Computational Photography
Photographie Algorithmique

Frédo Durand
MIT - EECS/CSAIL
Willow / INRIA / ENS

Langue

- **Frenglish...**
- **...ou franglais?**

Qui je suis / Who I am

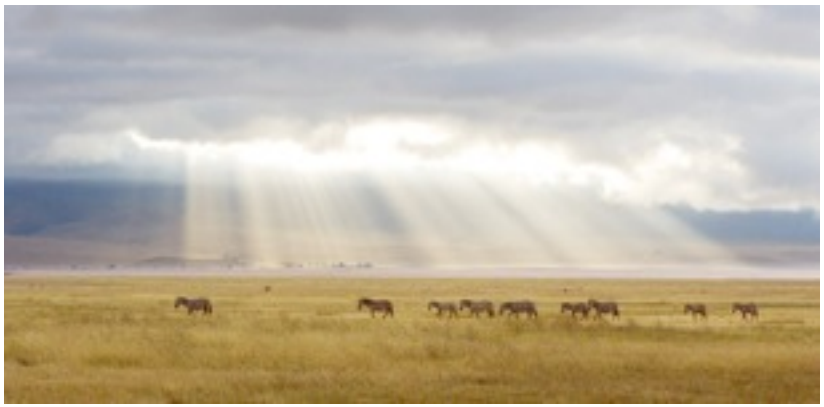
- **Eleve ENS 1993-97**
- **Doctorat a Grenoble 1999**
- **Post-doc au MIT 1999-2002**
- **Enseignant au MIT depuis 2002**
- **Prof invite a l'ENS et dans l'equipe ENS-INRIA Willow en automne 2009**

- **Par ailleurs photographe amateur**

Photography

- **amateur photographer, mostly wildlife, travel**

Photography



I like equipment

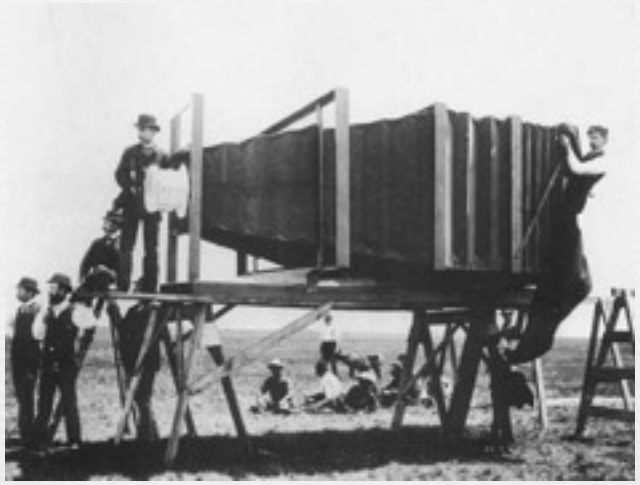
Today's plan

- Introduction of Computational Photography
- Course facts
- Syllabus
- History

- Color

The unfinished digital photography revolution

- Traditional photography:
  - optics focuses optical array onto sensor
  - chemistry records final image

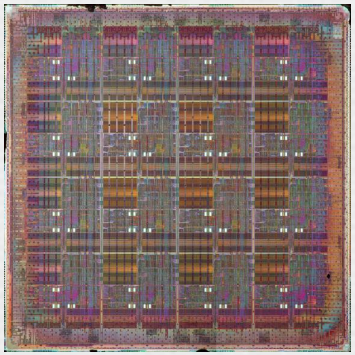


- Digital photography
  - optics focuses optical array onto sensor
  - digital sensor records final image

Computational Photography

- Arbitrary computation between the optical array and the final image
- Data recorded by sensor is not the final image

Generalized imaging



Lots of computation

Final image

Computational Photography

Arbitrary computation between optical array and final image (or final product)

- Post-process after traditional imaging
  - a.k.a. image processing (maybe more interactive)
  - But also combine multiple images to overcome limits of traditional imaging (HDR, panorama)
- Design imaging architecture together with computation
  - Computational cameras, computational illumination, coded imaging, data-rich imaging
- Extract more than just 2D images
- New media (panorama, photo tourism)

Quick demos

Computational Photography @ MIT

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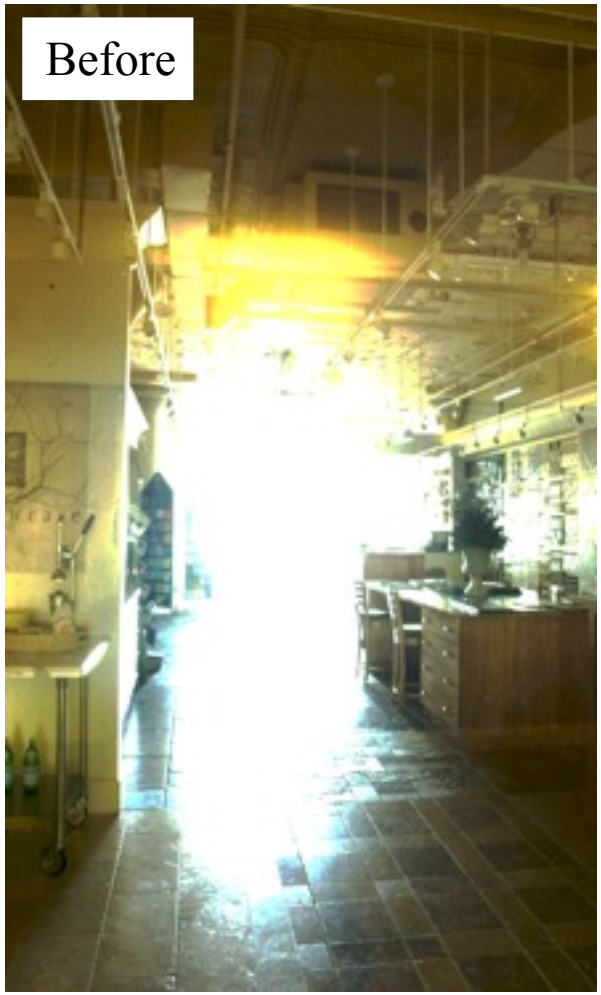
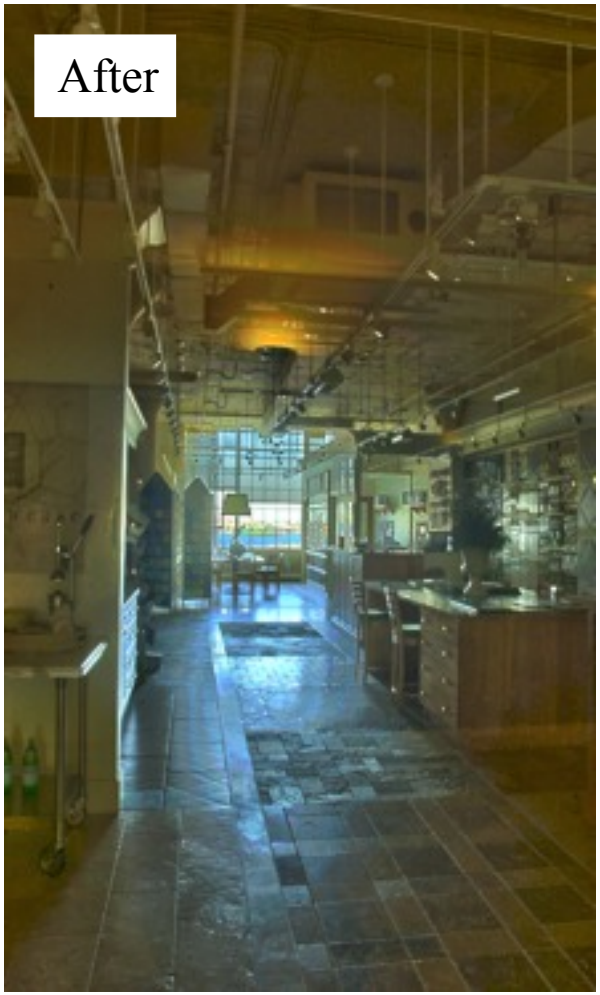
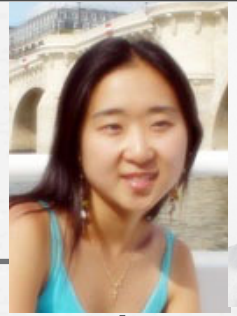
Tone mapping

- **One of your assignments!**





Black and white digital



- *with Soonmin Bae and Sylvain Paris [Siggraph 06]*
- Users often disappointed by BW photos

High-quality black and white

- Can we "transfer" some of the low-level qualities?
- *with Soonmin Bae & Sylvain Paris [Siggraph 06]*

Input photograph

With Bae & Paris [Siggraph 06]

Our result based on Adams' example

Motion magnification

- *with Liu, Torralba, Freeman & Adelson [Siggraph 2005]*
- Analyze motion in video (robust to occlusion)
- Magnify motion that is hard to see

Motion magnification

- *with Liu, Torralba, Freeman & Adelson [Siggraph 2005]*
- Analyze motion in video (robust to occlusion)
- Magnify motion that is hard to see

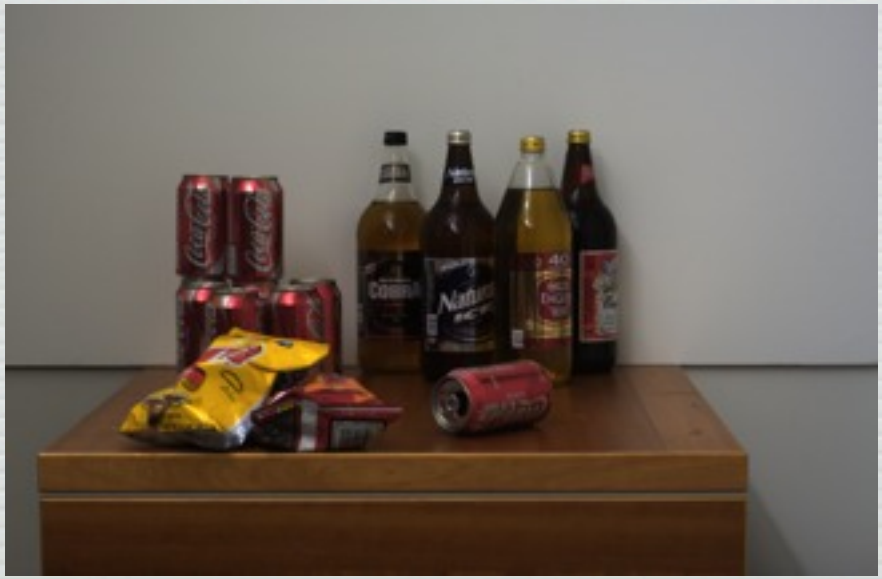
Modeling virtual scenes from images

- A former students, Max Chen, went to ILM (LucasFilm) to implement technology developed for his Master's. He received a technical Oscar for it.

