6.098 Digital and Computational Photography
6.882 Advanced Computational Photography

Bill Freeman

Frédo Durand

MIT - EECS

Today's plan

- **Introduction of Computational Photography**
- **Course facts**
- **Camera advice**
- **Syllabus**
- **History**

What is computational photography

- **Convergence of image processing, computer vision, computer graphics an dphotography**
- **Digital photography:**
  - Simply replaces traditional sensors and recording by digital technology
  - Involves only simple image processing
- **Computational photography**
  - More elaborate image manipulation, more computation
  - New types of media (panorama, 3D, etc.)
  - Camera design that take computation into account

Quick demos

Computational Photography @ MIT

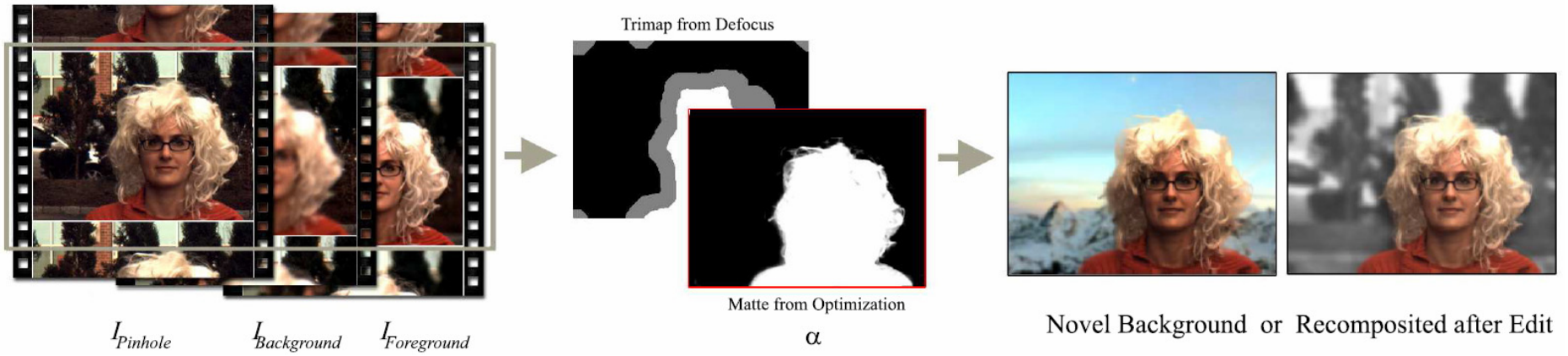
- **Tone mapping**
- **Defocus Matting**
- **Motion magnification**
- **Superresolution**

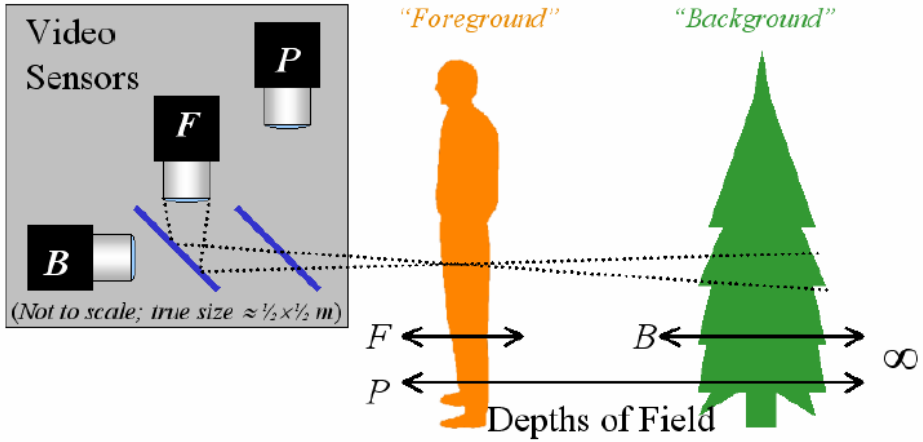
Tone mapping

- **One of your assignments!**

Defocus Matting

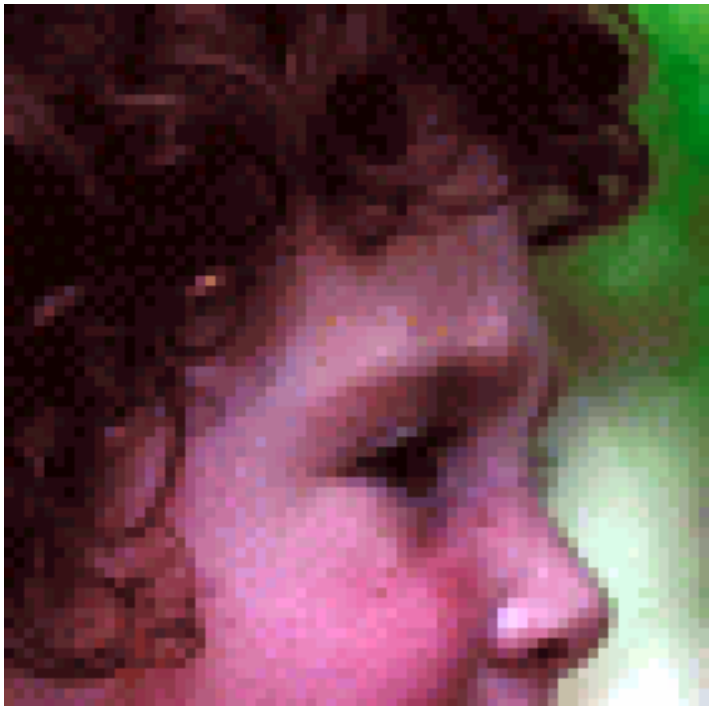
- **With Morgan McGuire, Wojciech Matusik, Hanspeter Pfister, John "Spike" Hughes**
- **Data-rich: use 3 streams with different focus**





Super-resolution

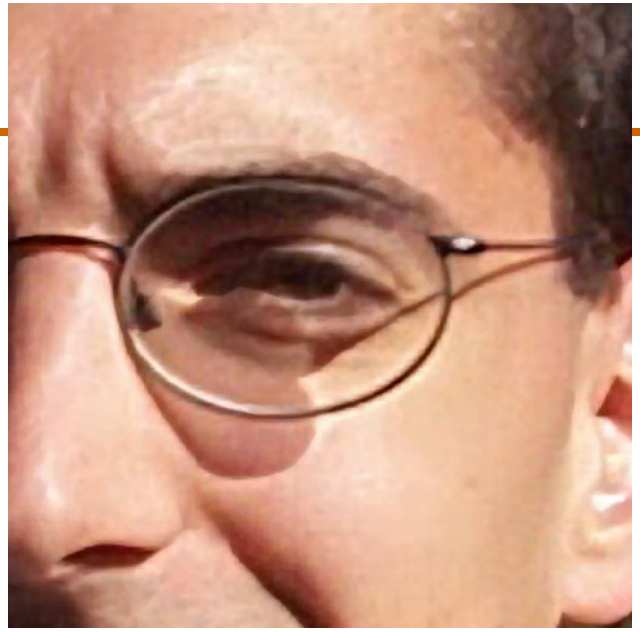
- **Get a sharp high resolution image from low resolution**
- **Important principle: Learn from examples**



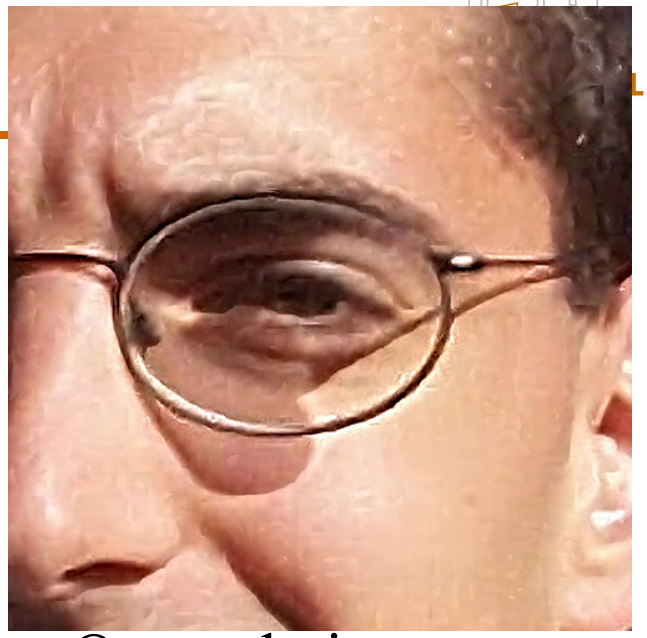
Original
70x70

Our technique
[Freeman et al]

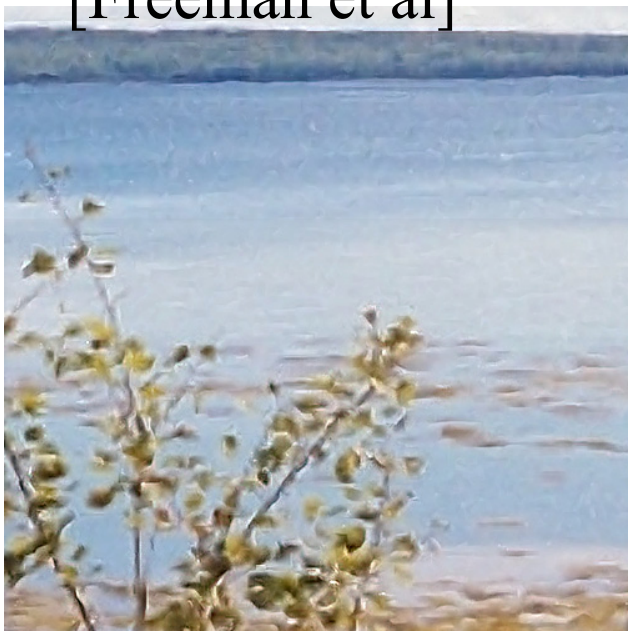
Bicubic spline



Altamira



Our technique
[Freeman et al]



Motion magnification

Today's plan

- **Introduction of Computational Photography**
- **Course facts**
- **Camera advice**
- **Syllabus**
- **History**

Administrivia

- **Staff**
  - Bill Freeman billf@csail.mit.edu
  - Frédo Durand fredo@csail.mit.edu
  - Ce Liu celiu@csail.mit.edu
  - comp-photo-staff@lists.csail.mit.edu
- **Office hours (email for other time)**
  - Bill Freeman: Tuesday 2:30-4pm, 32-D476
  - Frédo Durand: Friday 2:30-4pm, 32-D426
  - Ce Liu: Wednesday 2:30-4pm, 32-D460
- **Prereq: 18.06 & 6.003**
  - or equivalent level
- **Web page: http://groups.csail.mit.edu/graphics/classes/CompPhoto06/**
  - Lecture notes will be posted

Grading policy

- **6.098**
  - Assignments 75%
  - Final project 25%
- **6.882**
  - Assignment 70%
    - With additional questions compared to 6.098
  - Final project 22%
  - Paper review 8%
    - Read and write a review (Siggraph form) for a paper from the literature

+ participation

Assignment

- **Every two week**
- **written questions + programming**
- **Camera?**
  - Not required, but can help. Can be borrowed from us.
- **Matlab**
  - First office hour (Tuesday), Ce will give an intro
  - Or see Xiaoxu Ma's slides:

    http://courses.csail.mit.edu/6.869/handouts/6869%20Matlab%20Tutorial.ppt
- **Turn in code and results**
- **Final project**
  - Proposal due with PSet 5
  - Individual or teams of 2

Textbook

- **No textbook required**
- **Lots of resources on the net**
- **Siggraph course notes**
  - http://www.merl.com/people/raskar/photo/
- **Will post references with lectures**

Questions?

