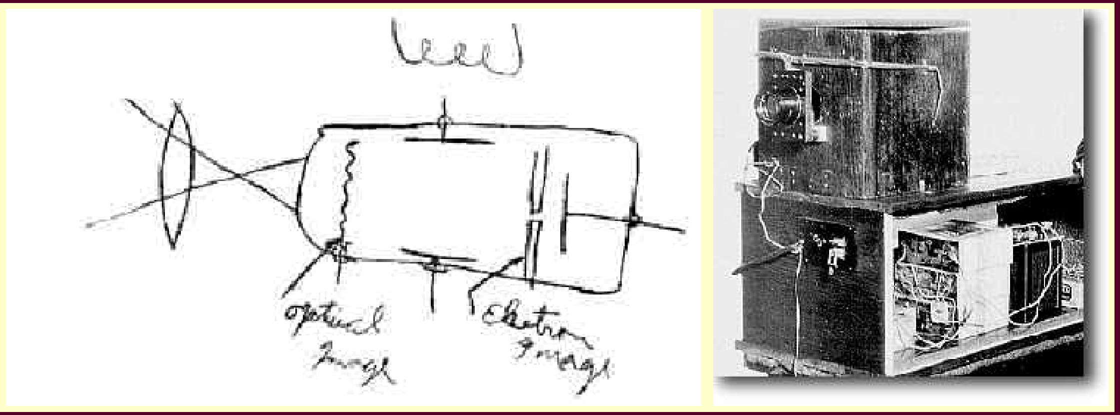
- A. A. CAMPBELL SWINTON AND ELECTRONIC PHOTOGRAPHY - 1908
- 25 images per second



Television (II)

- PHILO T. FARNSWORTH TELEVISION - 1932

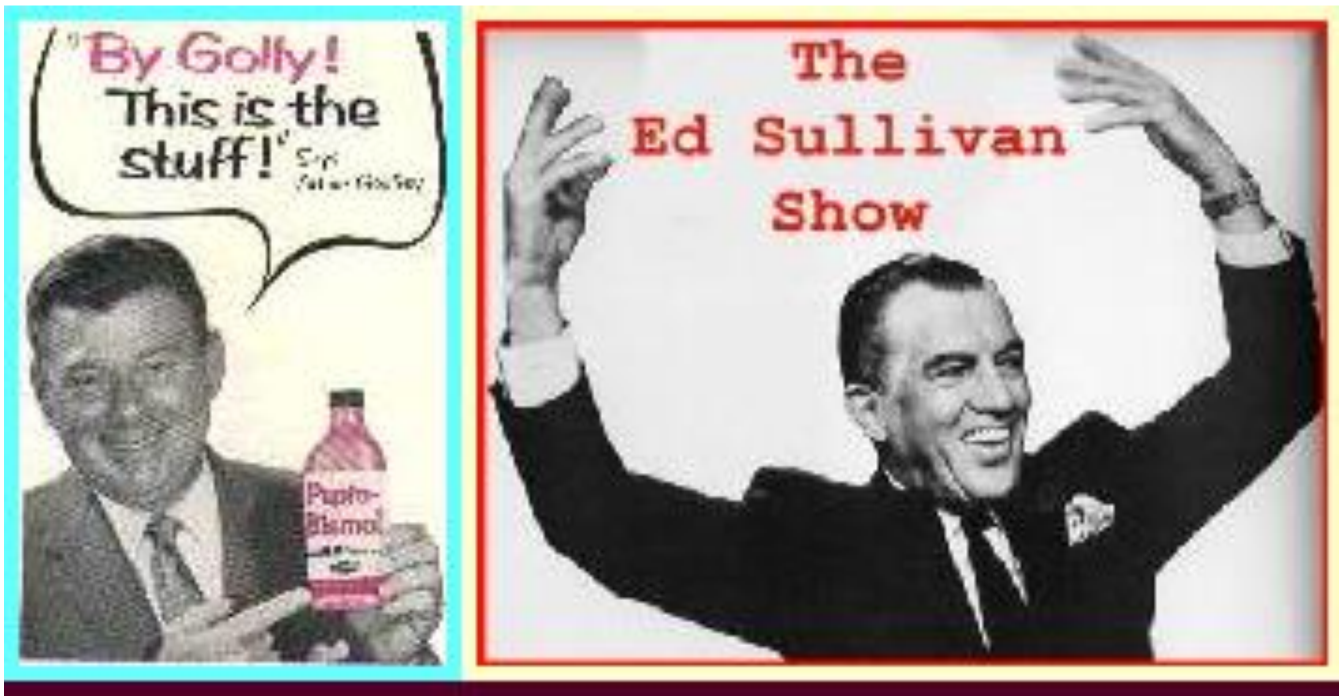
PHILO T. FARNSWORTH TELEVISION - 1932. A Utah-born Idaho farm boy, Philo T. Farnsworth helped create television as we know it today. At fourteen, he visualized trapping light in an empty jar and transmitting it one line at a time onto a magnetically deflected beam of electrons. By the time Farnsworth was 21 he had developed the first all-electronic system of television. A 1922 Sketch by Farnsworth shown to his high school physics and chemistry teacher illustrated how an image might be electronically transmitted through the air to a receiver by breaking the image up into a number of horizontal slices. This image process which we now call a raster image occurred to Farnsworth when as a fourteen-year old boy he looked across the rows of a field he was plowing. Besides his contributions to television, Farnsworth patented more than 130 inventions during his lifetime.



1922 Farnsworth High School Sketch of His TV Camera Tube and First Farnsworth TV Camera

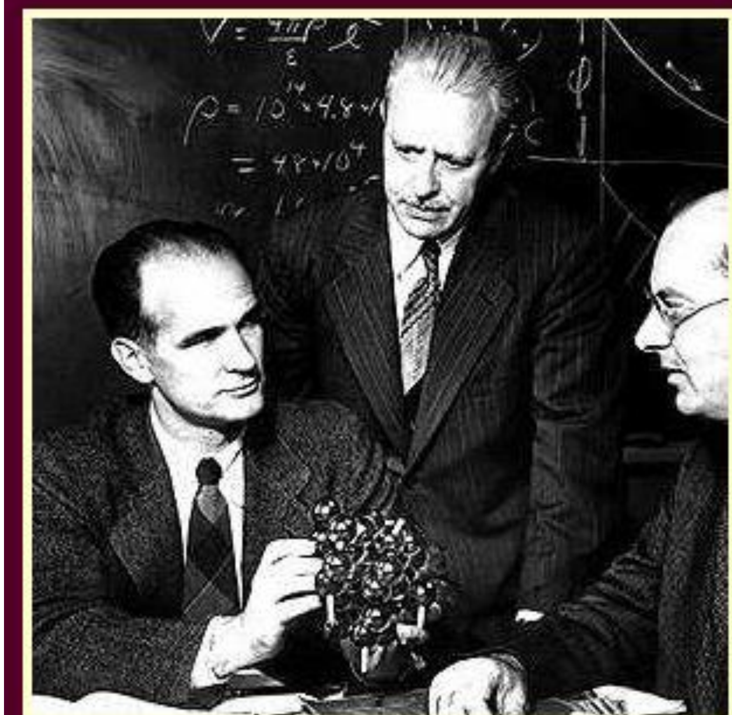
Color TV

- First broadcast in 1951, CBS



Transistor?

- 1947, Bell Labs (Nobel in 1956)
- William Shockley, John Bardeen and Walter Brattain



Shockley, Bardeen, and Brattain

The First Transistor
Click for Enlarged View

Integrated circuit?

- 1959 Bob Noyce of Fairchild Semiconductor
(co-founded Intel Corporation in 1968)
  - One transistor, one capacitor

- Also Jack Kilby of Texas Instruments
  - Also inventor of portable calculator

Intel gang

Texas Instruments' first IC

http://www.pbs.org/transistor/background1/events/icinv.html

Autofocus

- 1978, Konica

- 1981   Pentax ME-F.

- Canon T80 1985
  - Canon AL1 had focus assist but no actuator
- Minolta Maxxum 1985 (AF in body)

First microprocessor in a camera

- Canon AE-1976

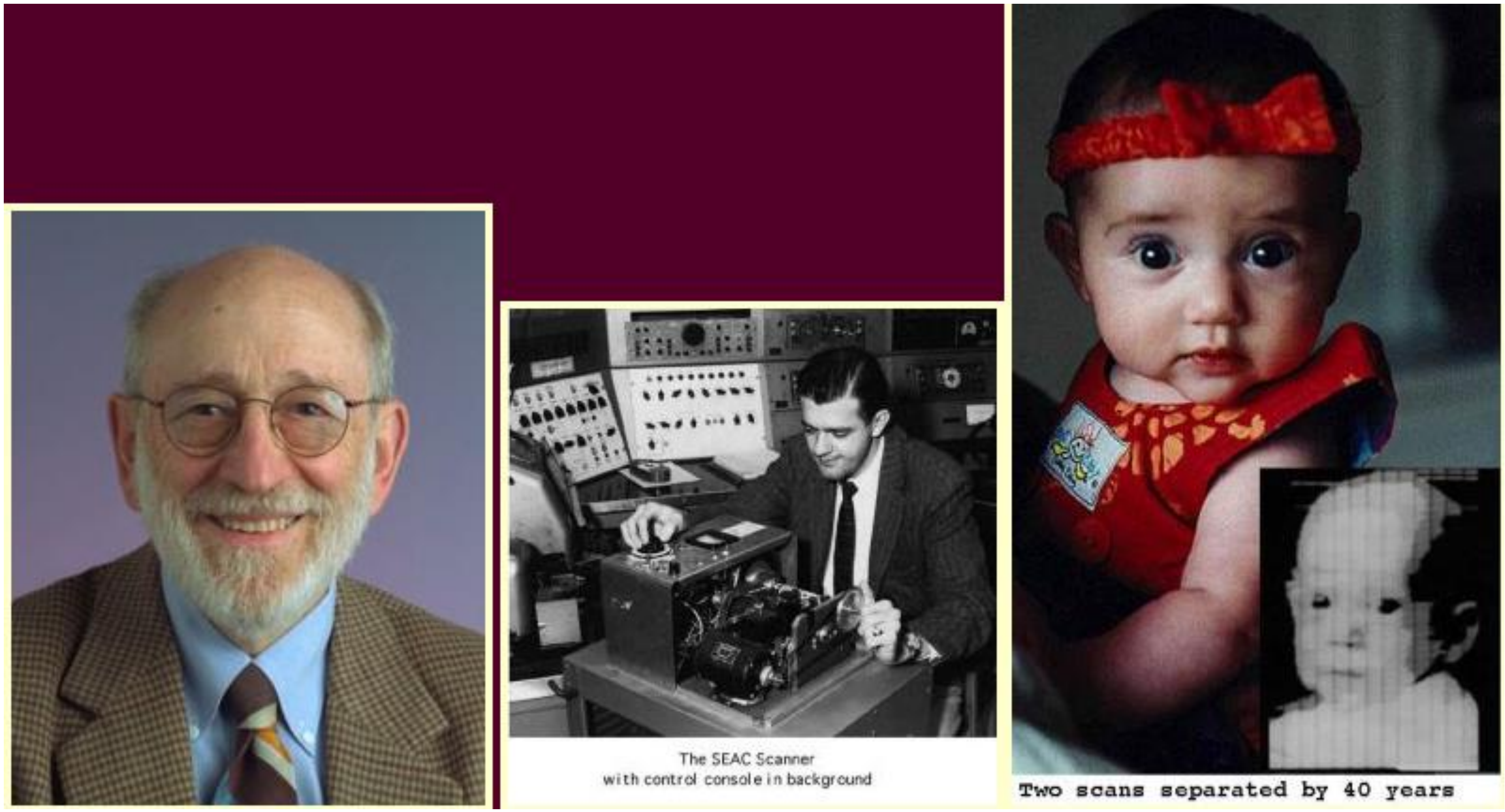
Japanese take over camera market?

- 1959 Nikon F
  - First motorized SLR
  - First 100% viewfinder
  - Mirror lockup

- Lots of pros switched from Leica to Nikon

First scanned photo?

- 1957, Russell A. Kirsch of the National Bureau of Standards, 176x176



CCD technology?

- 1969, Willard S. Boyle and George E. Smith, Bell Laboratories

CCD in astronomy

- 1979, 1-meter telescope at Kitt Peak National Observatory, 320x512, great for dim light
- Nitrogen cooled

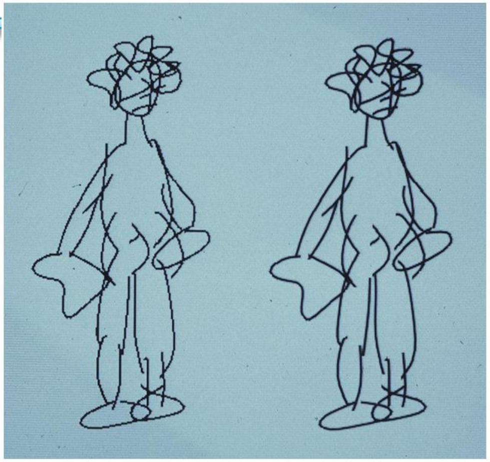
Computer Graphics?

Computers to create image

- Sketchpad, 1961, Ivan Sutherland's MIT PhD thesis

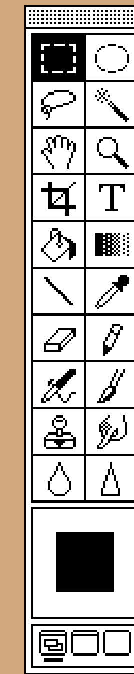
Paint program

- Dick Shoup: SuperPaint [1972-73]
  - 8 bits
  - http://www.rgshoup.com/prof/SuperPaint/
- Alvy Ray Smith (Pixar co-founder): Paint [1975-77]
  - 8 bits then 24 bits
  - http://www.alvyray.com/Awards/AwardsMain.htm
  - http://www.alvyray.com/Bio/BioMain.htm
- Tom Porter: Paint



Photoshop

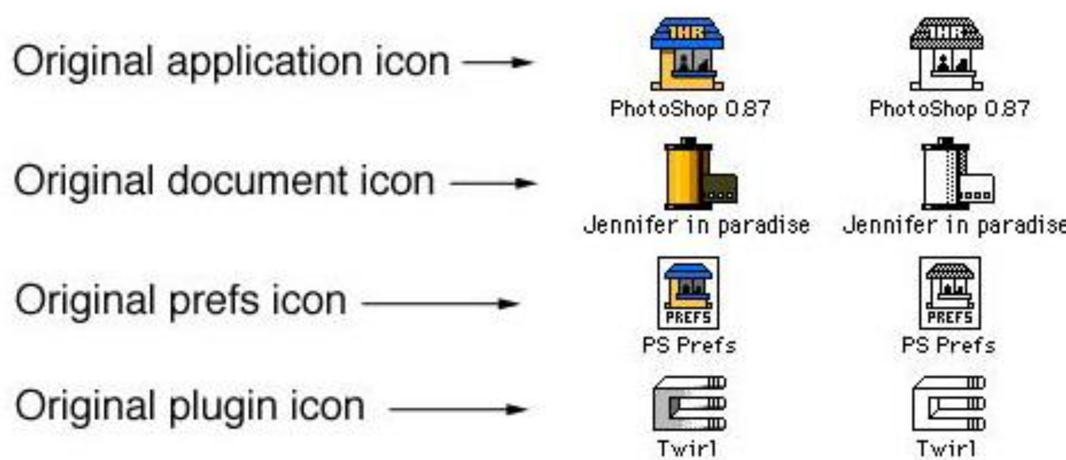
- Thomas Knoll and John Knoll began development in 1987
- Version 1.0 on Mac: 1990
- http://en.wikipedia.org/wiki/Photoshop#Development
- http://www.storyphoto.com/multimedia/multimedia_photoshop.html



Photoshop toolbar from version 1.07

John Knoll.
Photo by Jeff Schewe.

Thomas Knoll.
Photo by Jeff Schewe.