Image and Depth from a Conventional Camera with a Coded Aperture

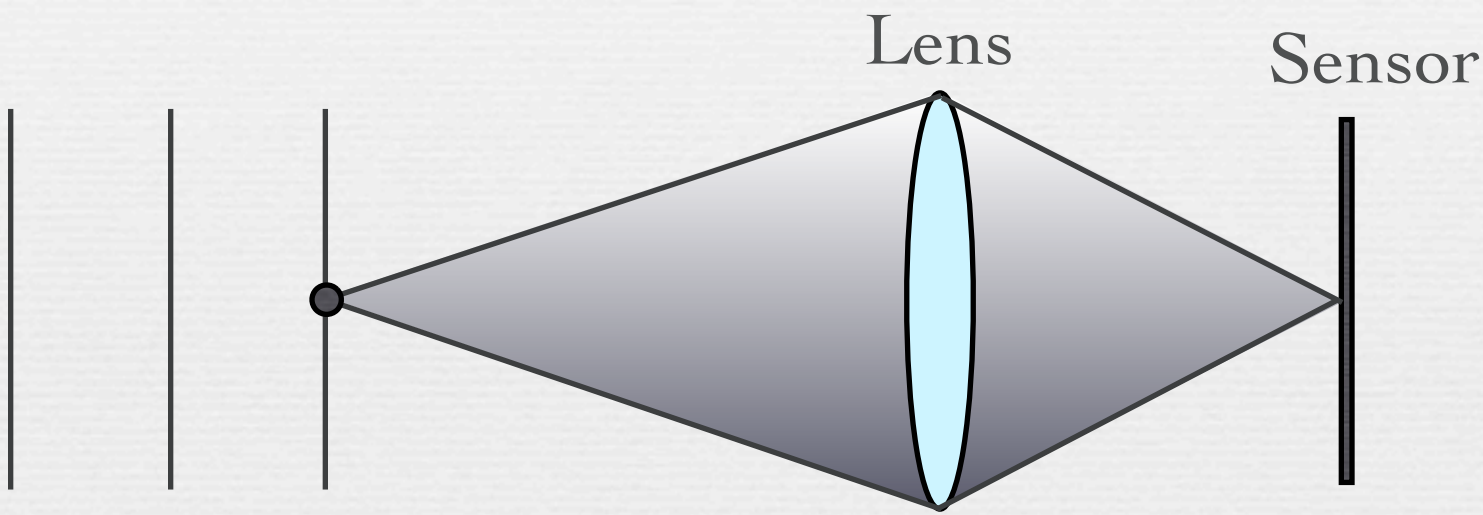
With Anat Levin, Rob Fergus, Bill Freeman [Siggraph 2007]

RGB & coarse depth from single image



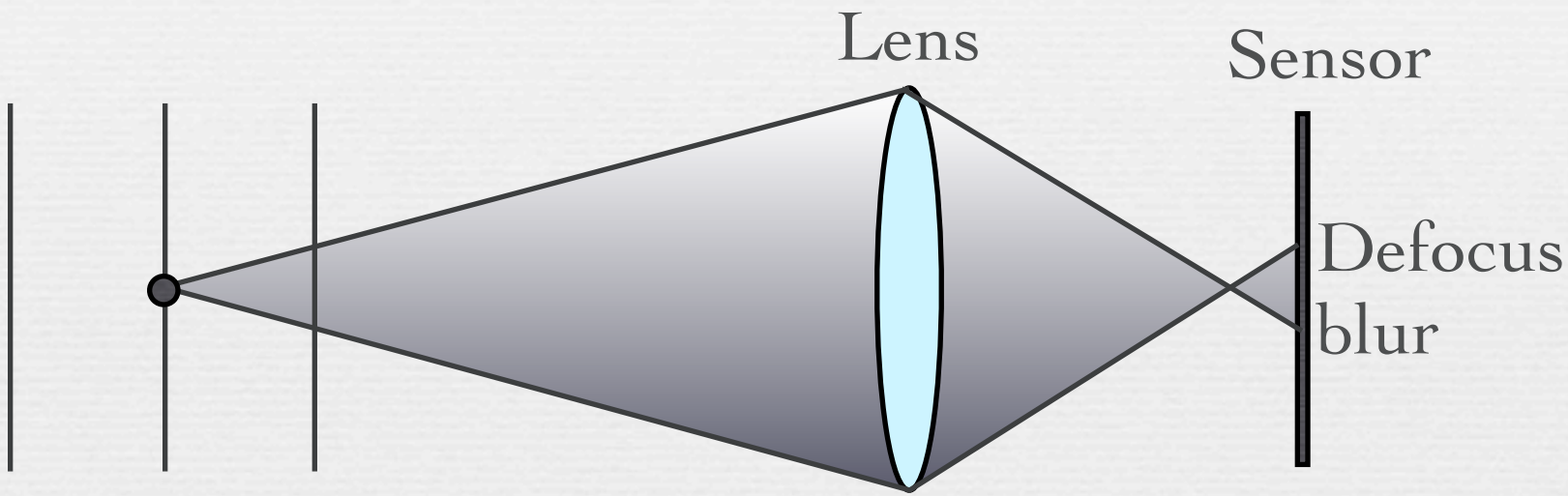
Defocus & depth

- Objects at focusing distance are sharp



Defocus & depth

- Objects far from focusing distance are blurrier



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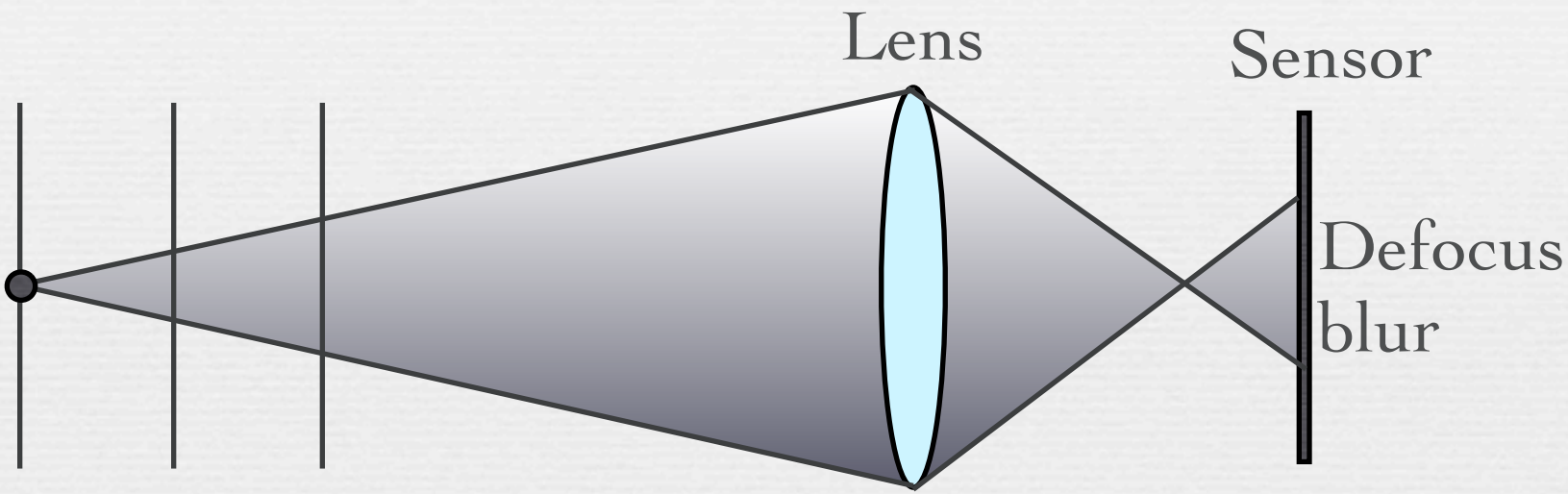

Defocus & depth

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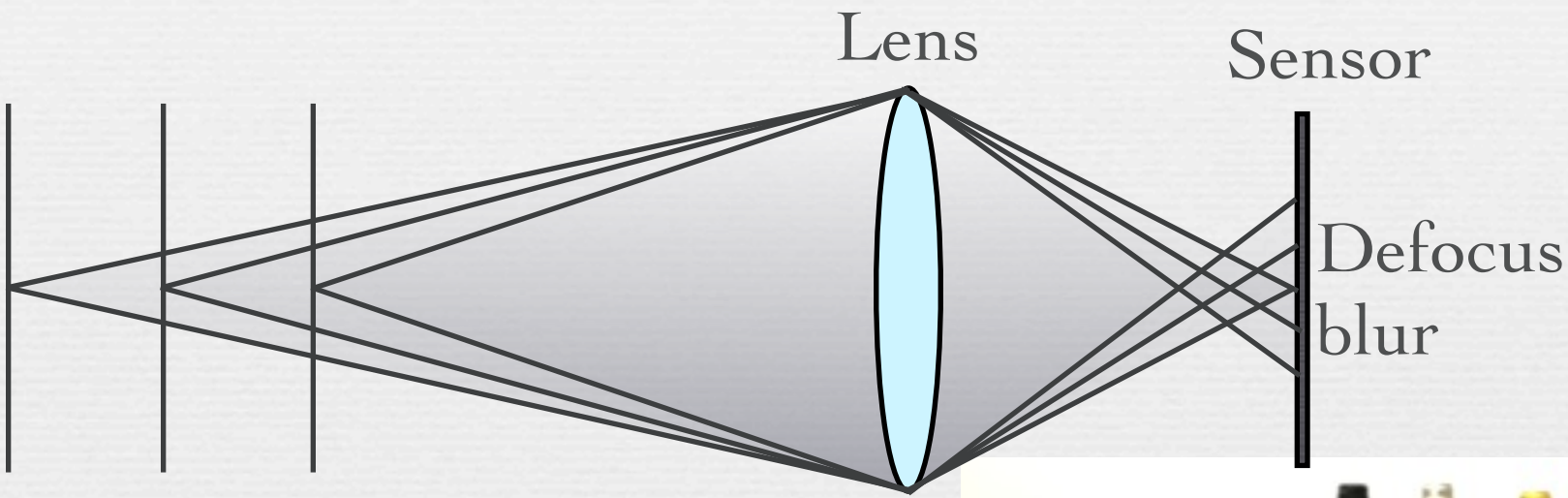
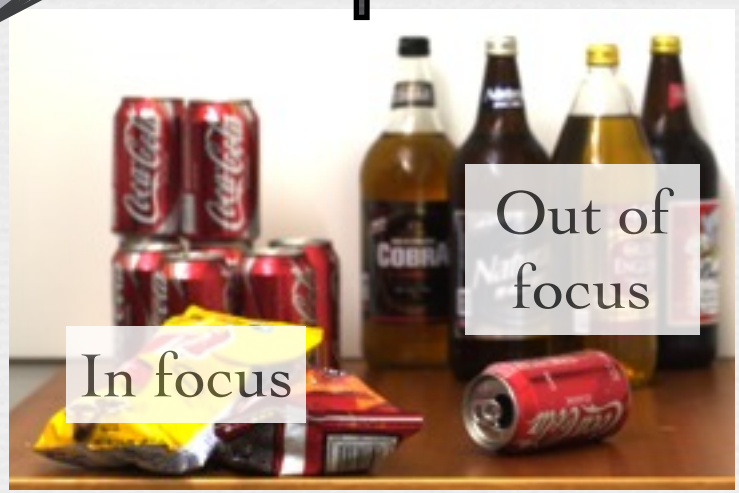