Introductions

- **Who are you?**
- **What do you know about photography?**
- **Why you want to take this class?**

What do you think you will learn?

What the class is not about

- **Little about art, photographers**
- **Little about EE (sensors, A/D, etc)**
- **Not much about optics**
  - but some cool stuff such as wavefront coding
- **Not how to use Photoshop**
  - But how its coolest tools work
- **Not much about 3D imaging**
- **Not too much fundamentals of signal processing**
- **Not much computational *imaging*, no tomography, no radar, no microscopy**
  - See Berthold Horn's class!
- **Not much computer vision, computer graphics**
  - We avoided overlap with 6.837 and 6.801/6.866

What the class is about

- **Software aspects of computational photography**
  - but a bit of hardware as well, lens technology, new camera designs
- **Basic tools**
  - Linear & non-linear image processing, color
- **Emphasis on applications**
  - High-dynamic range photography, photomontage, panoramas, foreground extraction, inpainting, morphing
- **Emphasis on recent research results**

Skills you will acquire

- **Implementation of basic tools**
  - Color demosaicing
  - Multiscale blending
  - Matting
  - Bilateral filter
  - Gradient reconstruction
  - Panorama stitching
  - Markov Random Field
  - Optical flow
- **General approaches to computational photography**
- **Important problems ion computational photography**
- **By the end of the class, you should be able to make contributions to the state of the art**
  - Your final project could lead to a publication

Non-photo motivation

- **It's about any kind of data !**
  - Speech, motion, geometry, etc.
  - Example:
    - Music
    - Motion graphs
    - Poisson mesh editing
    - BTF shop

Questions?

Today's plan

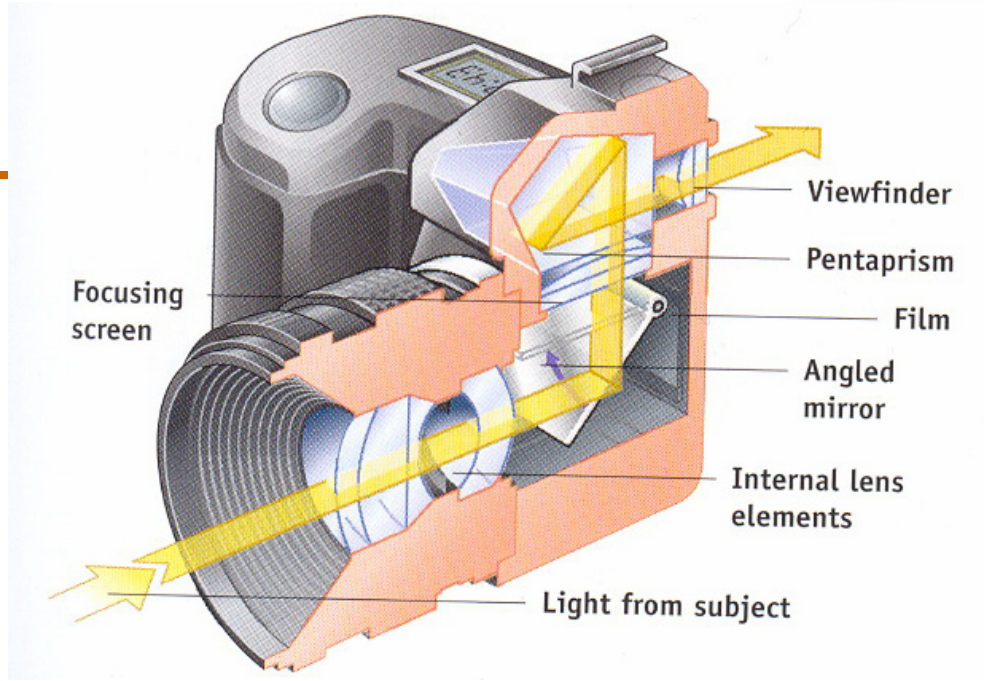
- **Introduction of Computational Photography**
- **Course facts**
- **Camera advice**
- **Syllabus**
- **History**

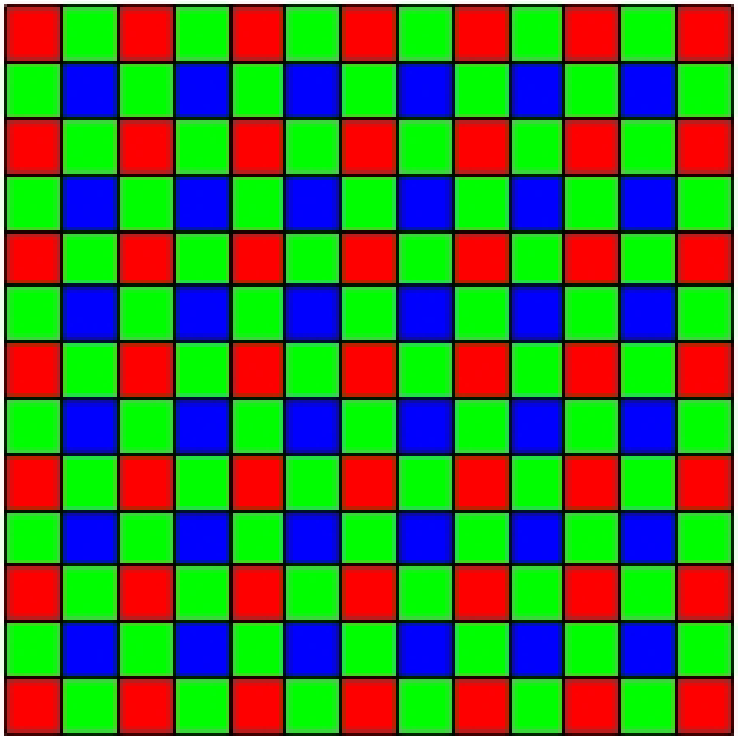
Syllabus

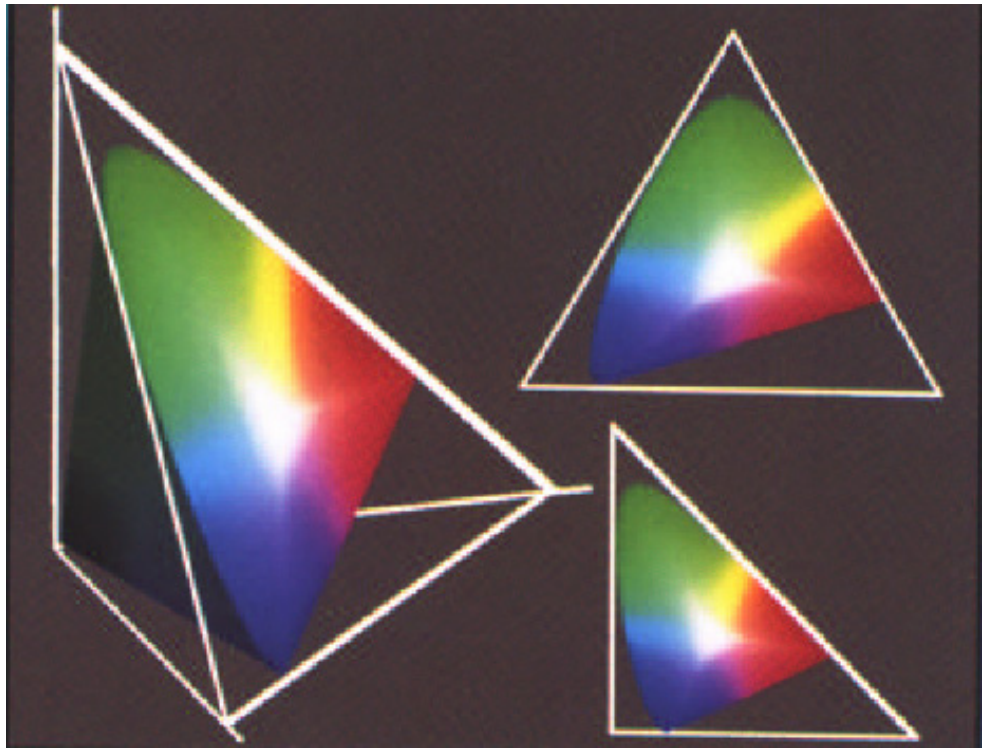
- Image formation
- Color and color perception
- Demosaicing
- Image processing and wavelets
- Applications of wavelets; pyramid texture synthesis
- Matting
- High Dynamic Range Imaging
- Bilateral filtering and HDR display
- Gradient image manipulation
- Taking great pictures
- Markov Random Fields
- Non-parametric image synthesis, inpainting, analogies
- Tampering detection and higher-order statistics
- Panoramic imaging
- Image and video registration
- Spatial warping operations
- Motion analysis
- Temporal sequence re-rendering
- Active flash methods
- Lens technology
- Depth and defocus
- Non-photorealistic rendering
- Future cameras
- Plenoptic function and light fields
- Student project presentations

