Digital Photography

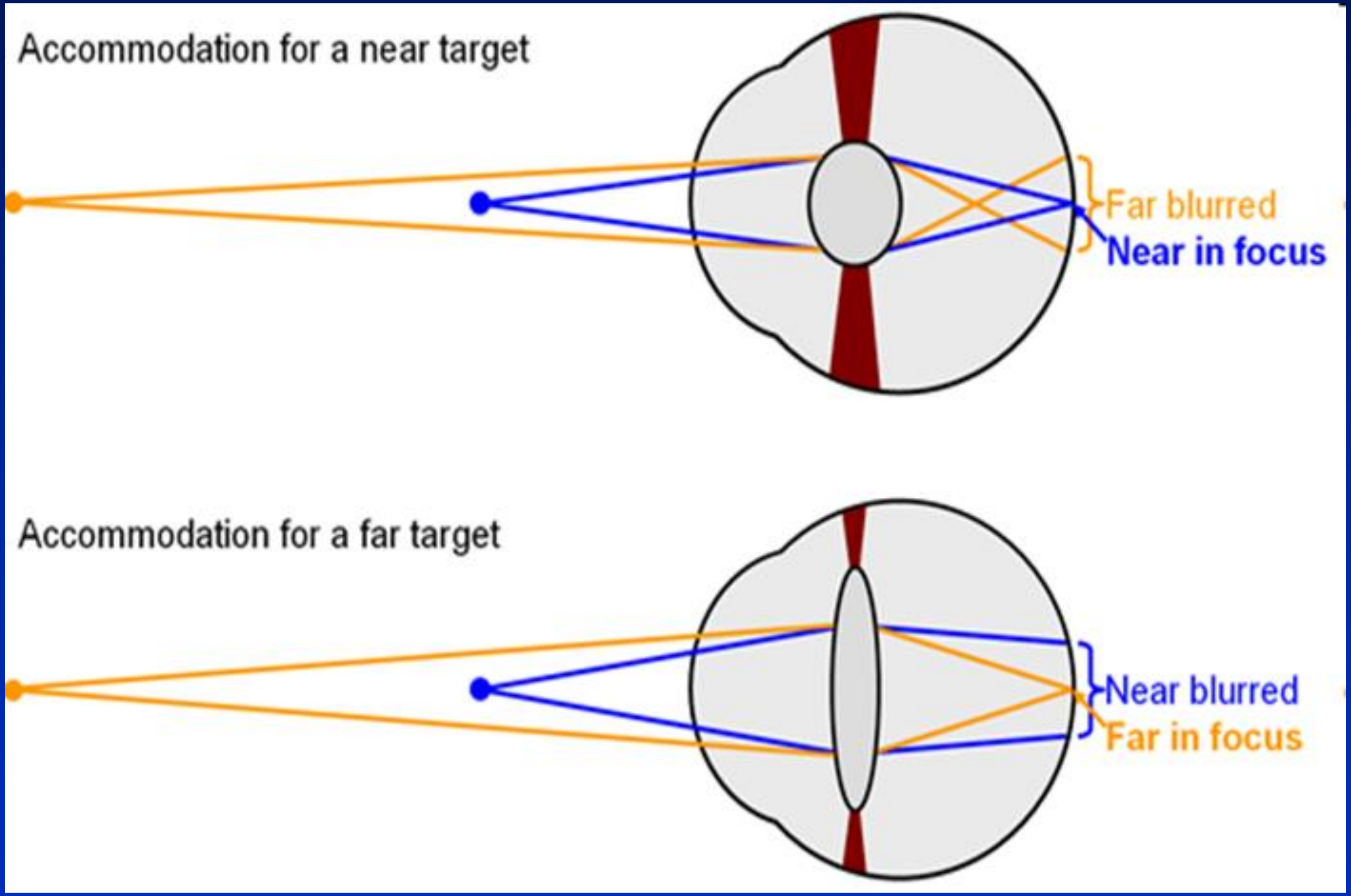
Visual Imaging in the Electronic Age

Lecture #10

Donald P. Greenberg

October 6, 2020

Focus Fundamentals

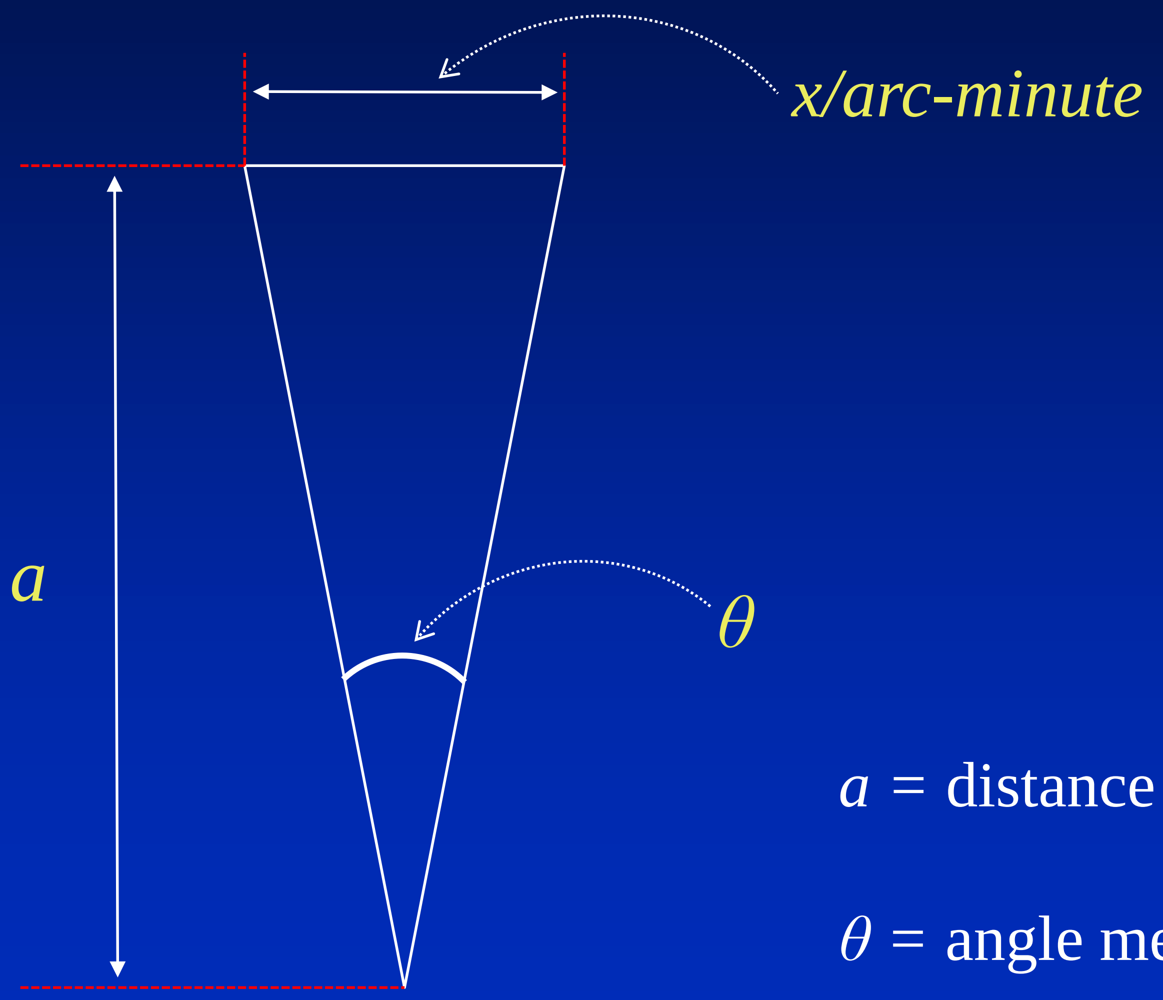


Review Visual Acuity Fundamentals

Visual Acuity

- Visual acuity is defined as “1/a where a is the response in arc-minutes”.
- This acuity is usually measured by a grating test pattern and thus is defined using a line pair.
- It takes two pixels to generate a line pair (black and white).
- Based on a large number of tests, the resolution of the human eye is approximately 0.3 arc minutes.

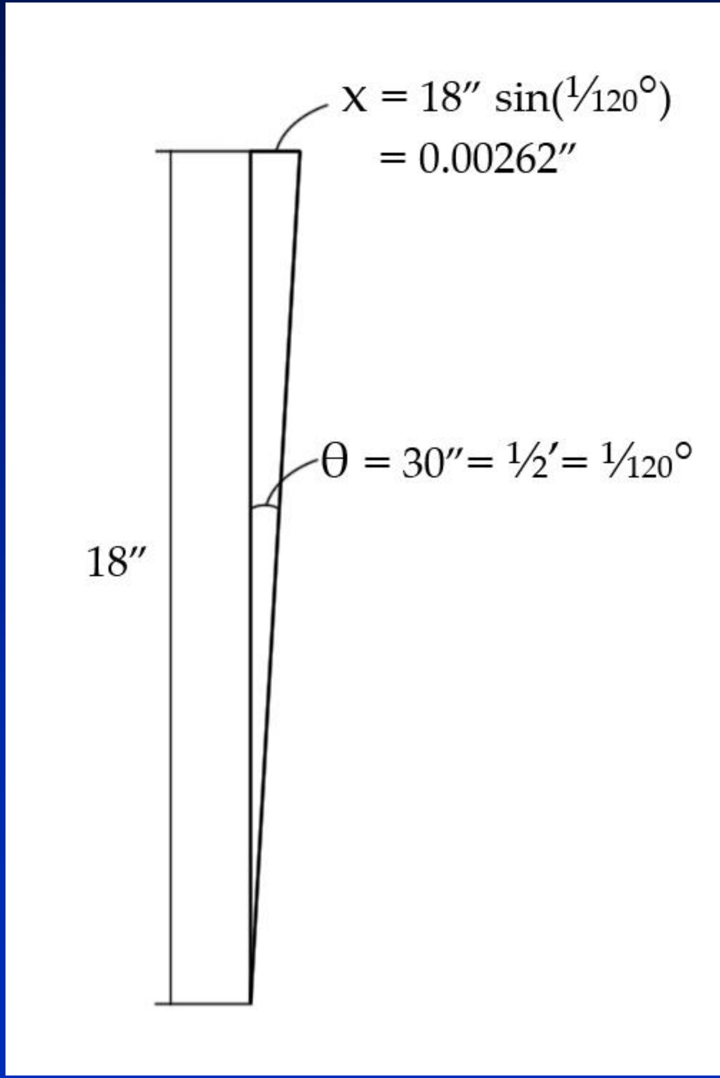
Resolution Limits



a = distance from the screen

θ = angle measured in arc-minutes

Resolution Limit for Reading at 18"



The triangle subtended by a 30 second angle

Sine of 30 sec = sine of 1/120 deg

= sin (0.0083333333)

= 0.000145444

Thus 18"sin(30 sec)

= 0.002617994"


c
b
a

End of Review

Moore's Law

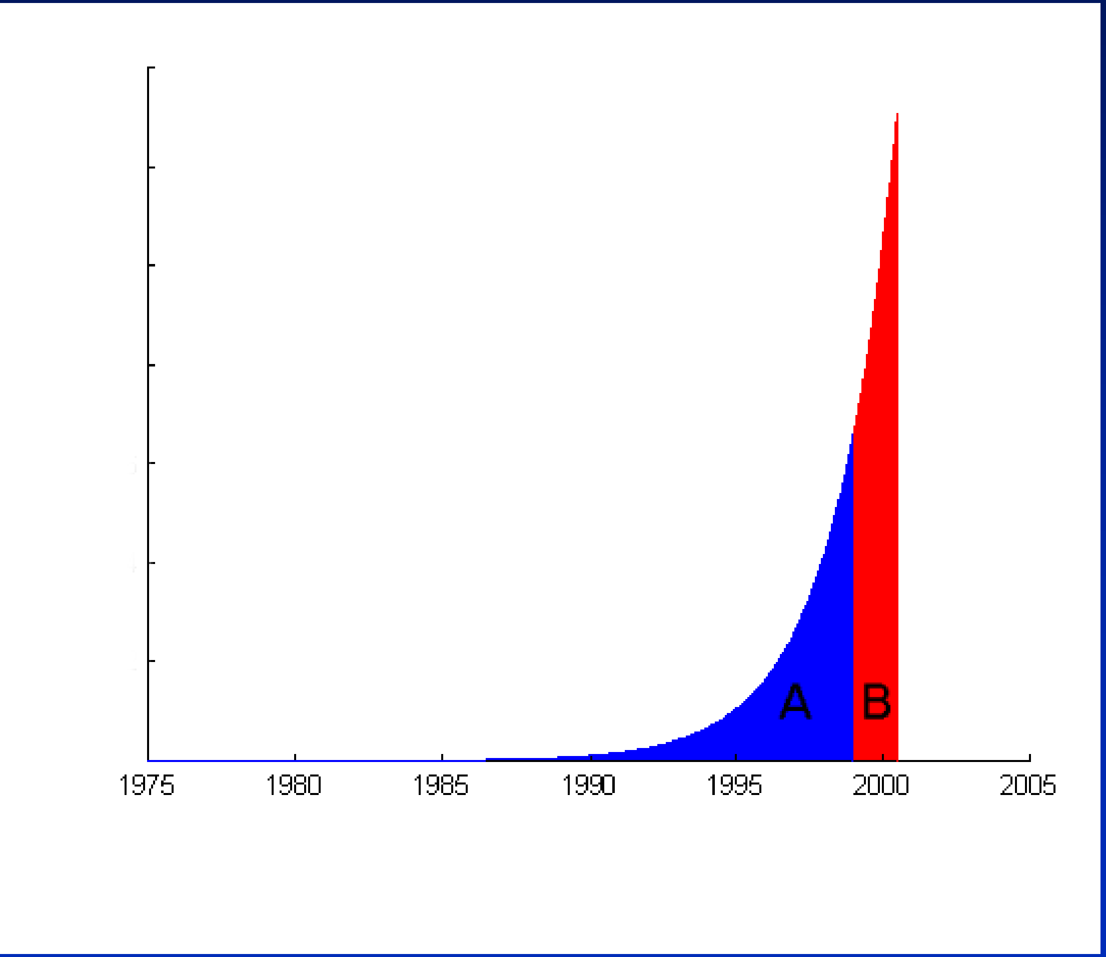
"Chip density doubles every 18 months."