- **By inferring blur, we can infer depth**



Build your own coded aperture

Open the lens

Open the lens

Open the lens

Open the lens

Open the lens

Open the lens

Open the lens

Now the critical part

Cardboard mask

Cardboard mask

Cardboard mask

Cardboard mask

Cardboard mask

Cardboard mask

Cardboard mask

Close it up

Close it up

Close it up

Close it up

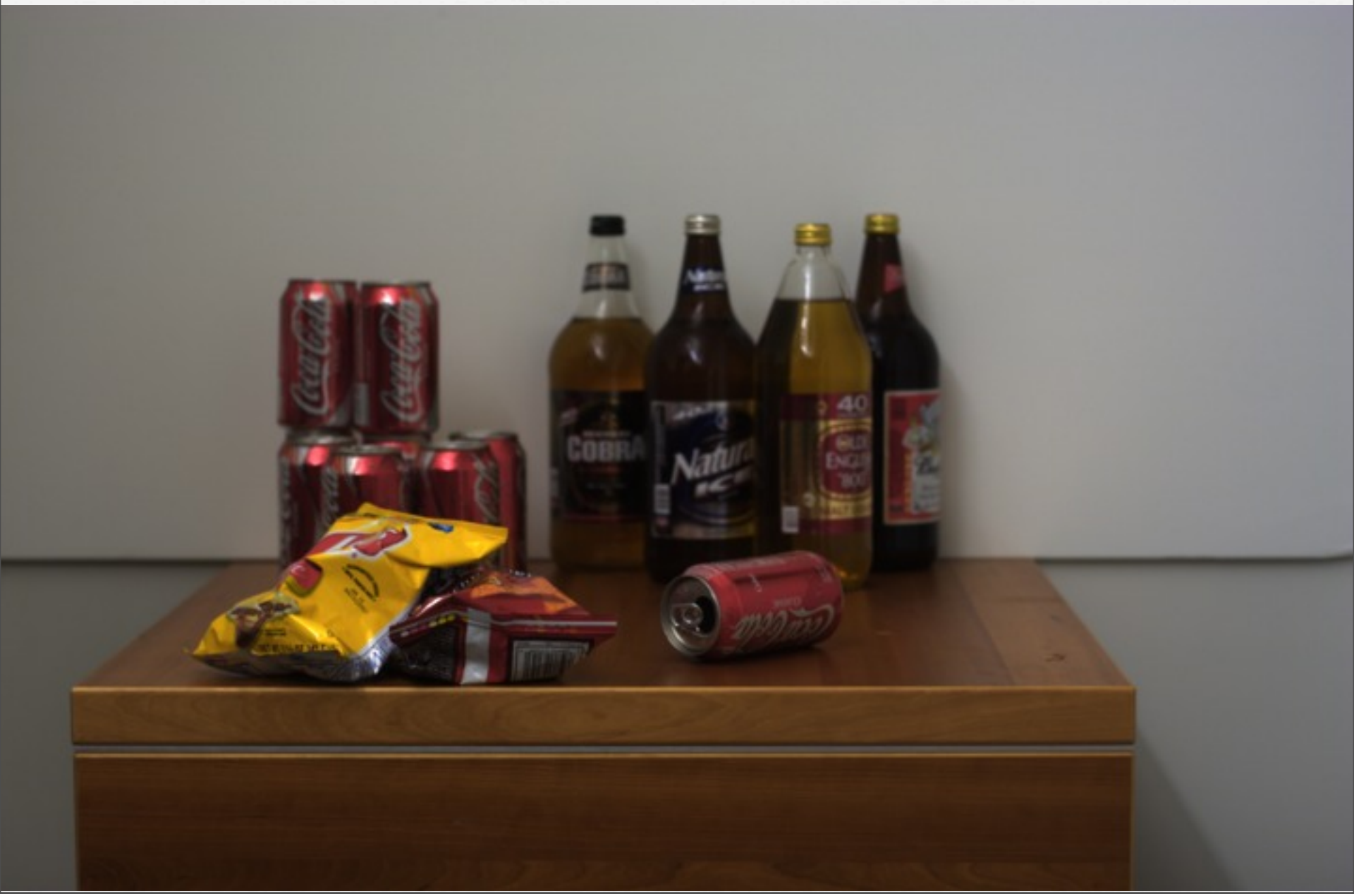
Close it up

Close it up

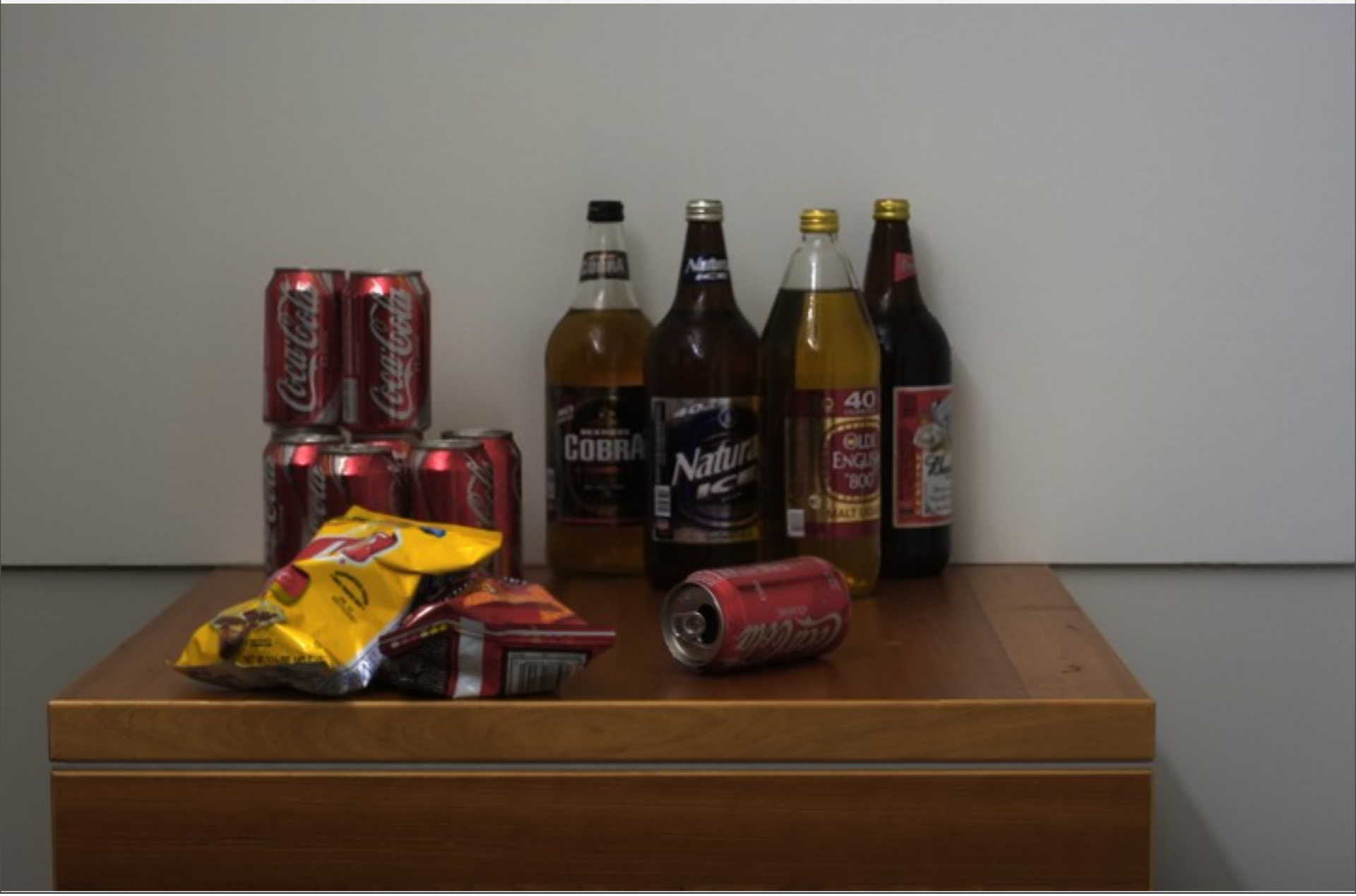
Close it up

Voilà!

Input



Deconvolved (all-focus)