Syllabus

- Image formation
- Color and color perception
- Demosaicing

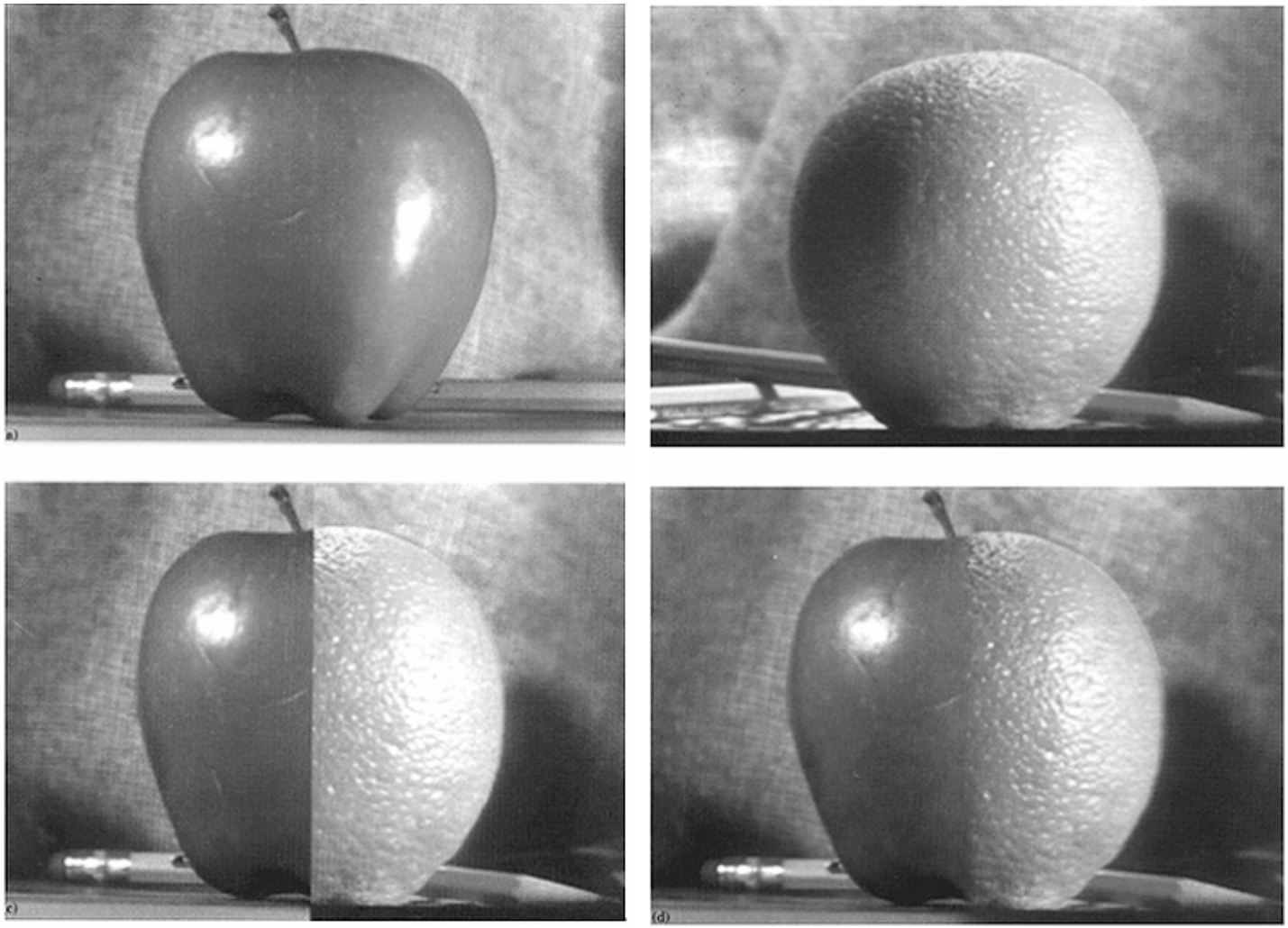






Syllabus

- **Image processing and wavelets**
- **Applications of wavelets; pyramid texture synthesis**

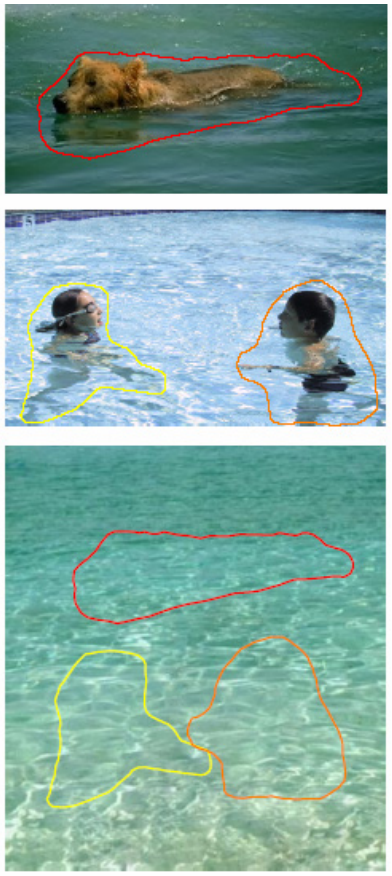


Syllabus

- High Dynamic Range Imaging
- Bilateral filtering and HDR display
- Matting

Syllabus

- **Gradient image manipulation**



sources/destinations

cloning

seamless cloning

Syllabus

- **Taking great pictures**

Art Wolfe

Ansel Adams

Syllabus

- **Markov Random Fields**

- **Non-parametric image synthesis, inpainting, analogies**

input images quilting results

A A' B B'

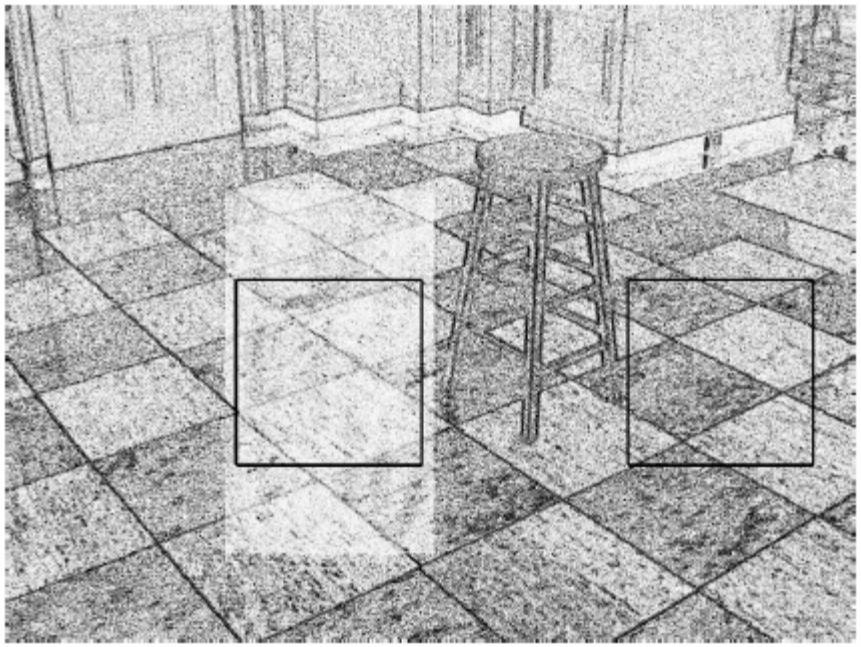
Figure 1 An image analogy. Our problem is to compute a new "analogous" image B' that relates to B in "the same way" as A' relates to A. Here, A, A', and B are inputs to our algorithm, and B' is the output. The full-size images are shown in Figures 10 and 11.

Syllabus

- **Tampering detection and higher-order statistics**

original

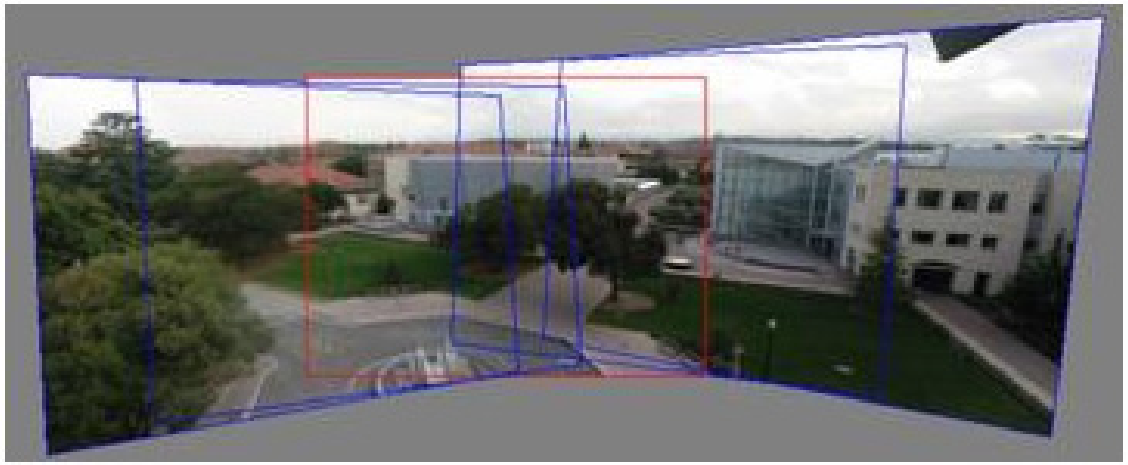
probability map (p)