Processing Power (P) in 15 years:

$$P = P_{today}(2)^{\frac{15\,years}{18\,months}} = P_t(2)^{\frac{15}{1.5}}$$

$$= P_t(2)^{10} = 1000P_t$$

Understanding Moore’s Law



History of Photography

Ancient — Camera Obscura – through pinhole

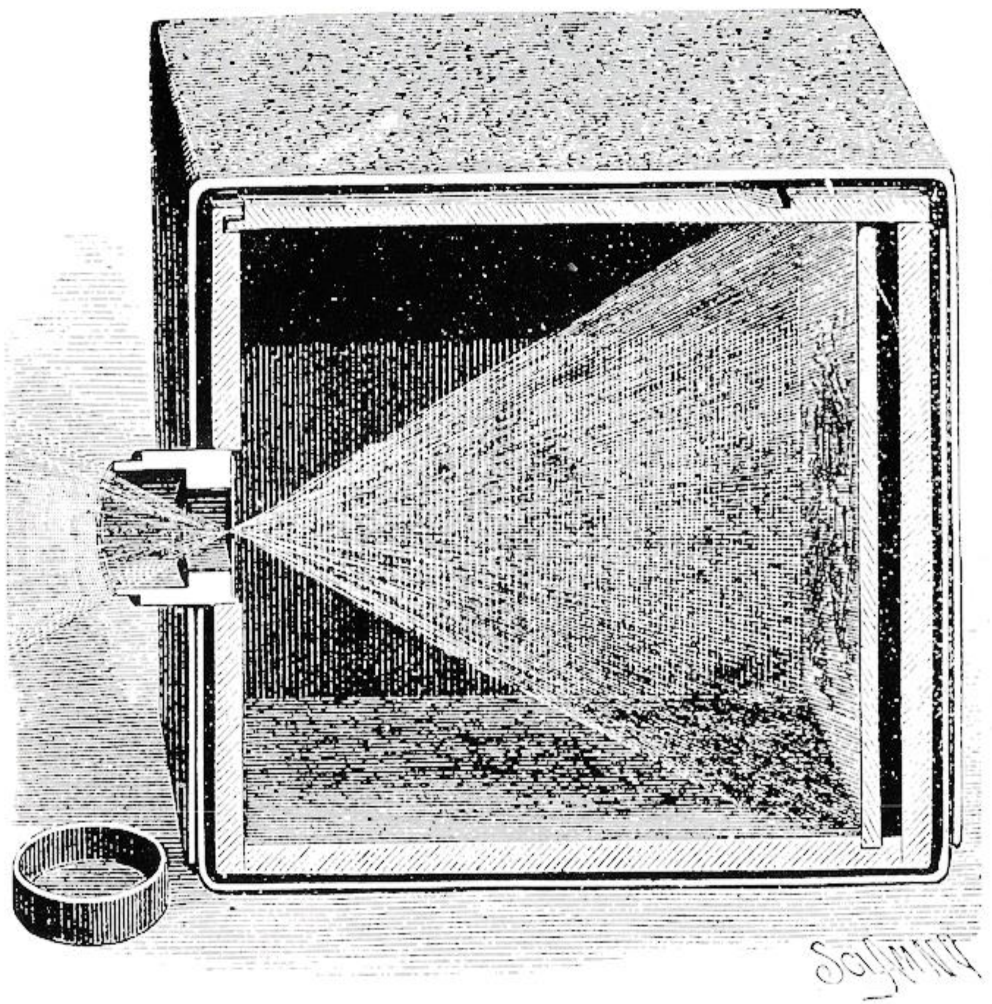
16th - 17th Century — Camera Obscura – improvements by enlarging hole and using telescopic lenses

1837 — Louis Daguerre – creates images on silverplated copper plates

1839 — Alexander Wolcott – added concave mirrors to increase light and was one of America’s first daguerrotype photographers

1861-65 — James Clerk-Maxwell – demonstrates color photography using RGB filters & 3 projectors

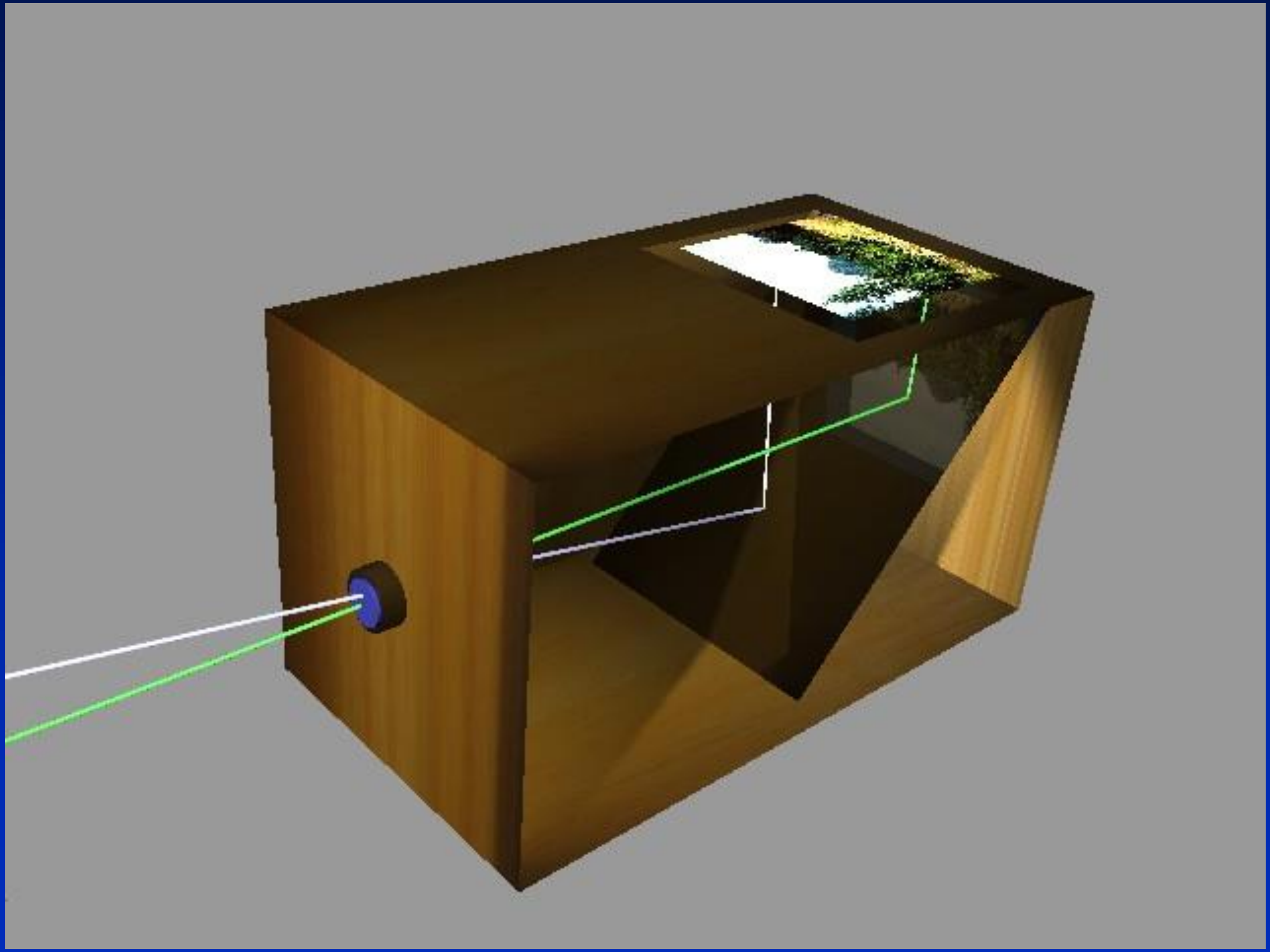
Pinhole Camera



Glen Camera from Scientific American Vol. 65, July 4, 1891

Note that the entire image through the pinhole is totally in focus on a single image plane.

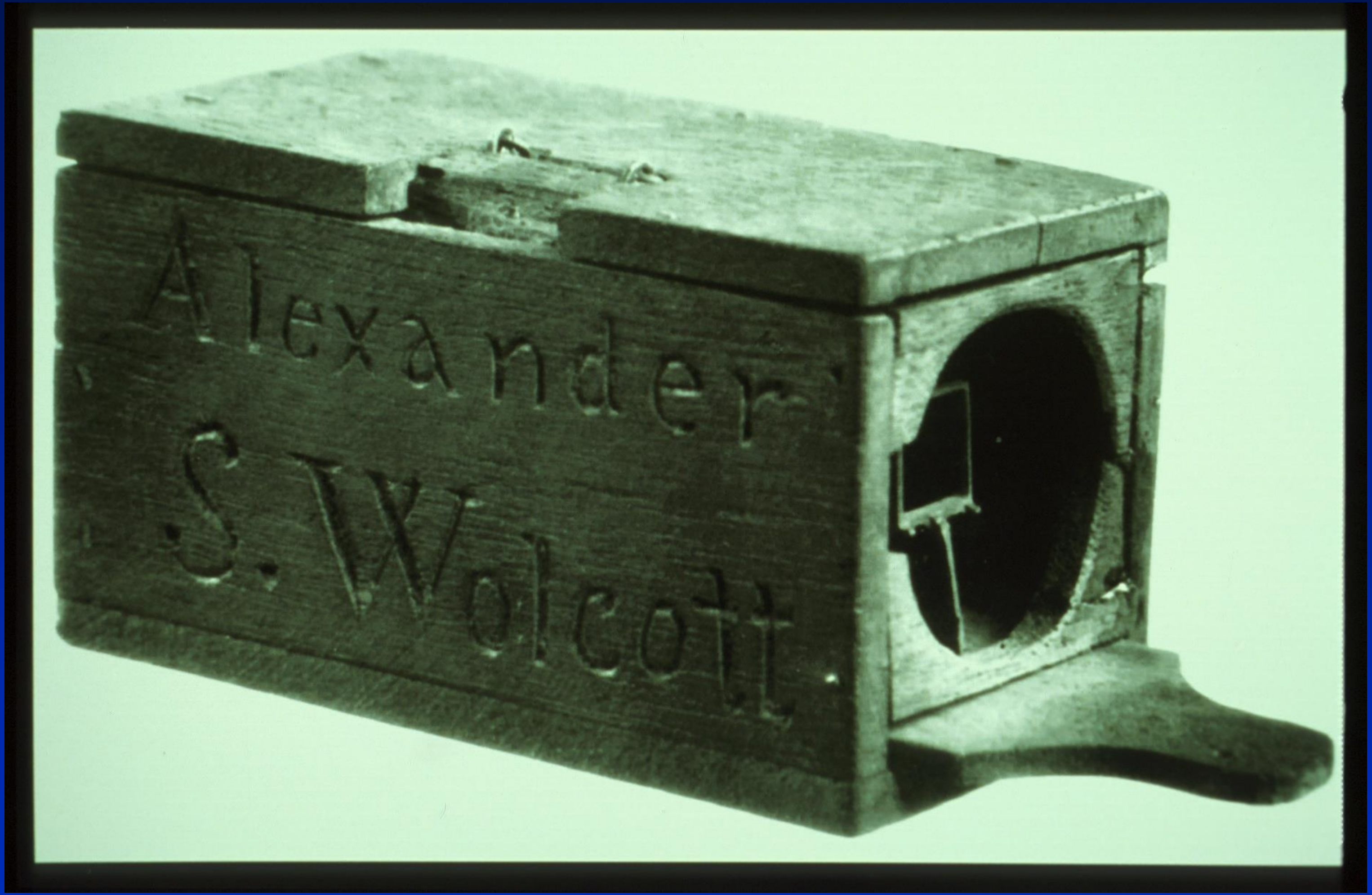
Camera Obscura



http://en.wikipedia.org/wiki/Camera_obscura

Daguerre’s Early Photograph 1838

Wolcott’s Camera 1859



William F. Strapp. “Technology of the Portrait, p. 108.

Civil War - Mathew Brady 1860’s

Image Paradigm Shift 1855-1872

- To move from black and white imagery to color pictures. James Clerk Maxwell showed that by using red, green, and blue projectors he could generate color images.
- A change from single lenses to multiple lenses.

Maxwell’s Color Projection 1855-1872

History of Photography (continued)

1860 — Mathew Brady – covers American Civil War, first photojournalism

1877 — Eadweard Muybridge – “Do a horse’s four hooves ever leave the ground at once?” Using time-sequenced photographs of Leland Stanford’s horses to settle a bet among rich San Franciscans

1880 — George Eastman – sets up Eastman Dry Plate Company in Rochester, NY

1934 — Mannes & Godowsky – developed full color Kodachrome film

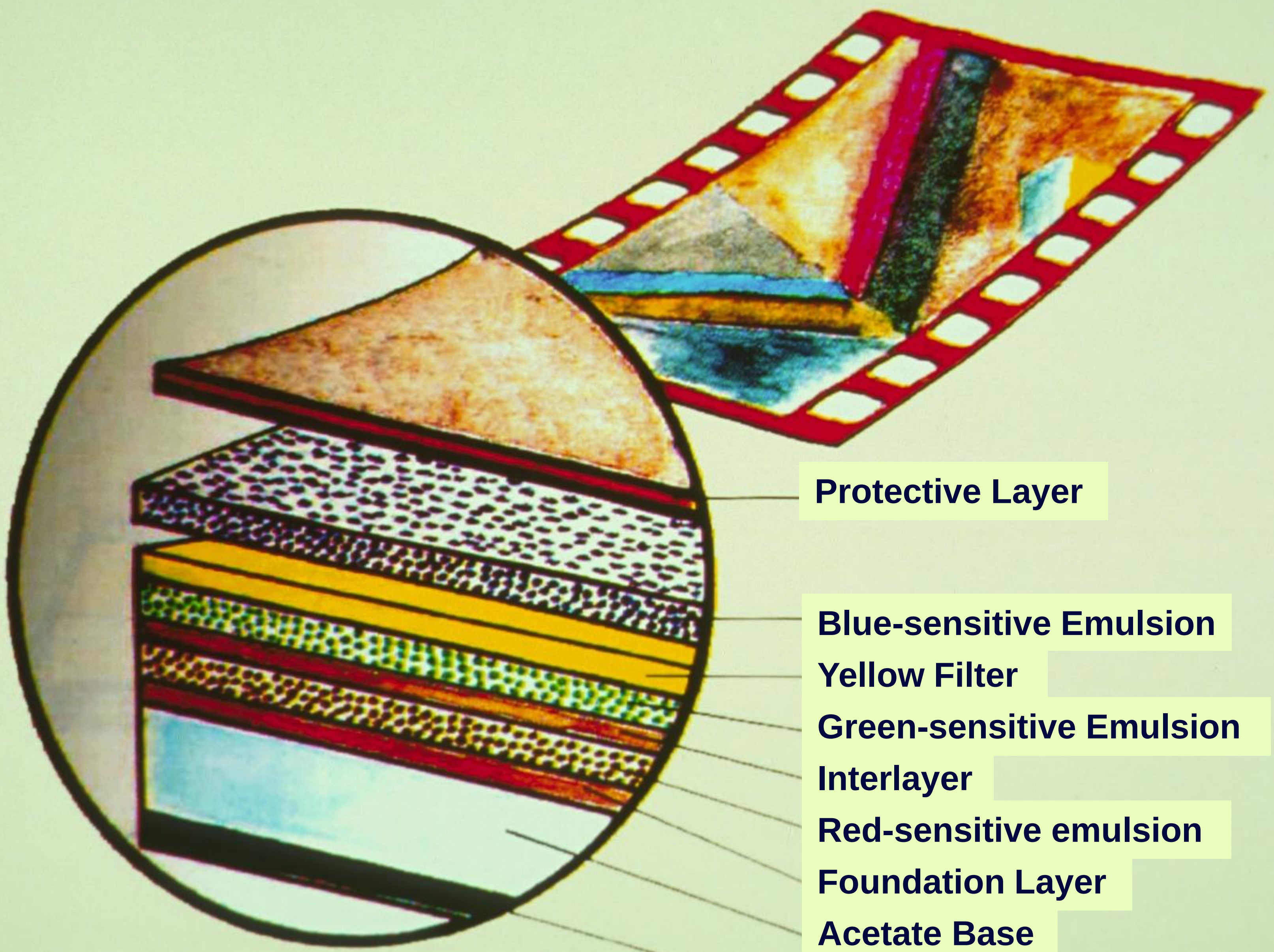
Color Film Paradigm Shift

From multiple lenses or multiple exposures
to multiple layered film

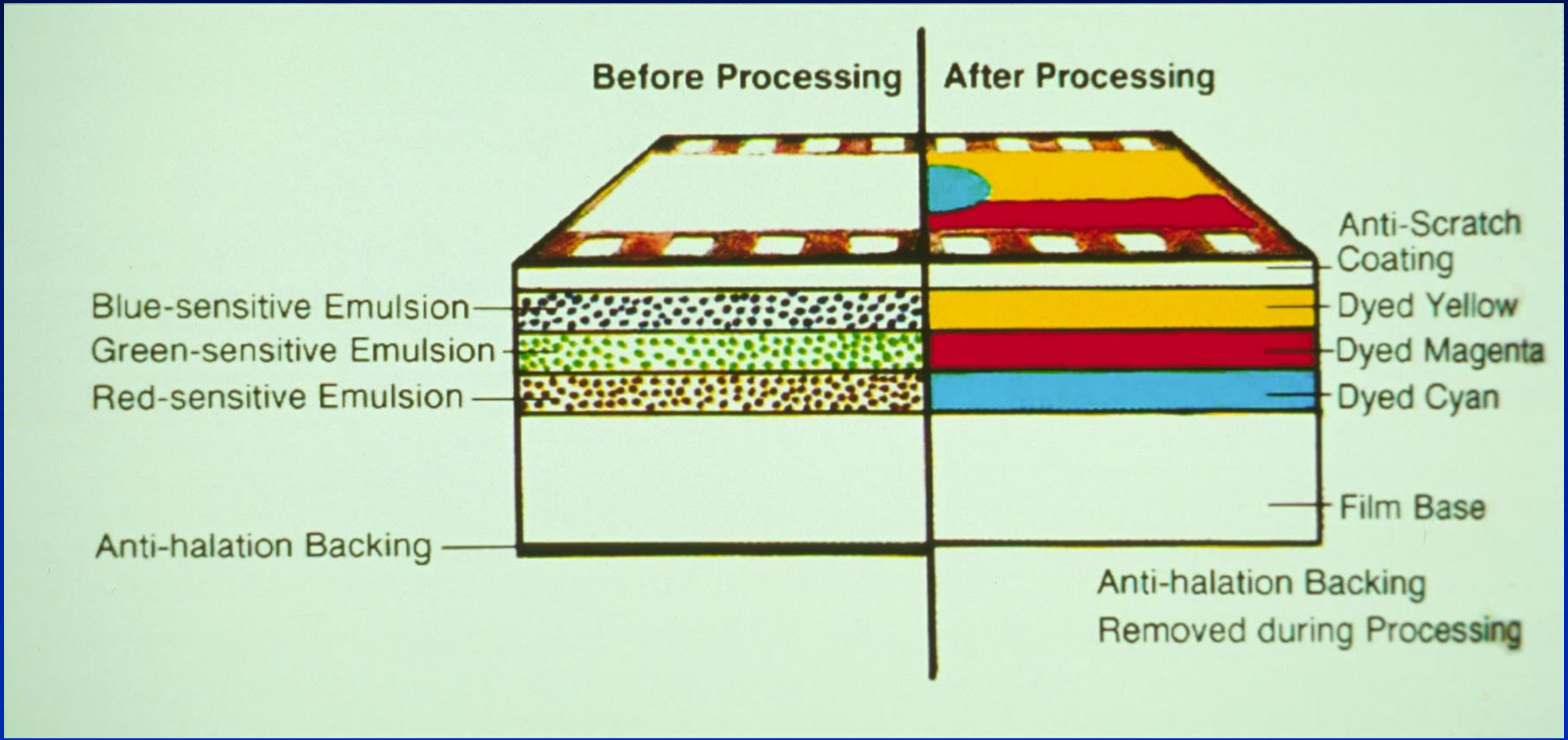
The transition from the optical approach to the
chemical approach formed the new basis for
color photography