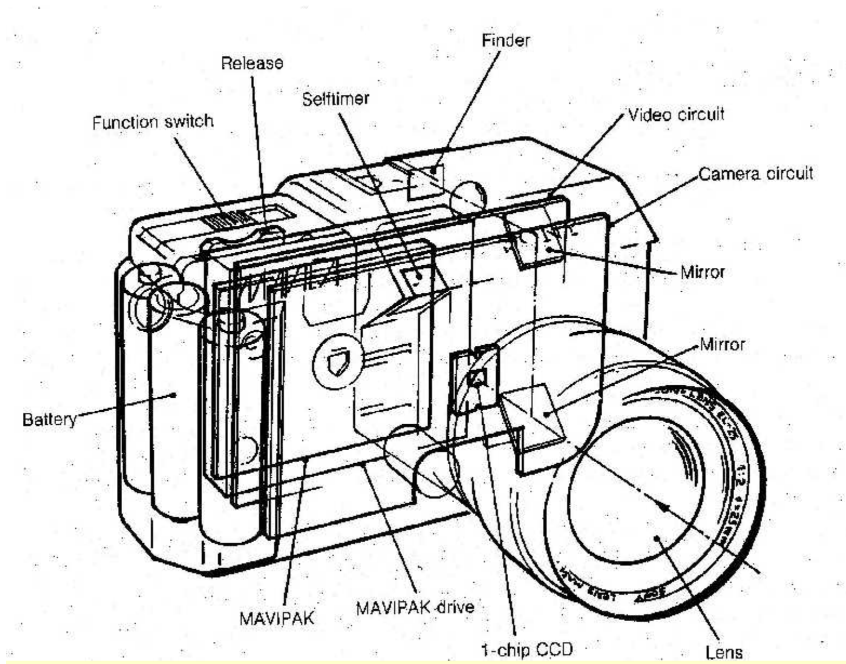
The original application icons designed by John Knoll.

First digital camera?

- 1975, Steve Sasson, Kodak
- Uses ccd from Fairchild semiconductor, A/D from Motorola, .01 megapixels, 23 second exposure, recorded on digital cassette

Still video camera

- Sony Mavica 1981
  - Electronic but analog



Cutaway View of 1981 Sony Mavica Prototype - First Ever Electronic Still Camera

Completely Digital Commercial camera

- 1991 first completely digital Logitech Dycam 376x240

Digital

- 1994 Apple quicktake, first mass-market color digital camera, 640 x 480 (commercial failure)

http://www-users.mat.uni.torun.pl/~olka/l

First megapixel sensor

- Of reasonable size?
- (Kodak) Videk 1987, 1.4MPixels

Digital SLR?

- 1992 Kodak DCS 200, 1.5 Mpixels, based on Nikon body

Professional digital camera?

- Nikon D1 1999, 2.7MPixels

Current cameras

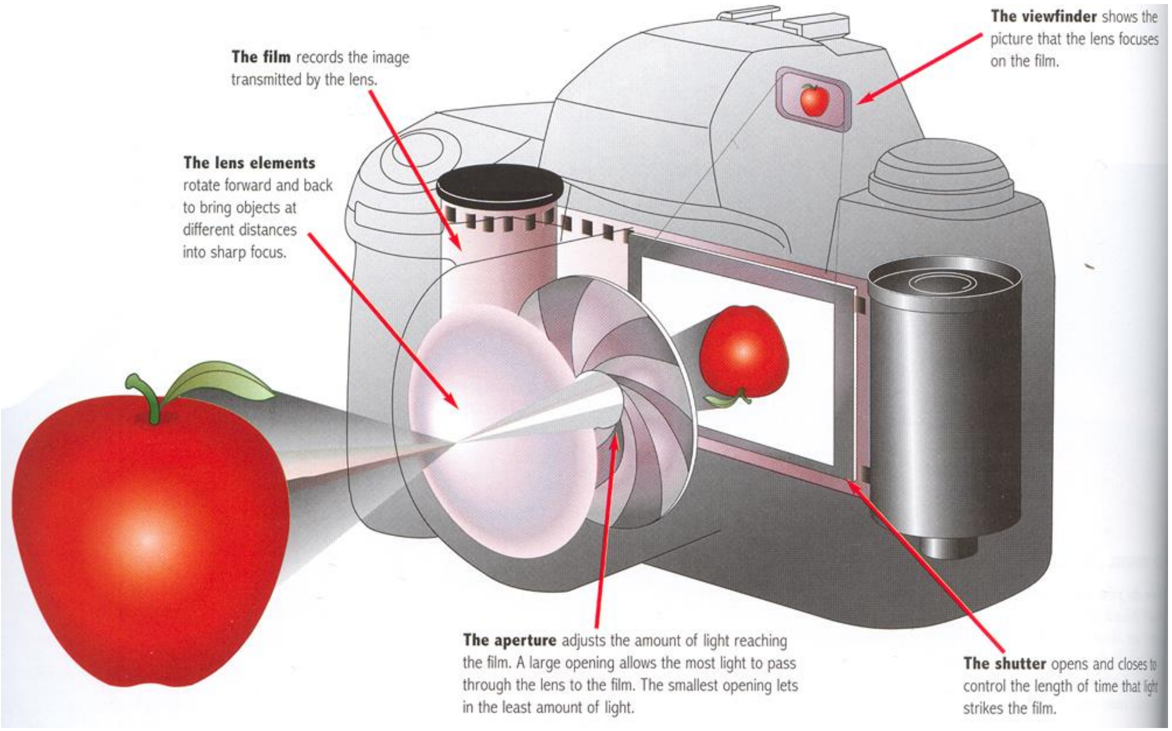
Canon 6D Mark II: 26MP
(DSLR)

Olympus Pen-F: 20MP (Mirrorless)

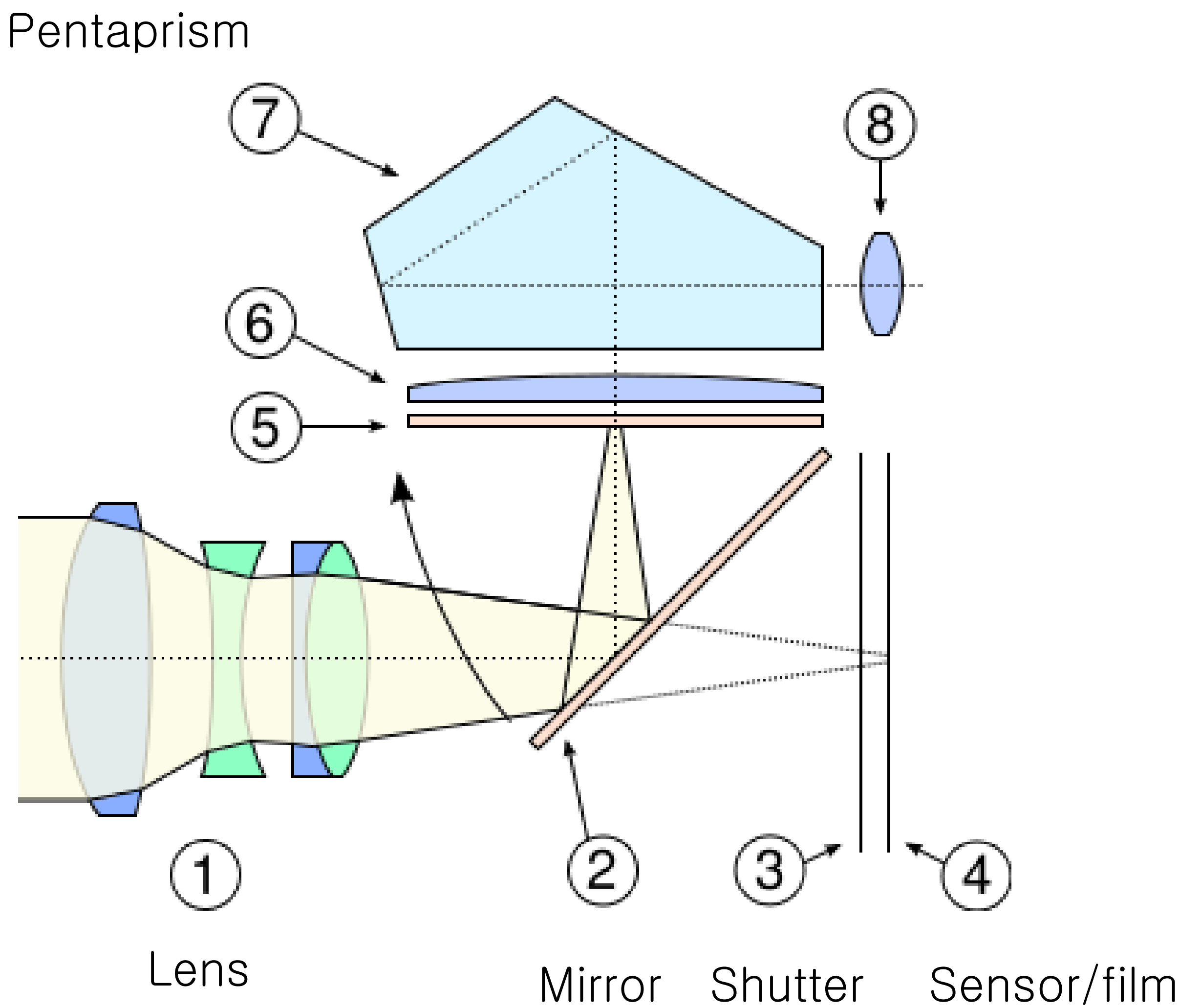
Hasselblad H3D: 39 MP (Large format)

Overview

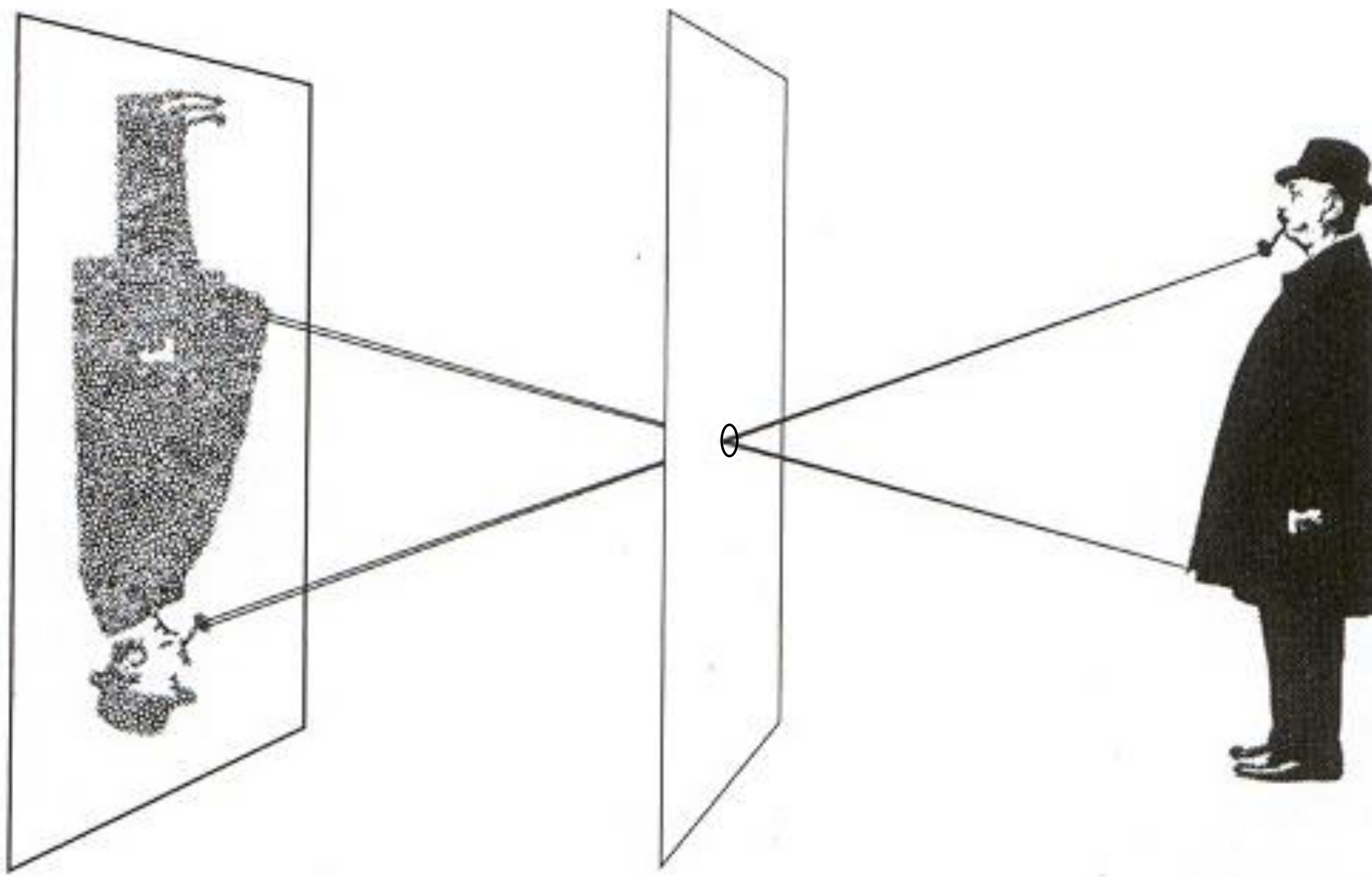
- Lens and viewpoint determine perspective
- Aperture and shutter speed determine exposure
- Aperture and other effects determine depth of field
- Film or sensor record image



SLR Design

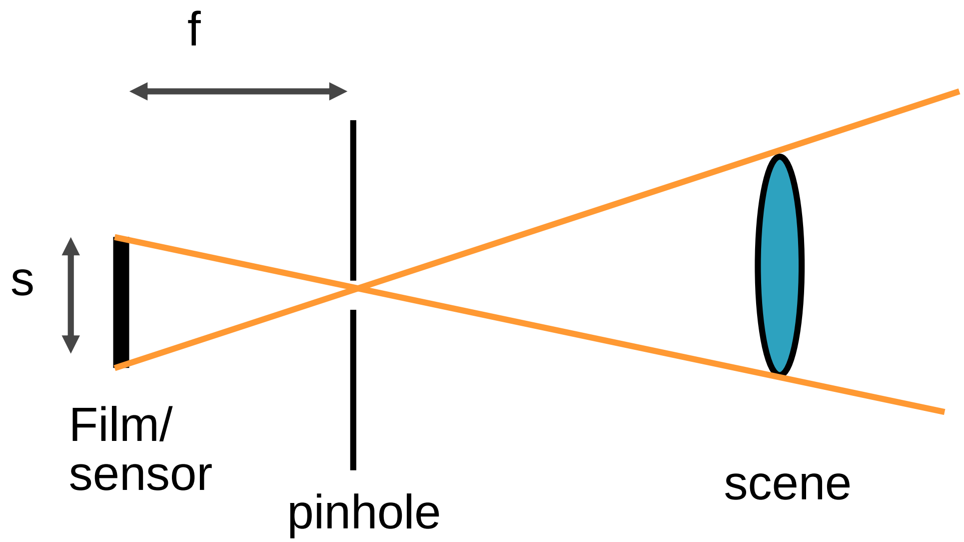


Pinhole



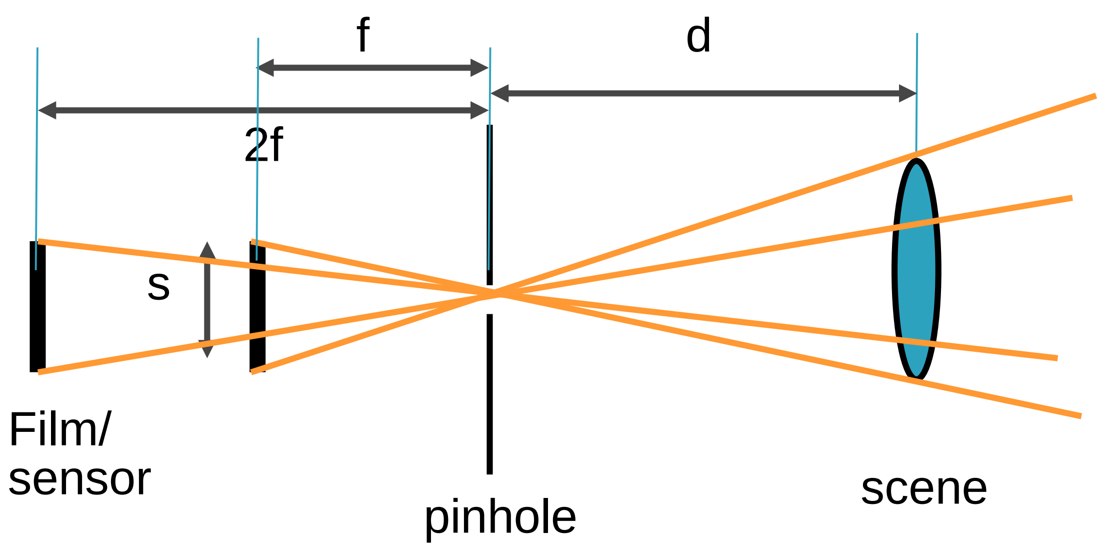
From Photography, London et al.