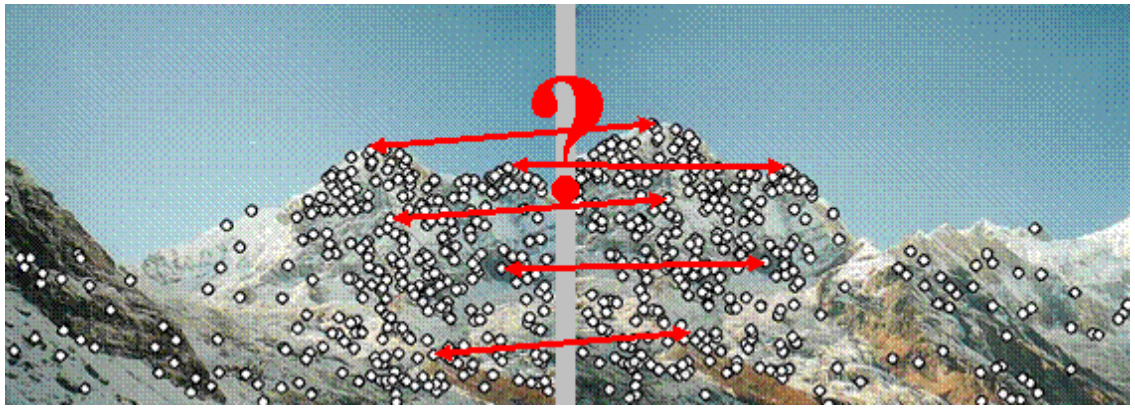
forgery

Syllabus

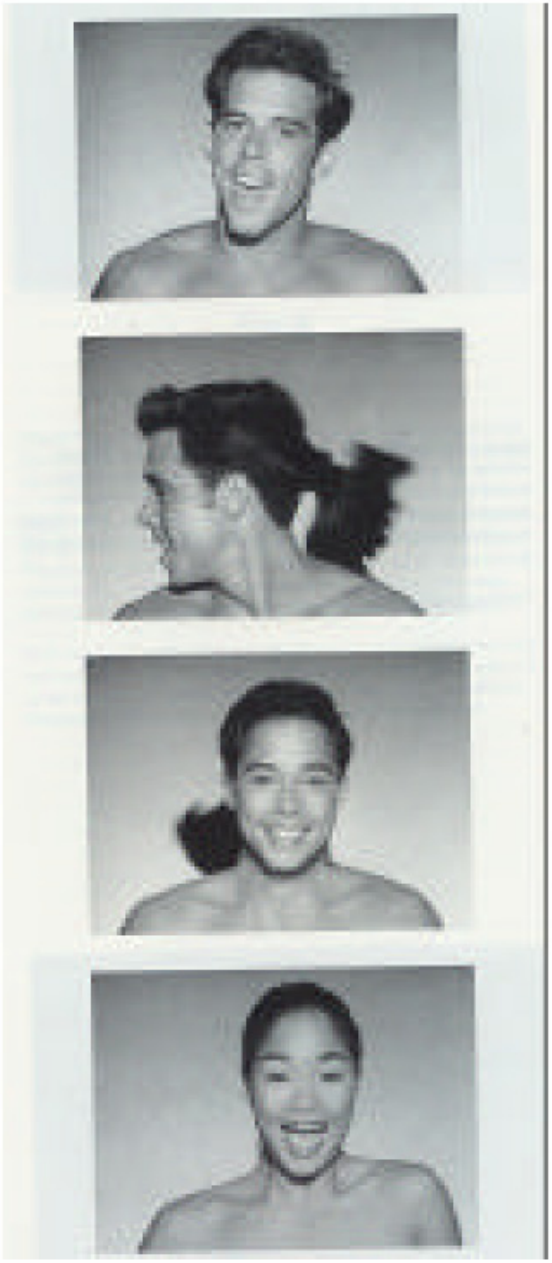
- **Panoramic imaging**



- **Image and video registration**

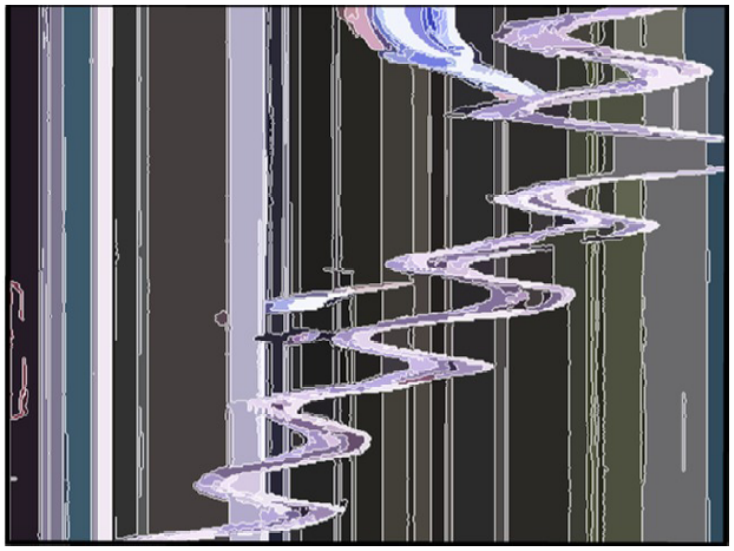


- **Spatial warping operations**



Syllabus

- **Motion analysis**

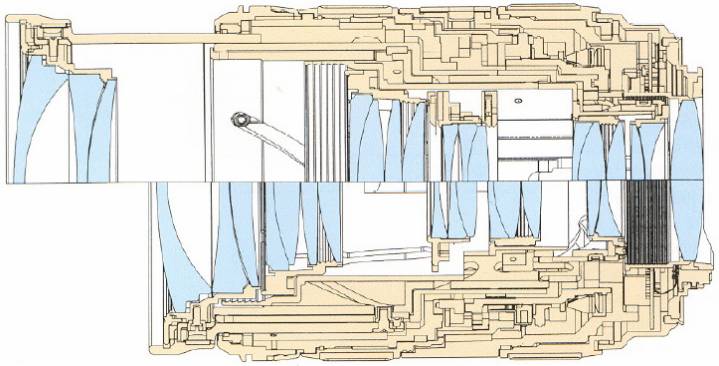


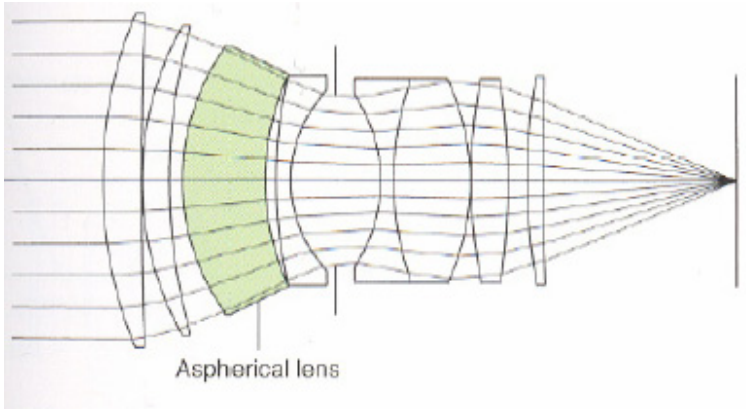
Syllabus

- **Temporal sequence re rendering**

Syllabus

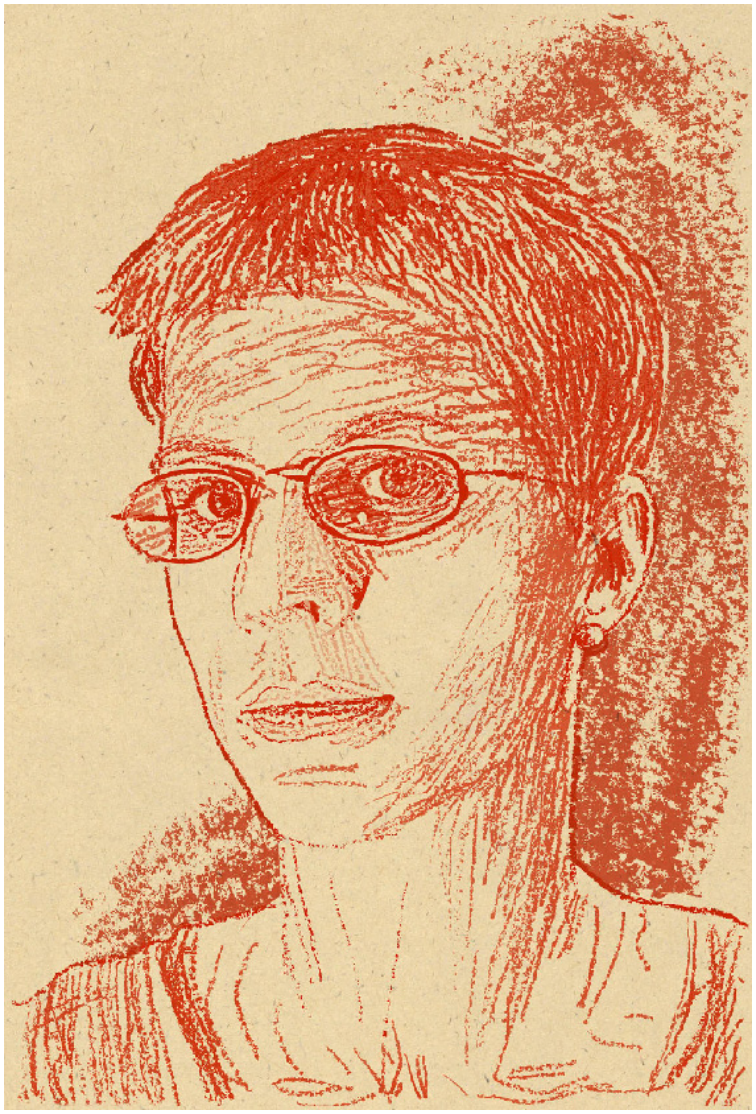
- **Active flash methods**
- **Lens technology**
- **Depth and defocus**





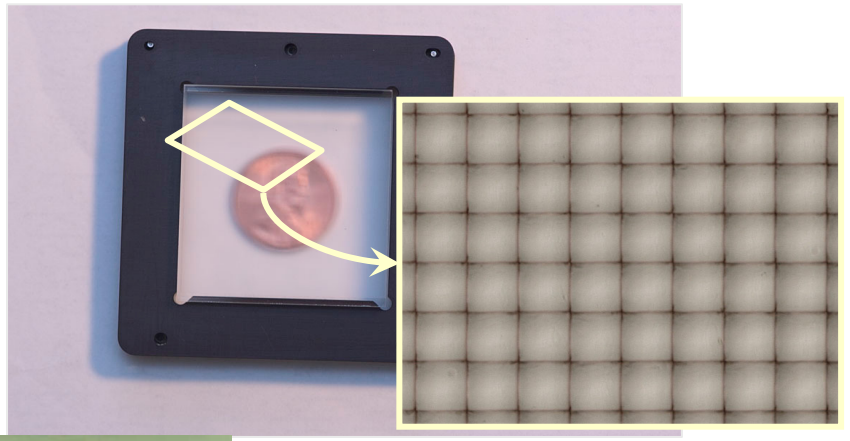
Syllabus

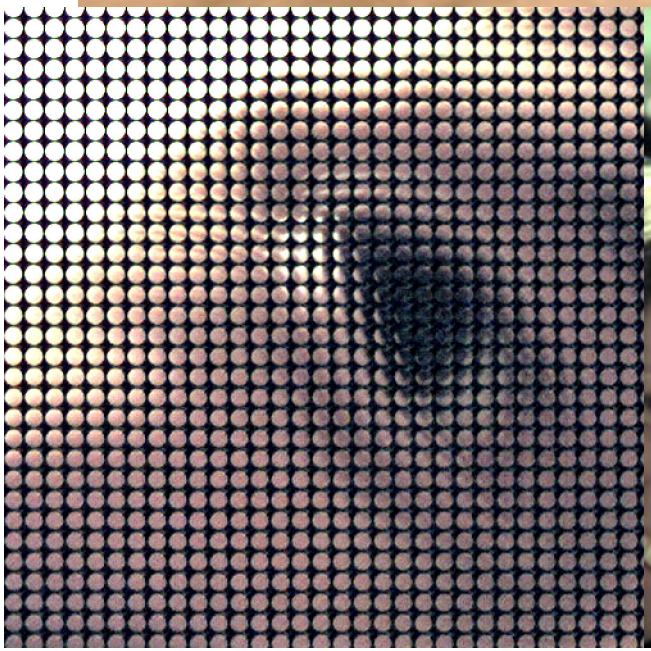
- **Non-photorealistic rendering**



Syllabus

- Future cameras
- Plenoptic function and light fields





Questions?