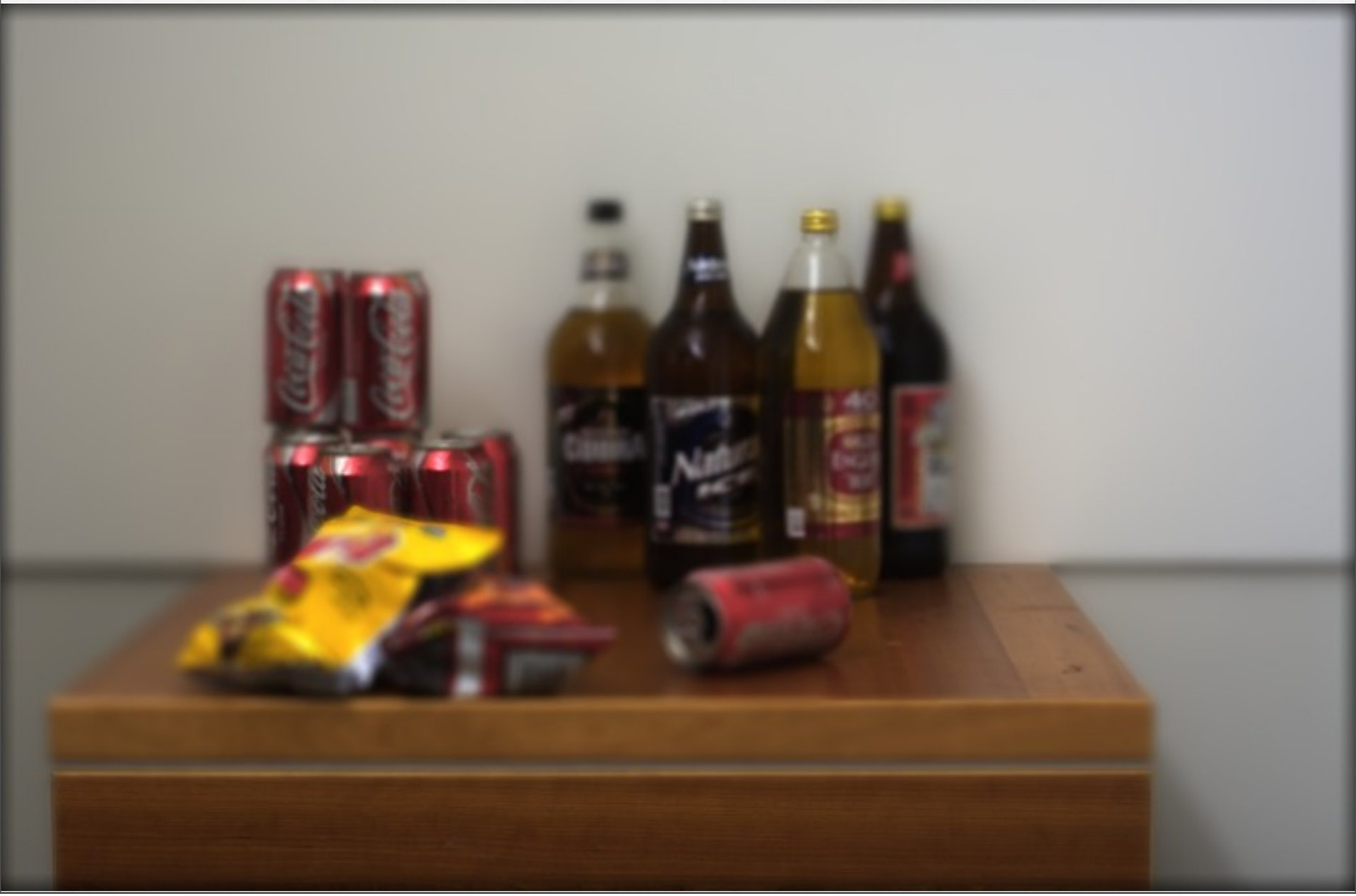


Close up

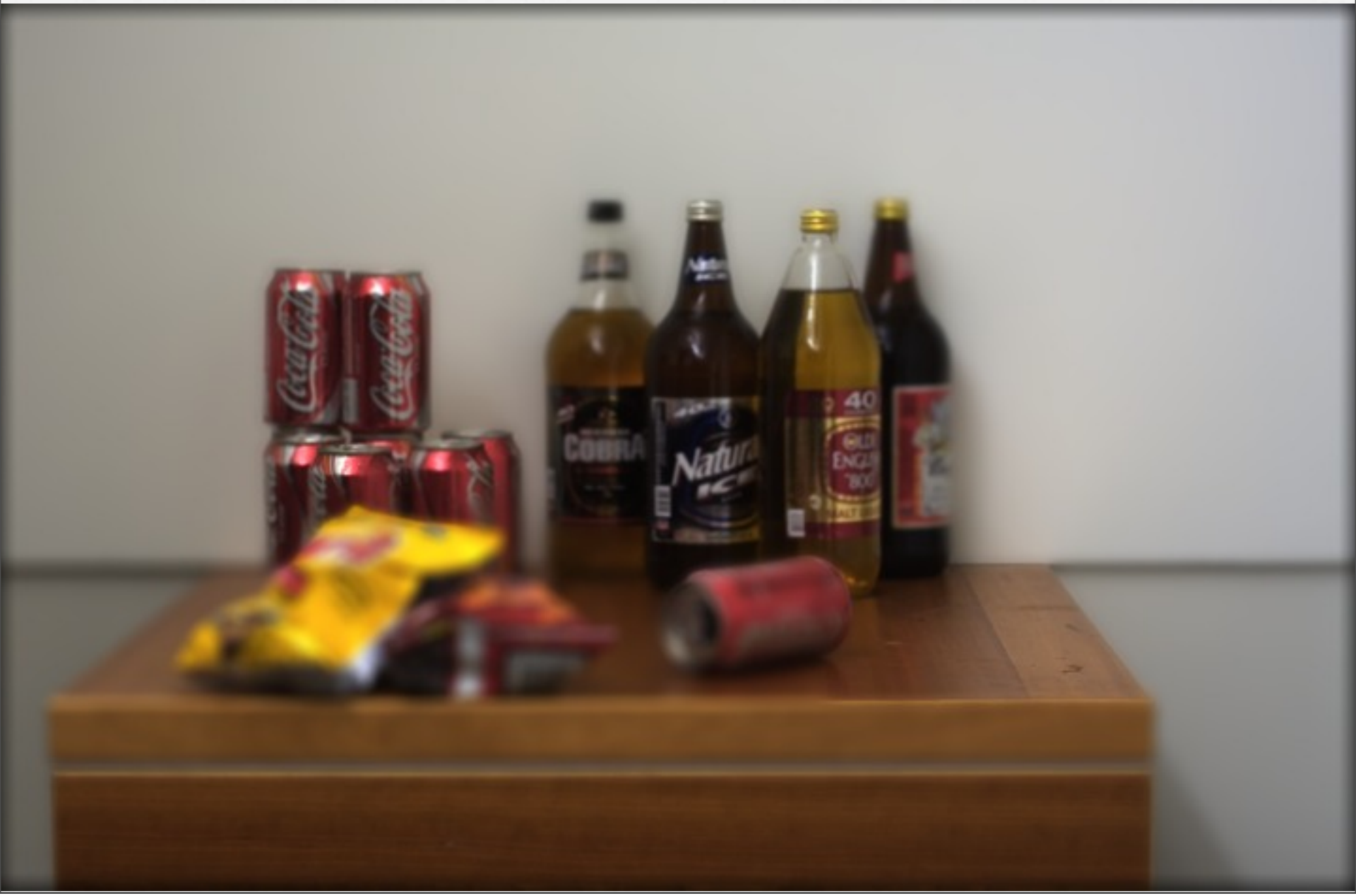
Depth

Refocusing (from single image!)

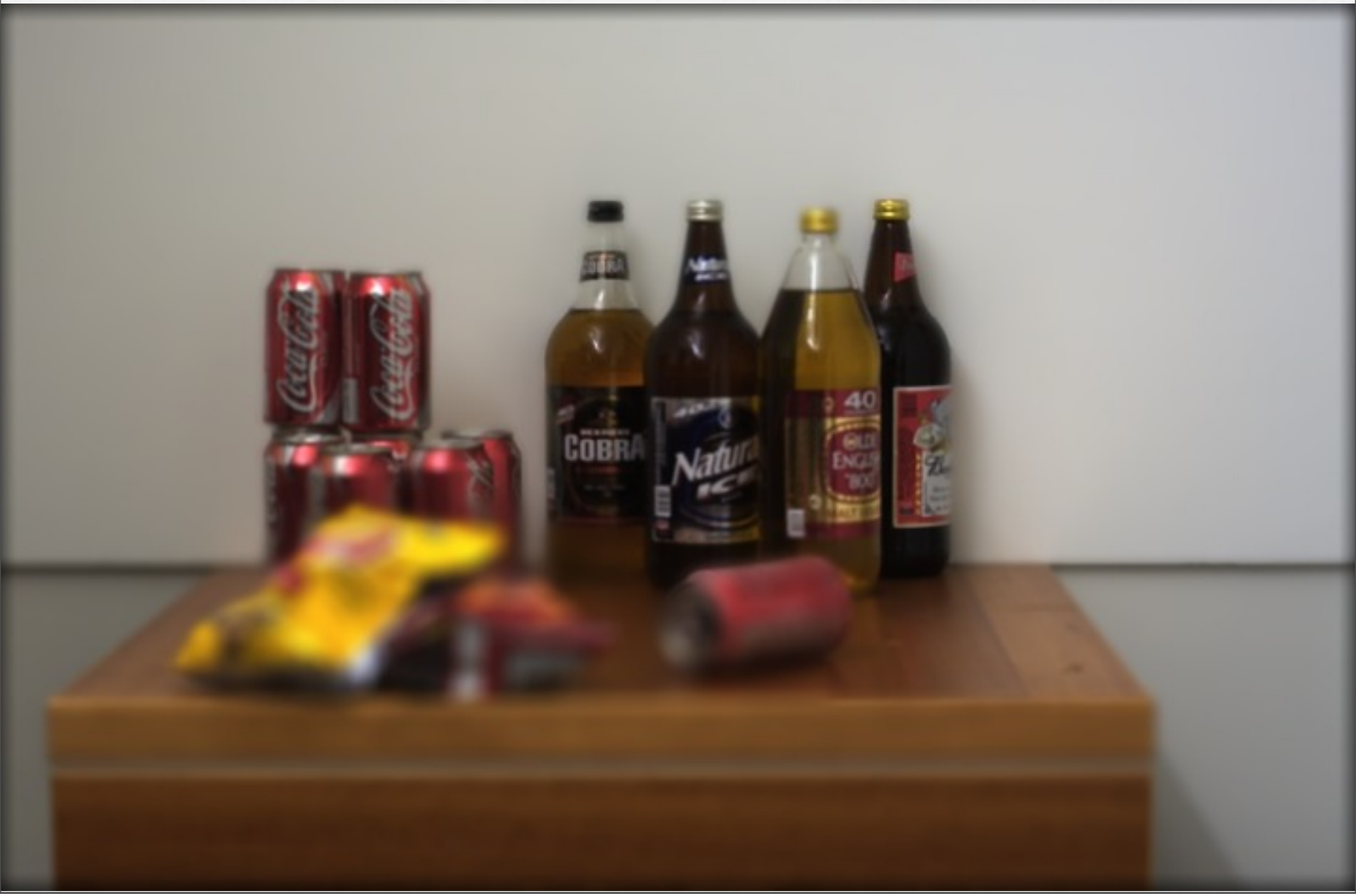
Refocusing (from single image!)



Refocusing (from single image!)



Refocusing (from single image!)



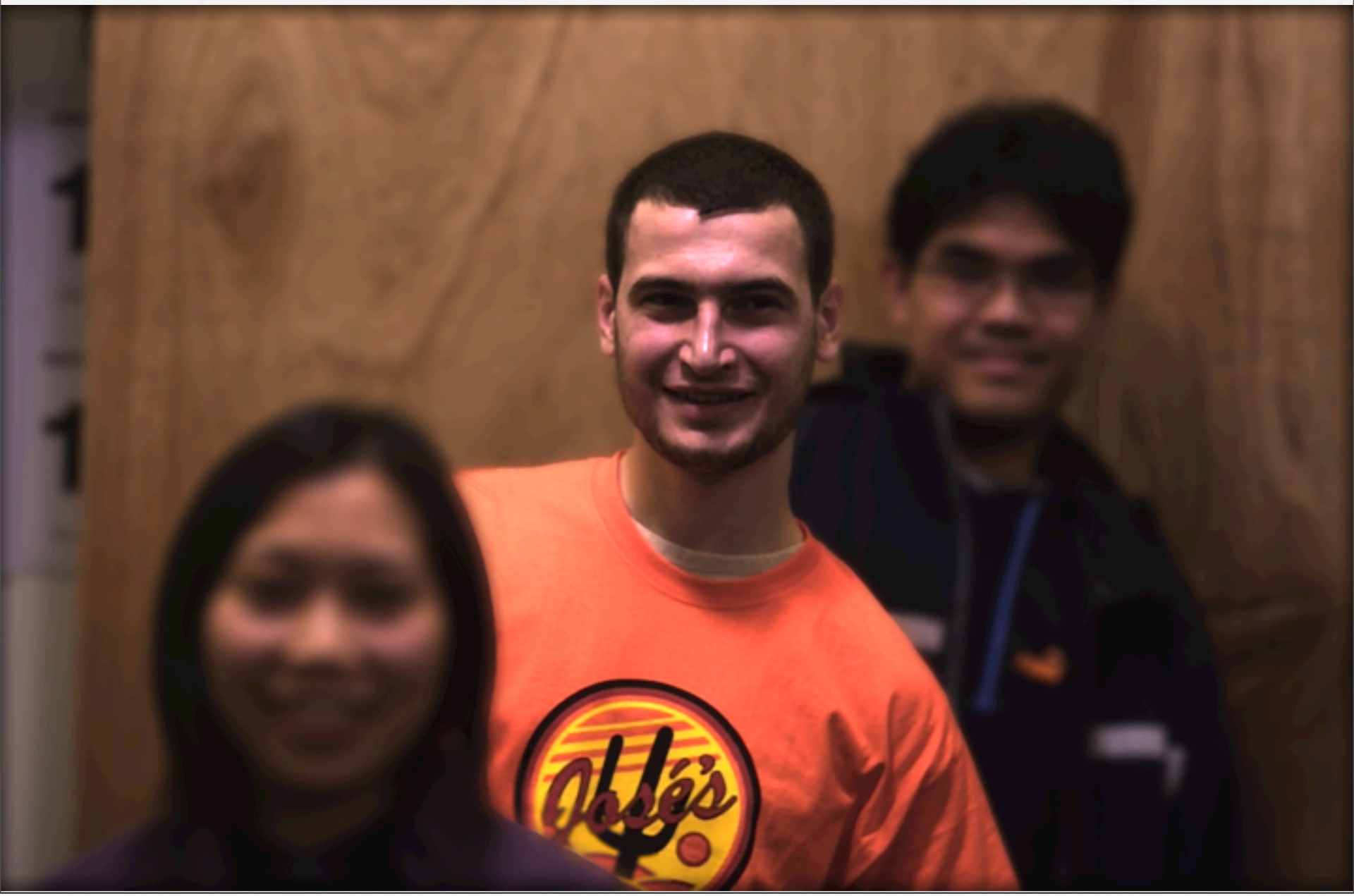
Results

Input

Deconvolved

Refocusing (from single image!)

Refocusing (from single image!)



Refocusing (from single image!)

Today's plan

- Introduction of Computational Photography
- Course facts
- Syllabus
- History

Administrivia

- **Staff**
  - Frédo Durand fredo@mit.edu
- **Web page:**
  - http://people.csail.mit.edu/fredo/Classes/Comp_Photo_ENS/
  - Lecture notes will be posted

Optional Assignment

- **http://stellar.mit.edu/S/course/6/sp09/6.815/homework/index.html**
- **Good way to understand material better**
- **Matlab is a good language to implement those algorithms**

Final project

- That's how you get graded
- Propose your subject or I'll post ideas.
- Talk to me to refine subject.
- Topic should be decided in the next couple of weeks
- Project due Nov 19

Textbook

- **No textbook required**
- **Lots of resources on the net**
- **Siggraph course notes**
  - http://www.merl.com/people/raskar/photo/
- **Will post lectures slides**
- **Links to articles in slides**

Questions?

Introductions

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

Math background?

- Linear algebra?
- PDEs?
- Linear programming?
- Fourier analysis?