Focal length



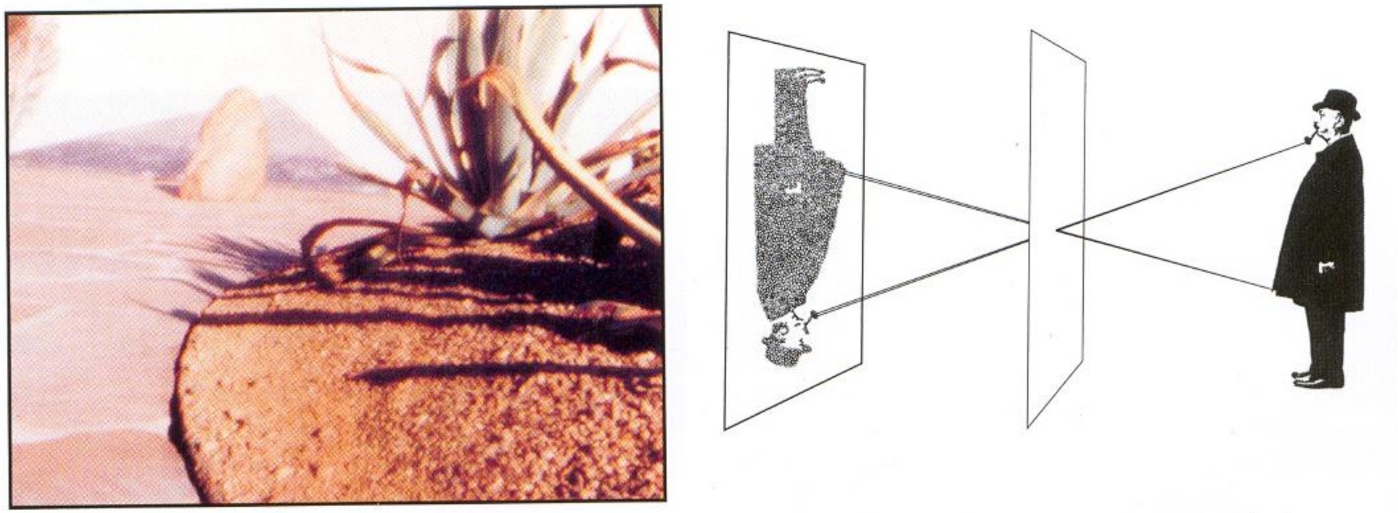
Focal length: pinhole optics

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

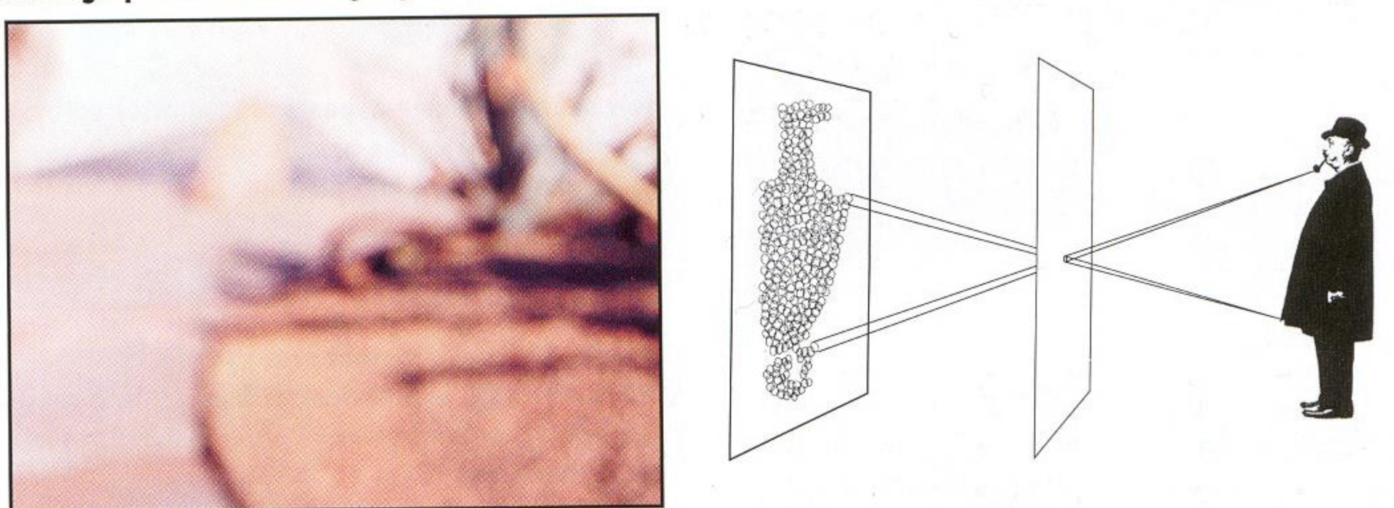


Pinhole size?

Photograph made with small pinhole



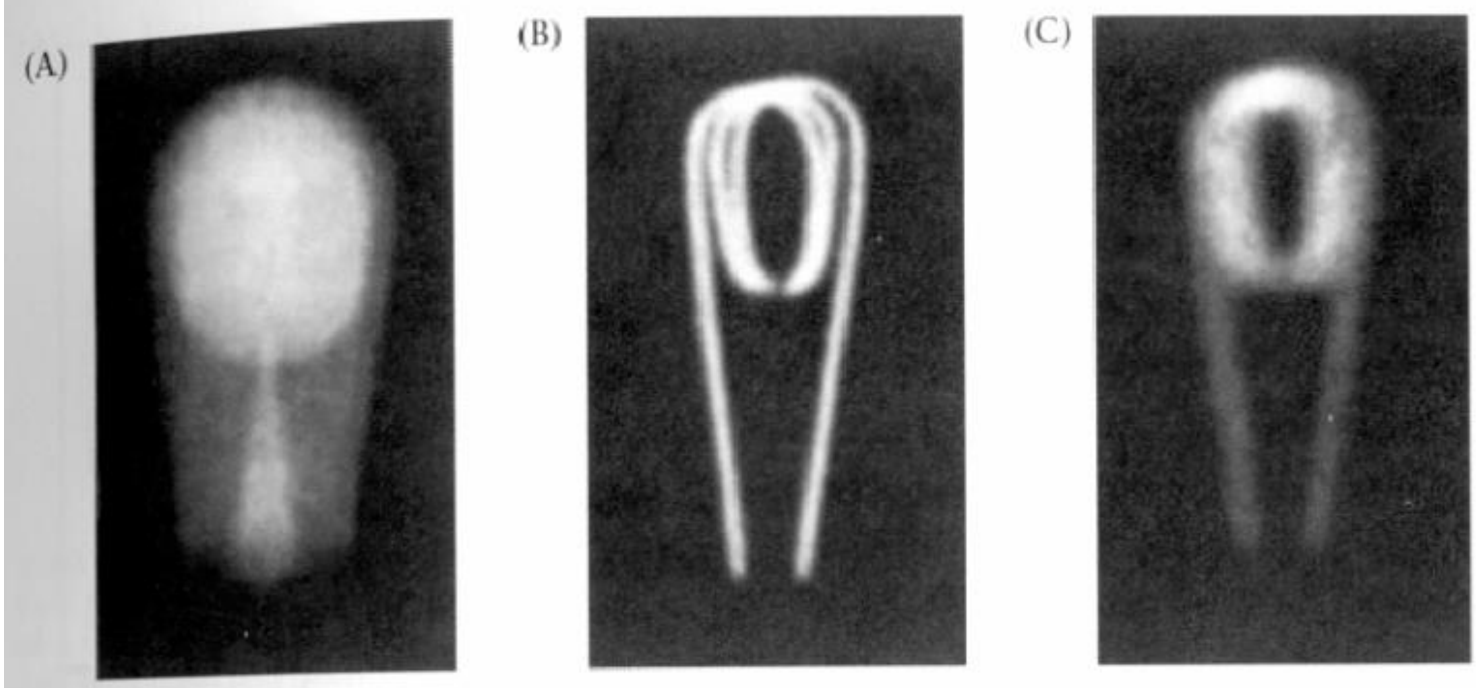
Photograph made with larger pinhole



From Photography, London et al.

Diffraction limit

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



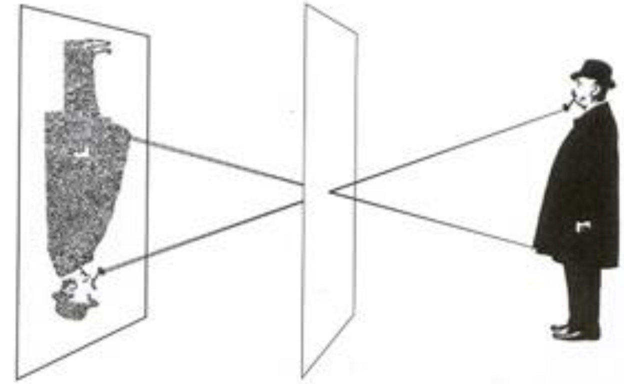
2.18 DIFFRACTION LIMITS THE QUALITY OF PINHOLE OPTICS. These three images of a bulb filament were made using pinholes with decreasing size. (A) When the pinhole is relatively large, the image rays are not properly converged, and the image is blurred. (B) Reducing the size of the pinhole improves the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

From Wandell

Lenses

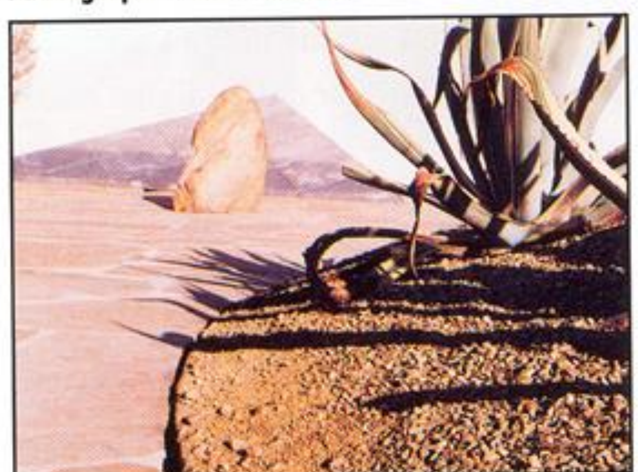
- gather more light!
- But need to be focused

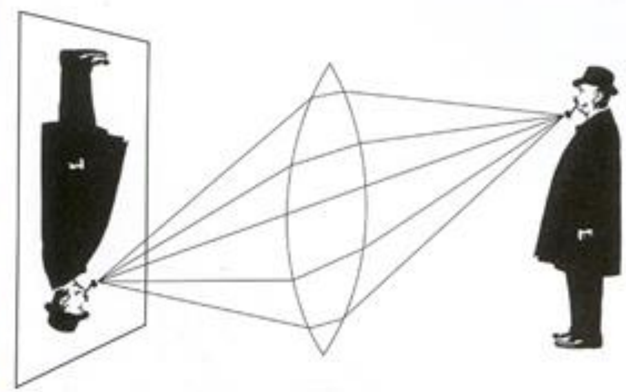
Photograph made with small pinhole



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





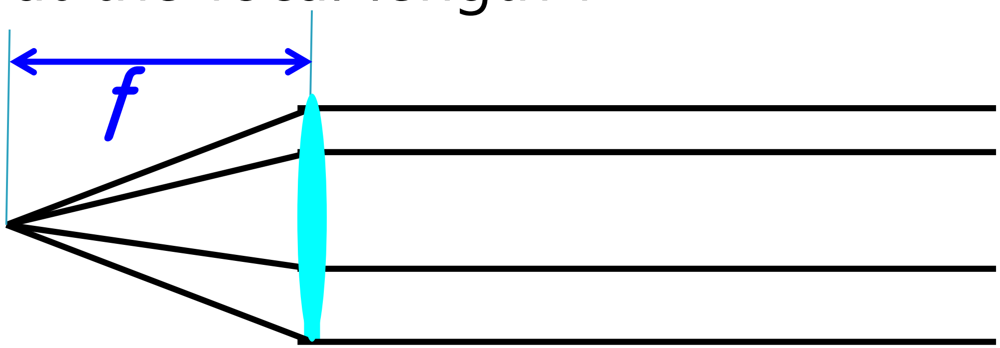
This time, using a simple convex lens with an f/16 aperture, *the scene appeared sharper than the one taken with the smaller pinhole, and the exposure time was much shorter, only 1/100 sec.*

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.

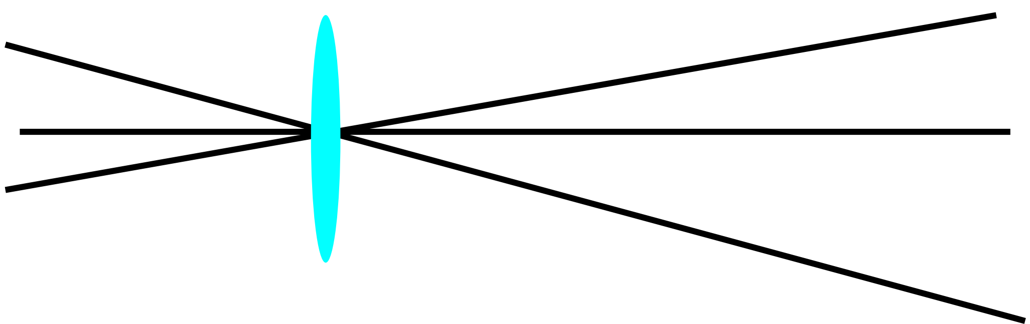
From Photography, London et a

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*

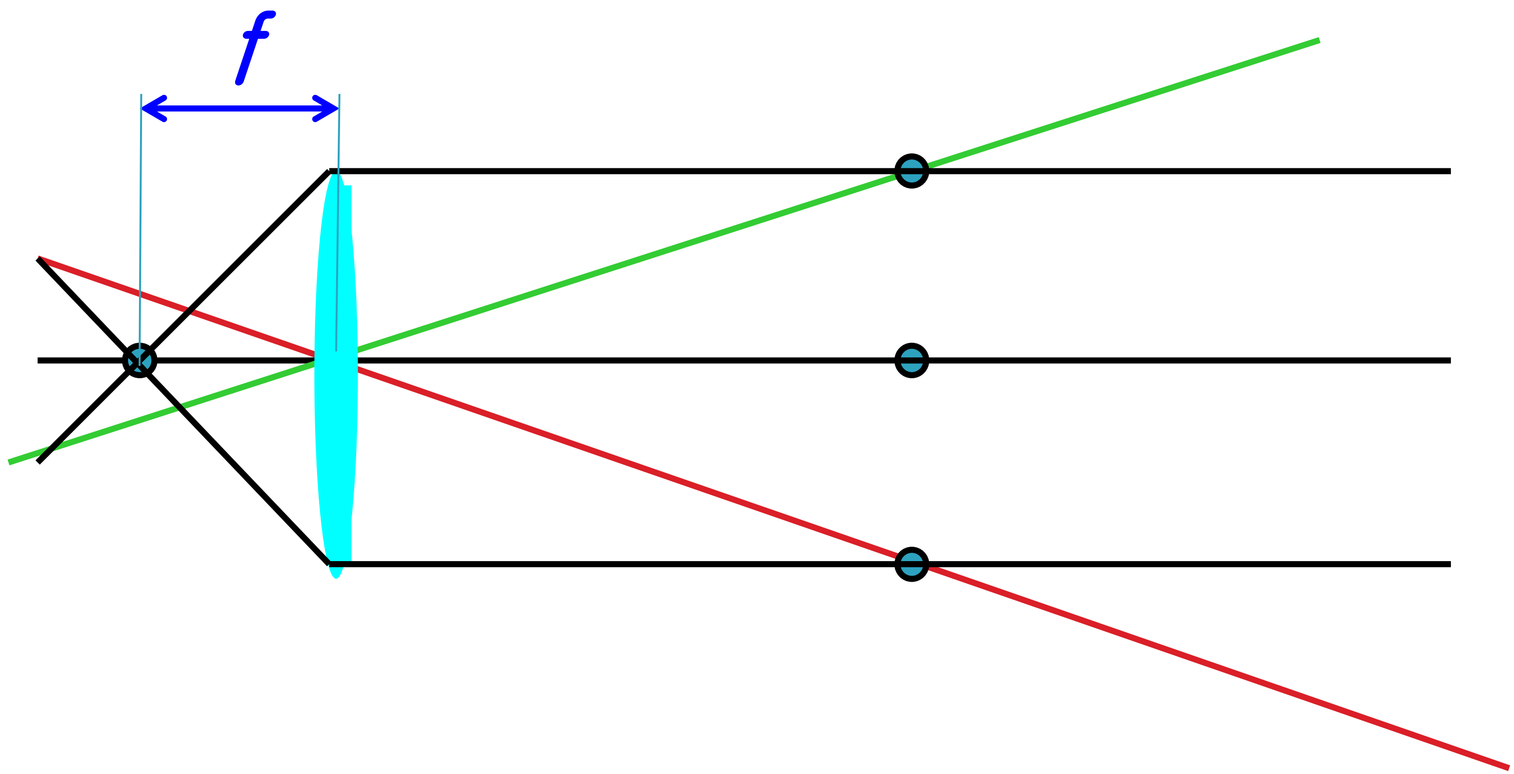


- All rays going through the center are not deviated
  - Hence same perspective as pinhole