Mannes & Godowsky
1920’s


(The Story of Kodak, Douglas Collins p. 205)



(fig. 1.6, Color Photography, Robert Hirsch, p. 5)



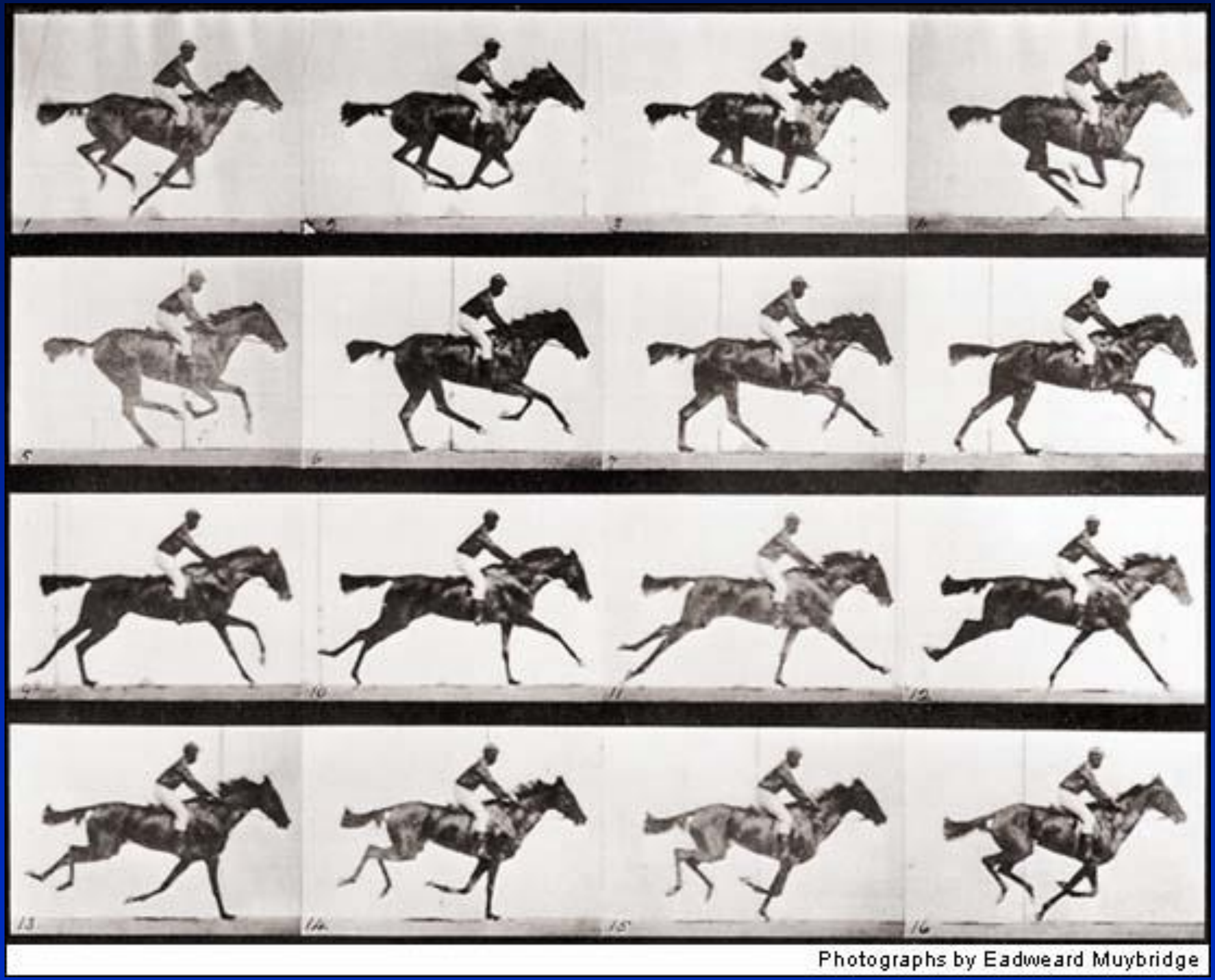
(fig. 1.8, Color Photography, Robert Hirsch, p. 6)

Kodak's Early Camera 1888

from The Story of Kodak, Douglas Collins 1990, p. 57

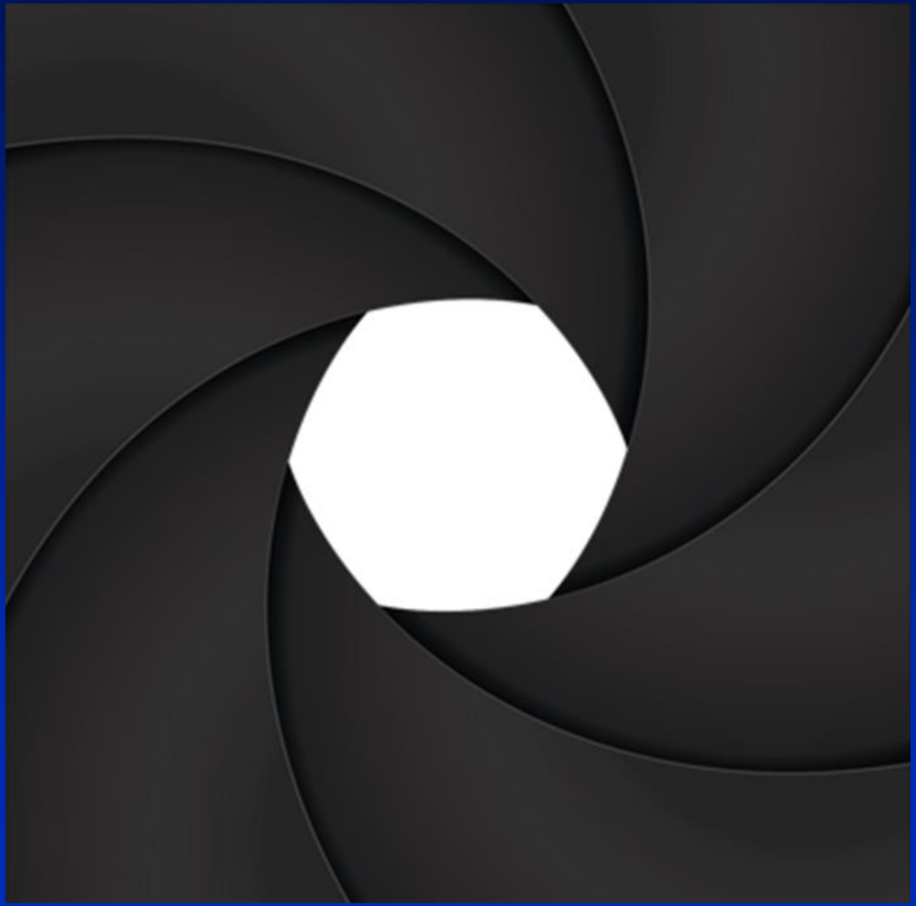
Capturing Motion Strobe Photograpgy

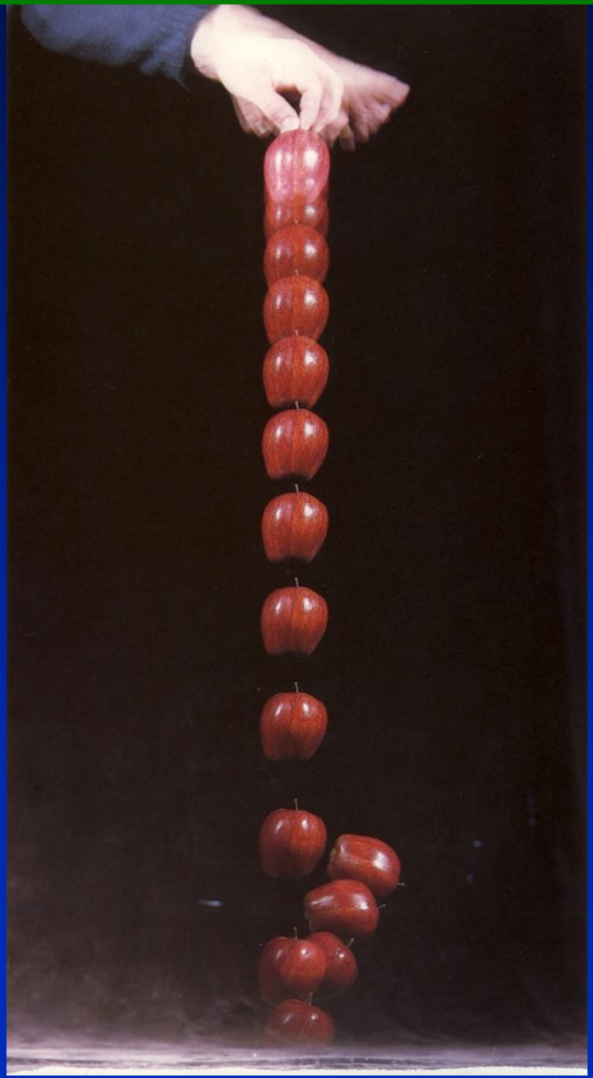
Eadweard Muybridge - Galloping Horse 1878



Newton’s Apple

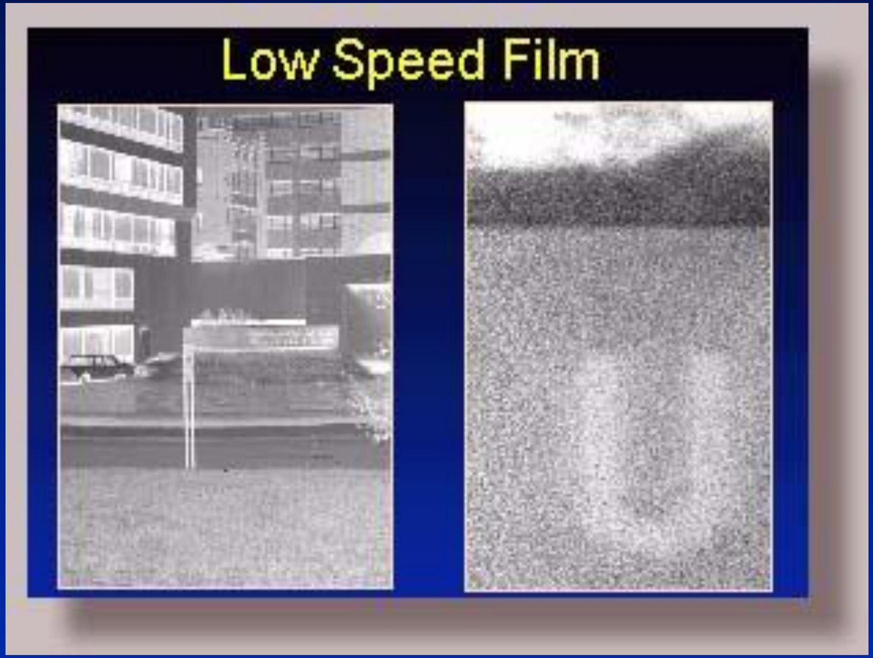
Edgerton 1970

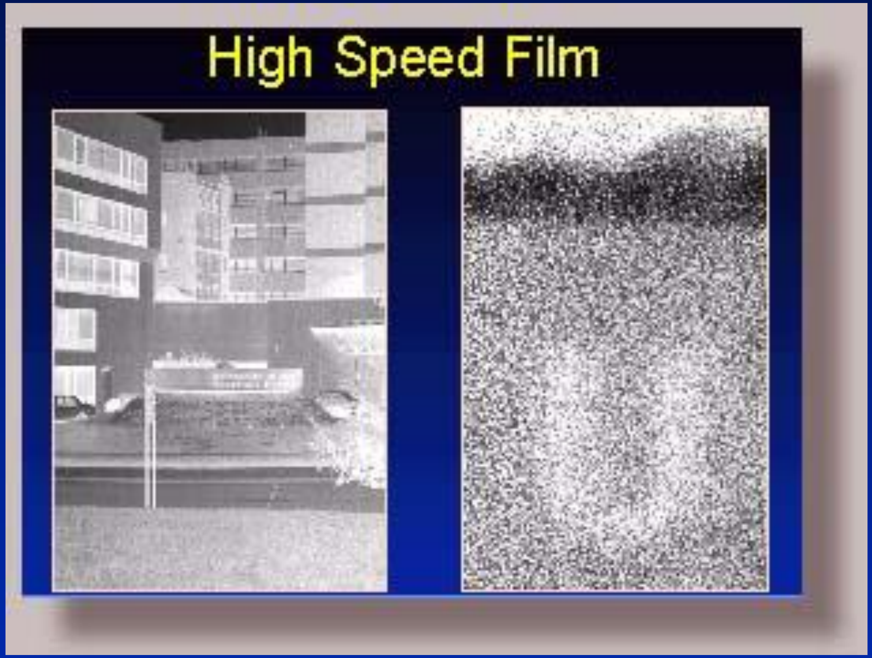




From Stopping Time, The Photographs of Harold Edgerton” by Harry N. Abrams, 1987.

Silver Halide





A low speed, ISO 32 film produces this fine grained image. The right image is a small portion of the whole negative on the left.

A high speed, ISO 400 film produces a coarser grain with less apparent sharpness in the image.

Paul R. Montague. “Digital Imaging Comparing Film with Digital Images,” The Ophthalmic Photographers’ Society, Inc. http://www.opsweb.org/Op-Photo/Digital/DigImage1.htm

Polaroid Land Camera

Kodak color 35mm Film


SPECIAL REPORT
THE BEST IN EXECUTIVE EDUCATION
BusinessWeek
OCTOBER 20, 1997
A PUBLICATION OF THE McGRAW-HILL COMPANIES
$3.50
Kodak
Royal Gold
200
CAN GEORGE FISHER FIX KODAK?
PAGE 116
Internet: www.businessweek.com America Online: Keyword: BW


GLOBAL 1000 THE TOP COMPANIES
TOBACCO HOW THE DEAL WILL CHANGE
U.S. ECONOMY NEW NUMBERS, ROSIER VIEW
BusinessWeek
JULY 7, 1997
A PUBLICATION OF THE McGRAW-HILL COMPANIES
$3.50
SHOOTOUT!
LEW PLATT, CEO, HEWLETT-PACKARD
HOW HP PLANS TO TAKE ON KODAK— AND REVOLUTIONIZE THE WAY YOU CAPTURE AND PRINT IMAGES
PAGE 100
Internet: www.businessweek.com America Online: Keyword: BW

Digital Cameras

CCD Technology

- 1969 George Smith & Willard Boyle invented the CCD image sensor at Bell Labs. The Nobel Laureates were looking to develop a video phone.
- 1970 They built the world's first solid state video camera
- 1981 Sony produced the Mavica, the first digital camera
- 1991 Kodak scientist creates the first professional digital camera with a 1.3 Megapixel sensor

How CCD's Work

Photons incident on the silicon surface generate a charge that can be read by electronics.