Today's plan

- **Introduction of Computational Photography**
- **Course facts**
- **Camera advice**
- **Syllabus**
- **History**

Equipment

- **Do get an SLR, compacts are way too limited**
- **Don't worry about brand**
- **Don't worry about the body, get the cheapest one**
- **Worry about lenses**
  - Zooms are convenient but quality can be a problem
    - avoid the basic zoom, but the one above is usually great
    - Maximum aperture matters (the smaller the number, the better)
  - Get a prime in the 35-85mm range
    (cheap, high quality, wide aperture)
    50mm f/1.8 (both Canon & Nikon)
- **Get a tripod**
- **Get an external flash if you want to take "event" pictures**
  - And orient towards ceiling
  - Good flash photography is very difficult
- **Count ~1k for camera+standard zoom+50mm**

Nikon

Tends to be a tad cheaper

- **D50 is a great body. D70 is a little better.**
- **18-70**
- **55-200 is surprisingly not so bad and super cheap**
- **Get the 50mm f/1.8**

Canon

- **Rebel XT or 20D**
- **17-85**
- **70-200 f/4.0 (amazing lens)**
- **50mm f/1.8**
- **100mm f/2.8 macro (great also for portraits)**

Other brands

Not as big a range, future not always clear (see Minolta), have been slower to get to digital SLR

- **Olympus**
  - Good system, but smaller sensor
- **Konica-Minolta**
  - Just announced they stop photography!
- **Pentax**
  - Good entry camera
- **Sigma**
  - Intriguing sensor (Foveon)
- **Fuji**
  - One-trick pony (the sensor)
  - Nikon body
- **Sony**
  - Interesting hybrid, the R1
  - Very silent, good images, crappy viewfinder, no interchangeable lenses

Shooting

- **Use aperture priority, work on depth of field**
- **Change your viewpoint**
- **Don't center things**
- **Learn to adjust ISO**

- **Shoot raw**
- **Check your histogram**

Editing (Photoshop)

- **Crop to improve composition**
- **Manage contrast using curve and adjustment layers**
- **Sharpen a bit**
- **Convert to black and white with gradient map**

Questions?

Today's plan

- **Introduction of Computational Photography**
- **Course facts**
- **Camera advice**
- **Syllabus**
- **History**

History of traditional and digital photo

- http://www.digicamhistory.com/

Quiz (0.001% of grade)

- **When was photography invented?**
- **By whom?**
  - Exposure time?

Quiz

- **When was photography invented? 1825**
- **By whom? Niepce**
  - Exposure time? 8 hours

World's Oldest Known Photograph, Circa 1825

- **William Henry Fox Talbot invents the *calotype* in 1834 which pretty much invents the negative**

First production camera?

First production camera?

- **1839. Daguerrotype**

Beginning of hobby photography?

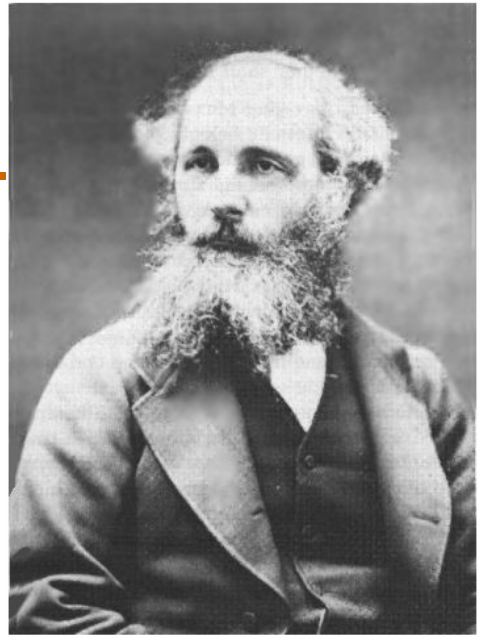
- **1900 Kodak Brownie (a heck of a job!)**

Quiz

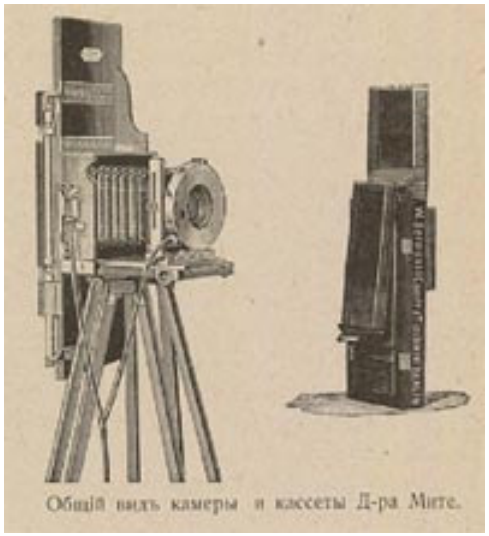
- **Who did the first color photography?**

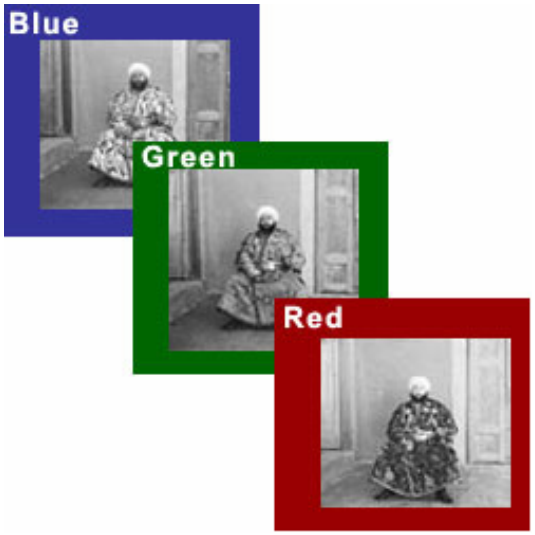
- **When?**

Quiz



- **Who did the first color photography?**
  - Maxwell
    (yes, the same from the EM equations)
- **When? 1861**
- **Oldest color photos still preserved: Prokudin-Gorskii** http://www.loc.gov/exhibits/empire/





Prokudin-Gorskii

- **Digital restoration**

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

Prokudin-Gorskii

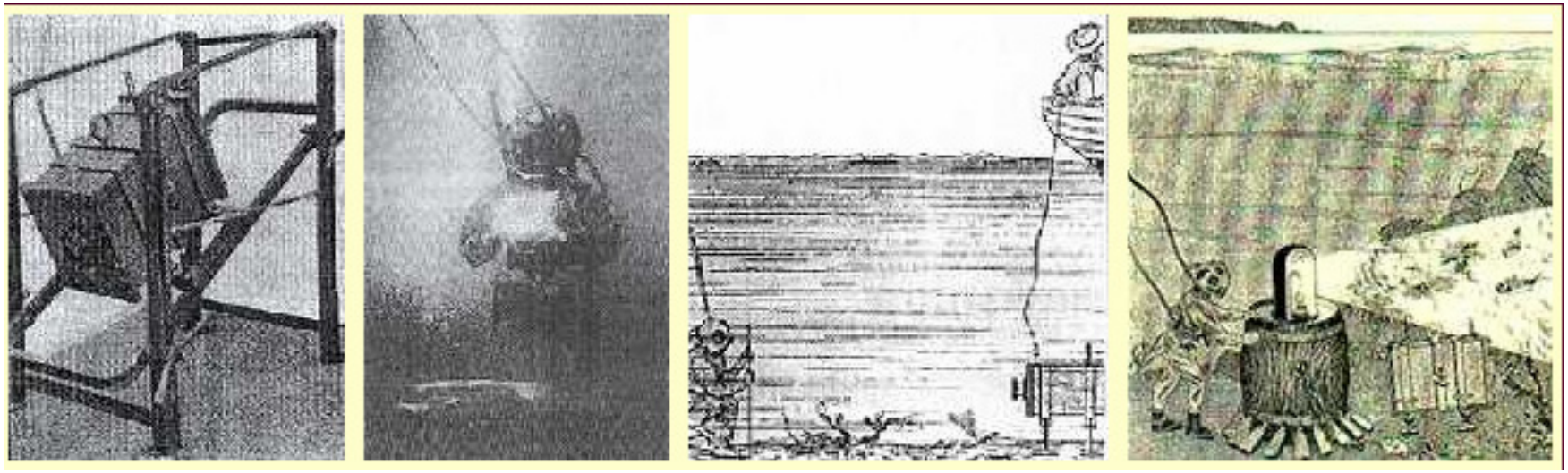
Prokudin-Gorskii

Flash bulb?

- **As opposed to podwer systems**

Flash bulb?

- As opposed to podwer systems
- BOUTAN-CHAUFFOUR FLASH BULB - 1893
- For underwater photography



Instant photography?

Instant photography?

- **1947, Edwin Land (Polaroid founder)**

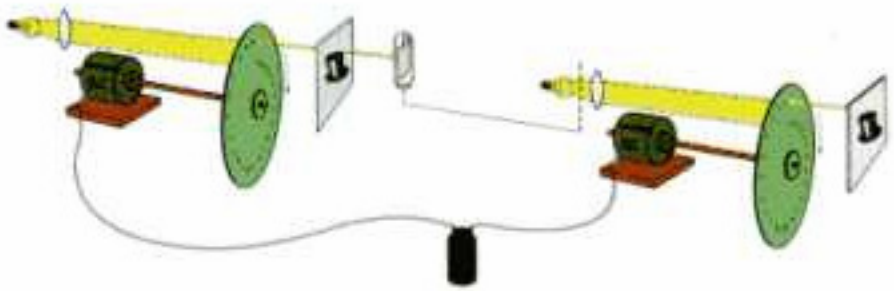
First TV?

Transmission of moving images

First TV?