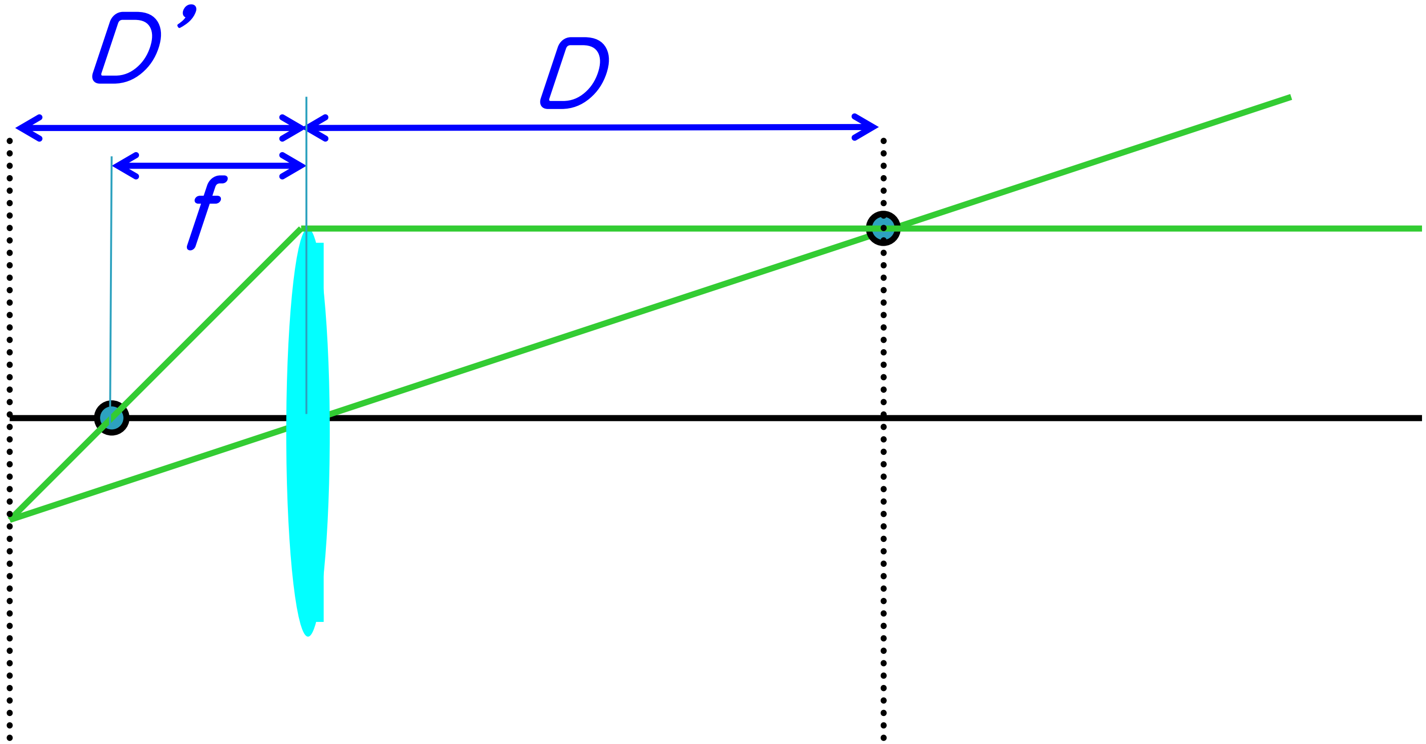
How to trace rays

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



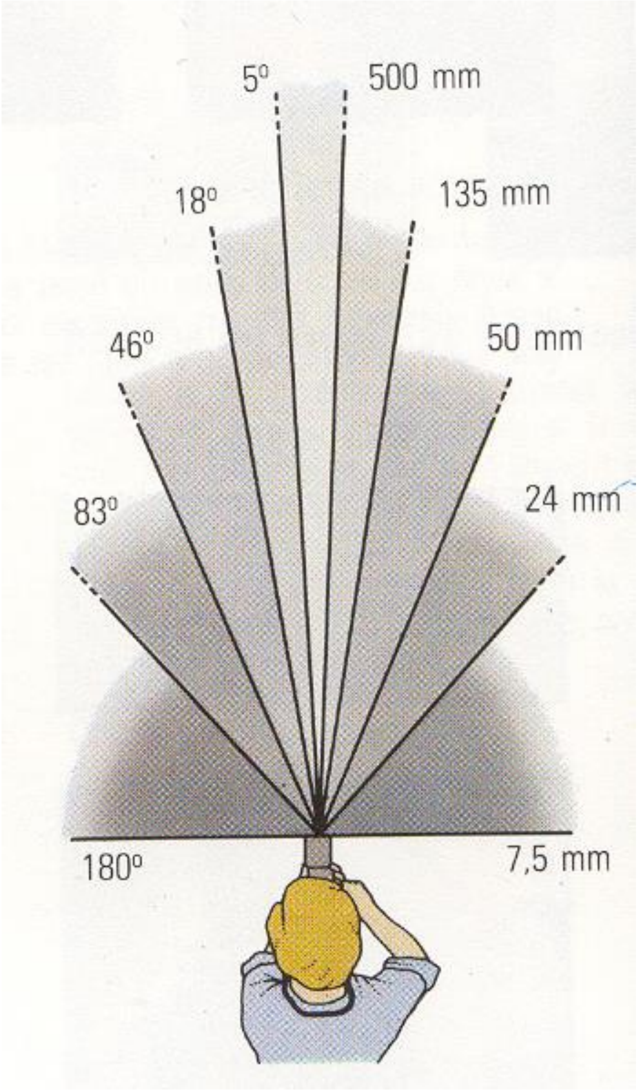
Thin lens formula

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

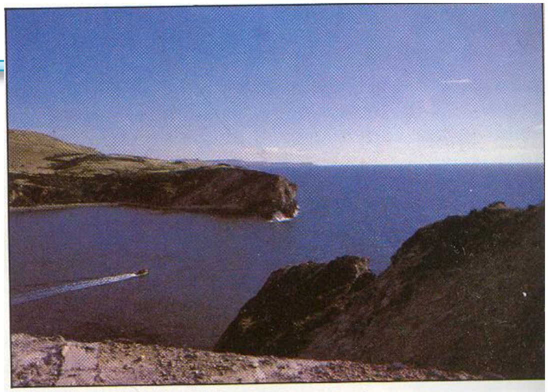


Focal length in practice

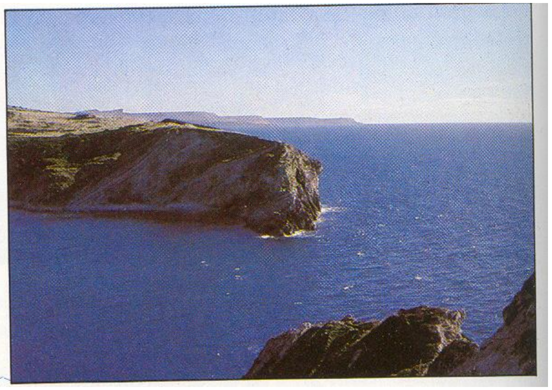
Focal length in practice



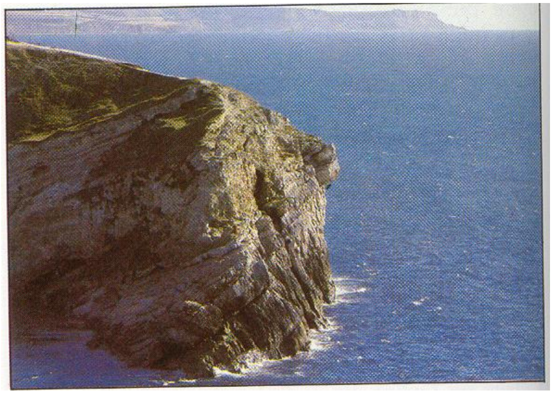
24mm



50mm



135mm



Perspective vs. viewpoint

400 mm

200 mm

100 mm

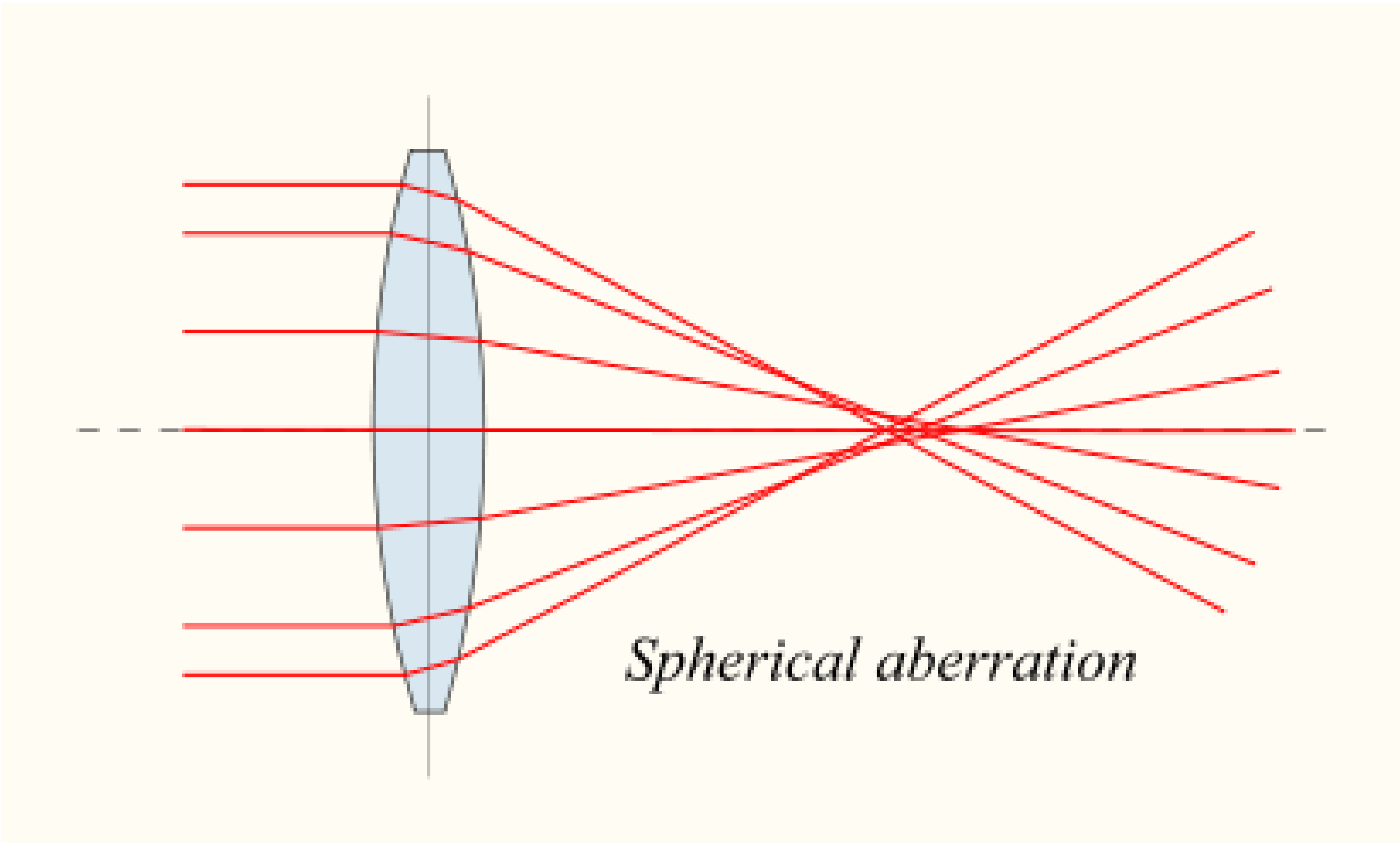
50 mm

28 mm

17 mm

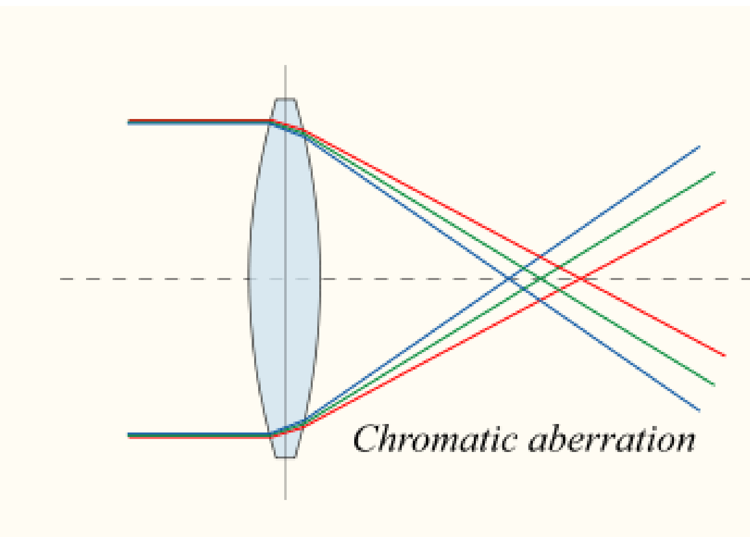
Lens imperfections

1. Spherical aberration



Lens imperfections

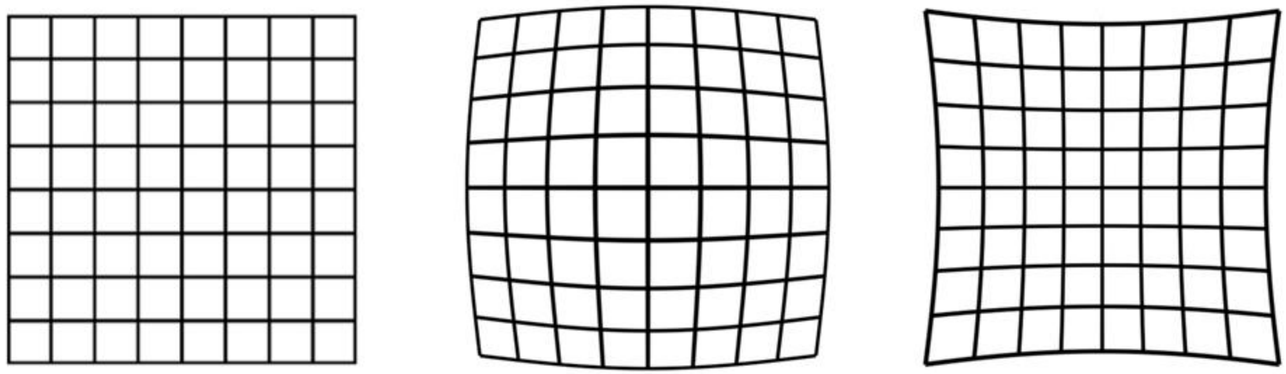
2. Chromatic aberration



From Wikipedia

Lens imperfections

3. Pincushion and Barrel distortion



Object Barrel Distortion Pincushion Distortion

Example of image distortion

Exposure

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

Shutter speed

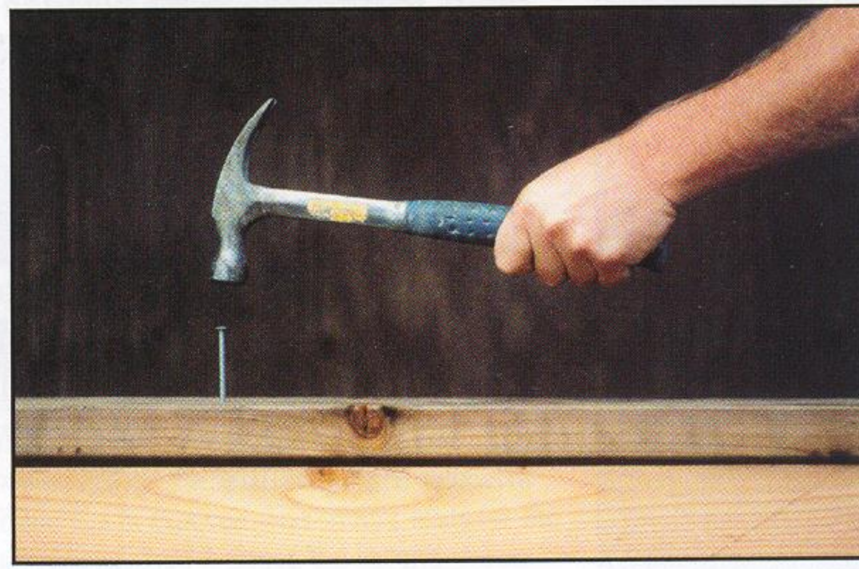
- Controls how long the film/sensor is exposed
- Pretty much linear effect on exposure
- Usually in fraction of a second:
  - 1/30, 1/60, 1/125, 1/250, 1/500
  - Get the pattern ?
- On a normal lens, normal humans can hand-hold down to 1/60
  - In general, the rule of thumb says that the limit is the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

Main effect of shutter speed

- Motion blur

Slow shutter speed

Fast shutter speed



From Photography, London et al.