CCD Technology

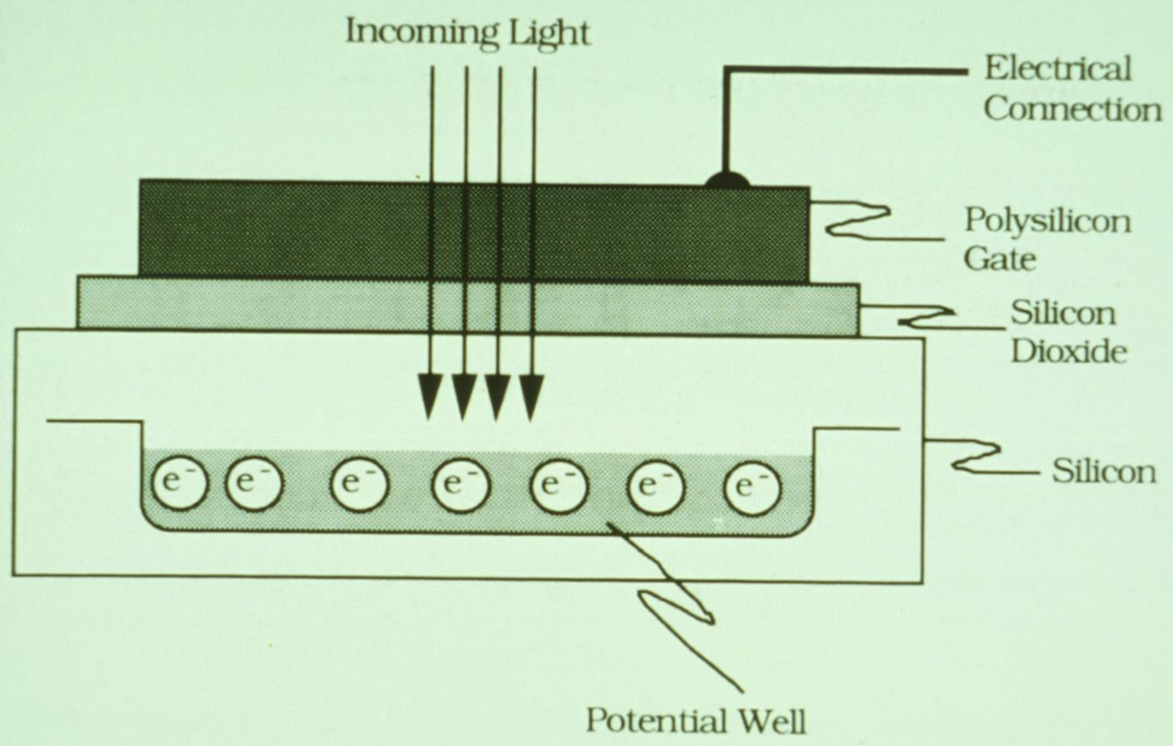


Fig. 2. Simple photodetector

(Charge-Coupled Devices for Quantitative Electronic Imaging, 1991 Photo-metrics, Ltd. p. 6)

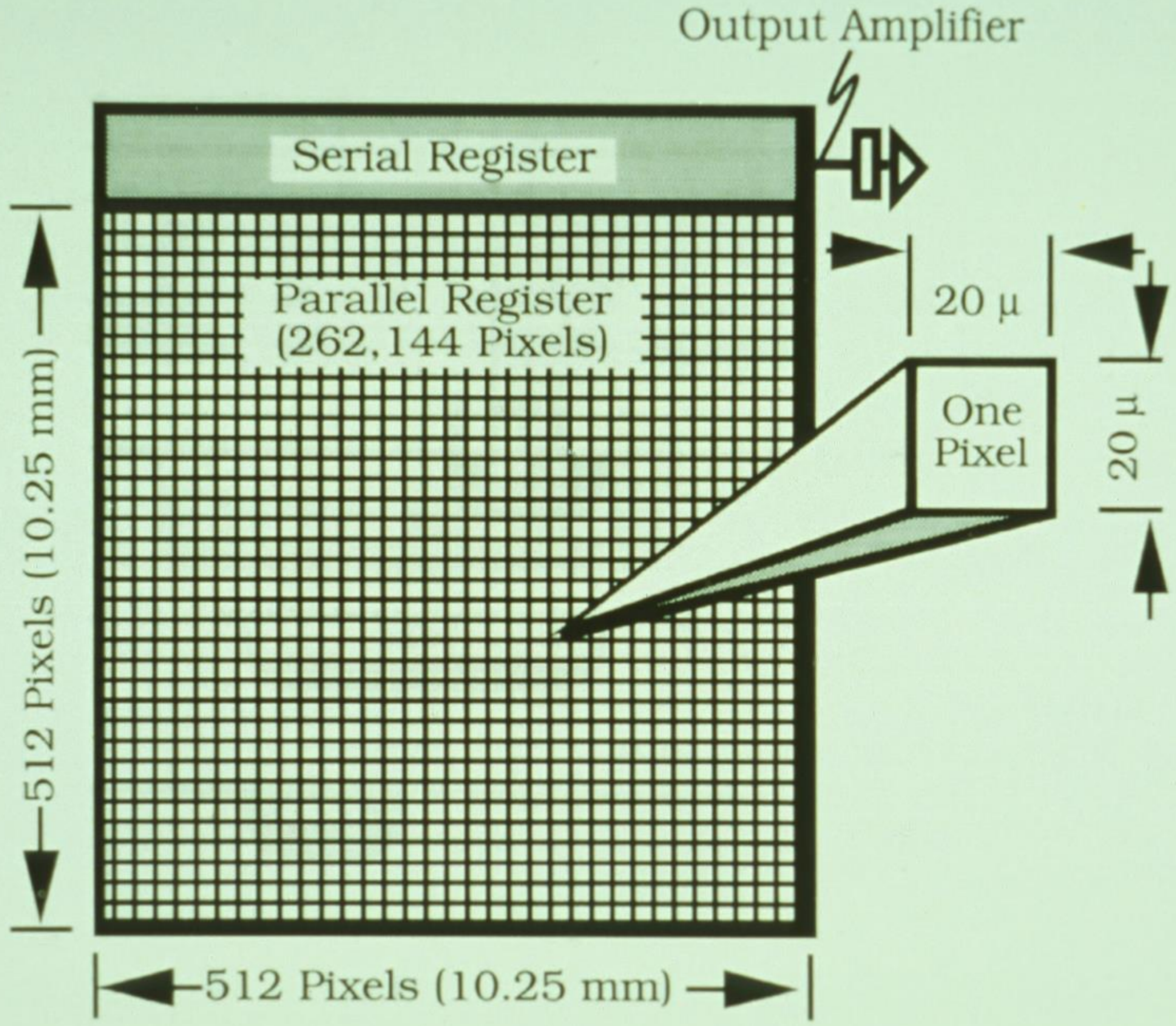
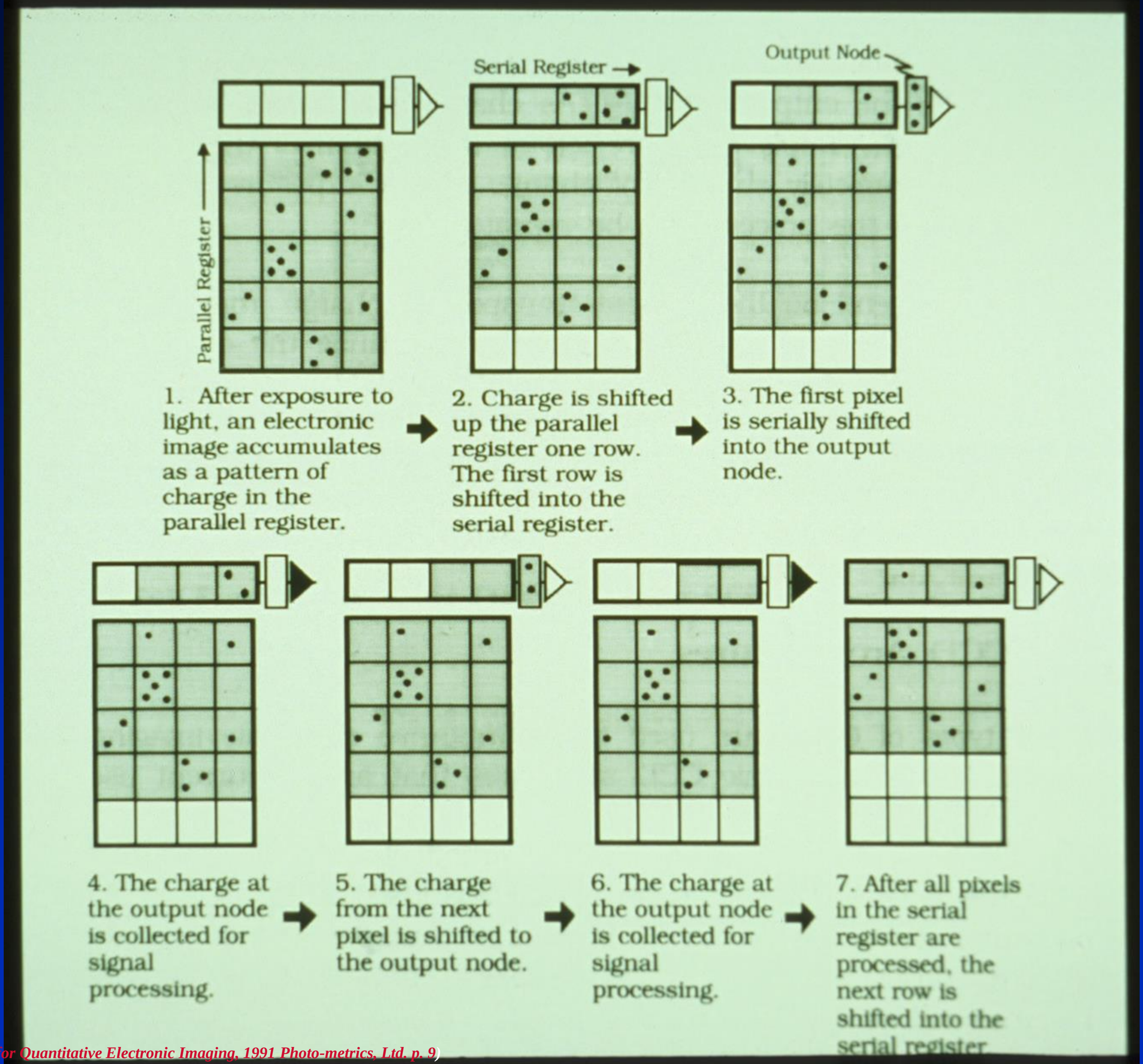


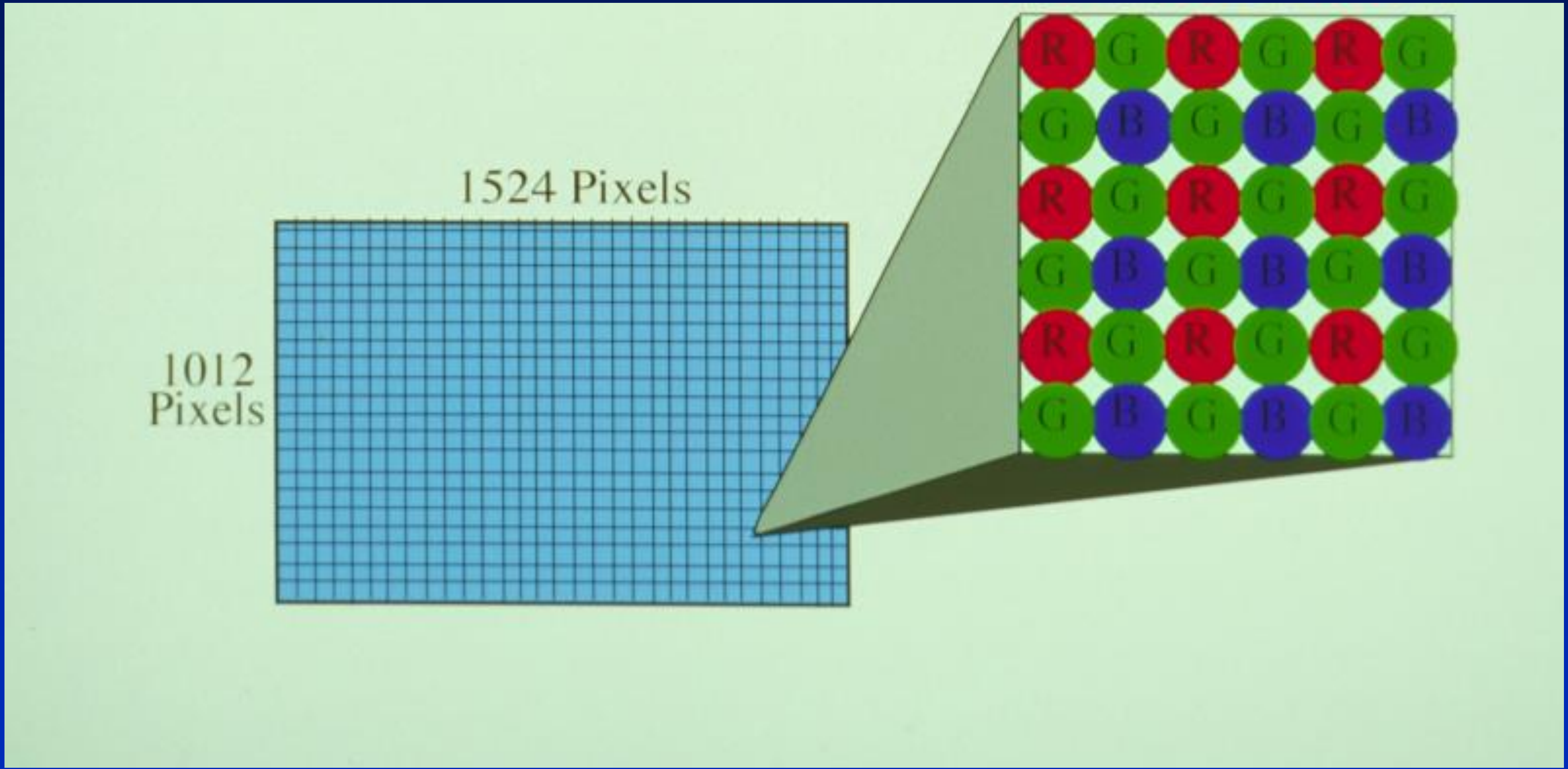
Fig. 4. Typical scientific-grade CCD imager

(Charge-Coupled Devices for Quantitative Electronic Imaging, 1991 Photometrics, Ltd. p. 8)



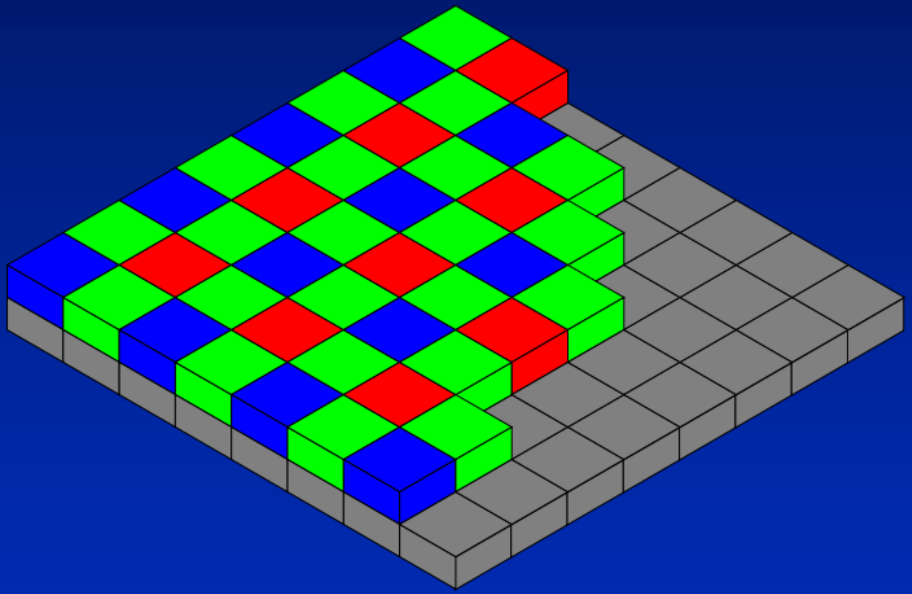
(Charge-Coupled Devices for Quantitative Electronic Imaging, 1991 Photo-metrics, Ltd. p. 9)