Transmission of moving images

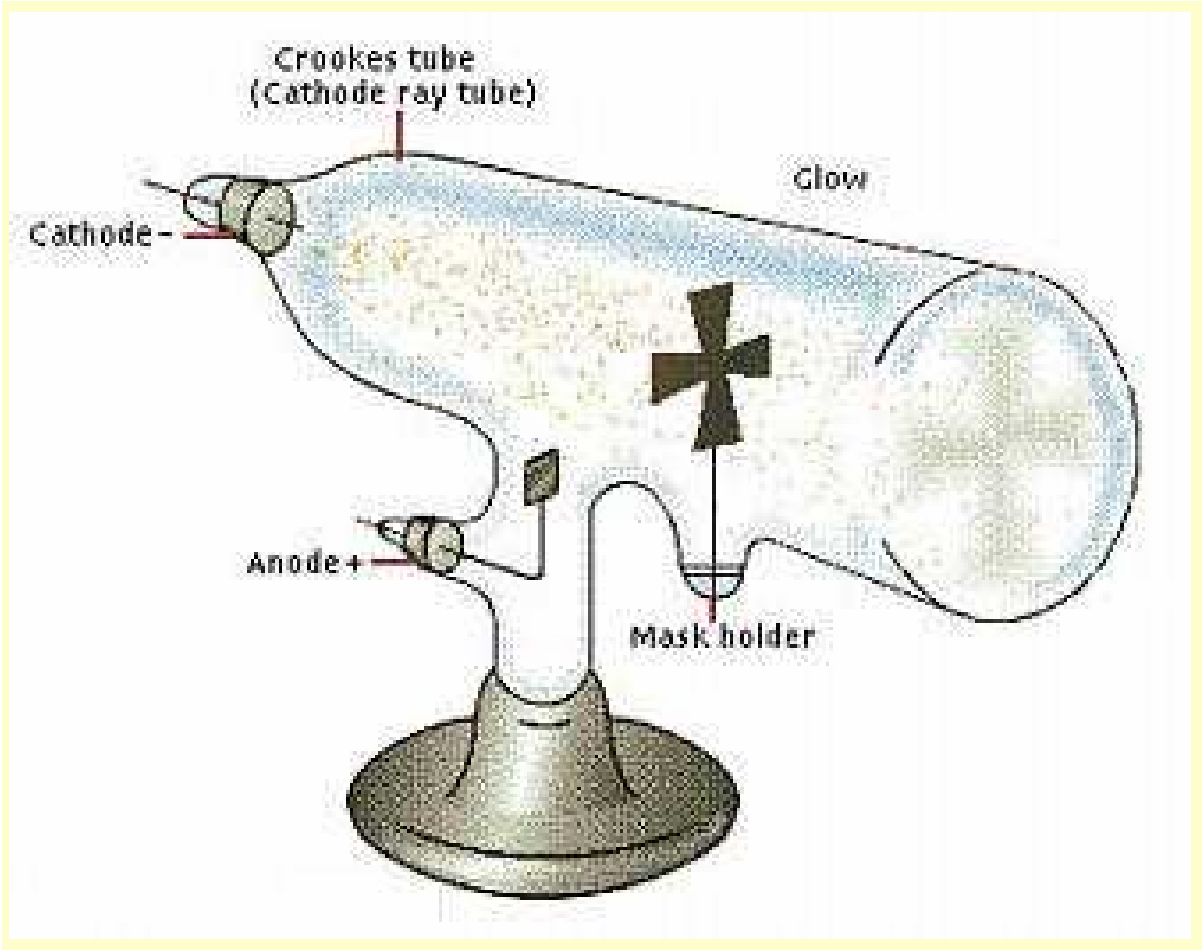
- **1884 - Paul Nipkow**
  - Using rotating disk with raster spiral
  - But amplification problems



CRT?

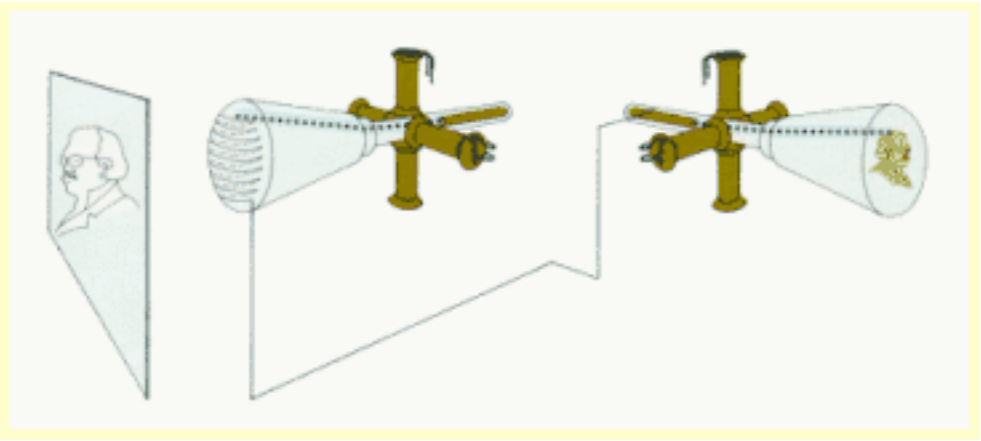
CRT?

- **1897**
- **Karl Braun**



Electronic photography?

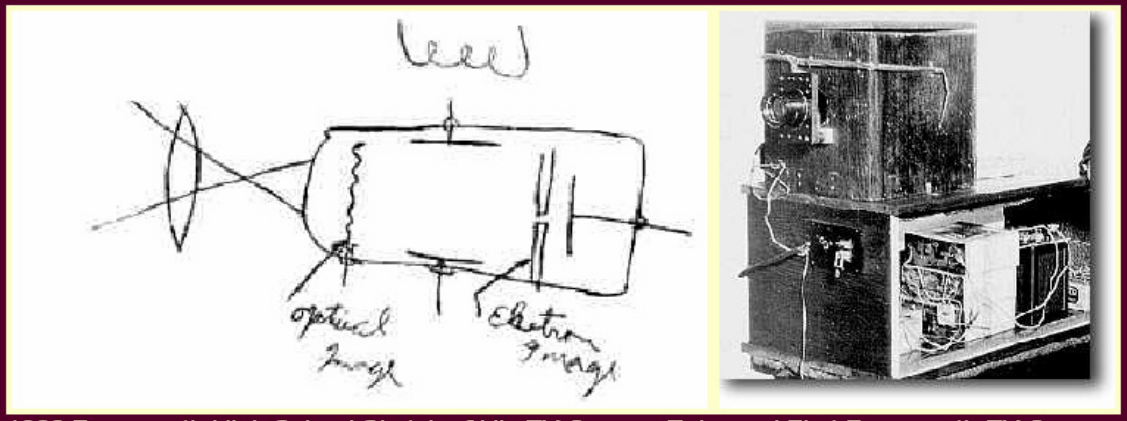
- **A. A. CAMPBELL SWINTON AND ELECTRONIC PHOTOGRAPHY - 1908**
- **25 images per second**



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.