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 a lot 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**
- **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
  - Seam carving
  - Matting
  - Bilateral filter, tone mapping
  - Gradient reconstruction
  - Panorama stitching
- **General approaches to computational photography**
- **Important problems in computational photography**

Non-photo motivation

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

Questions?

Today's plan

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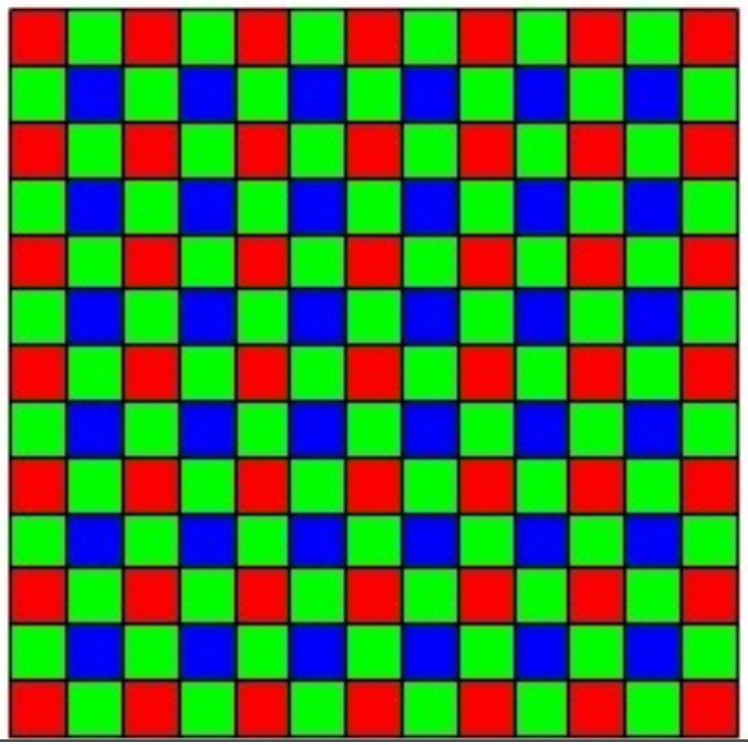
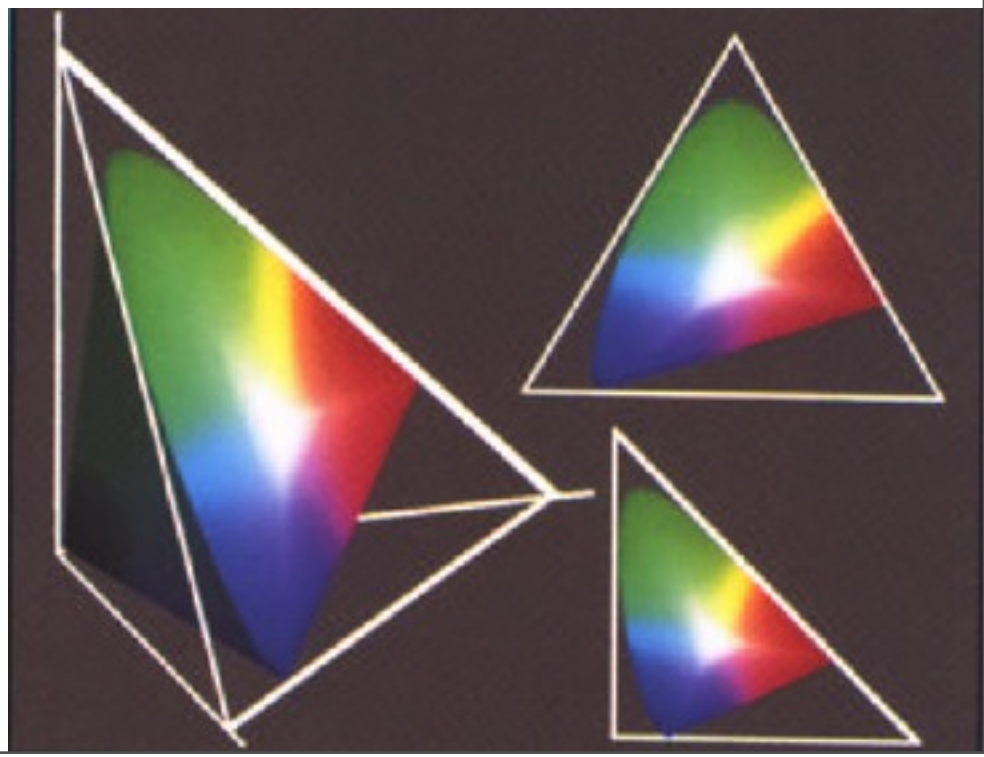
A la carte

- **This course is a shortened version of my MIT class.**
- **We can adapt to your interest. Email me or tell me which of the following topics are most interesting to you.**
- **By default I will favor the early ones.**

Syllabus

- **Color and color perception**
- **Demosaicing**



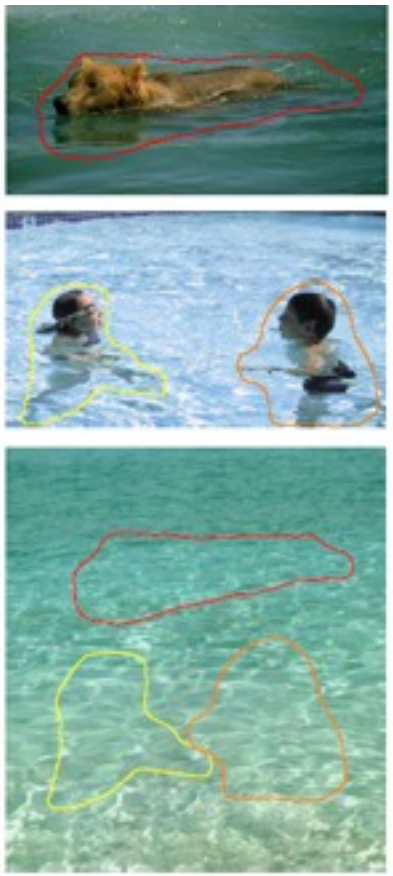


Syllabus

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

Syllabus

- **Gradient image manipulation**



sources/destinations

cloning

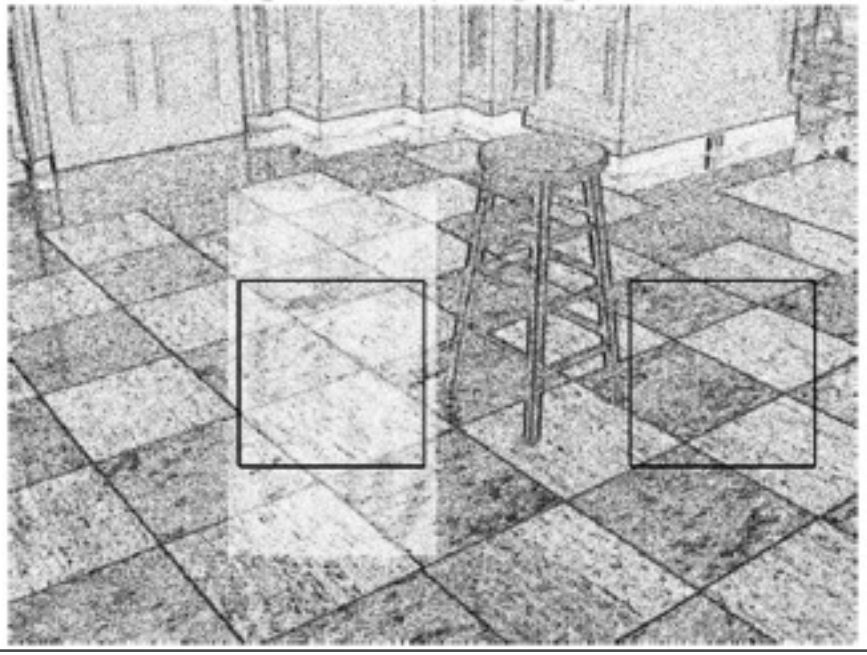
seamless cloning

Syllabus

- **Tampering detection**

original

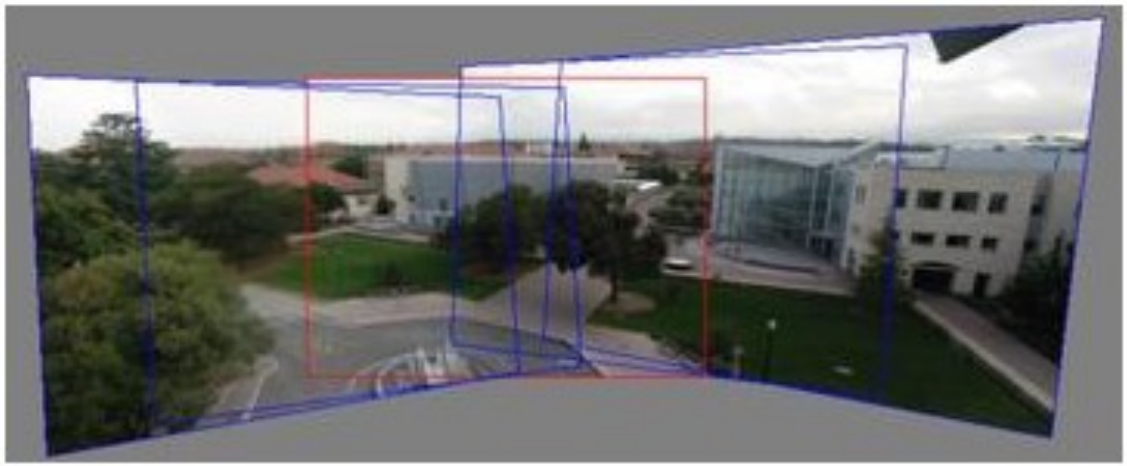
probability map (p)