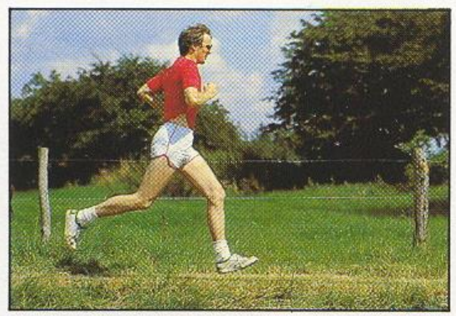
Effect of shutter speed

- Freezing motion

Walking people

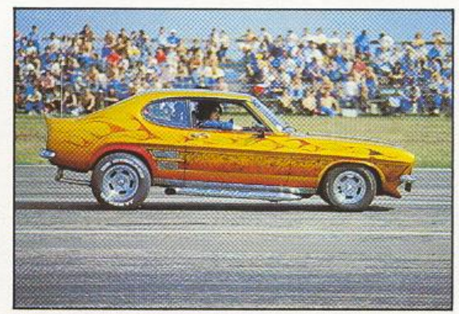
1/125

Running people



1/250

Car



1/500

Fast train

1/1000

Shutter

- Various technologies
- Goal: achieve uniform exposure across image

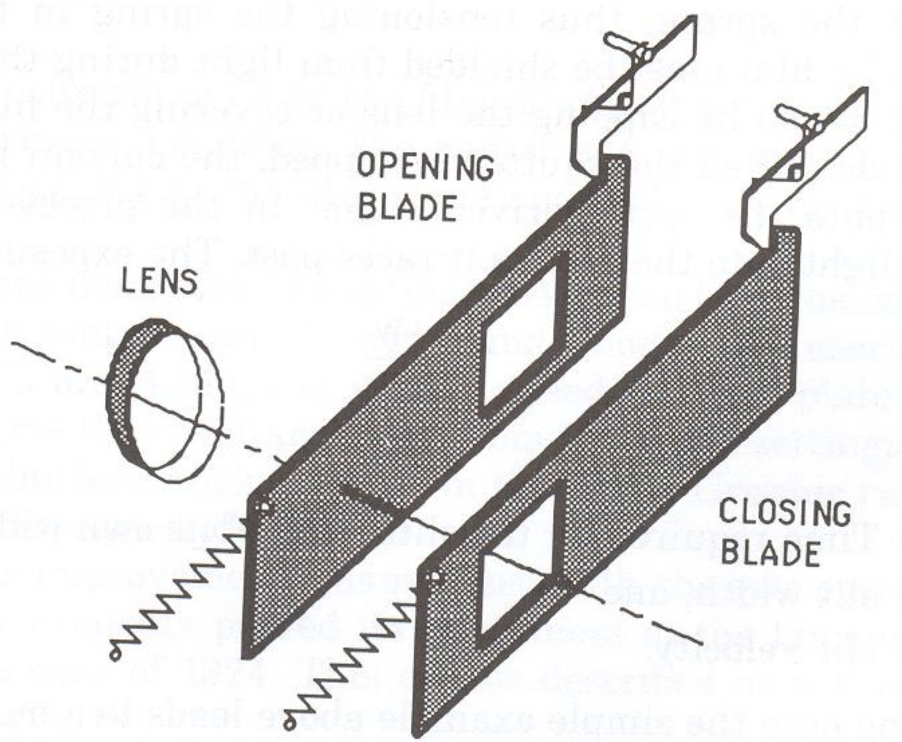


FIG. 2.8 Two-blade guillotine shutter.

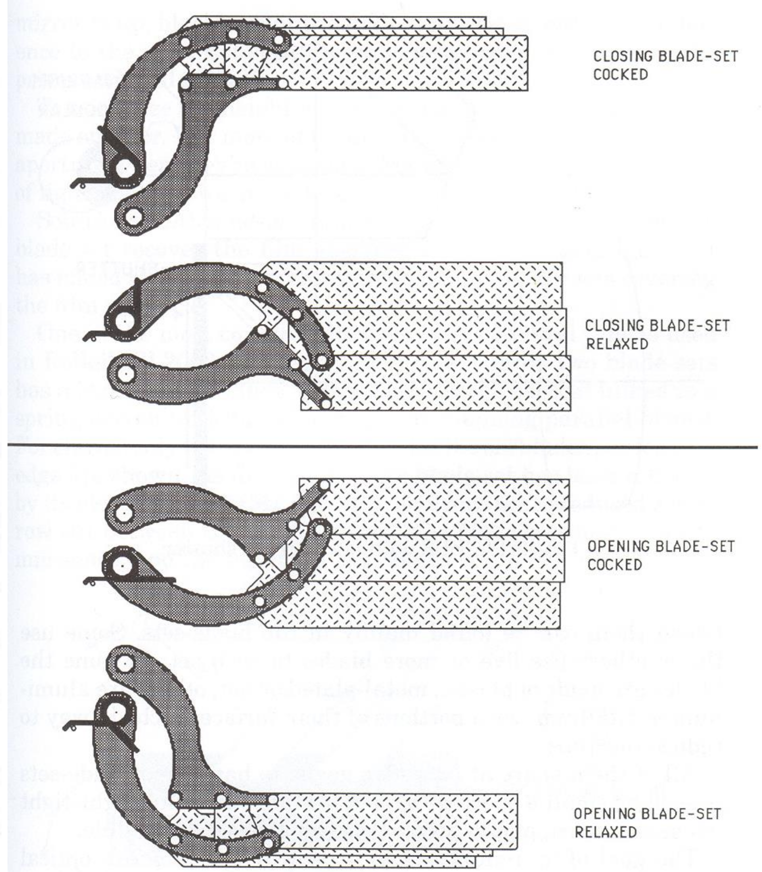


FIG. 2.12 Copal square.

From Camera Technology, Goldberg

Aperture

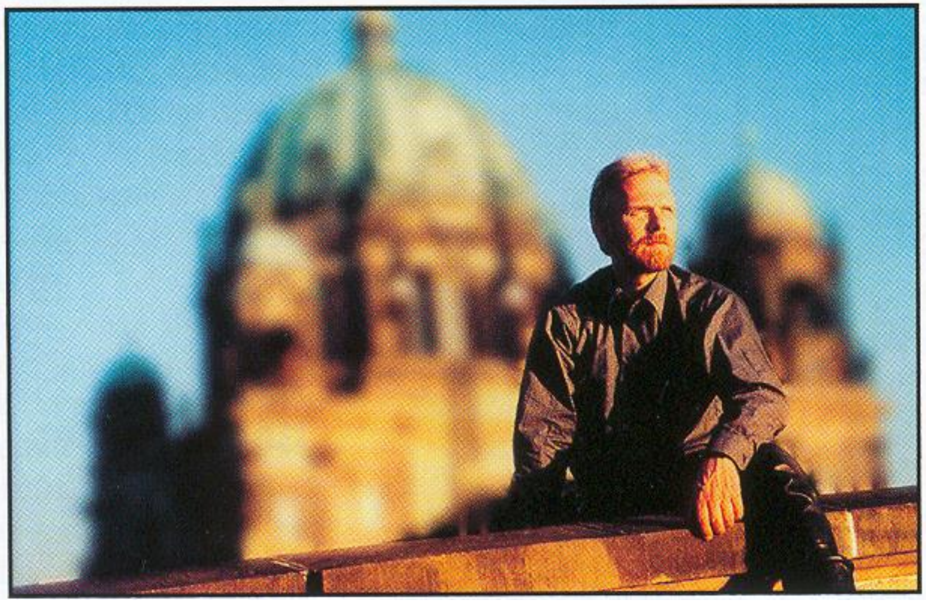
- Diameter of the lens opening (controlled by diaphragm)
- Expressed as a fraction of focal length, in f-number
  - f/2.0 on a 50mm means that the aperture is 25mm
  - f/2.0 on a 100mm means that the aperture is 50mm
- Disconcerting: small f number = big aperture
- What happens to the area of the aperture 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?

$$\text{Area} = \pi \left(\frac{f}{2N} \right)^2$$

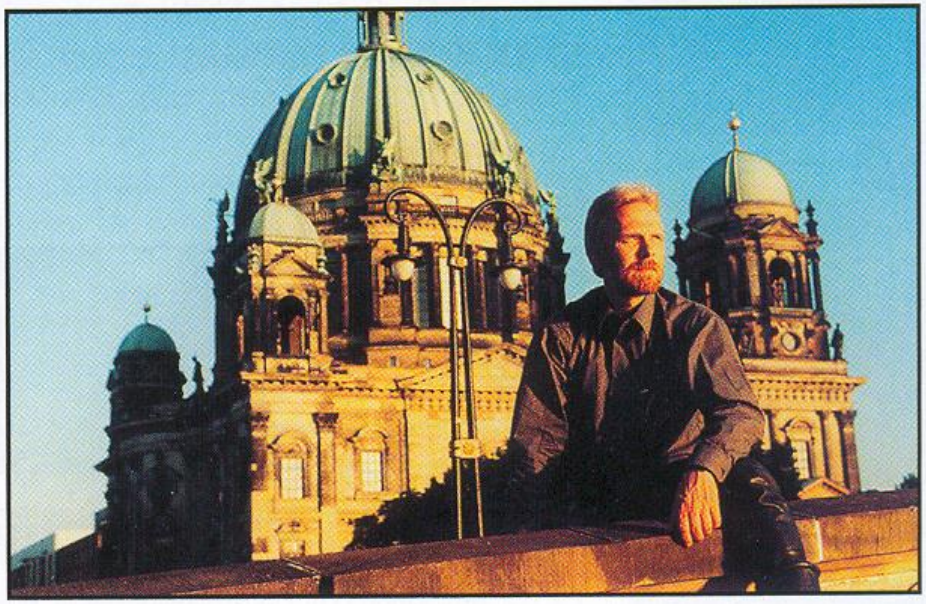
Main effect of aperture

- Depth of field

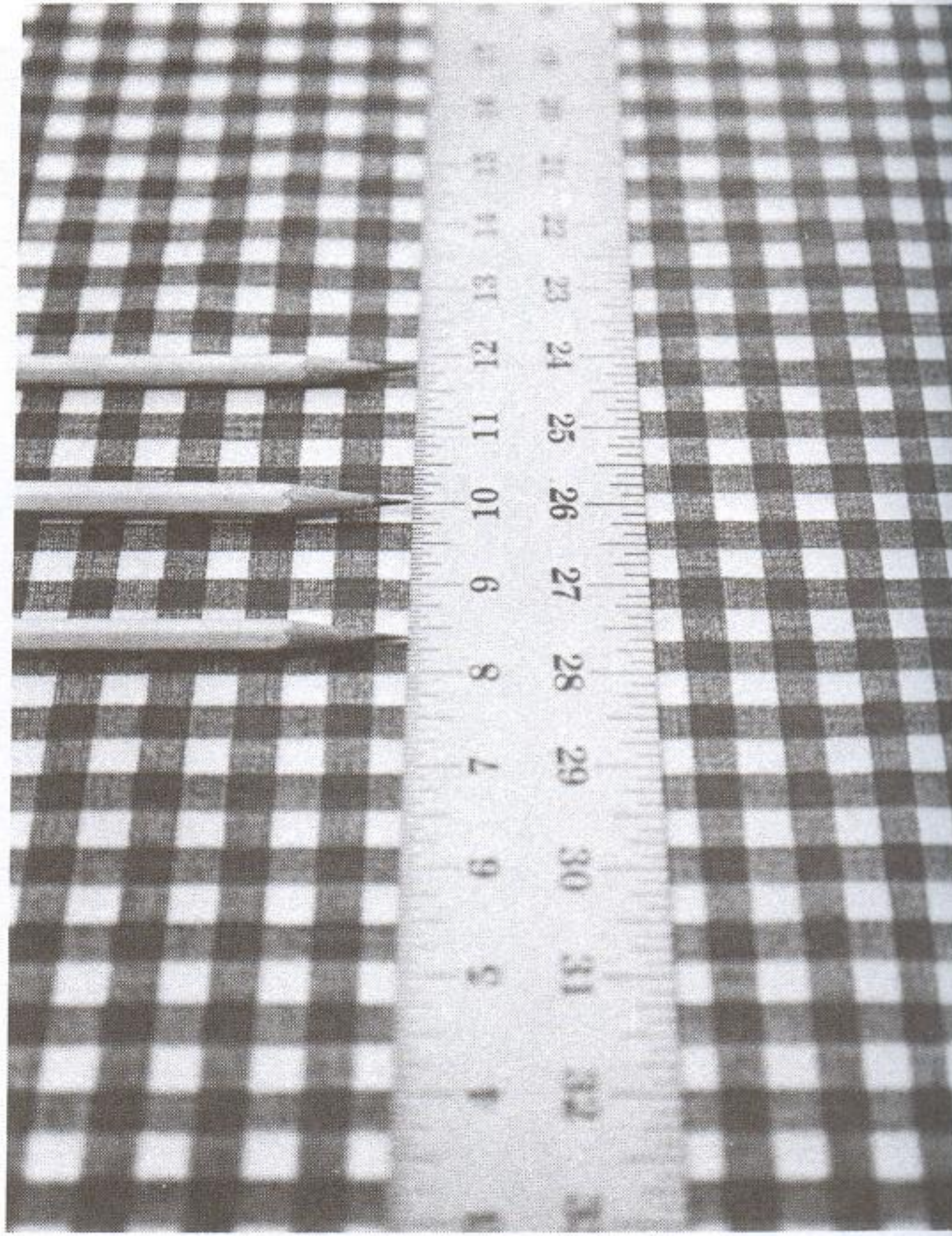
Large aperture opening



Small aperture opening

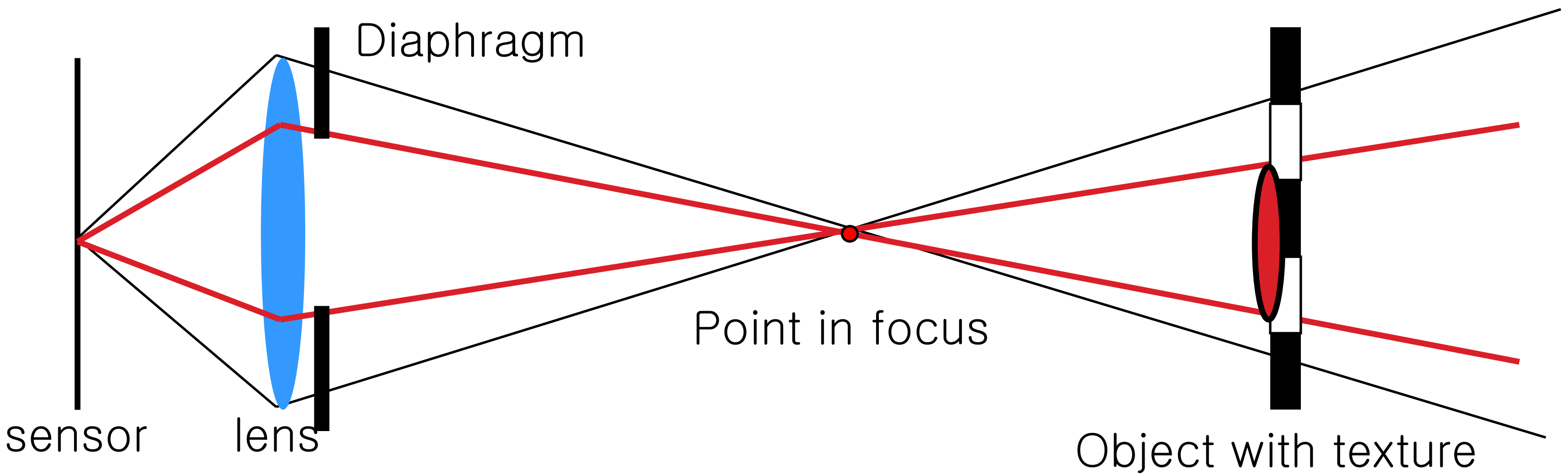


From Photography, London et al.