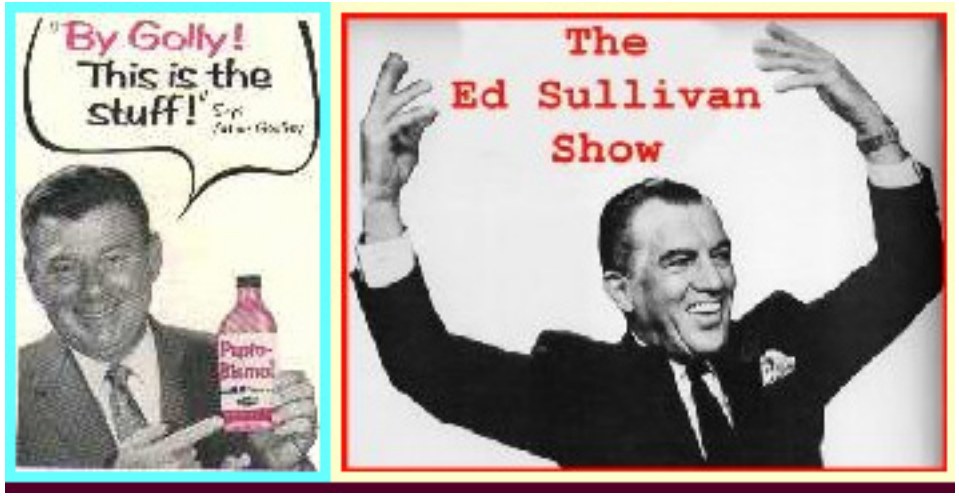


1922 Farnsworth High School Sketch of His TV Camera Tube and First Farnsworth TV Camera

Color TV

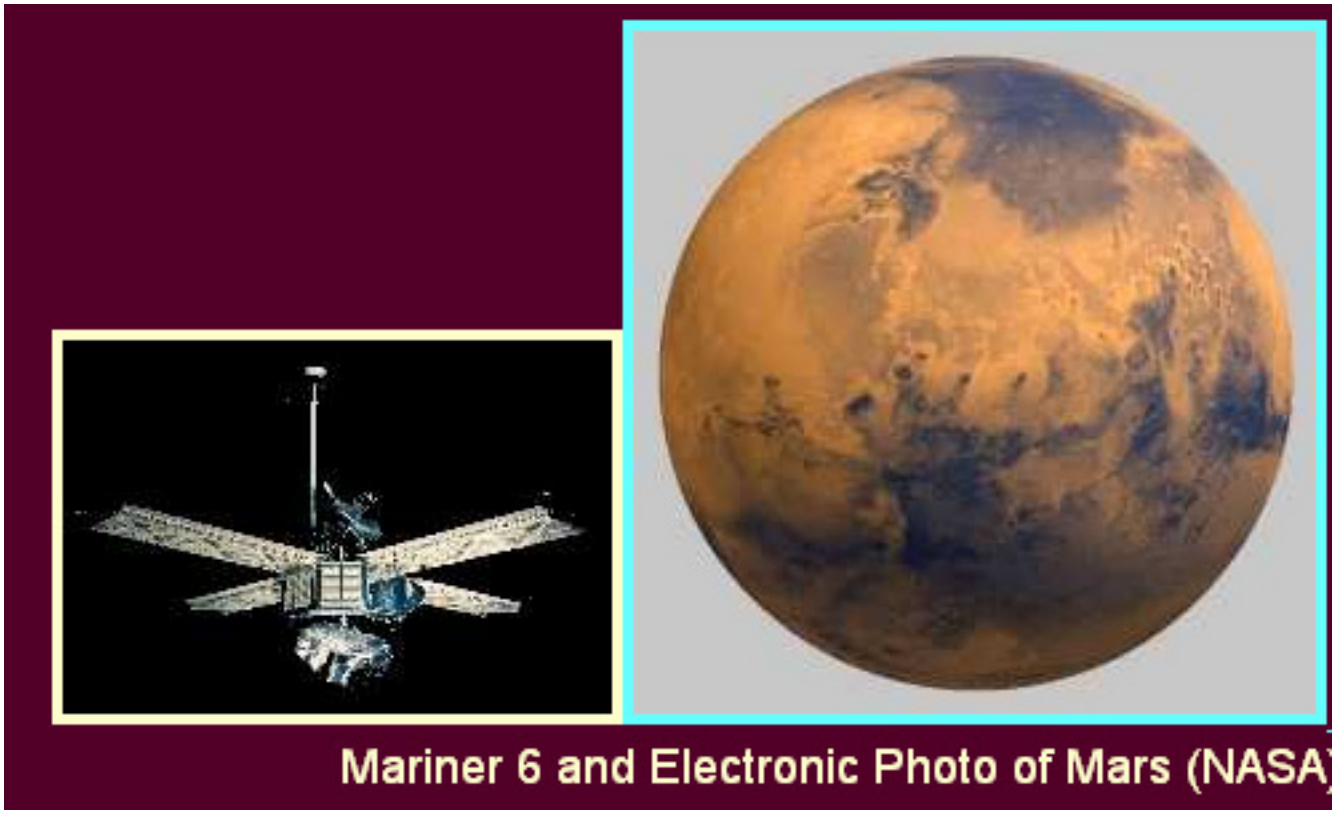
Color TV

- **First broadcast in 1951, CBS**



First electronic photo of Mars

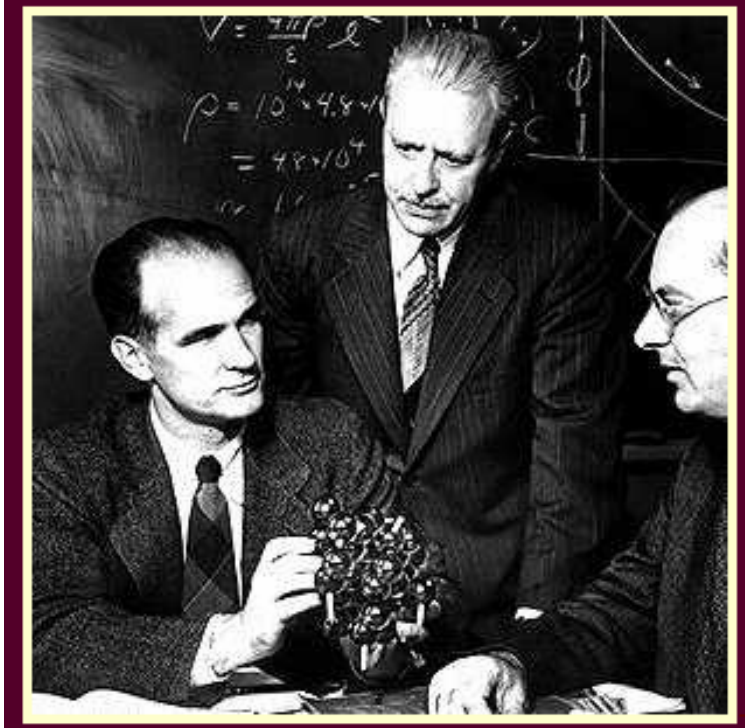
- **1964, NASA JPL**



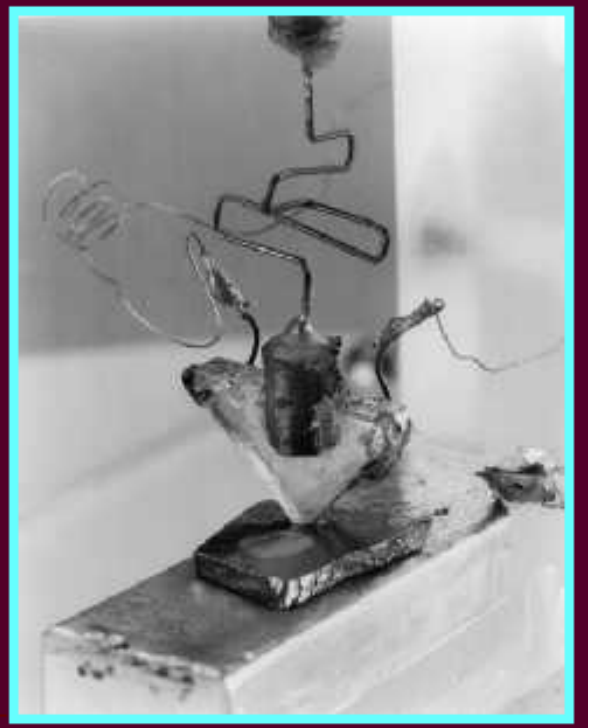
Mariner 6 and Electronic Photo of Mars (NASA)

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

Silicon technology?

- **1956, William Shockley and Victor Jones, Beckman Instruments, Palo Alto, California**
- **http://people.deas.harvard.edu/%7Ejones/shockley/first_crystal.html**
- **"Using a novel technique invented by William Shockley and Victor Jones, this silicon crystal was grown by Jones around the middle of 1956 at the Shockley Semiconductor Laboratory of Beckman Instruments, Palo Alto, California. The crystal was "pulled" through a surface heater that was used to produce a molten pool of silicon in a solid silicon body held at a temperature just below the silicon melting point (see figure below). The fundamental concept underlying the Shockley-Jones invention was that a silicon crystal would not be contaminated by crucible impurities if the effective "crucible" was formed in zone refined silicon. the shaping was a result of changes (mostly intentional) in the power supplied to the surface heater."**

Integrated circuit?

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

Intel gang

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

Texas Instruments' first IC

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

TTL metering?

TTL metering?

- **1964, Pentax Spot Eye (Spotmatic) camera**

Autofocus

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-11976**

Japanese take over camera market?

Japanese take over camera market?

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

- **Lots of pros switched from Leica to Nikon**

Voice-controlled camera

Voice-controlled camera

- **KONICA KANPAI - 1989**
- **Would rotate and take a picture whenever it hears sound**

First scanned photo?

First scanned photo?

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

The SEAC Scanner
with control console in background

Two scans separated by 40 years

CCD technology?

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

Computer Graphics?

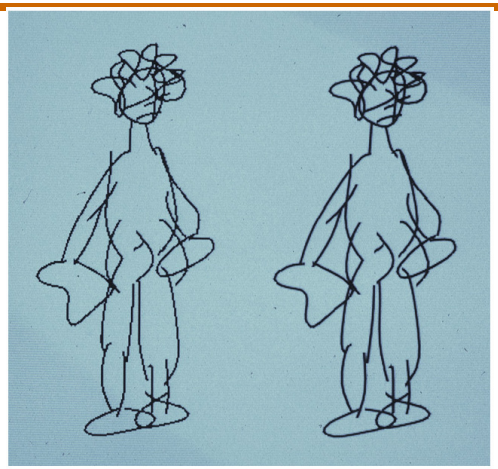
Computers to create image

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

Paint program

Paint program

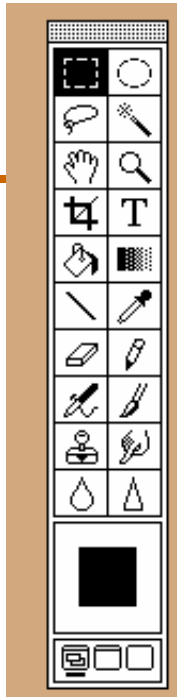
- **Dick Shoup: SuperPaint [1972-73]**
  - 8 bits
  - http://www.rgshoup.com/prof/SuperPaint/
- **Alvy Ray Smith (Pixar co-founder): Paint [1975-77]**
  - 8 bits then 24 bits
  - http://www.alvyray.com/Awards/AwardsMain.htm
  - http://www.alvyray.com/Bio/BioMain.htm
- **Tom Porter: Paint**



Photoshop

Photoshop

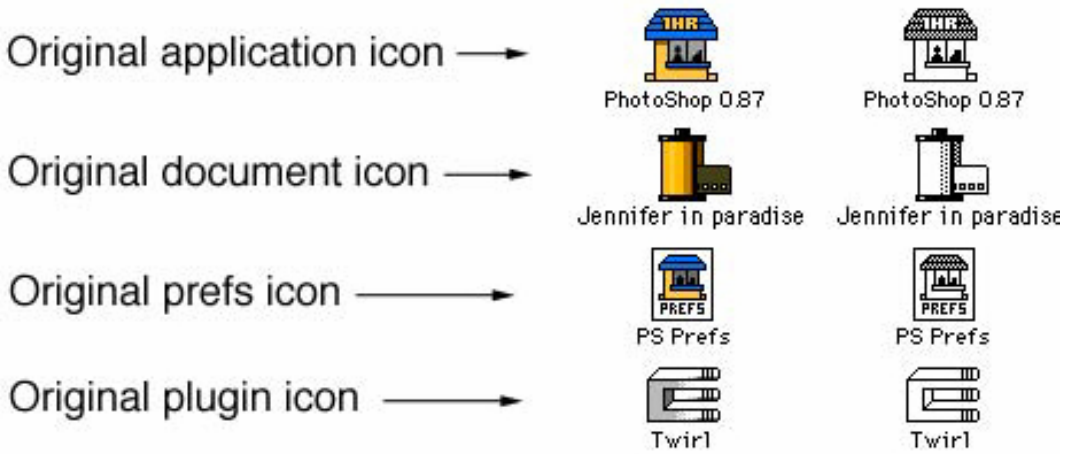
- **Thomas Knoll and John Knoll began development in 1987**
- **Version 1.0 on Mac: 1990**
- **http://en.wikipedia.org/wiki/Photoshop#Development**
- **http://www.storyphoto.com/multimedia/multimedia_photoshop.html**



Photoshop toolbar from version 1.07

John Knoll.
Photo by Jeff Schewe.

Thomas Knoll.
Photo by Jeff Schewe.