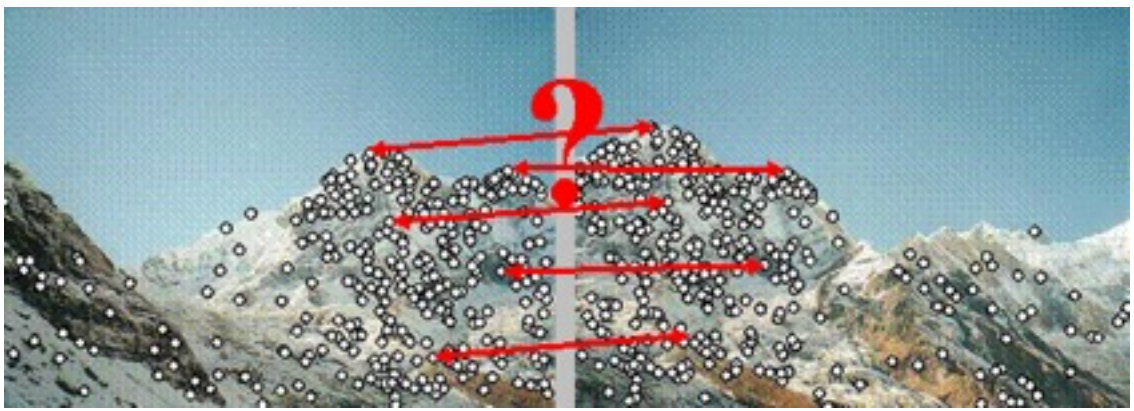
forgery

Syllabus

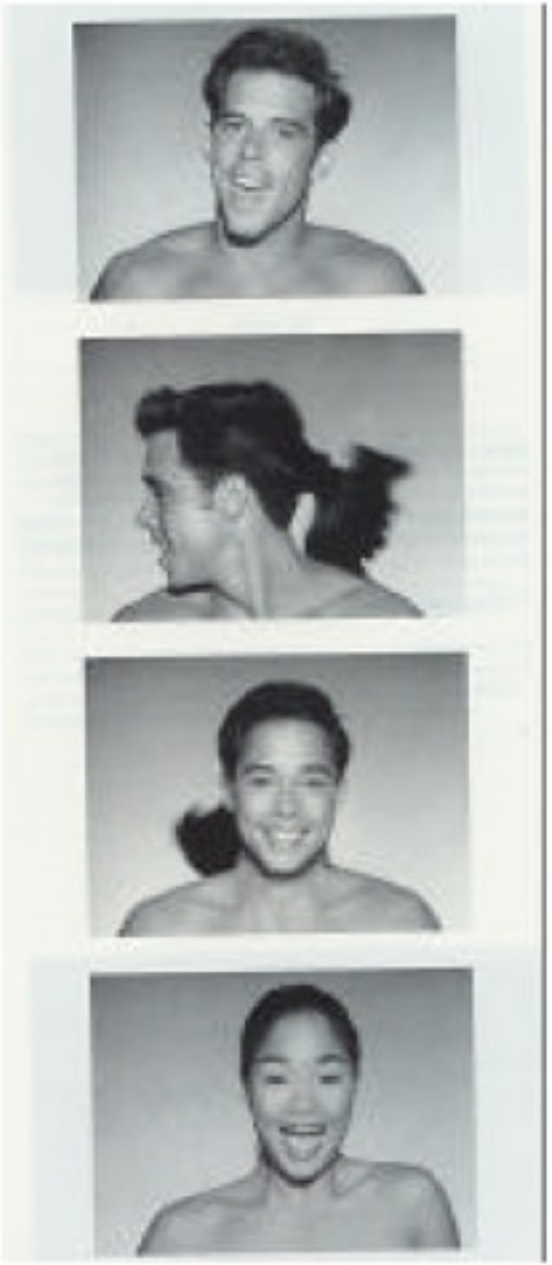
- **Panoramic imaging**



- **Image and video registration**



- **Spatial warping operations**

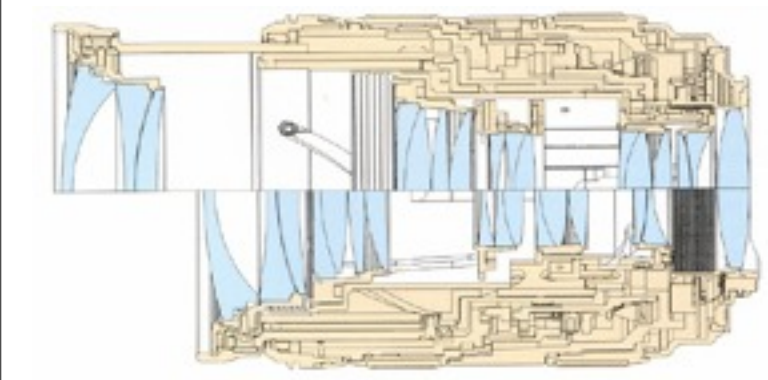


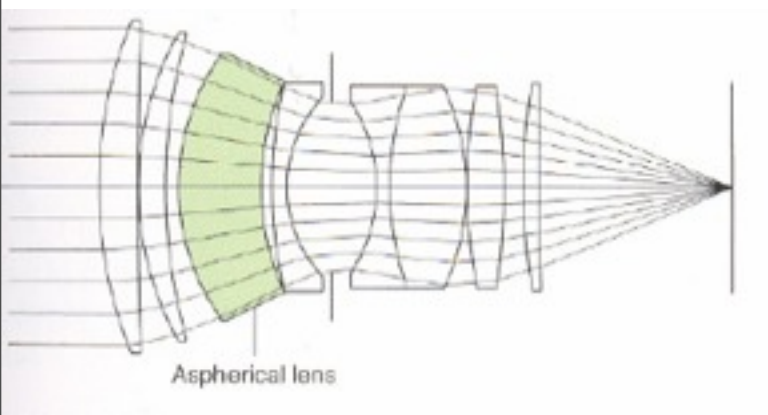
Improved Seam Carving for Video Resizing

Michael Rubinstein
Mitsubishi Electric Research Lab
Ariel Shamir
The InterDisciplinary Center
Shai Avidan
Adobe Systems Inc.

Syllabus

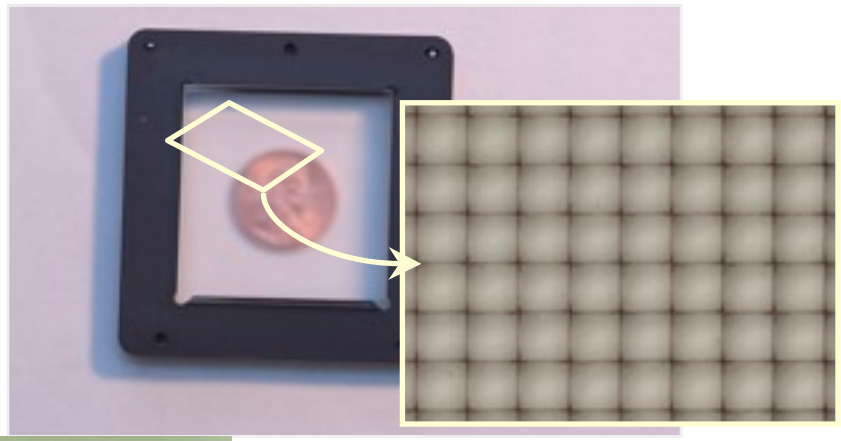
- **Active flash methods**
- **Lens technology**
- **Depth and defocus**





Syllabus

- **Future cameras**
- **Plenoptic function and light fields**



Questions?

Quick equipment discussion

- **If you're wondering how to get serious about photography**

- **Ask me for more advice if needed.**
- **I can do an SLR initiation session if requested**

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
    - Avoid large focal range (18-300: yuck!)
    - Maximum aperture matters (the smaller the number, the better)
  - Get a 50mm f/1.8
    (cheap, high quality, wide aperture)
- **Get a tripod**
- **Get an external flash if you want to take "event" pictures**
  - And orient towards wall/ceiling
  - Good flash photography is very difficult
- **Count ~1k for camera+standard zoom+50mm**

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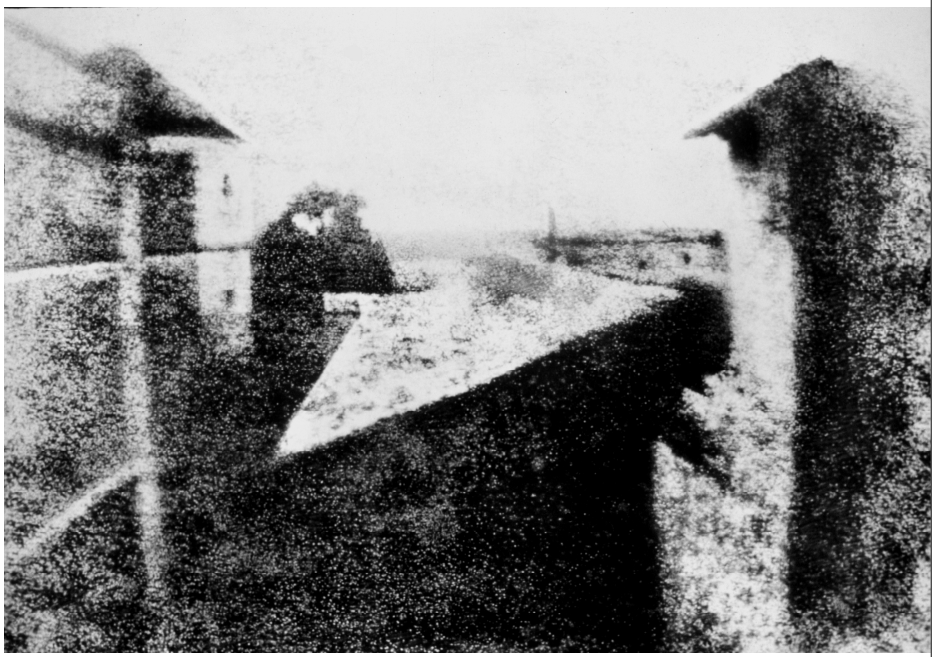
Quiz (0.001% of grade)

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

Quiz

- **When was photography invented? 1826**
- **By whom? Niepce**
  - Exposure time? 8 hours



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

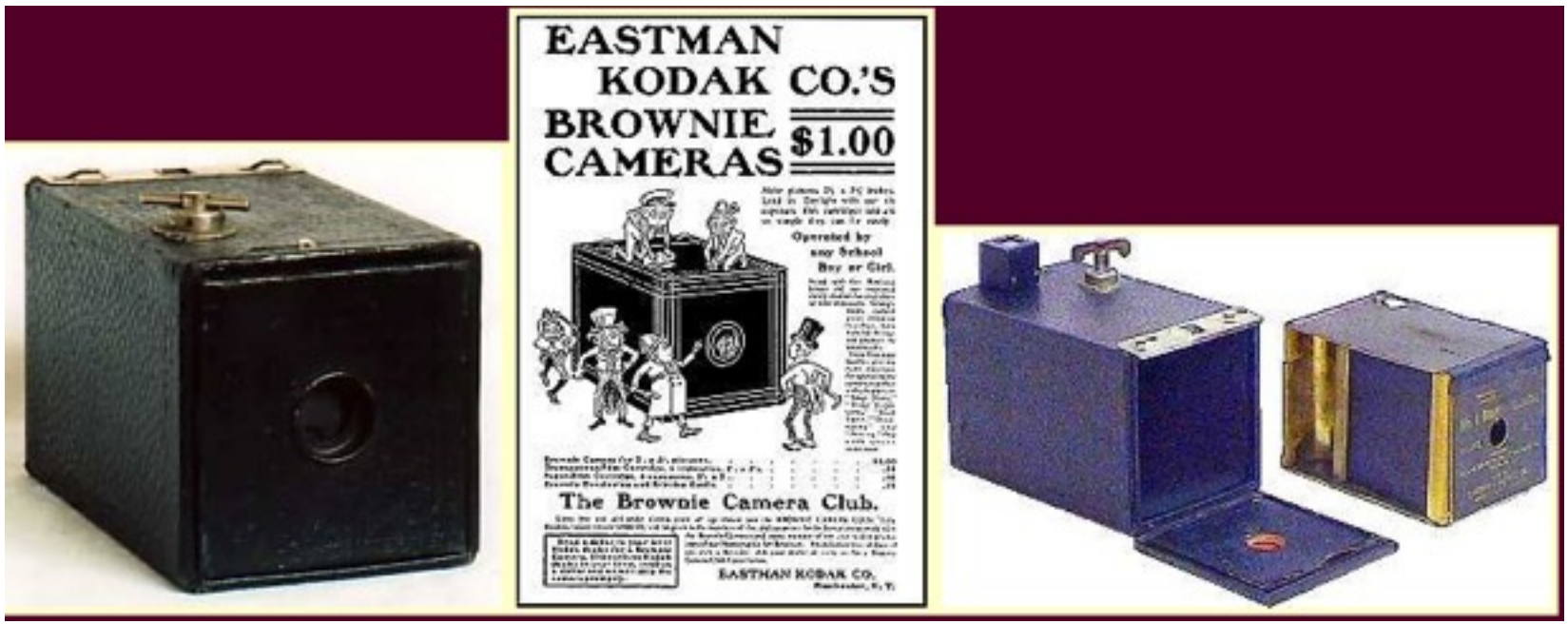
First production camera?

First production camera?

- **1839. Daguerrotype**

Beginning of hobby photography?