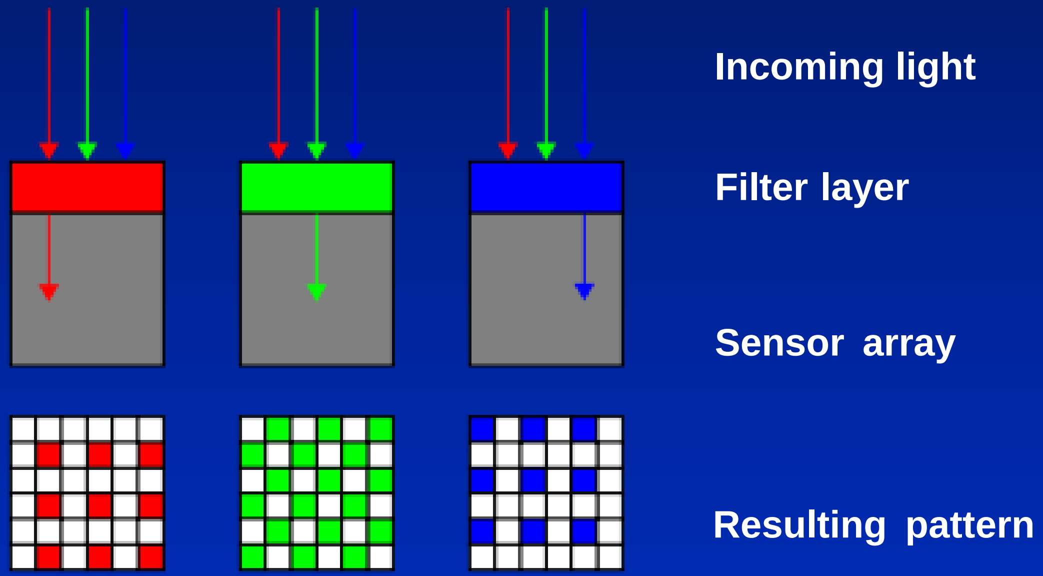
Kodak DCS420 (Charge-Coupled Device)



$14,000 -
June 1994

Bayer pattern





Cost of CMOS image sensors ~ $1

Wikipedia

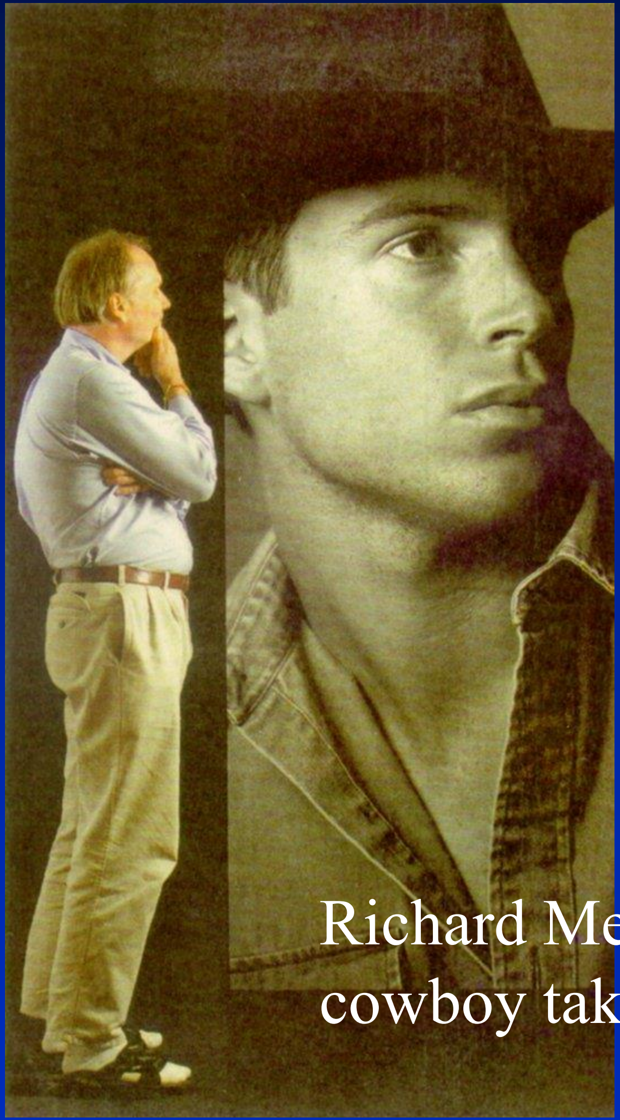
Foveon

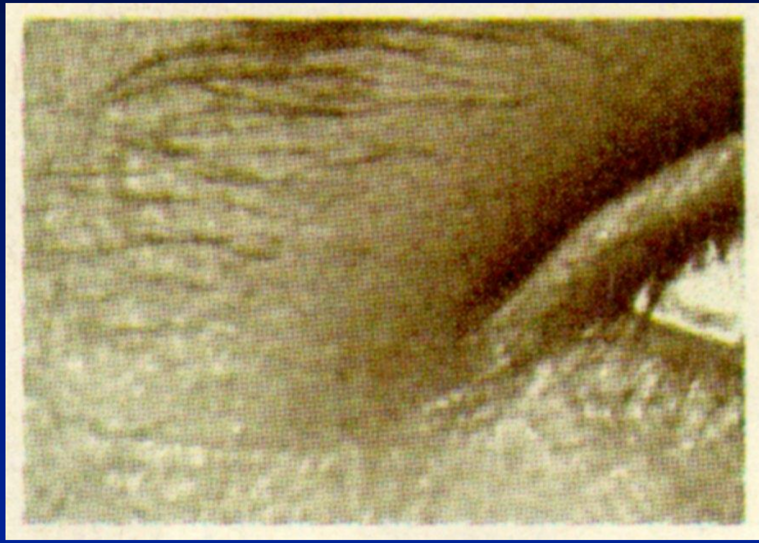
- Founded by Dr. Carver Mead (1997)
- Uses CMOS technology (not CCD)

- Specifications and Performance
  - Resolution 16.8 Mpixels
  - 7 active transistors behind each pixel
  - Less interference, better focusing
  - More precise exposure times
  - Smarter pixels

Foveon Camera 16.8 Megapixels

New Chip Technology





The fine detail of an eyebrow, above, showing hairs without breaking up into dots, or pixels.

Richard Merrill, Foveon’s senior scientist, beside a print of a cowboy taken using the company’s new chip technology

John Markoff. NYT, “Low-Price, Highly Ambitious Digital Chip”, 9/11/00, C1.

U.S. Patent 5,965,875 (Oct. 12, 1999)

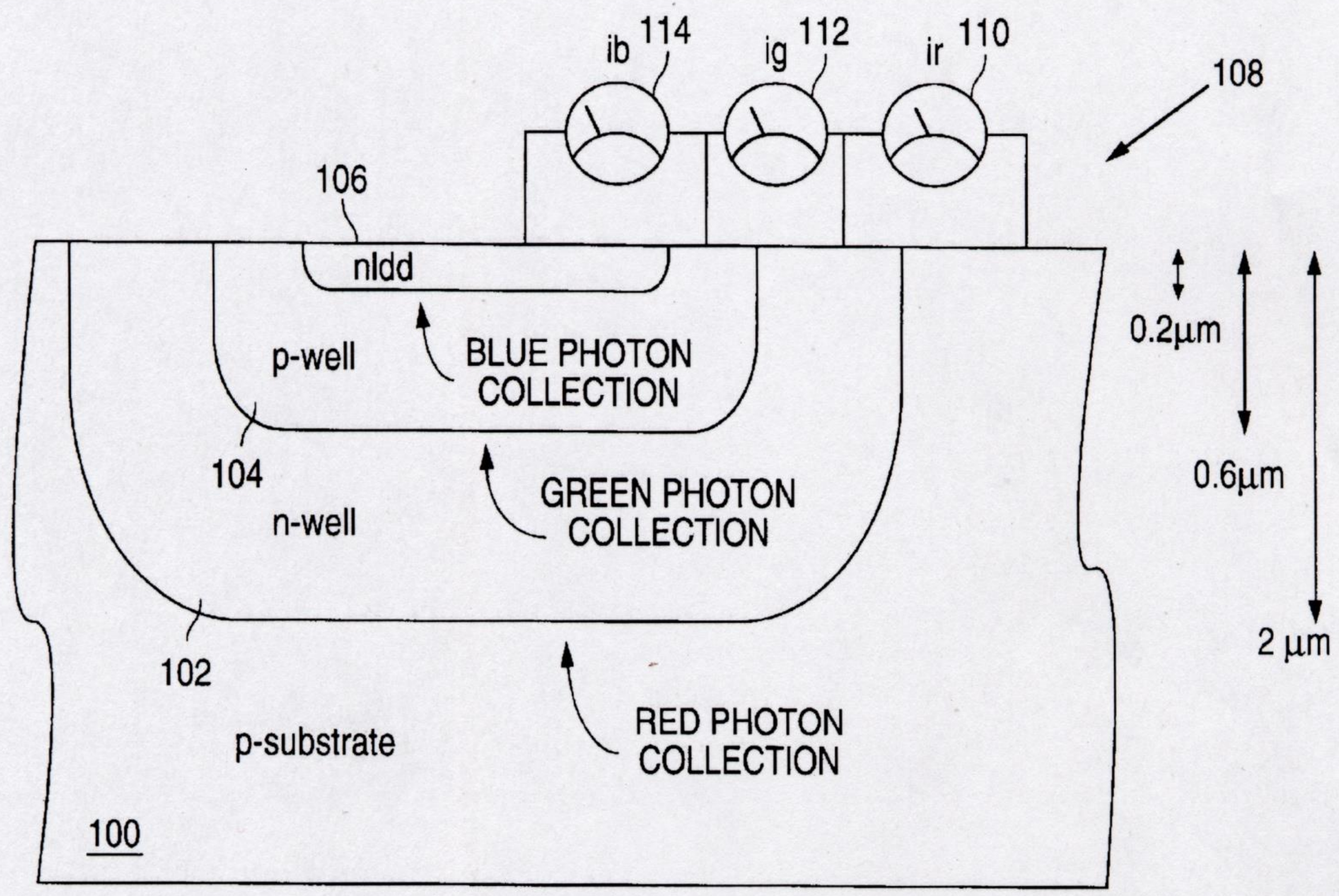
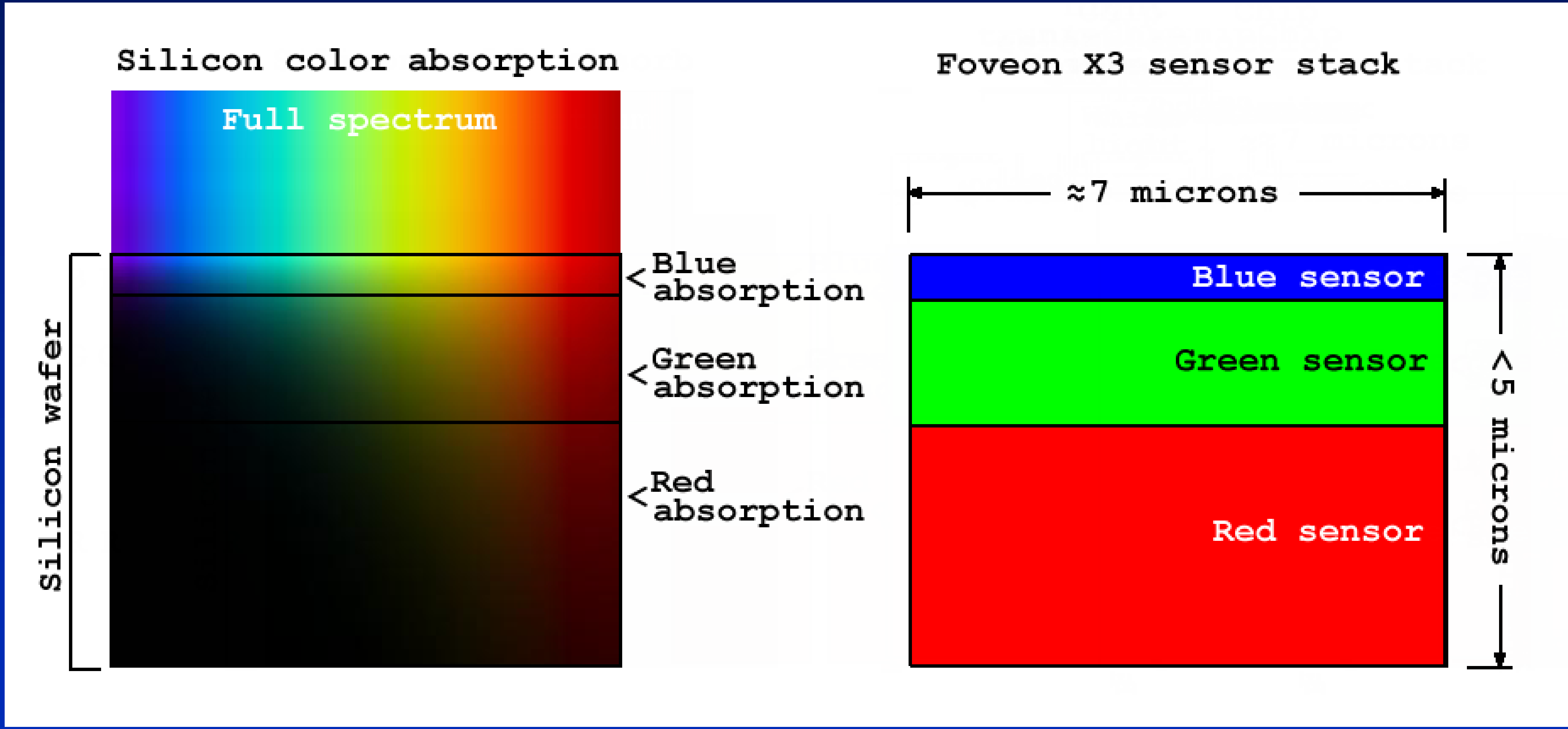