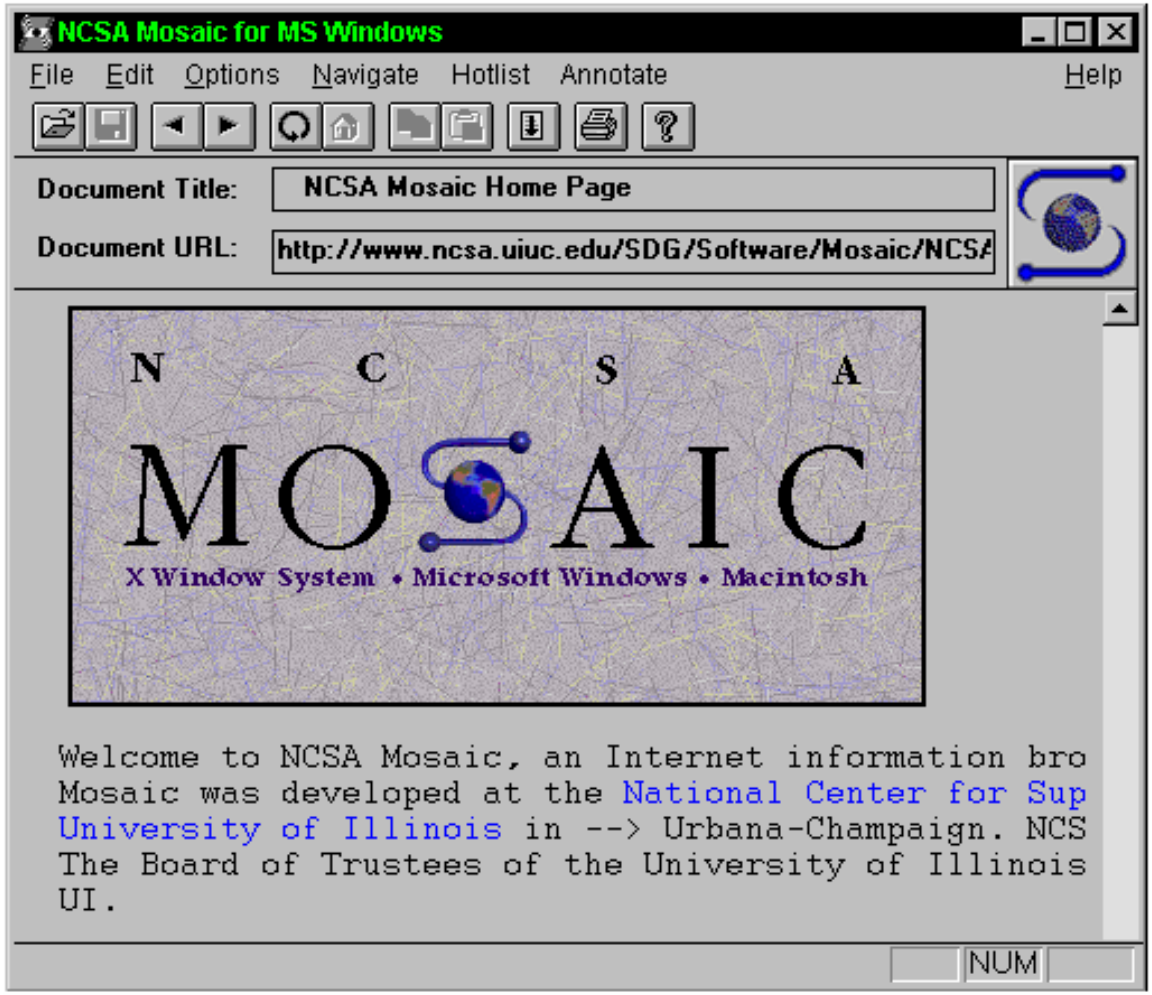
The original application icons designed by John Knoll.

Internet photo browsing

- **(Web browser that can display photos)**

Internet photo browsing

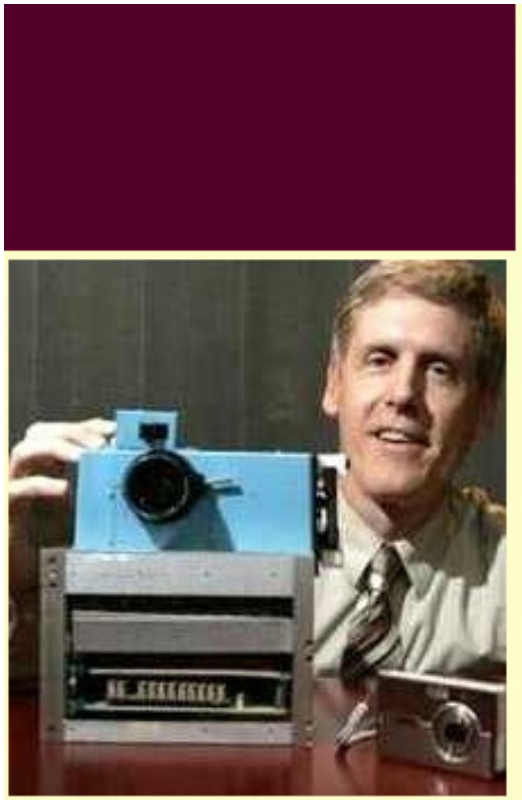
- (Web browser that can display photos)
- Mosaics, NCSA, Urbana Champaign, 1992

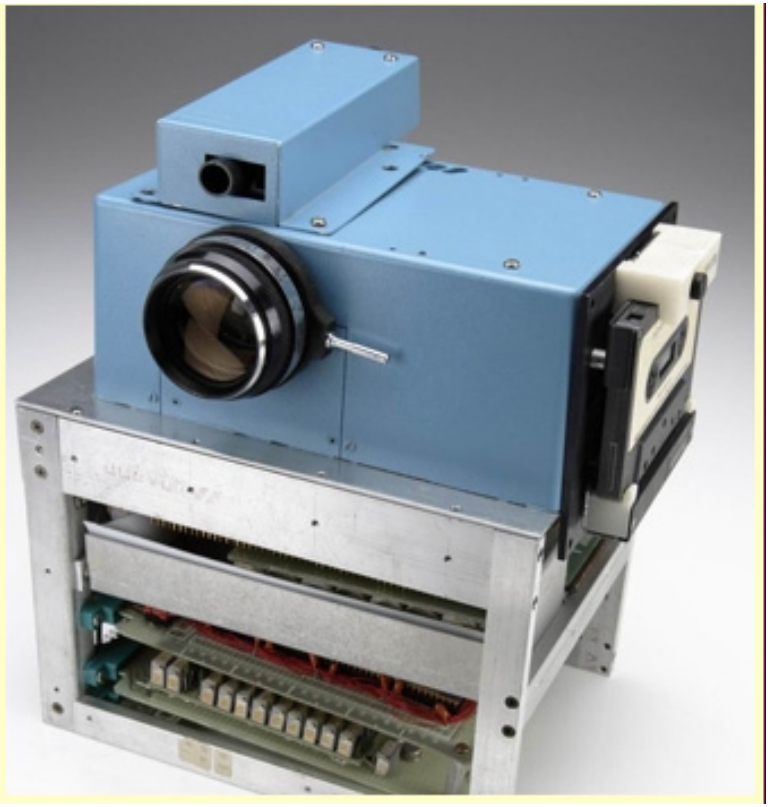


First digital camera?

First digital camera?

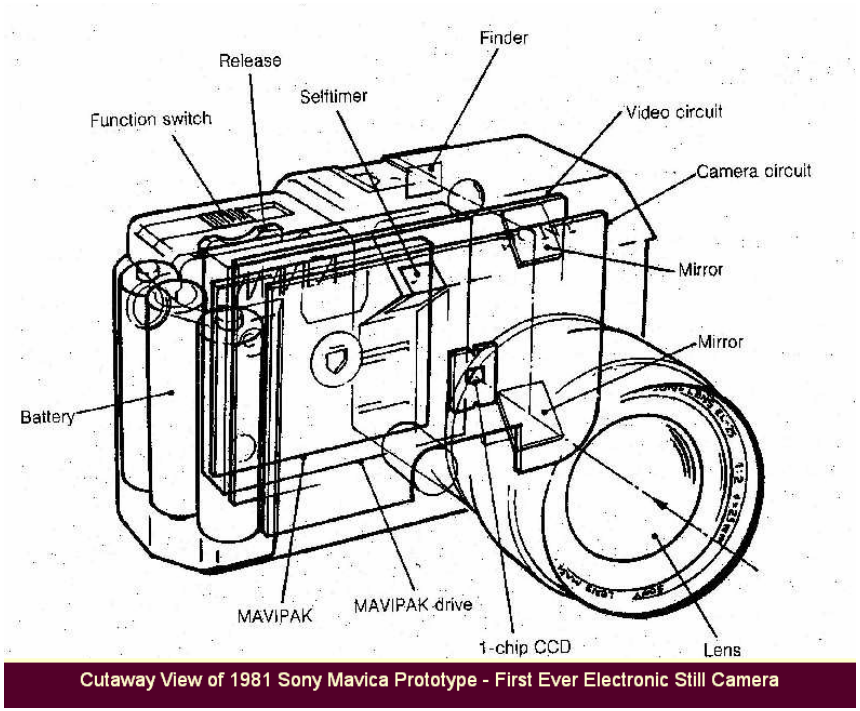
- **1975, Steve Sasson, Kodak**
- **Uses ccd from Fairchild semiconductor, A/D from Motorola, .01 megapixels, 23 second exposure, recorded on digital cassette**





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

http://www.g4tv.com/l

Completely Digital Commercial camera

- **1991 first completely digital Logitech Dycam 376x240**

http://www.g4tv.com/l

Digital

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

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

Digital

- **CANON RC-250 XAPSHOT (Ion in Europe, Q-PIC in Japan) - 1988**

First megapixel sensor

- **Of reasonable size?**

First megapixel sensor

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

Digital SLR?

Digital SLR?

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

Pros adopt digital?

Pros adopt digital?

- **Nikon D1 1999, 2.7MPixels**

Consumer digital SLR?

Consumer digital SLR?

- **Canon D30, 2000 3MPixels**

Camera phone?

Camera phone?

- **In November 2000 Sharp and J-Phone introduced the first camera-phone in Japan**

Traditional Photography

- **XVIth century (drawing by da Vinci) *Camera Obscura***
- **XVIIth century Robert Boyle finds that silver chloride darkens under exposure, but he believes it's due to air.**
- **Angelo de Sala figures out it's the sun**
- **early nineteenth century, Thomas Wedgwood captures silhouettes but they disappear**
- **1825, Niepce makes first photo (8 hour exposure!)**
- **Daguerre reduces this to half an hour (development) *Daguerreotype*, public in 1839. Impossible to reproduce.**
- **William Henry Fox Talbot invents the *calotype* in 1834 which pretty much invents the negative**
- **Frederick Scott Archer in 1851 reduces exposure to a couple seconds**
- **1855 beginning of stereo mania**
- **1861 Maxwell shows the fist color photograph**
- **1877 Edweard Muybridge photographs running horses**
- **1893 Flash bulb, invented for underwater photography**
- **1906 Panchromatic film that truly enable color photography**
- **1924 Leica 35mm interchangable camera**
- **1930 flash bulb (Paul Vierkotter)**
- **1936 Kodak SLR camera**
- **1948 Pentax introduces automatic diaphragm**
- **1949 Zeiss developes the Contax, the first SLR with pentaprism for uninversed image**
- **1963: Polaroid instant film**
- **1964 Pentax TTL (through the lens) metering**
- **1981 Pentax autofocus camera**

Refs

- http://www.digicamhistory.com/

- http://www.photo.net/history/timeline
- http://inventors.about.com/library/inventors/blphotography.htm
- http://www.loc.gov/exhibits/empire/
- http://www.spartacus.schoolnet.co.uk/USAphotographers.htm
- http://www.eyeconart.net/history/photography.htm
- http://www.scphoto.com/html/history.html
- http://www.g4tv.com/callforhelparchive/features/44534/Witness_to_History_The_Digital_Camera.html
- http://www.digicamhistory.com/
- http://www-users.mat.uni.torun.pl/~olka/
- http://inventors.about.com/od/pstartinventions/a/Photography.htm
- http://www.ted.photographer.org.uk/camera_designs_3.htm
- http://accad.osu.edu/~waynec/history/timeline.html
- http://en.wikipedia.org/wiki/History_of_the_single-lens_reflex_camera

Next time:

- **Image formation & camera basics**