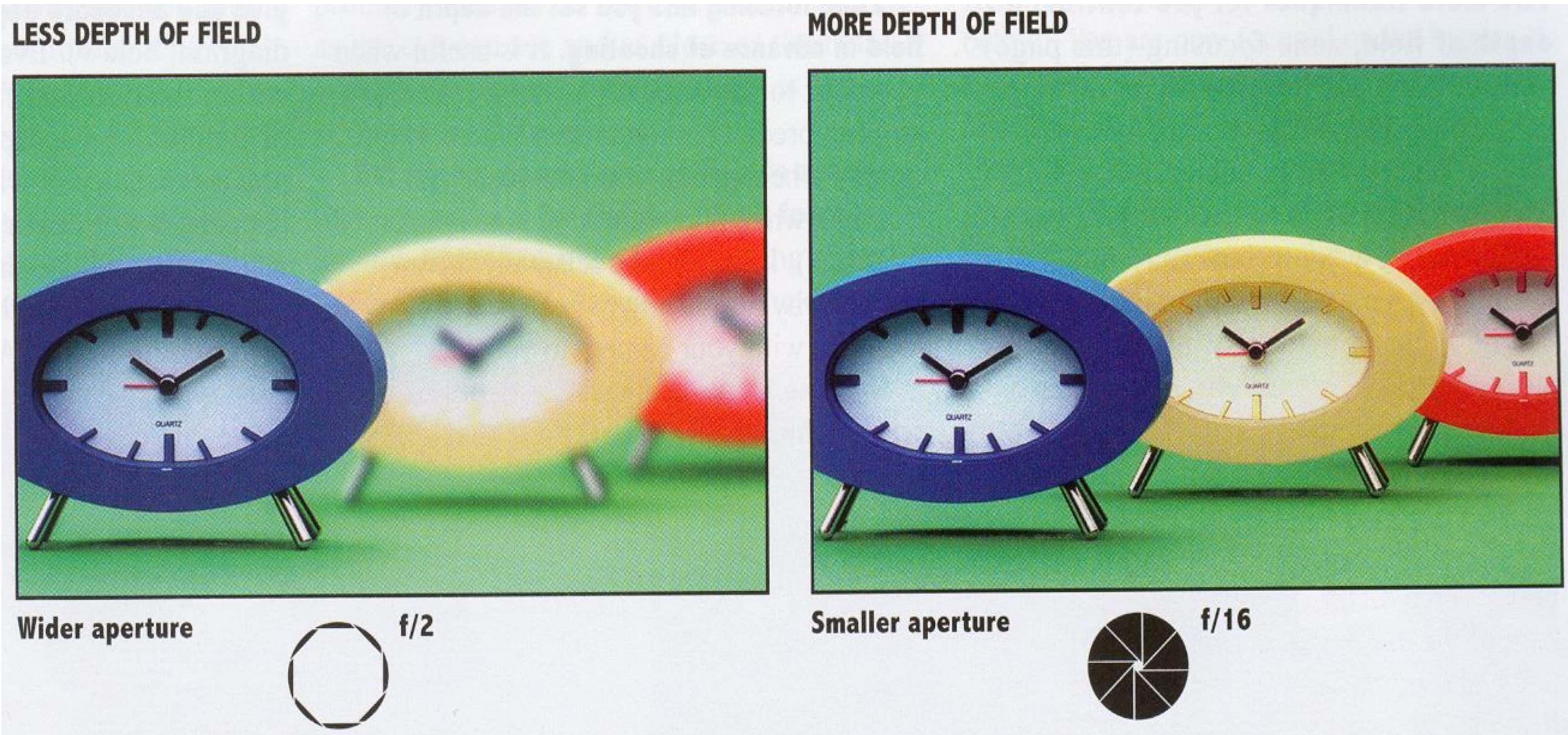

22 23 24 25 26 27 28 29 30 31 32
13 12 11 10 9 8 7 6 5

Depth of field

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



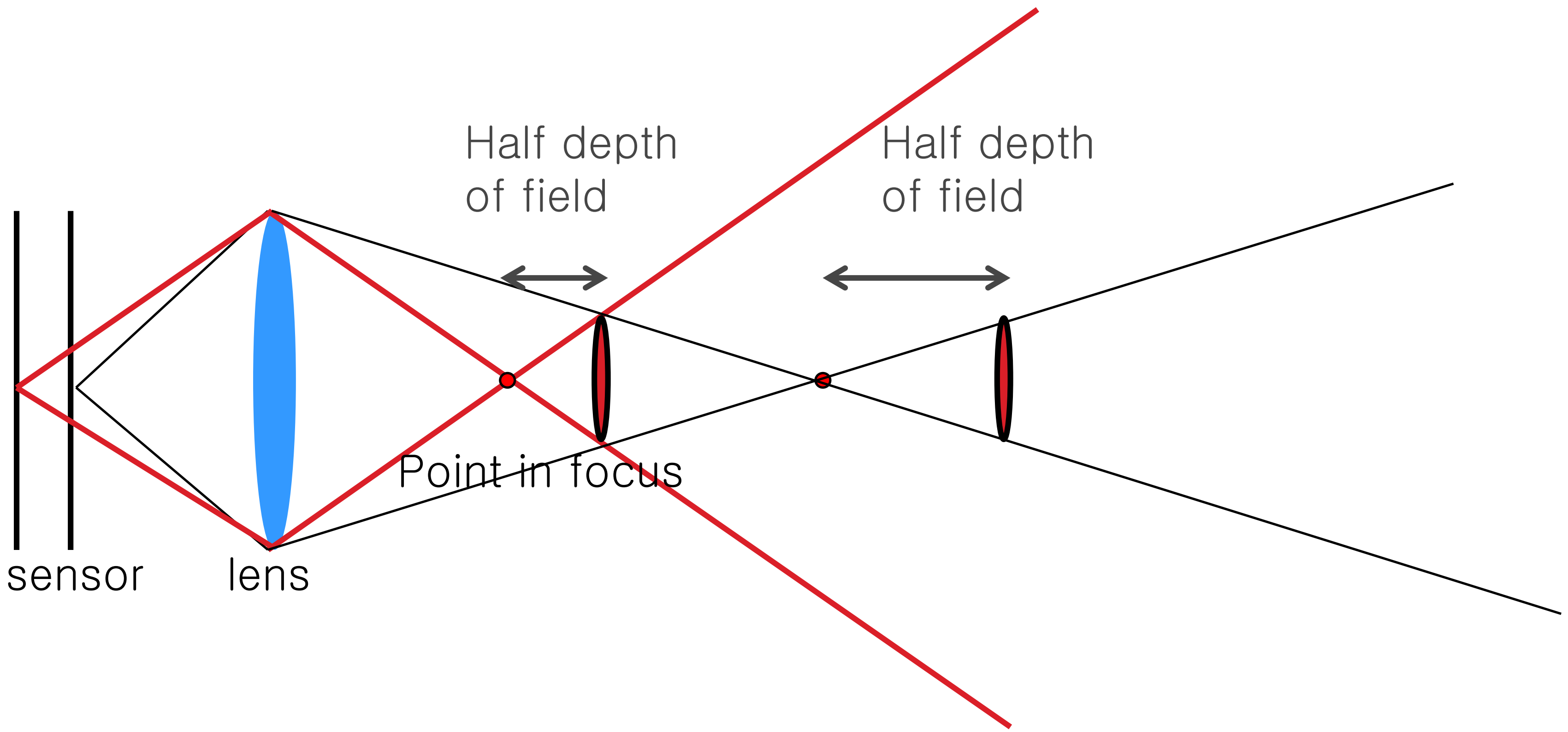
Depth of field



From Photography, London et

Depth of field & focusing distance

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



Depth of field & focusing distance

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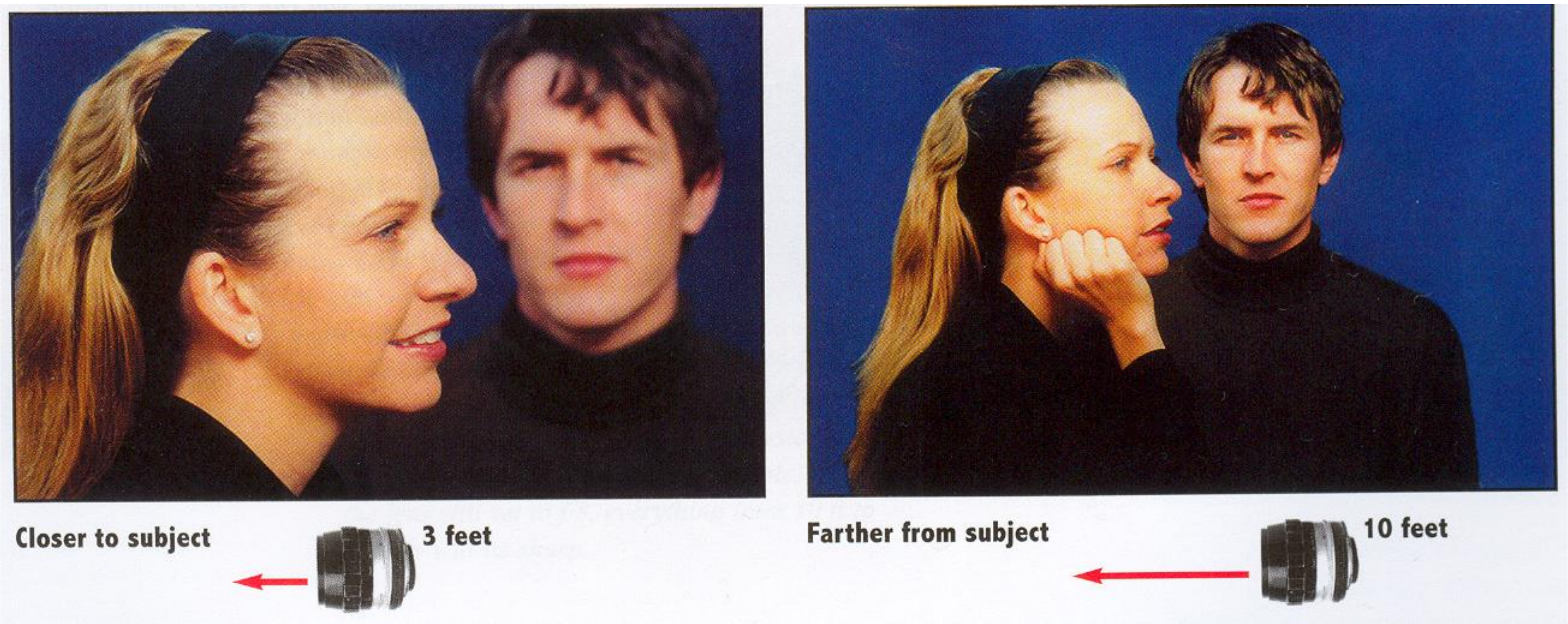


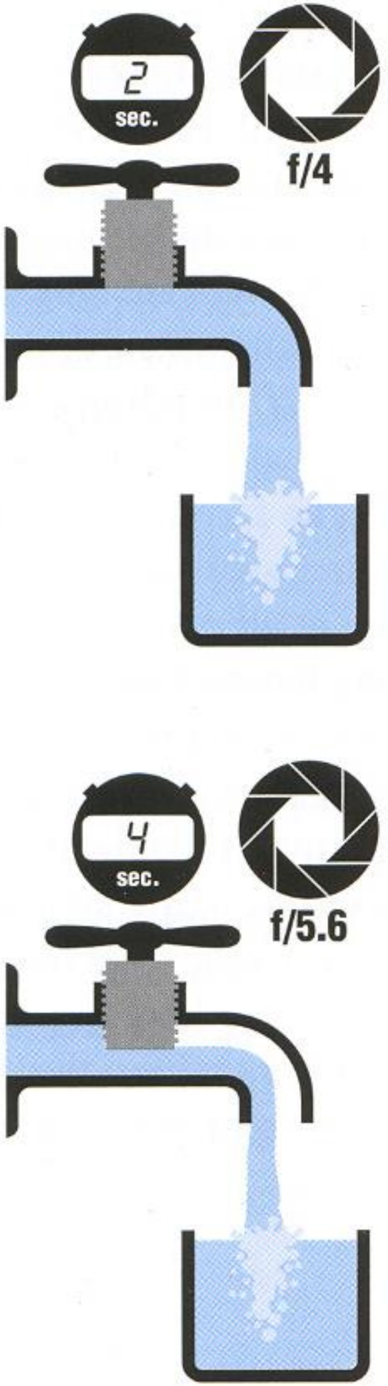
From Photography, London et

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

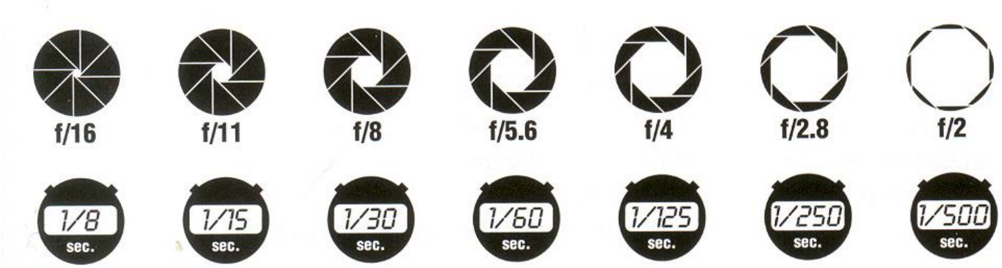
  - Hence square root of two progression of f stops vs. power of two progression of shutter speed
  - Reciprocity can fail for very long exposures



From Photography, London et

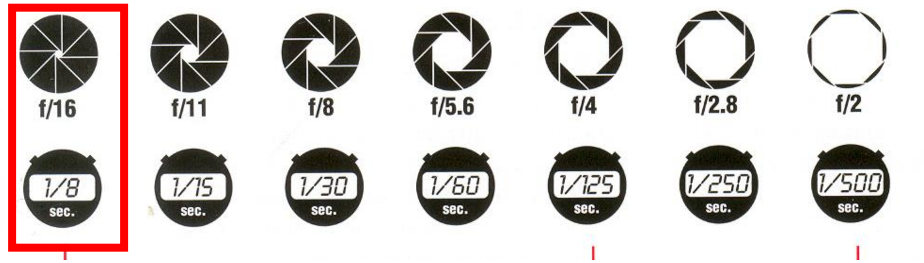
Reciprocity

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

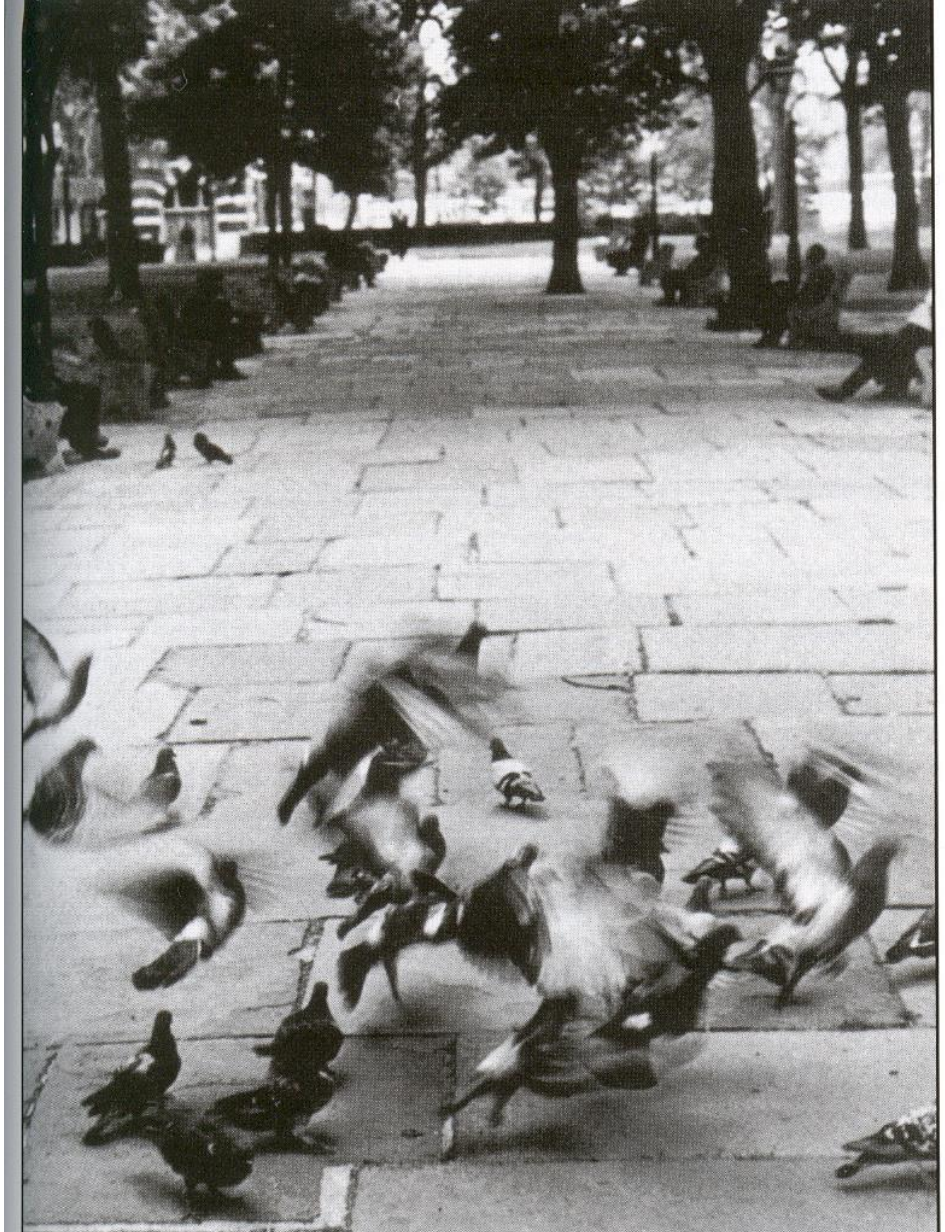


- What will guide our choice of a shutter speed?
  - Freeze motion vs. motion blur, camera shake
- What will guide our choice of an aperture?
  - Depth of field, diffraction limit
- Often we must compromise
  - Open more to enable faster speed (but shallow DoF)