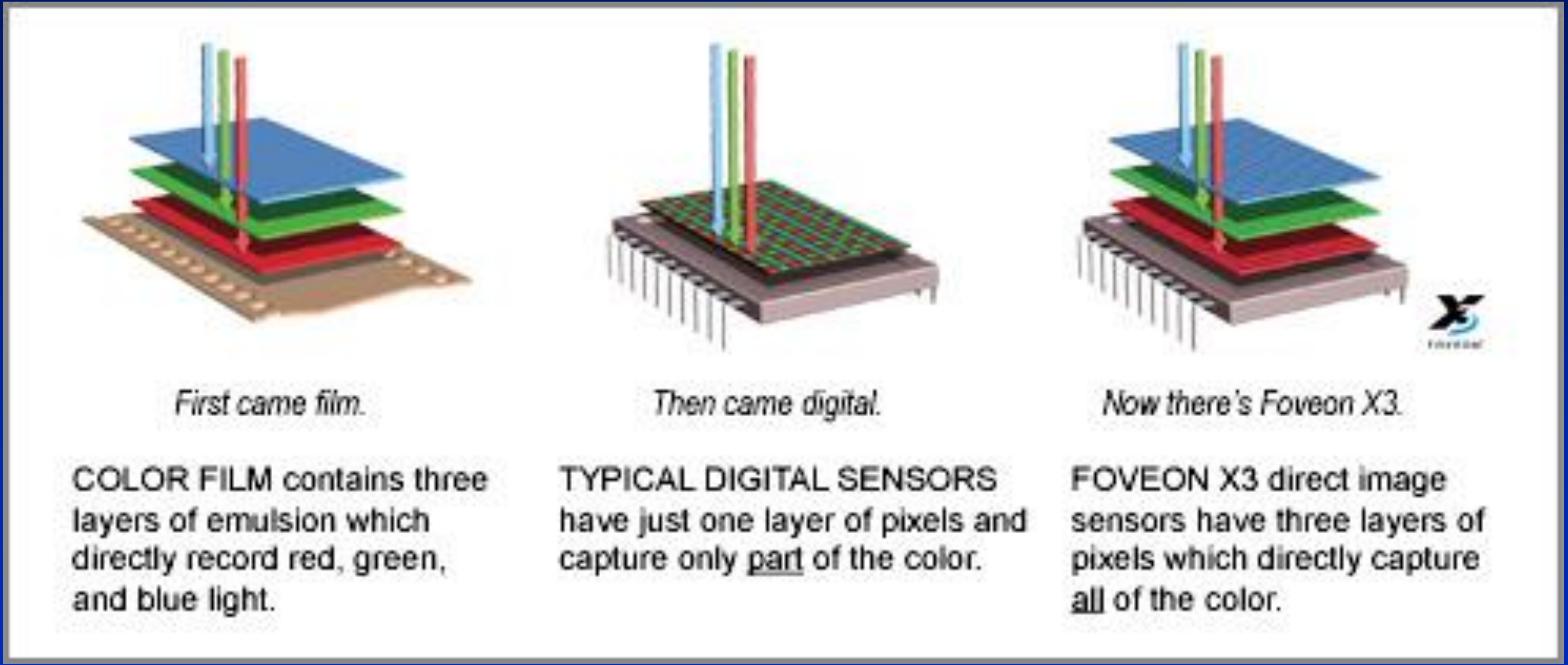
FIG. 6

Foveon



Silicon color absorption
Full spectrum
Silicon wafer
Blue absorption
Green absorption
Red absorption
Foveon X3 sensor stack
≈7 microns
Blue sensor
Green sensor
Red sensor
<5 microns

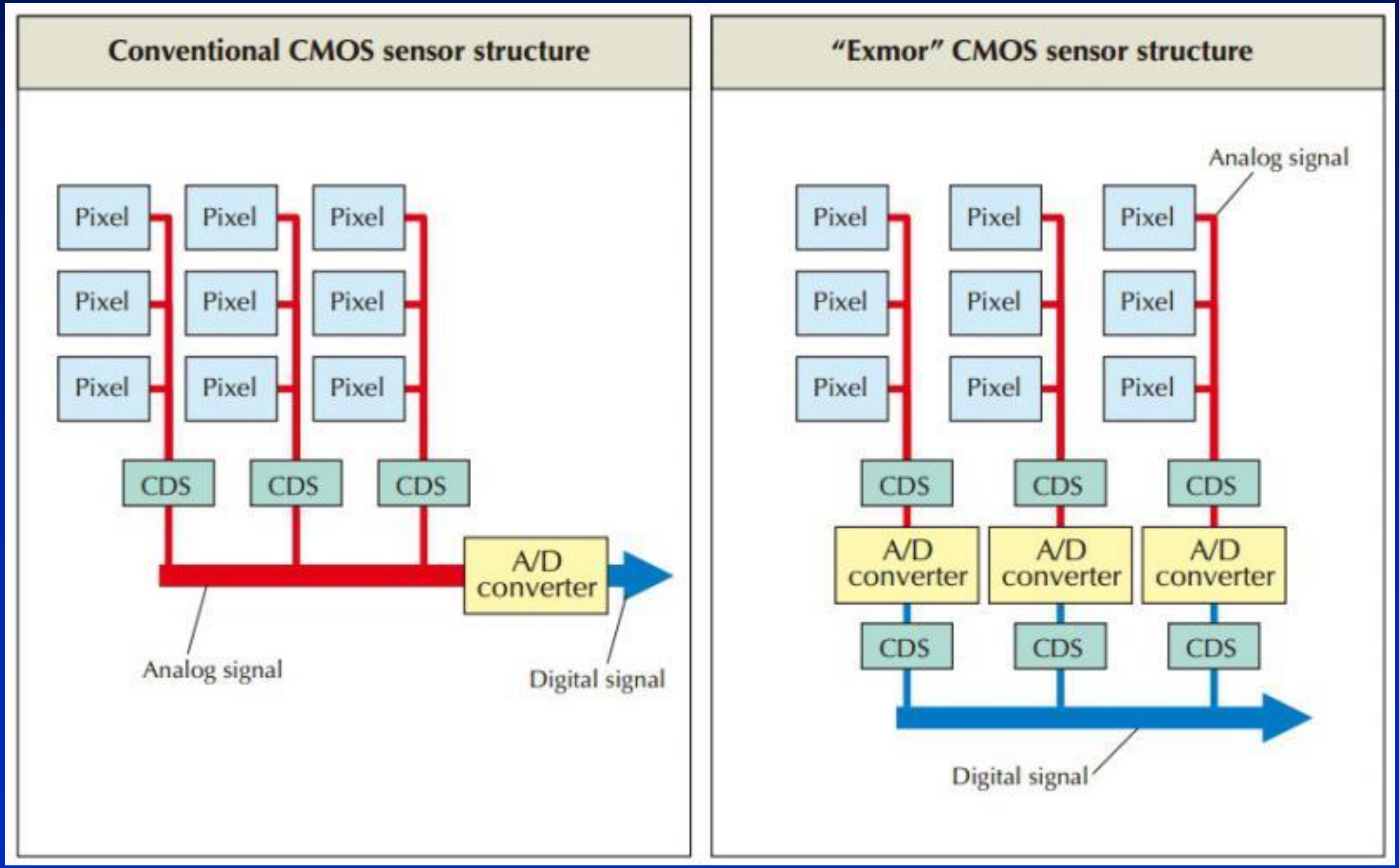
Film, Digital, and Foveon Comparison



Kodak DCS 460

- 1995 – the highest resolution digital camera ($35,600)
- 2000 – price had dropped to $2,500

CMOS Sensors



Requirements For Pervasive Digital Photography

- High resolution, low cost image acquisition devices
- Sufficient computer processing power and memory systems for digital manipulation
- Image enhancement software with easy-to-use interfaces
- High density, low-cost local storage systems

Requirements For Pervasive Digital Photography

- Cheap LCD displays for previewing
- Bandwidth! Bandwidth! Bandwidth!
  - High network bandwidth (wired) for distant transmission
  - Fast throughput (e.g. Firewire) for local transmission
  - Wireless bandwidth (local) for ease of use
- High quality, low cost digital printers