- **1900 Kodak Brownie**



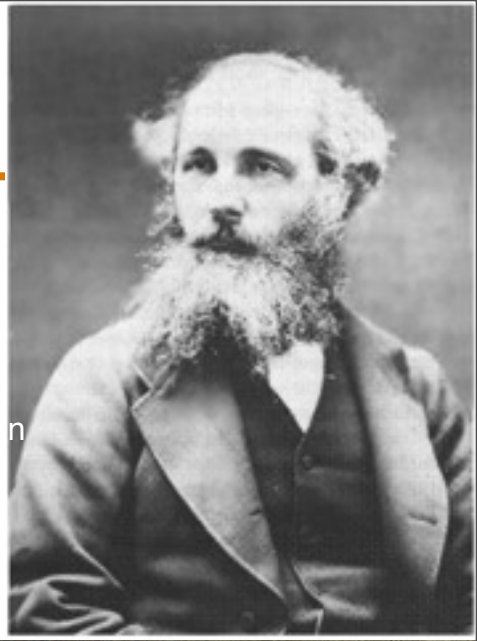
Quiz

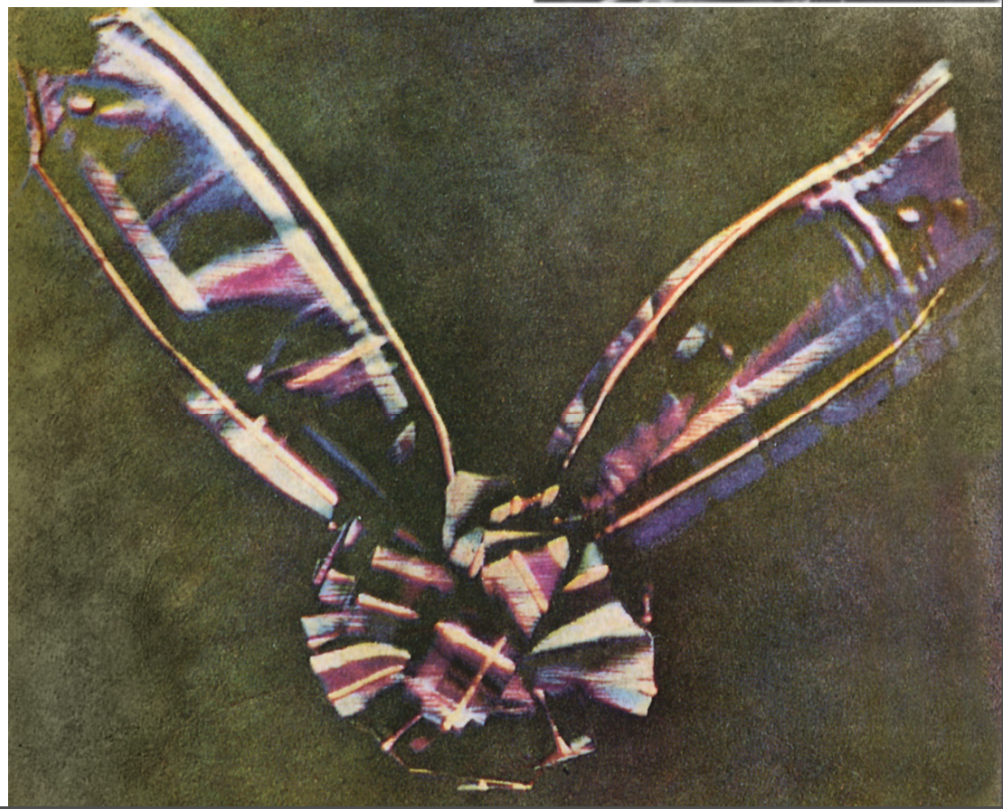
- **Who did the first color photography?**

- **When?**

Quiz

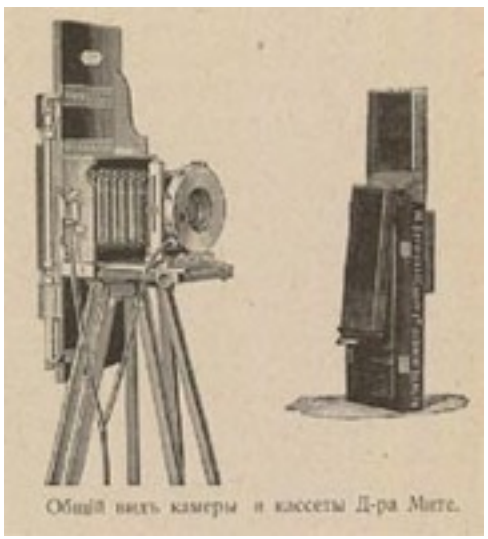
- **Who did the first color photography?**
  - Maxwell
    (yes, the same from the EM equations)
- **When? 1861**

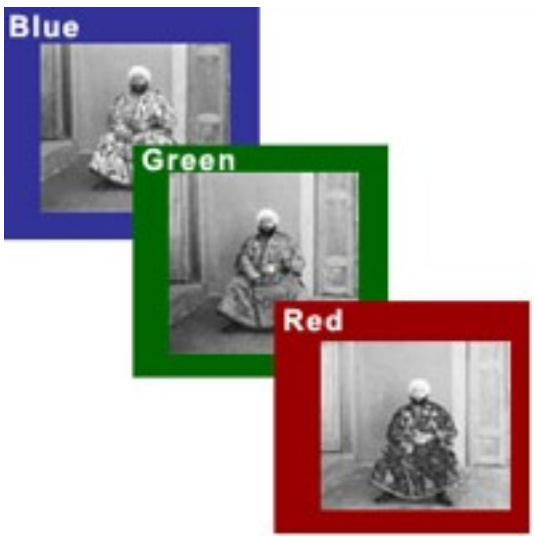




Quiz

- **Some of the 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

Instant photography?

Instant photography?

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

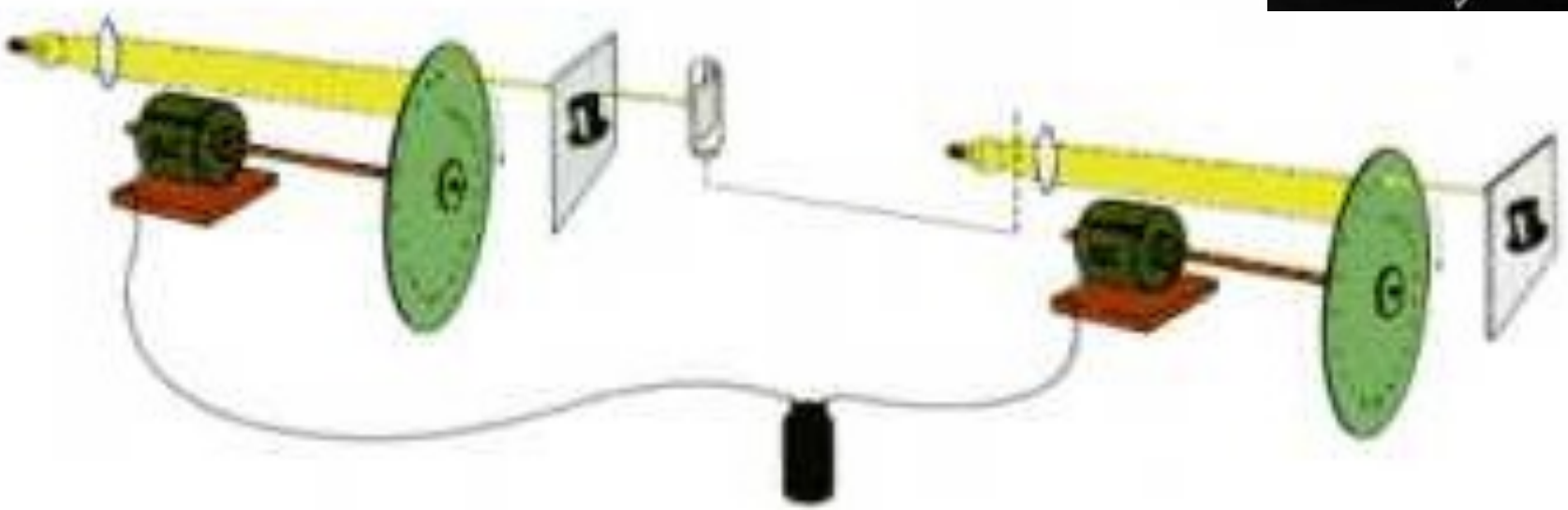
First TV?

Transmission of moving images

First TV?

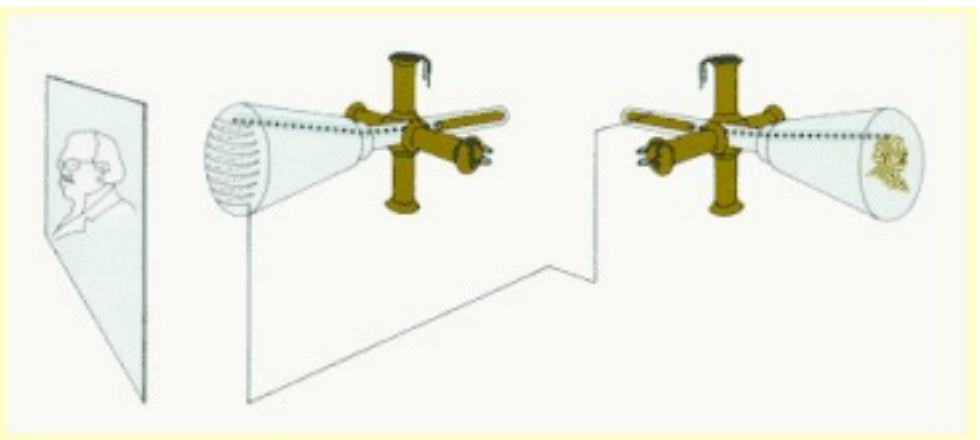
Transmission of moving images

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



Electronic photography?

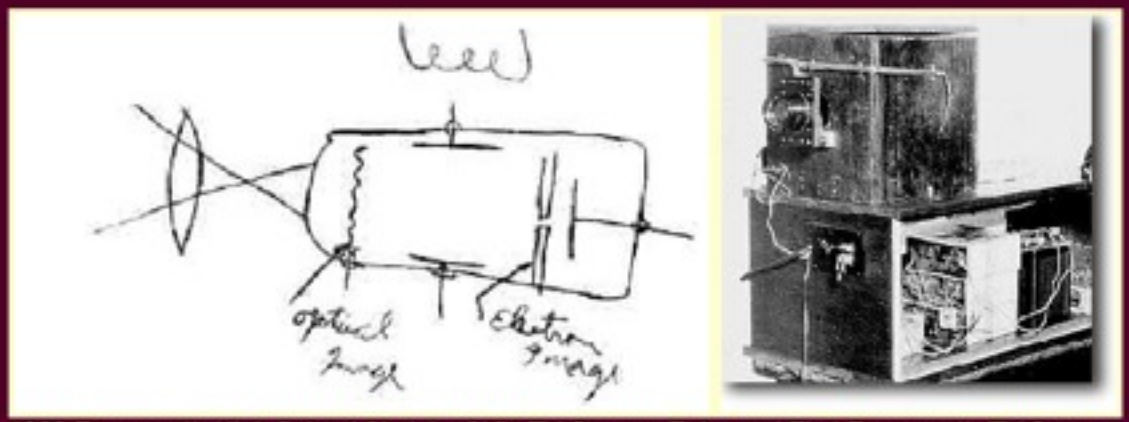
- **A. A. CAMPBELL SWINTON AND ELECTRONIC PHOTOGRAPHY - 1908**
- **25 images per second**



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.