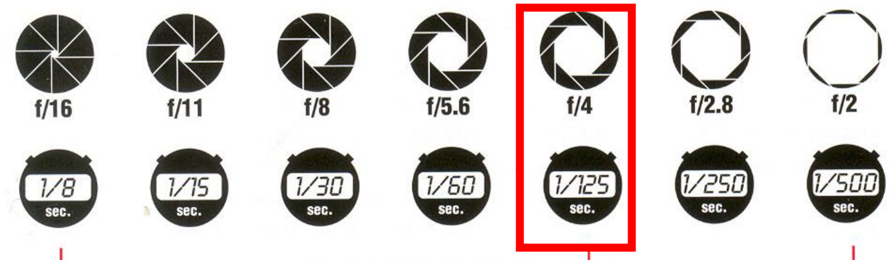
Small aperture (deep depth of field), slow shutter speed (motion blurred). *In th*
scene, a small aperture (f/16) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed (1/8 sec) was needed; it was too slow to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



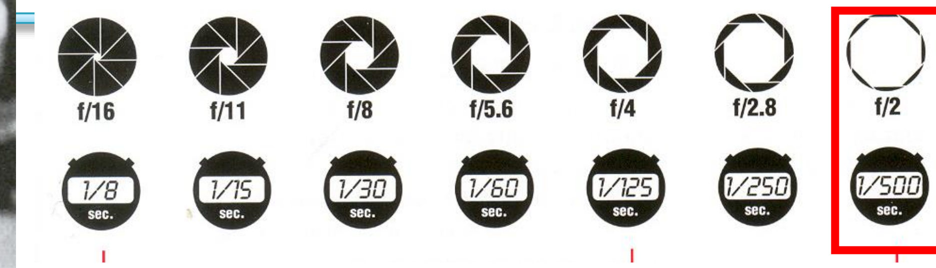
From Photography, London et al.



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.*



From Photography, London et al.

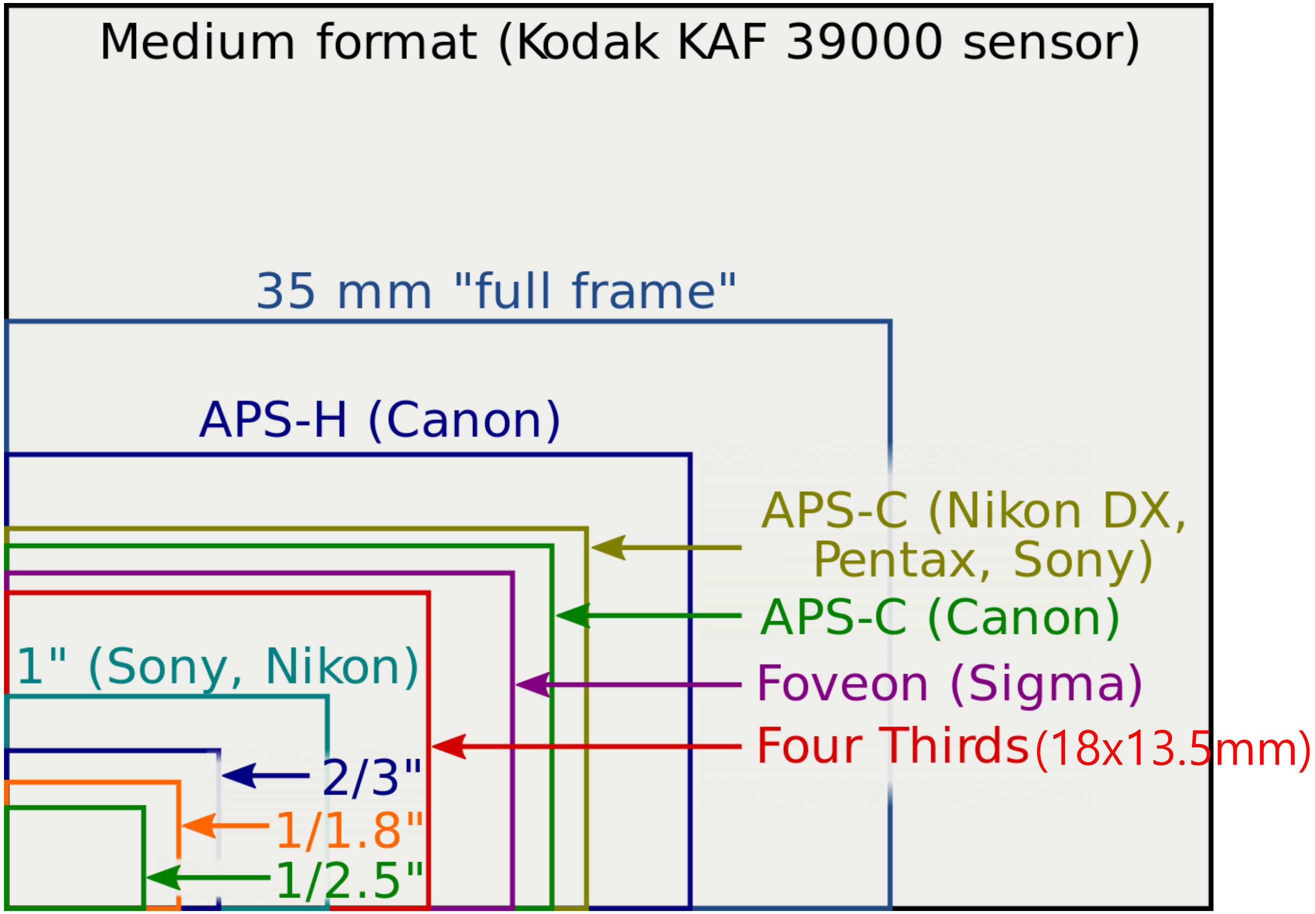


Large aperture (shallow depth of field), fast shutter speed (motion sharp). *A fa shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little depti of field that the background is now out of focus.*

From Photography, London et al.

Sensor format

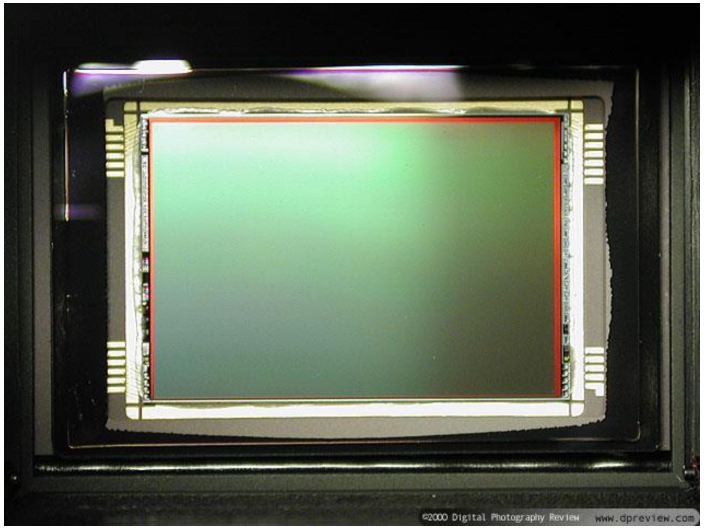
- Many different types of sensor are available
  - for different purpose and price



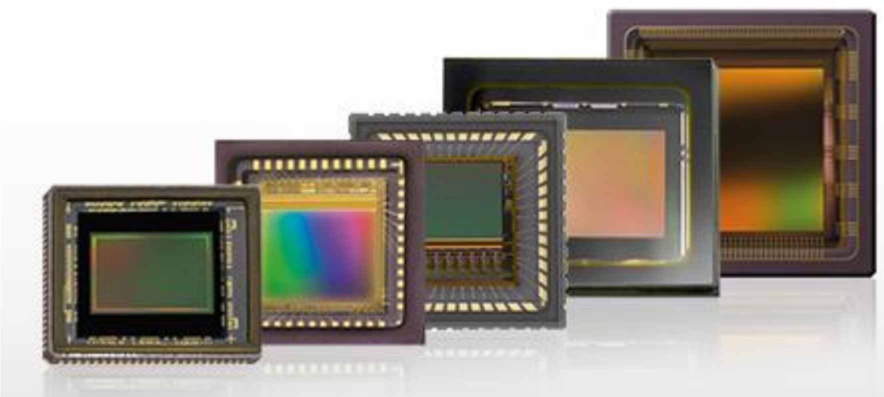
source: Wikipedia

CCD vs CMOS

- CCD (charge coupled device) is less susceptible to noise (specia l process, higher fill factor)
- CMOS (complementary metal oxide semiconductor) is more flexi ble, less expensive (standard process), less power consumption

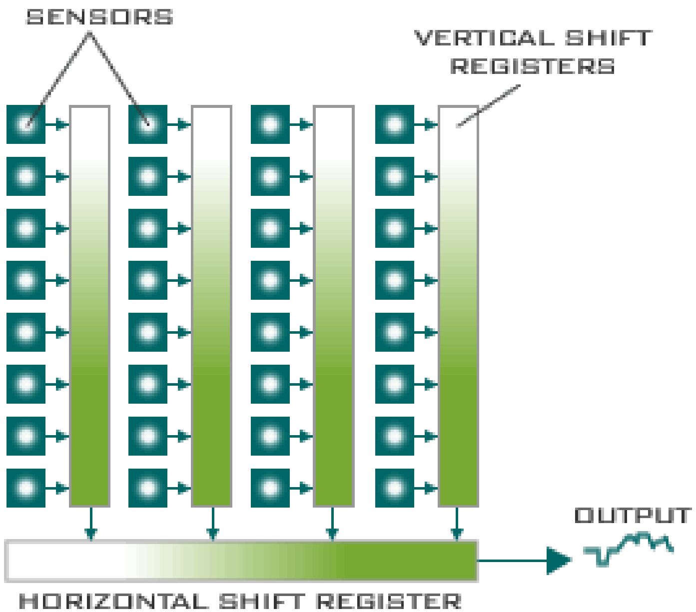


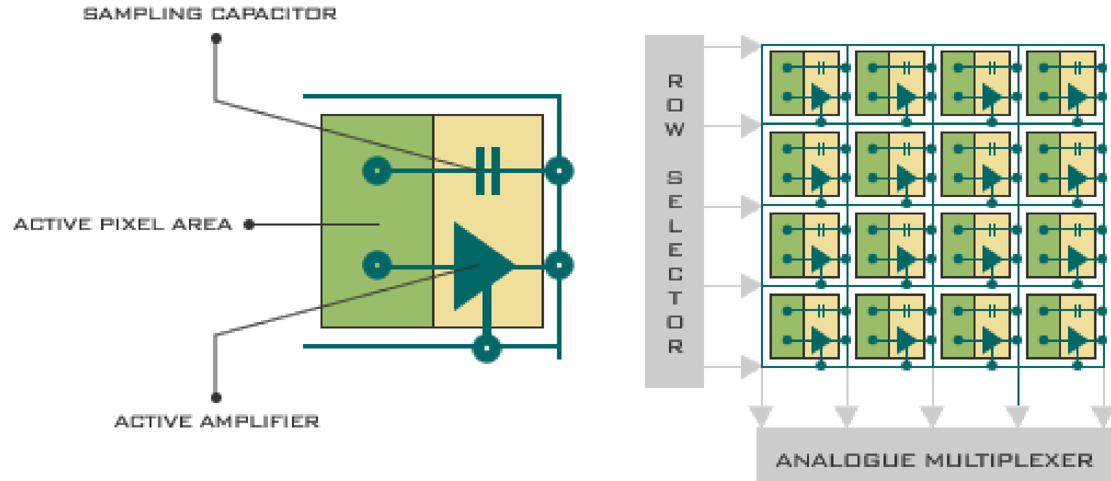
CCD



CMOS

CCD vs CMOS





CMOS sensor structure

CCD sensor structure

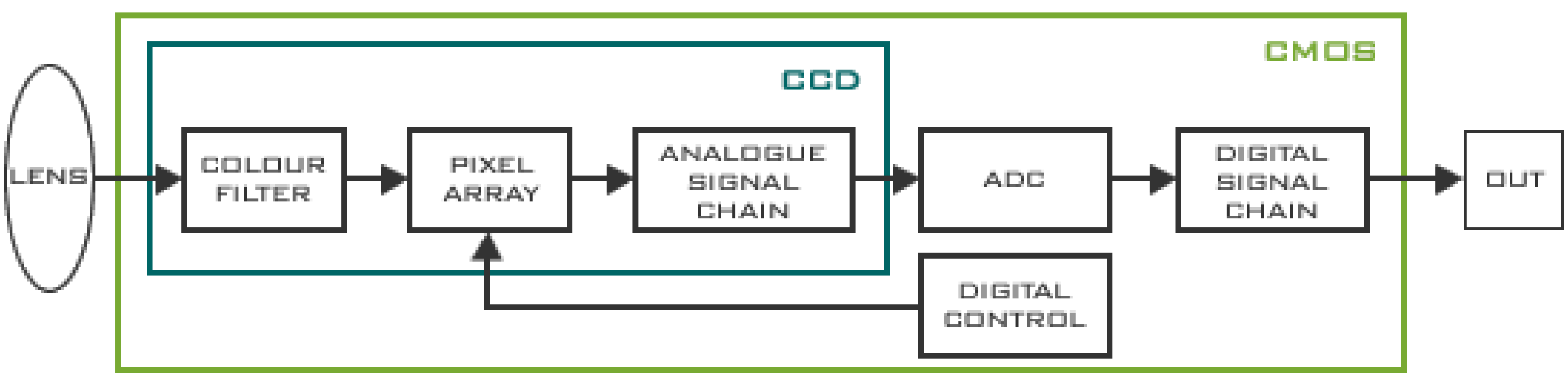
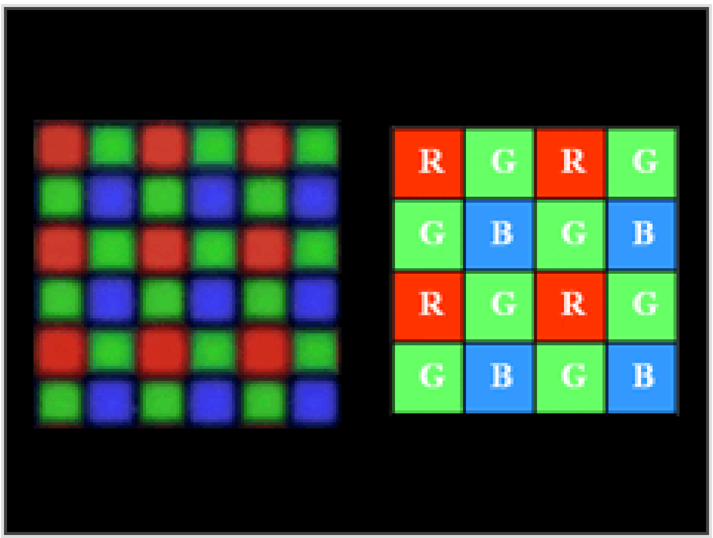