CONSUMER
Digital Cameras 2012

Sony CyberShot
20 MegaPixels
$80

Kodak EASYSHARE Touch
M5370
Cost: $129.95
16 Megapixels

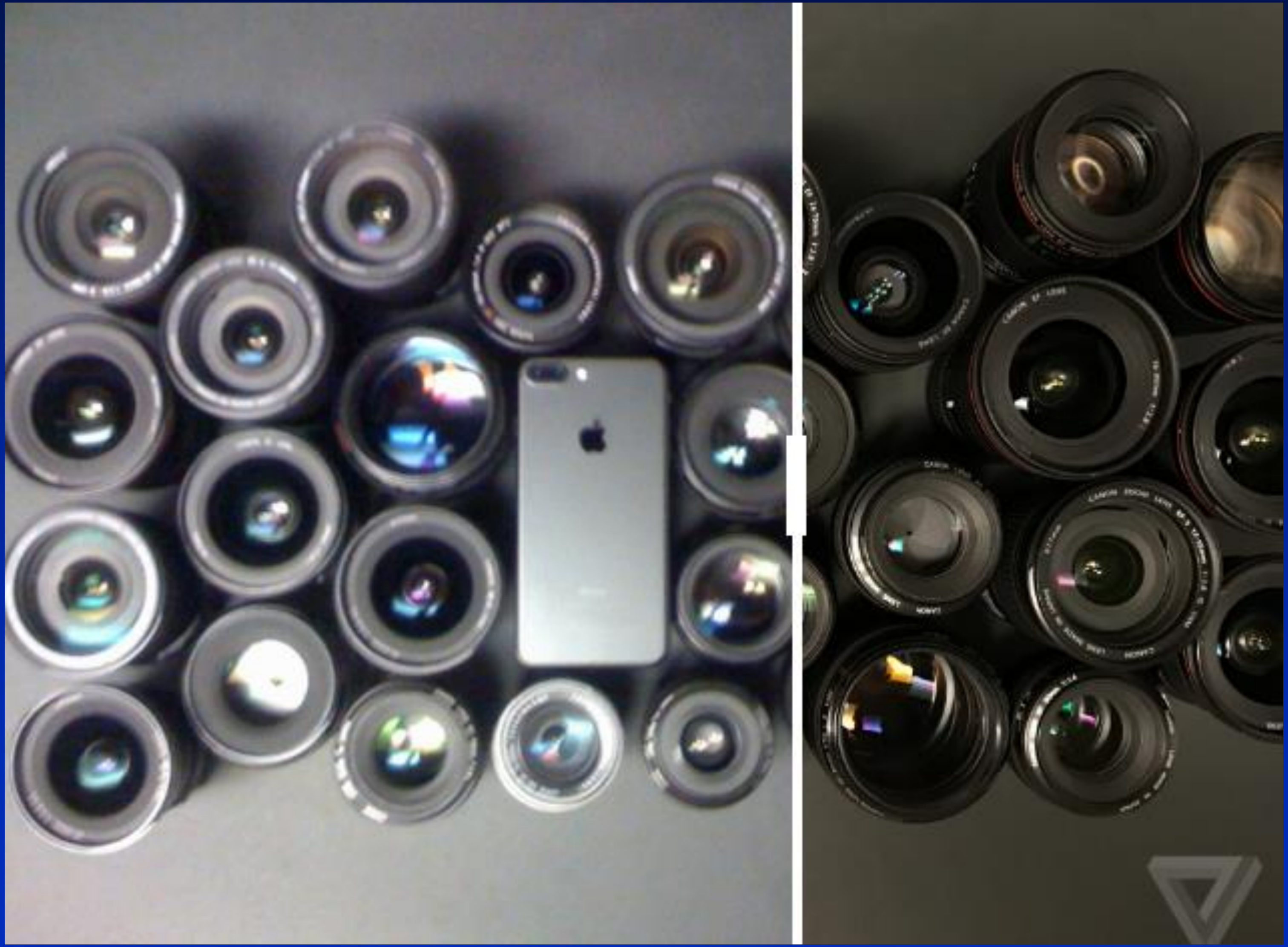
PROFESSIONAL Digital Cameras 2014

Canon EOS 5DSR
50.6 MegaPixels
$3,899

Nikon Digital SLR
16.2 MegaPixels
$5,999

iPhone 6S Camera – 12 Mpixels 2014

iPhone 7 Plus Sept. 2016



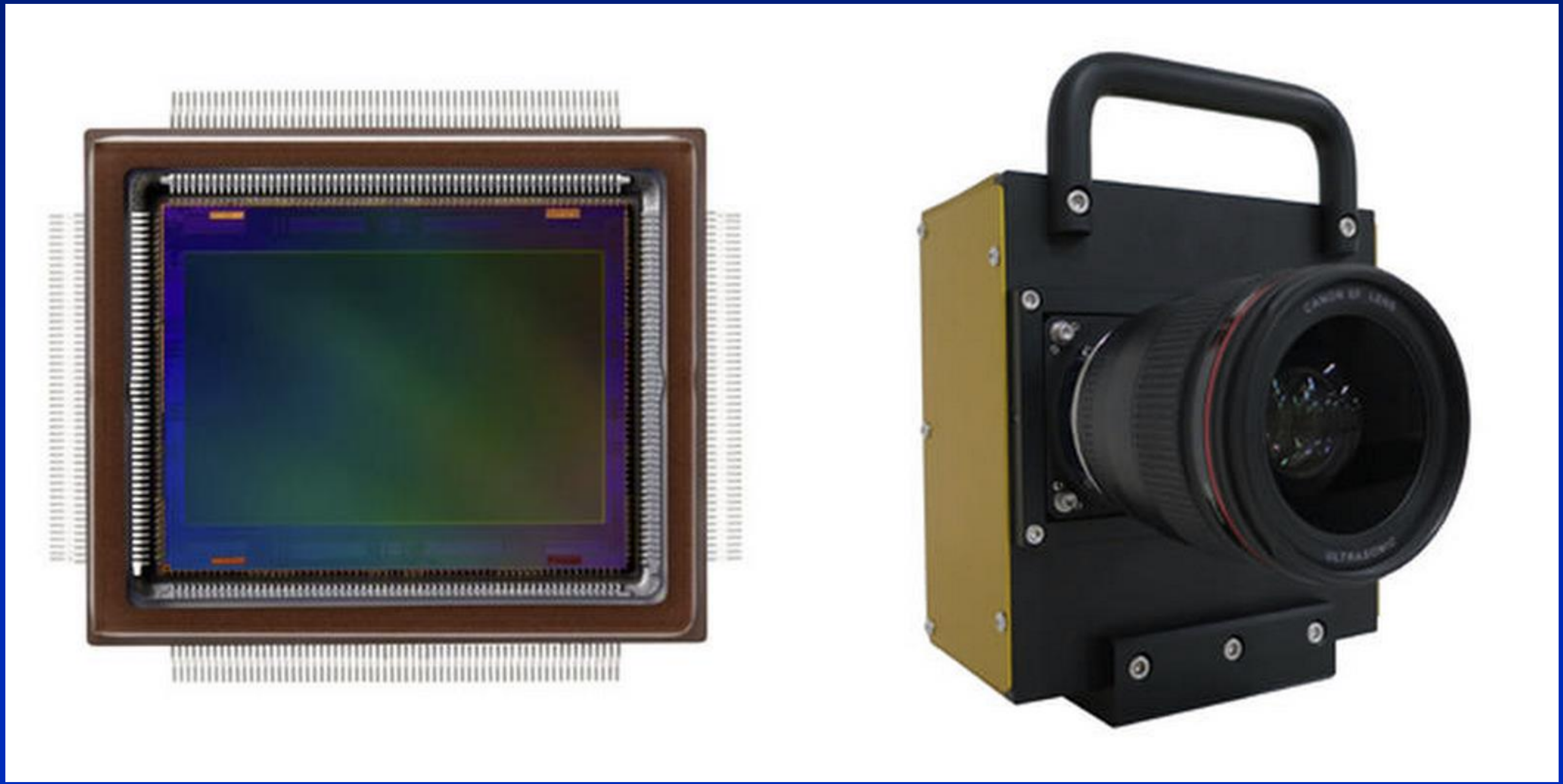
iPhone 7 Plus Sept. 2016




Nokia Lumia 1020 – 41 MPixels

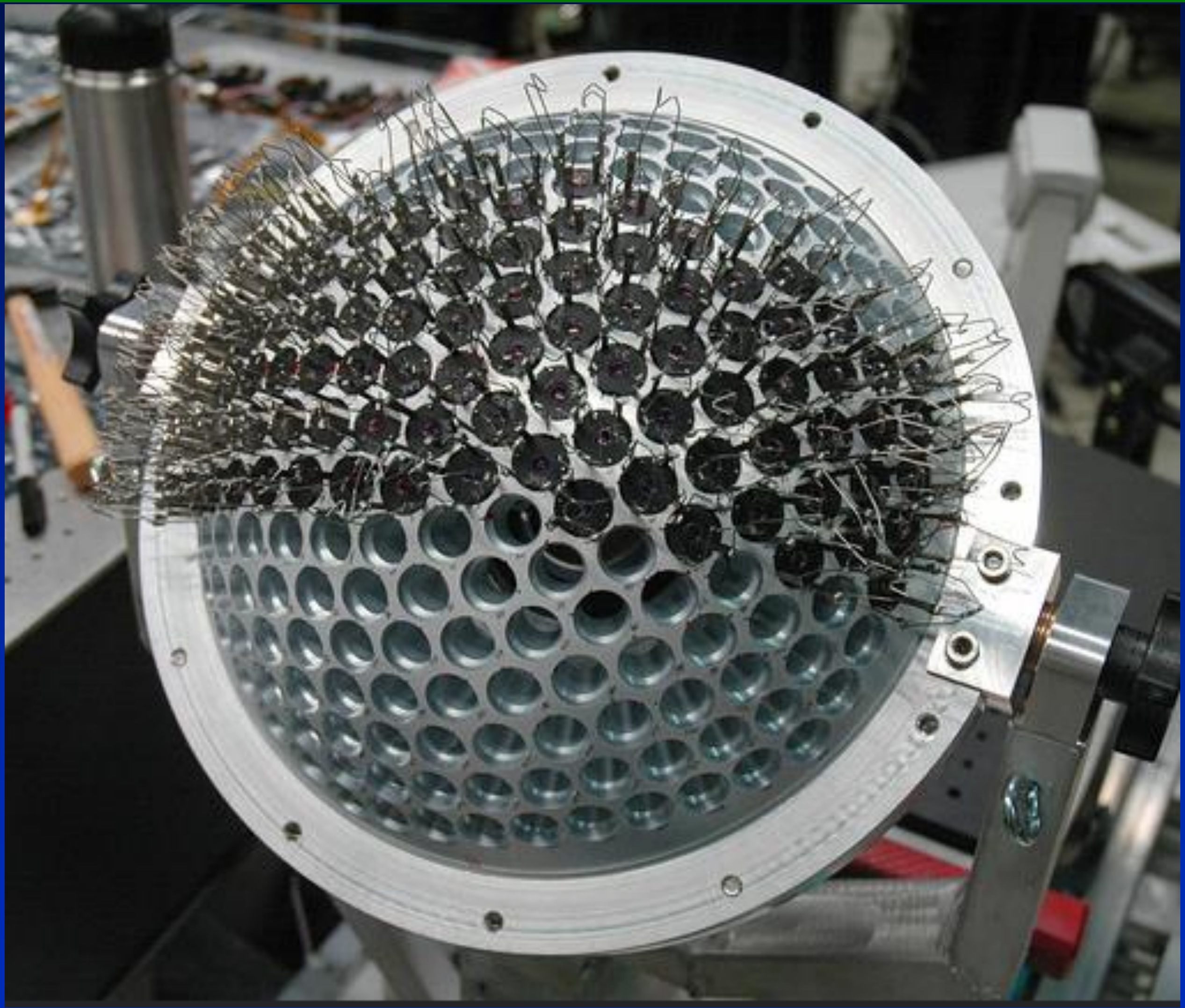
Canon's 250-megapixel camera sensor 09/08/15

- Can read letters on an airplane 11 miles away!
- 418,000 pixels/1 sq. mm (ball point pen)



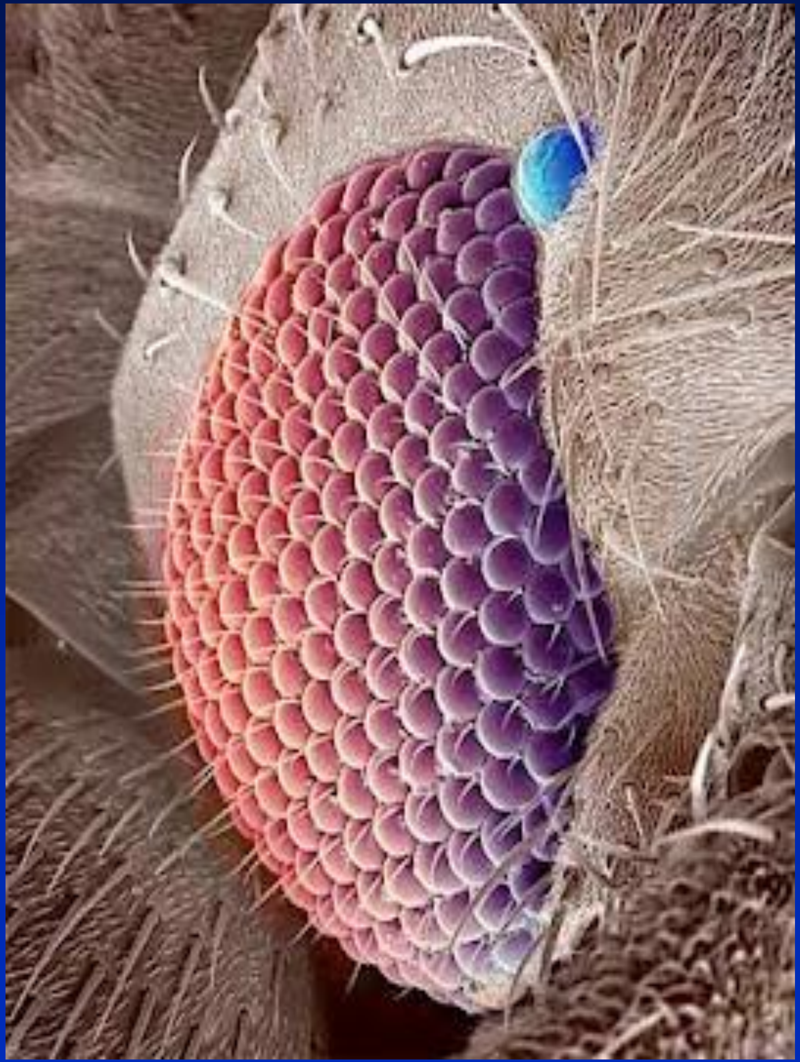
Fly’s Eye

AWARE-2

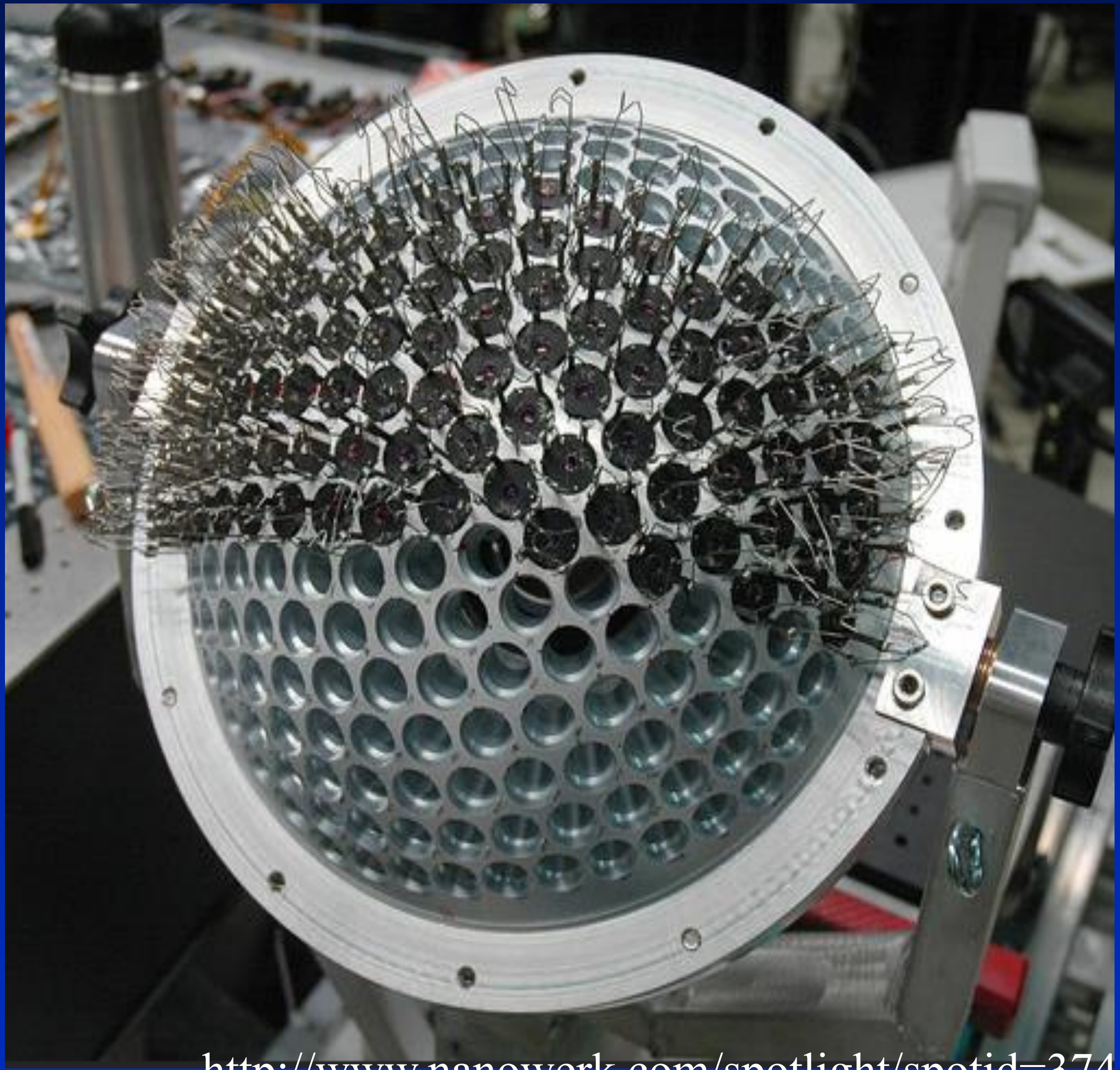


http://mosaic.disp.duke.edu:90/aware/image_list/image_list/public

Eye of a Fly



AWARE-2 Duke University



http://www.nanowerk.com/spotlight/spotid=3744.php

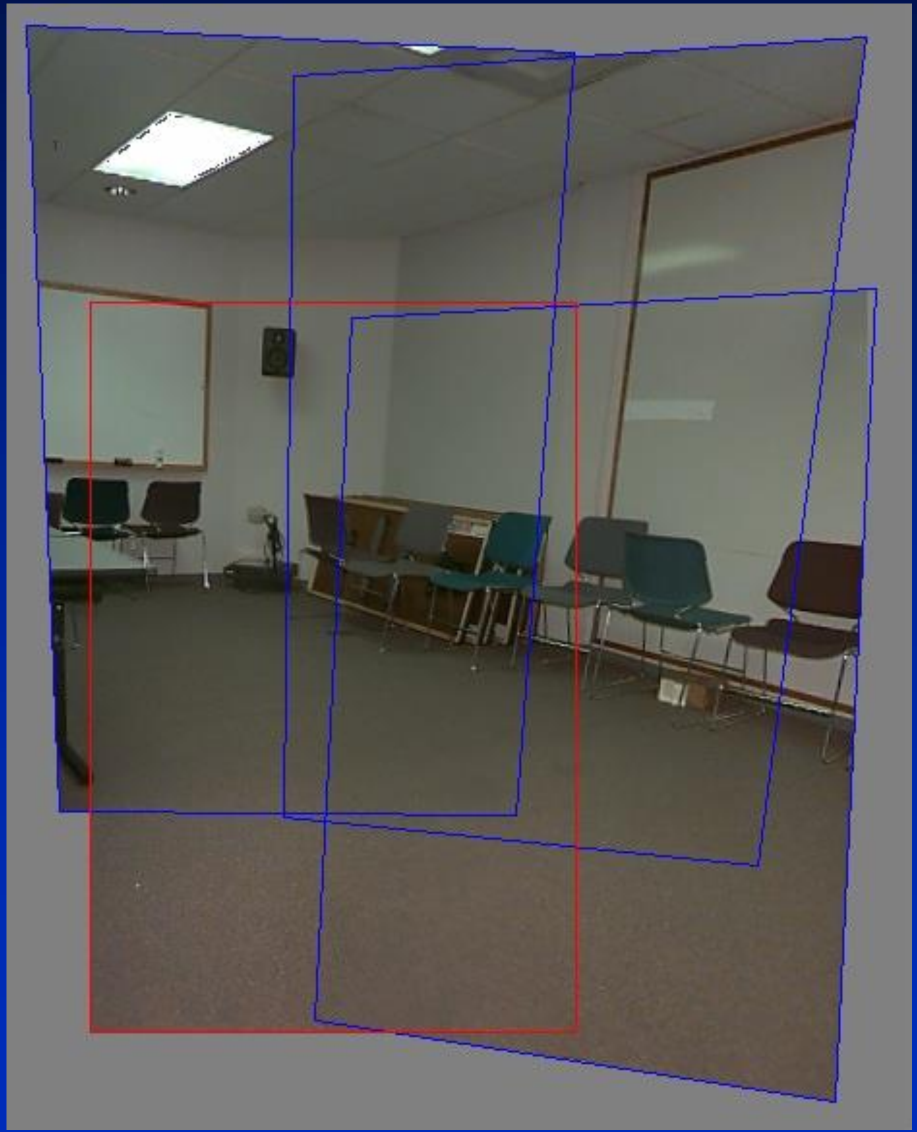
AWARE-2

http://www.kickstarter.com/projects/aqueti/carolina-zoomin

AWARE-2

http://www.kickstarter.com/projects/aqueti/carolina-zoomin

Creating Full View Panoramic Image Mosaics and Environment Maps



3D rotation registration of four images taken with a hand-held camera

Szeliski, R., Shum, H.-Y. (1997). "Creating full view panoramic image mosaics and environment maps", *Proc. ACM SIGGRAPH*, ACM Press, pp. 251-258.

Photo Stitching Panoramas

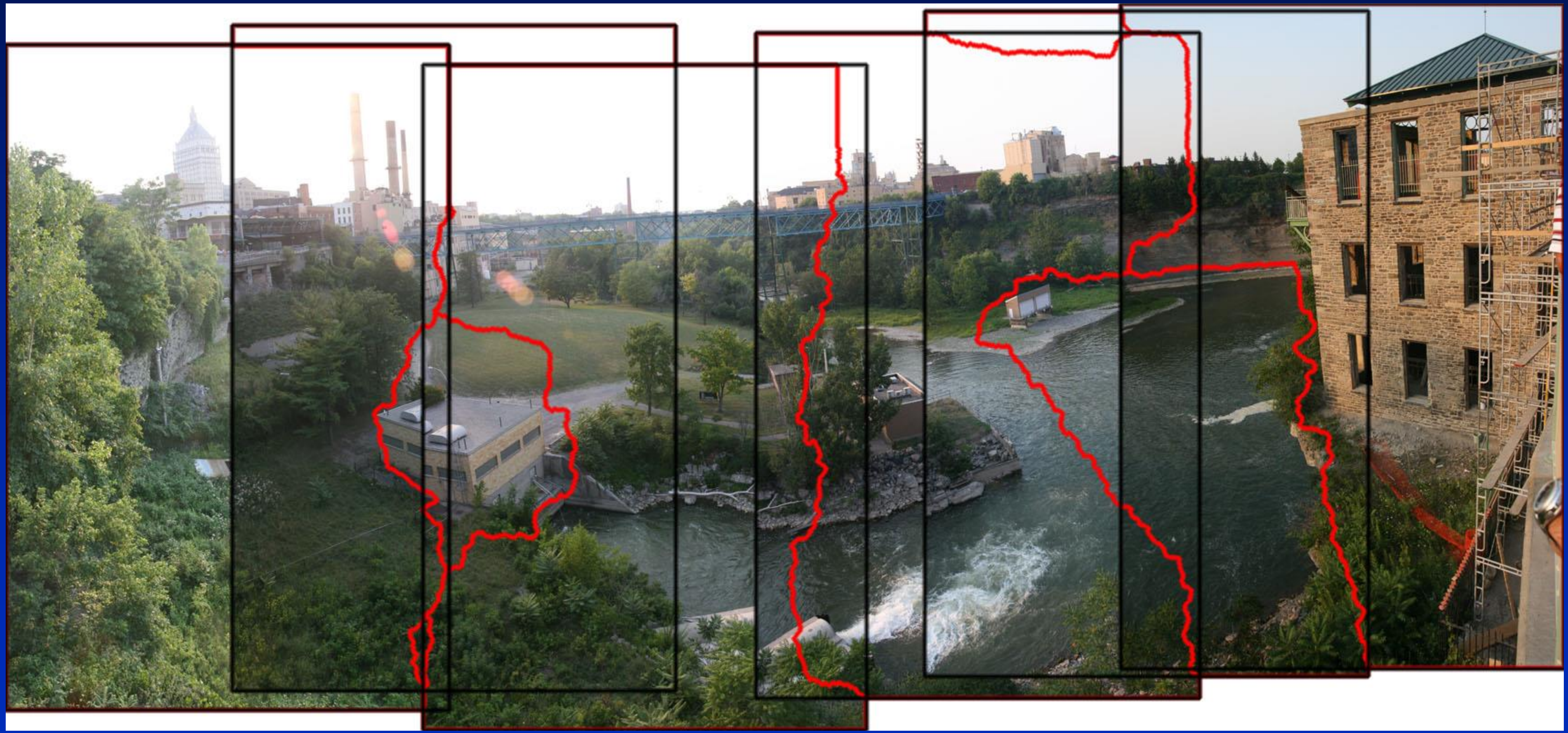


Photo Stitching Panoramas

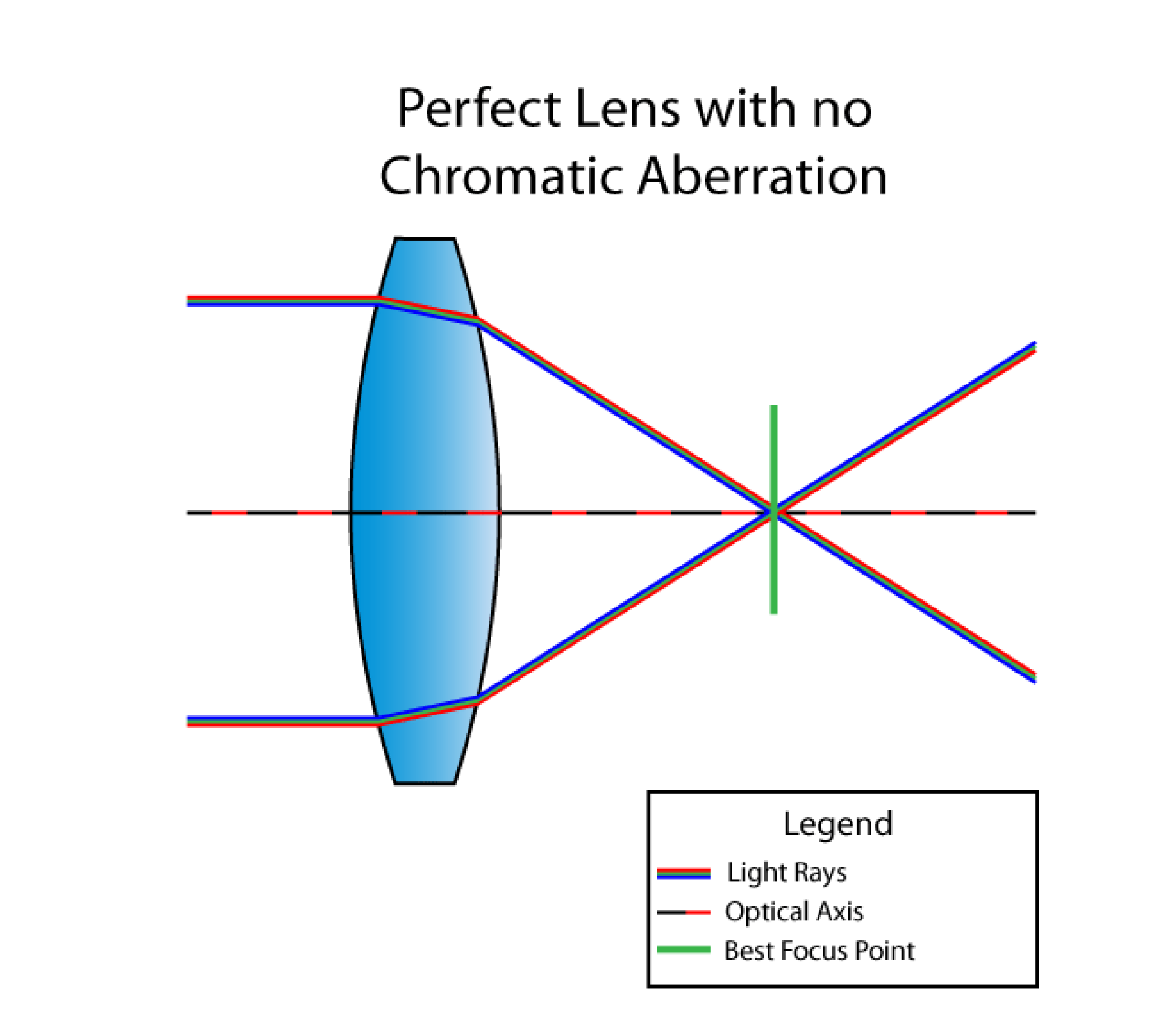
- Registration
  - Matching features
- Calibration
  - Exposure
  - Lens corrections
- Blending

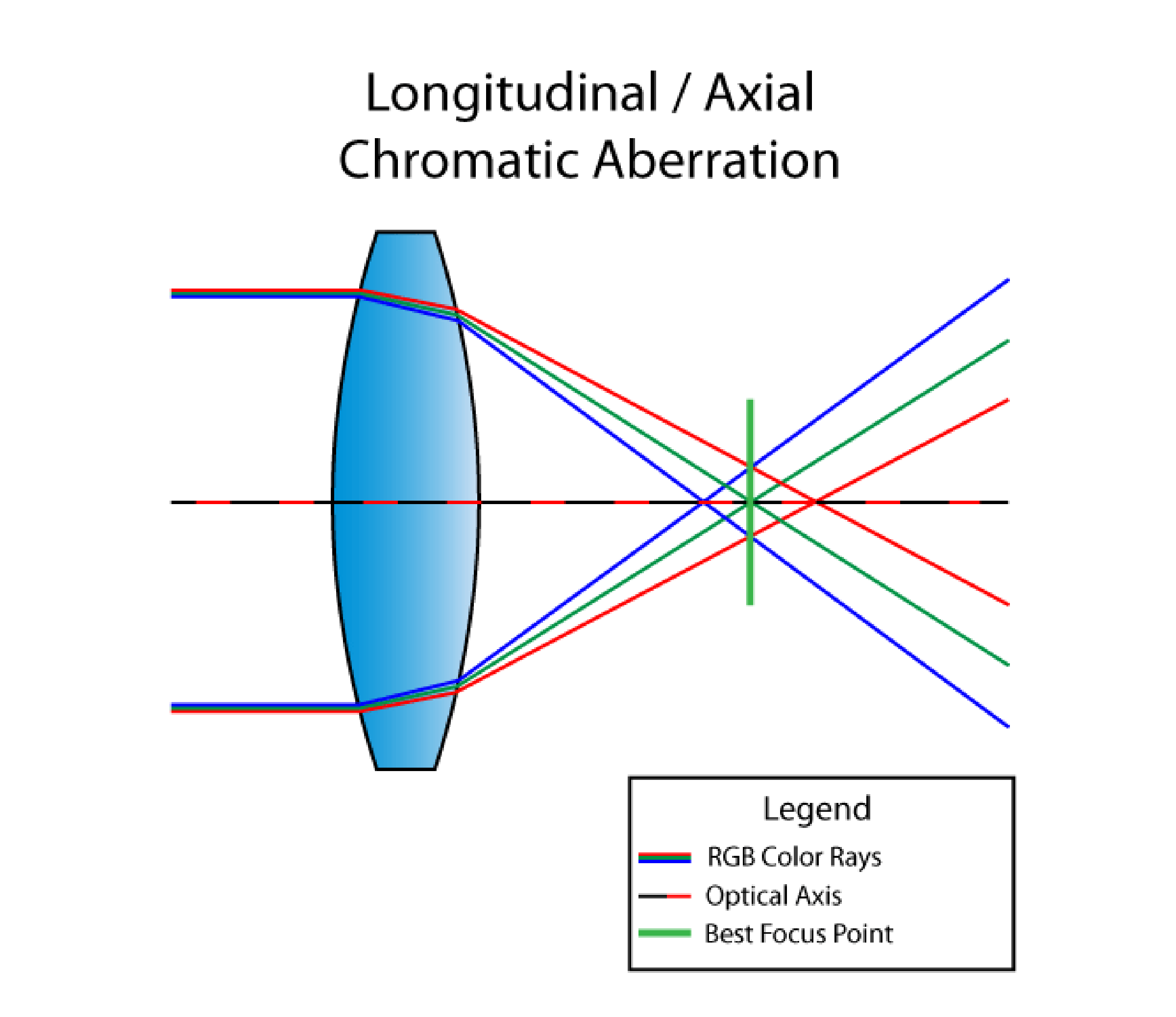
Professor Pedro Sander

- GigaPan: Corcovado 67GP (first stitch)

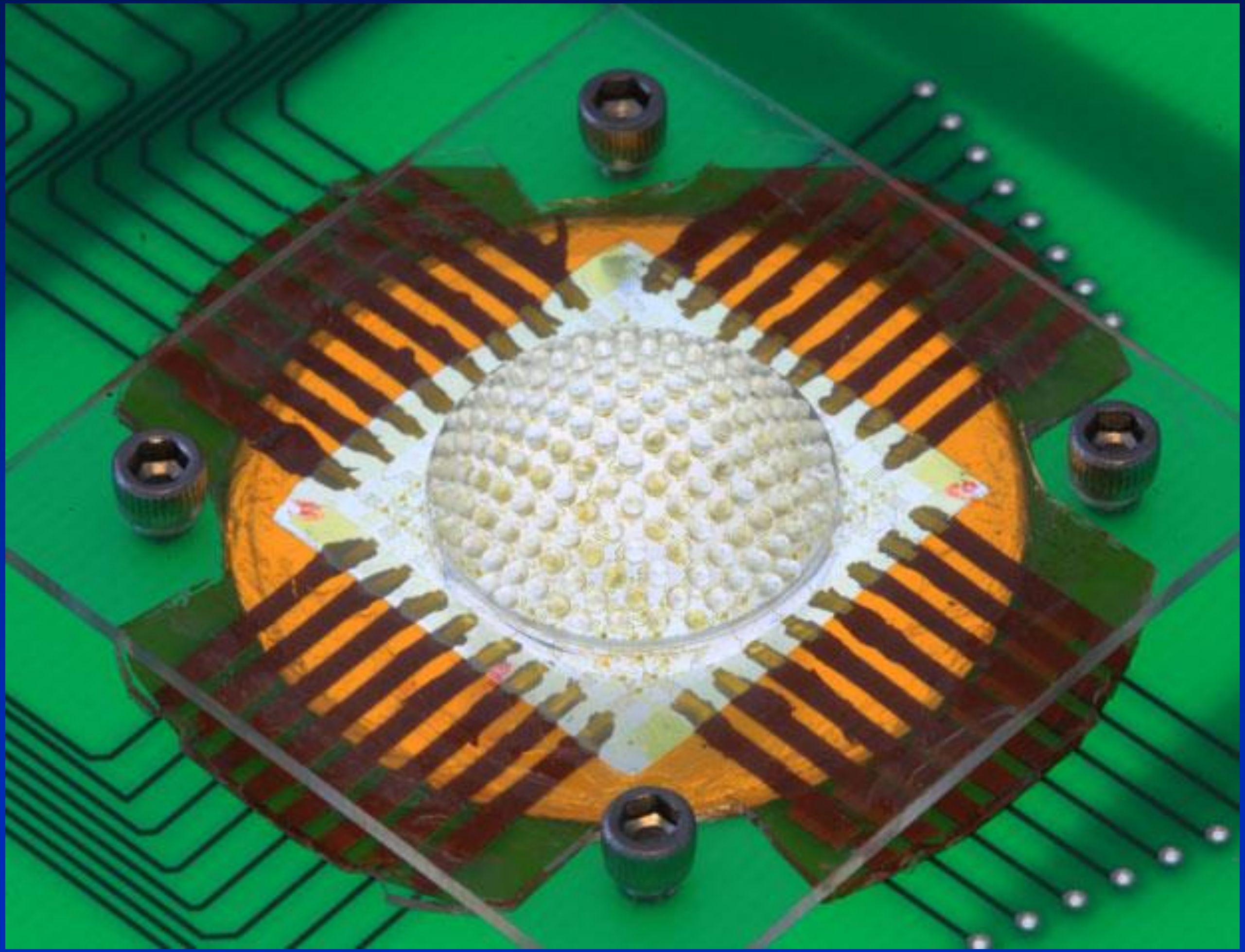
End

Chromatic Aberration

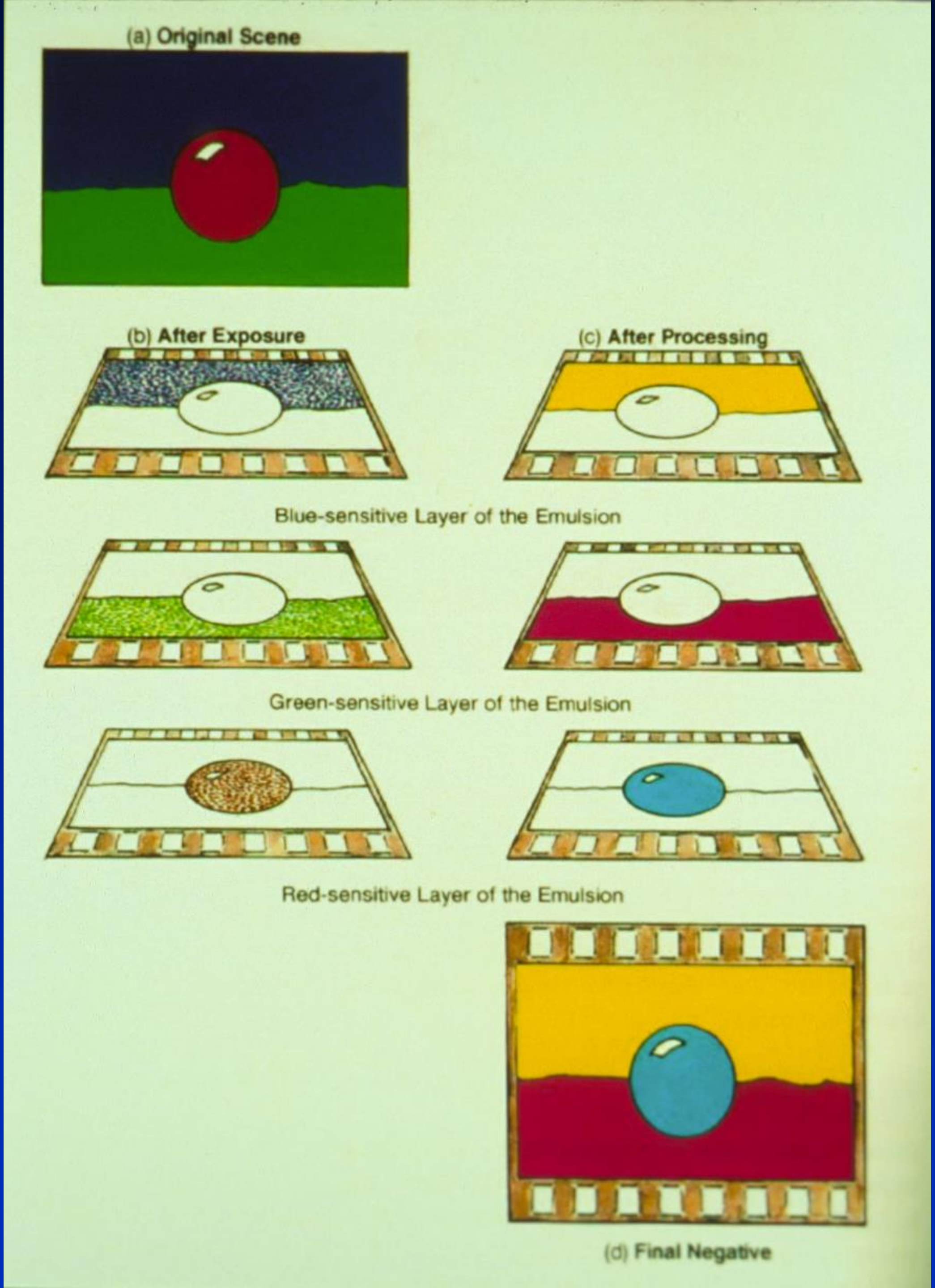




Insect-Eye Camera MAVs 2016



http://spectrum.ieee.org/robotics/robotics-hardware/insecteye-camera-offers-wideangle-vision-for-tiny-drones



(fig. 1.7, Color Photography, Robert Hirsch, p. 6)