Image source: Loop technology

Color CCD



Bayer Pattern

G	B 1	G
R 1	G	R 2
G	B2	G

G=G, R=(R1+R2)/2
B=(B1+B2)/2

G	R 1	G
B 1	G	B2
G	R 2	G

G=G, R=(R1+R2)/2
B=(B1+B2)/2

R 1	G 1	R 2
G 3	B	G 2
R 3	G 4	R 4

B=B
R=(R1+R2+R3+R4)/4
G=(G1+G2+G3+G4)/4

B 1	G1	B 2
G3	R	G 2
B 3	G 4	B 4

R=R
B=(B1+B2+B3+B4)/4
G=(G1+G2+G3+G4)/4

Bayer Pattern

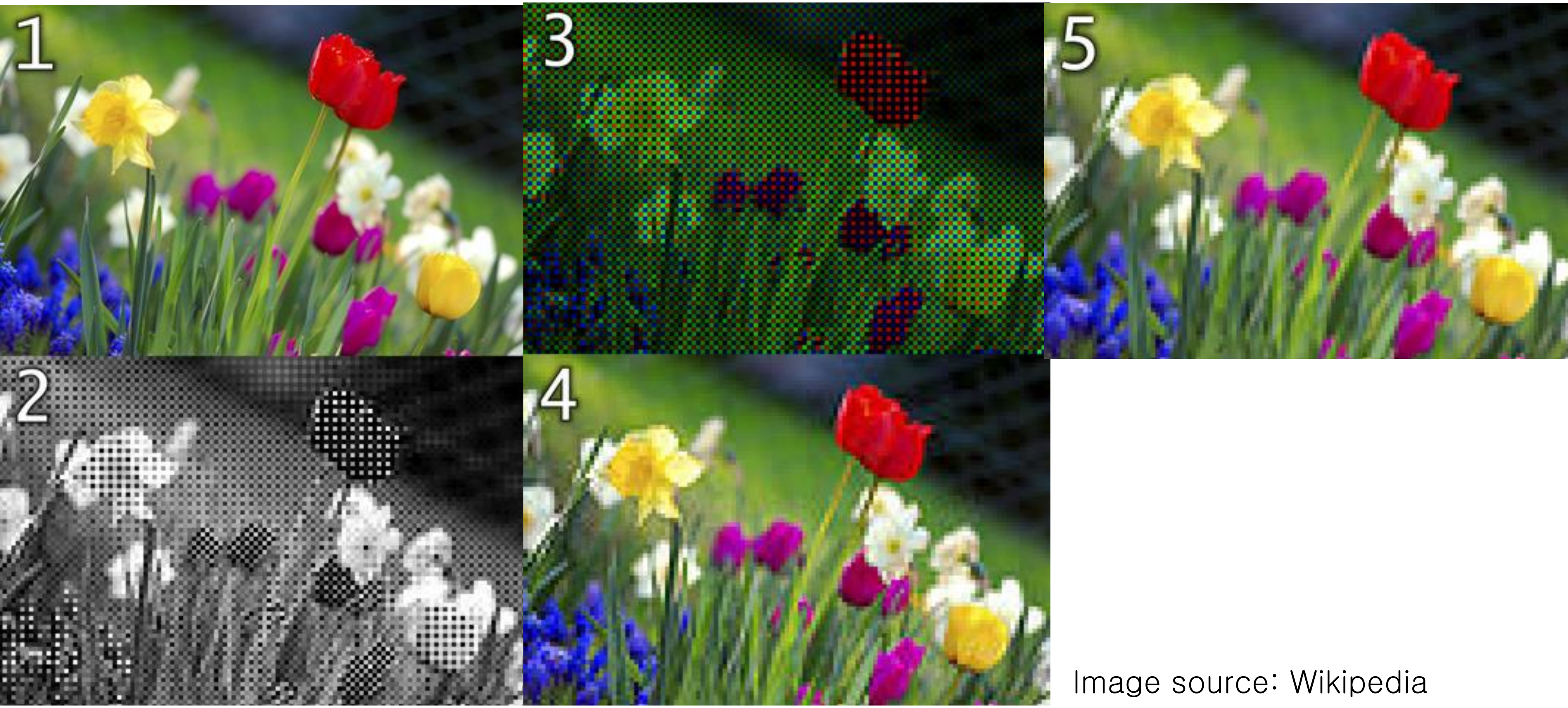
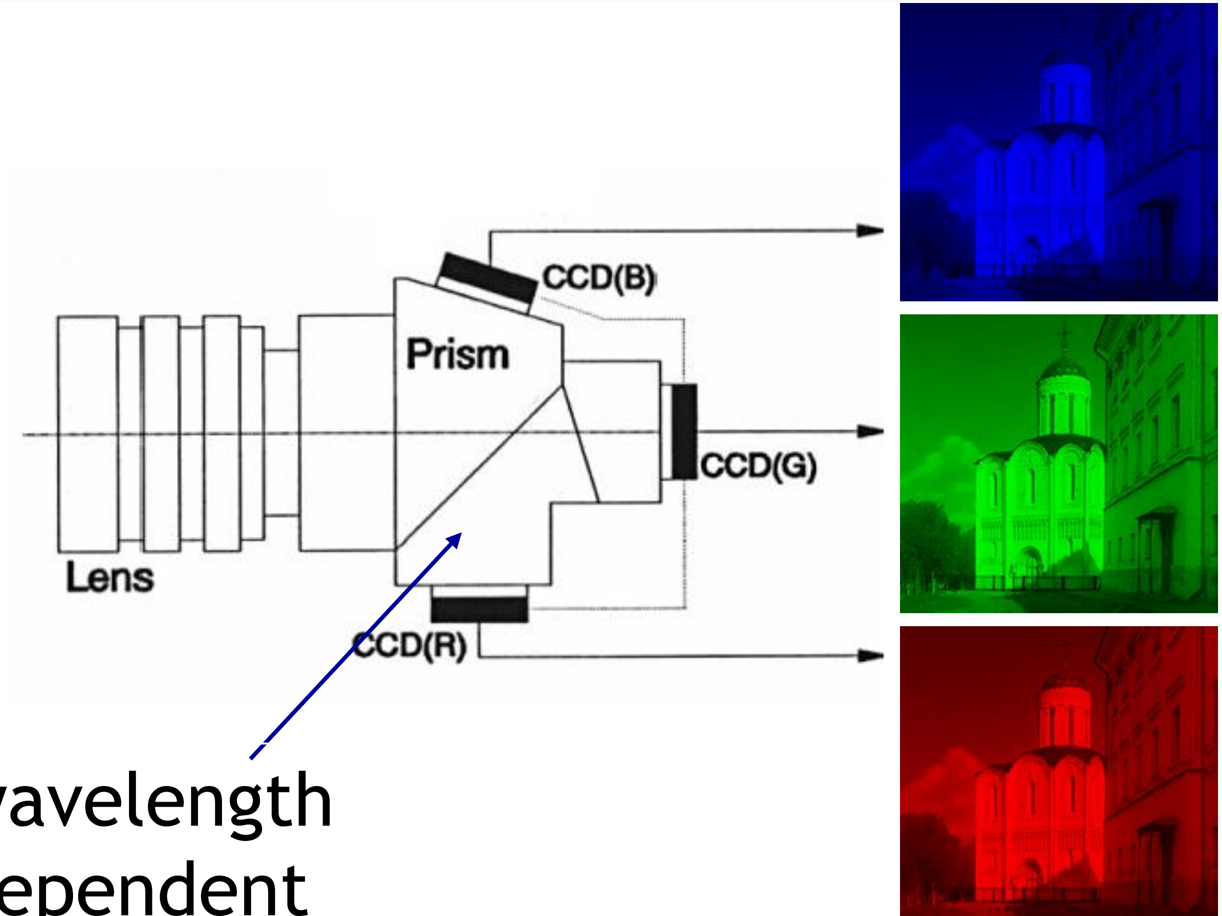
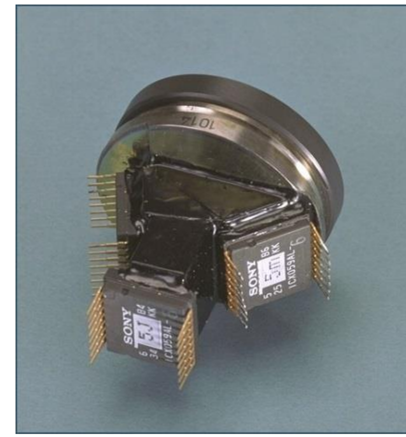


Image source: Wikipedia

1. Original scene
2. Output of a 120×80-pixel sensor with a Bayer filter
3. Output color-coded with Bayer filter colors
4. Reconstructed image after interpolating missing color information
5. Full RGB version at 120×80-pixels for comparison

Multi-chip

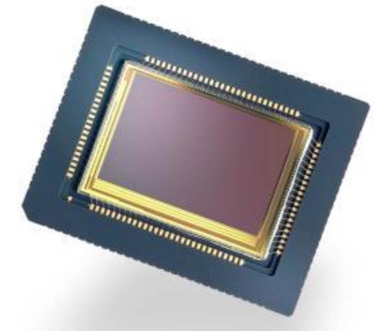


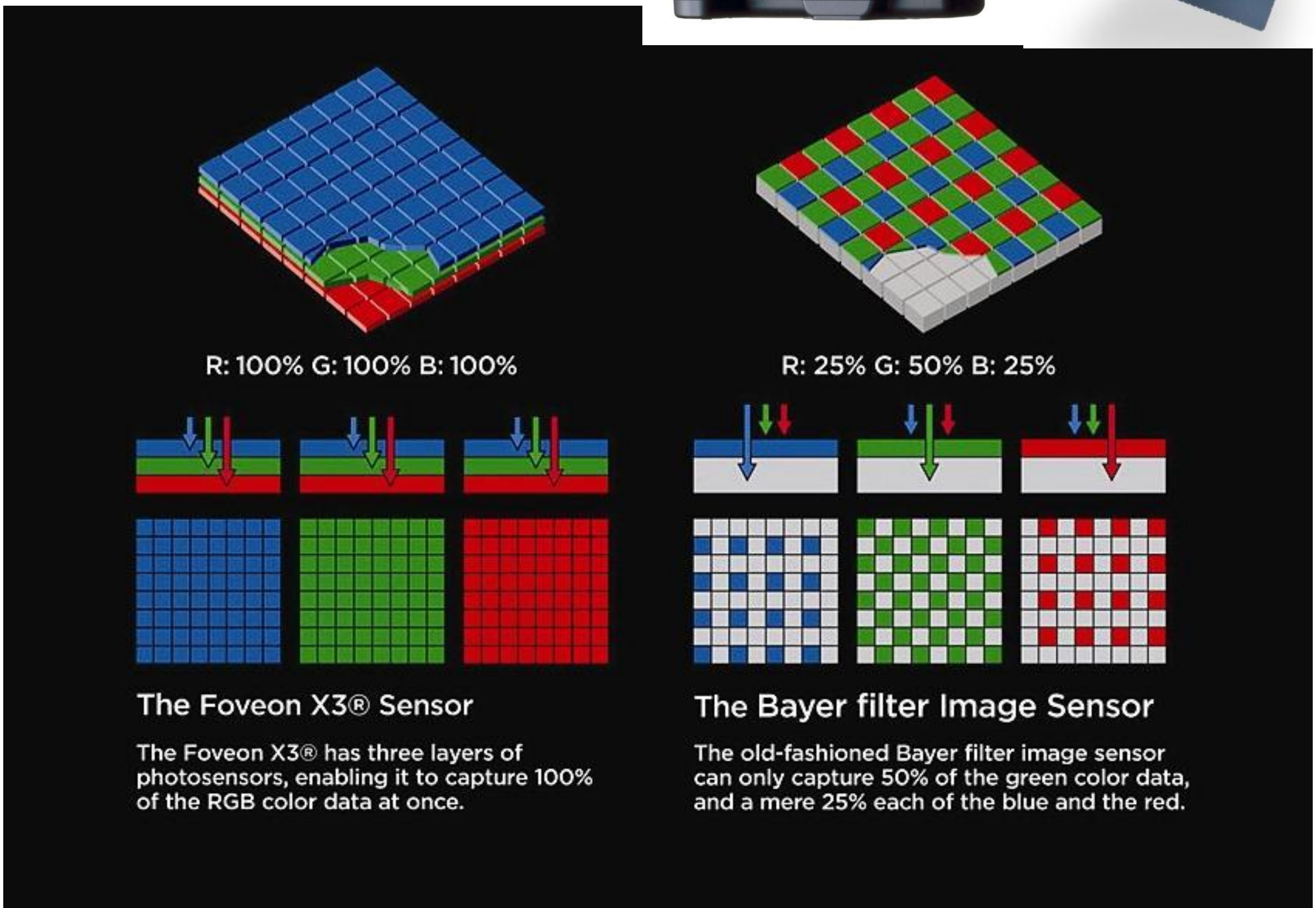


wavelength
dependent

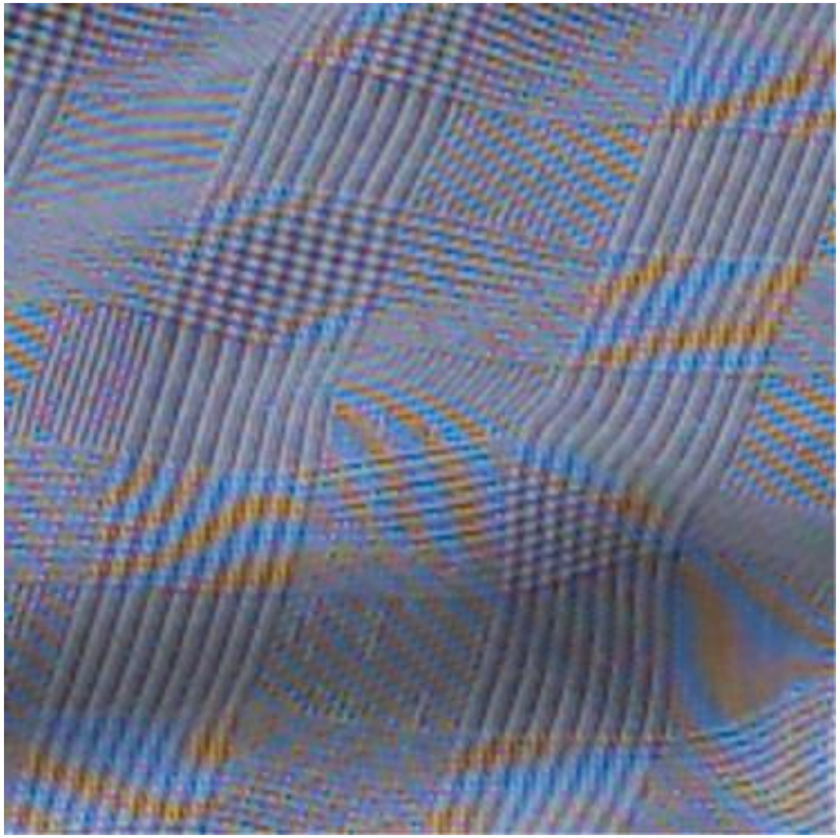
Foveon CCD


SIGMA
SD10

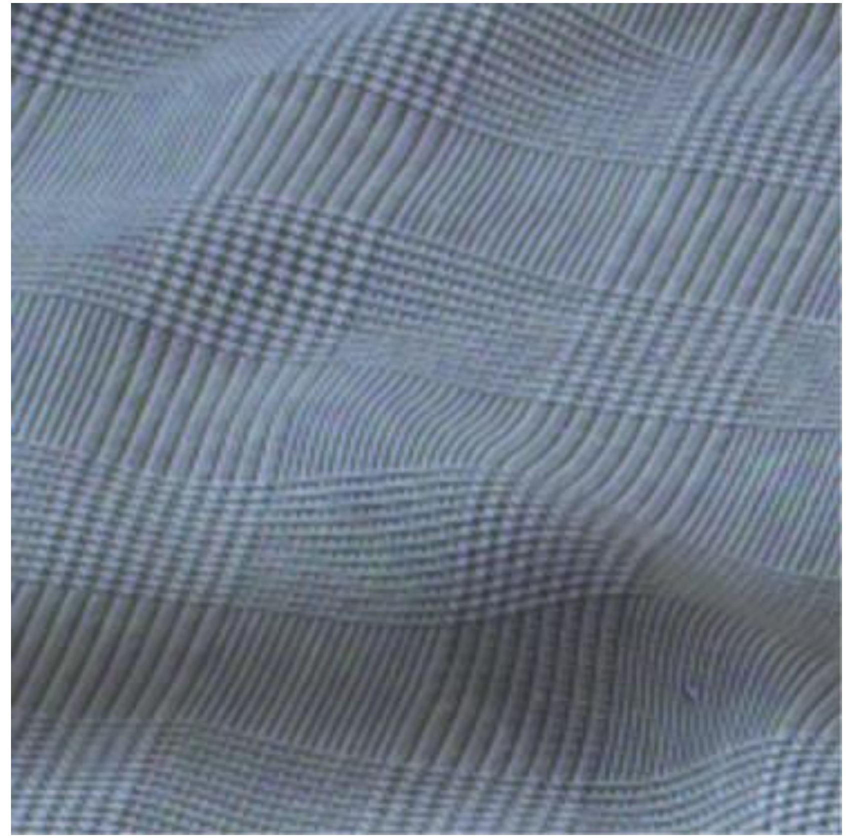



R: 100% G: 100% B: 100%
R: 25% G: 50% B: 25%
The Foveon X3® Sensor
The Foveon X3® has three layers of photosensors, enabling it to capture 100% of the RGB color data at once.
The Bayer filter Image Sensor
The old-fashioned Bayer filter image sensor can only capture 50% of the green color data, and a mere 25% each of the blue and the red.

Foveon CCD



Bayer CFA



X3 sensor