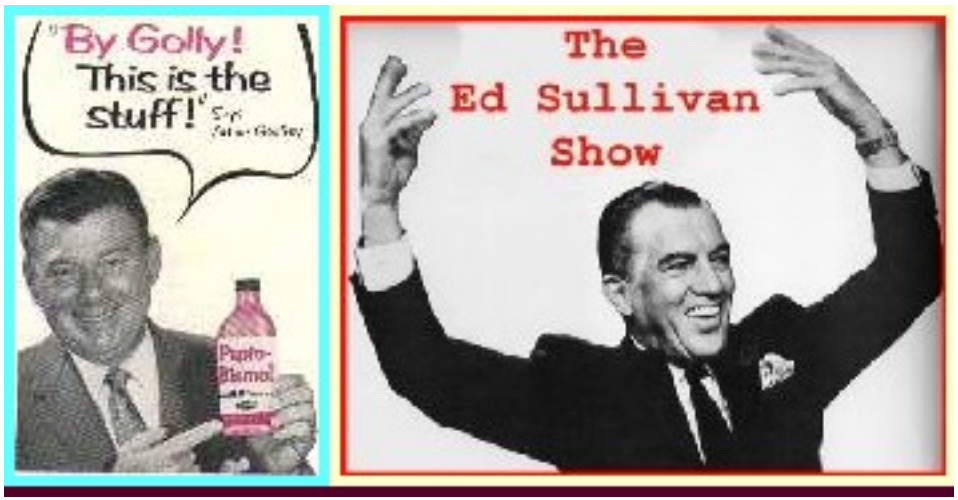


1922 Farnsworth High School Sketch of His TV Camera Tube and First Farnsworth TV Camera

Color TV

Color TV

- **First broadcast in 1951, CBS**



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)**

Japanese take over camera market?

Japanese take over camera market?

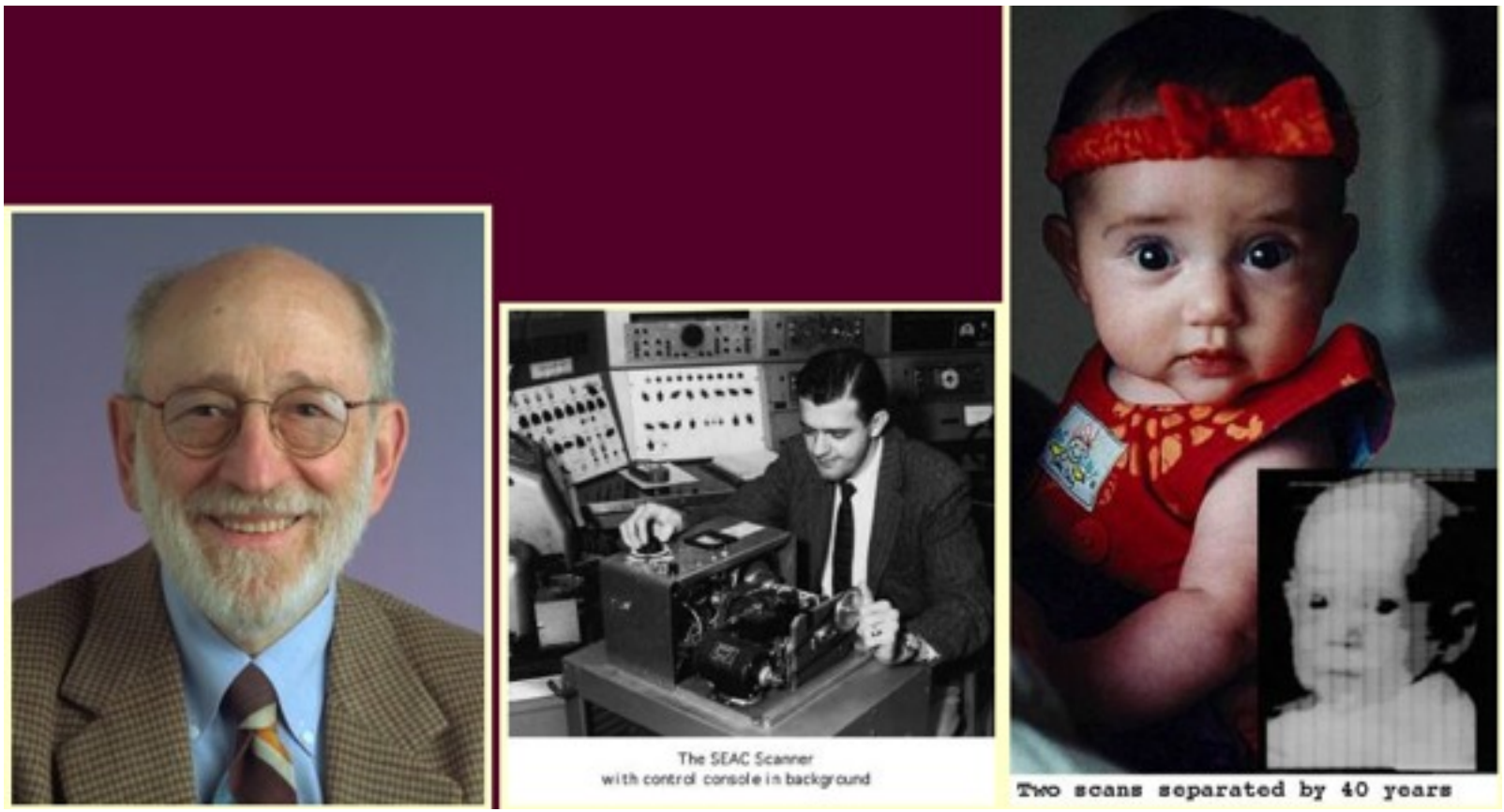
- **1959 Nikon F**
  - First motorized SLR
  - First 100% viewfinder
  - Mirror lockup

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

First scanned photo?

First scanned photo?

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



CCD technology?

CCD technology?

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

- **Just got the Nobel prize!**

Computer Graphics?

Computers to create image

Computer Graphics?

Computers to create image

- **Sketchpad, 1961, Ivan Sutherland's MIT PhD thesis (advised by??**

Computer Graphics?

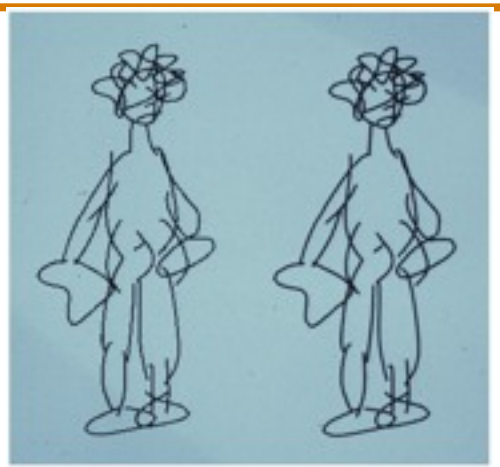
Computers to create image

- **Sketchpad, 1961, Ivan Sutherland's MIT PhD thesis (advised by Claude Shannon)**

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

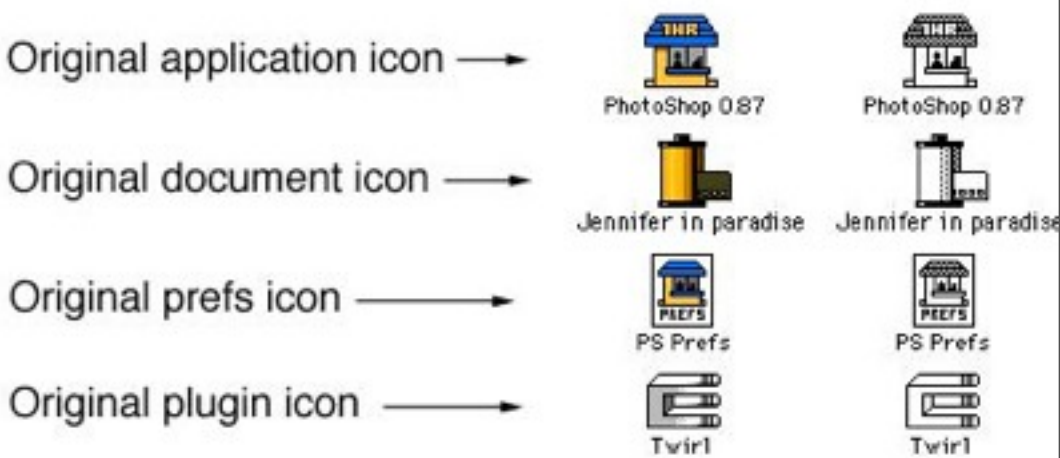
Photoshop

- **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.



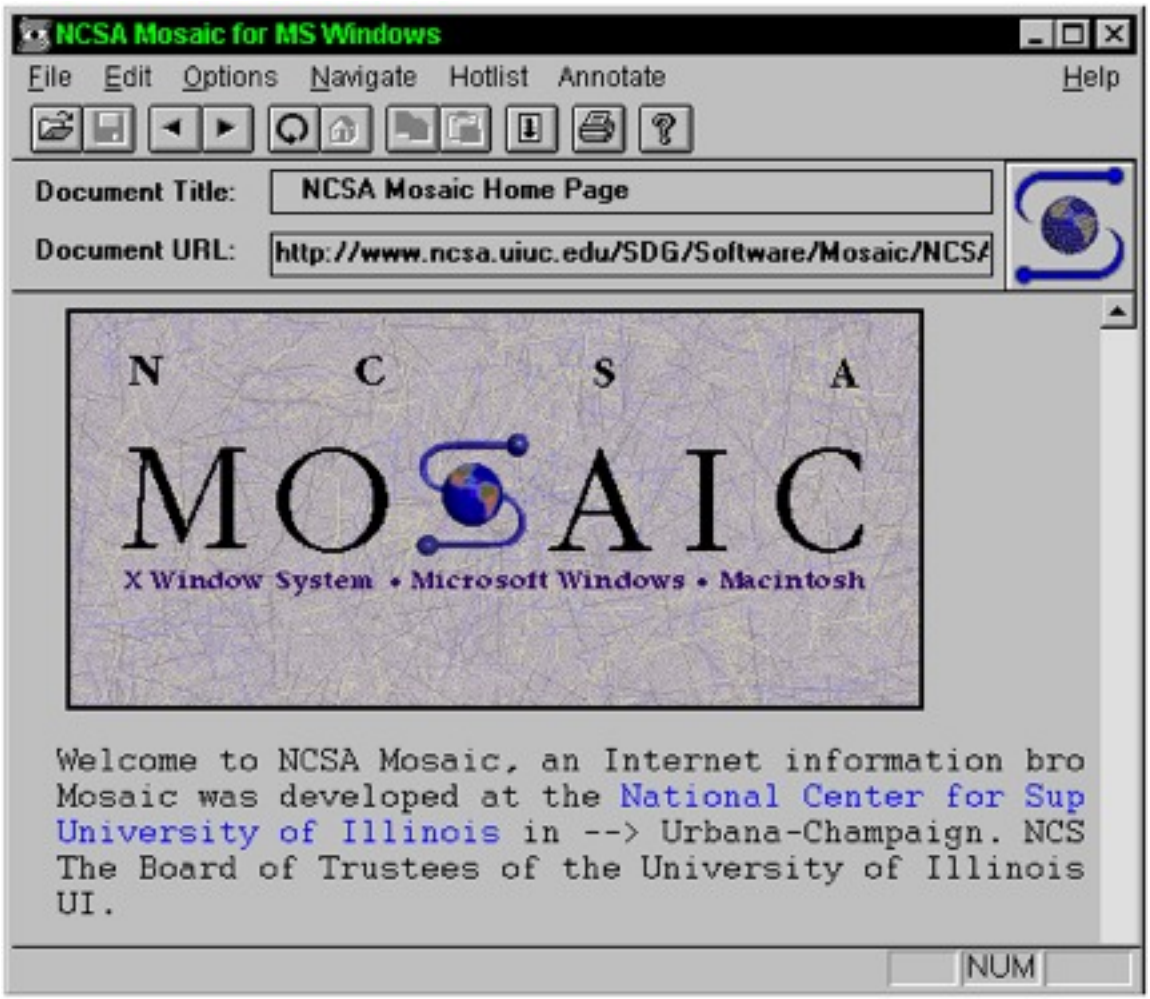
The original application icons designed by John Knoll.

Internet photo browsing

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

Internet photo browsing

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



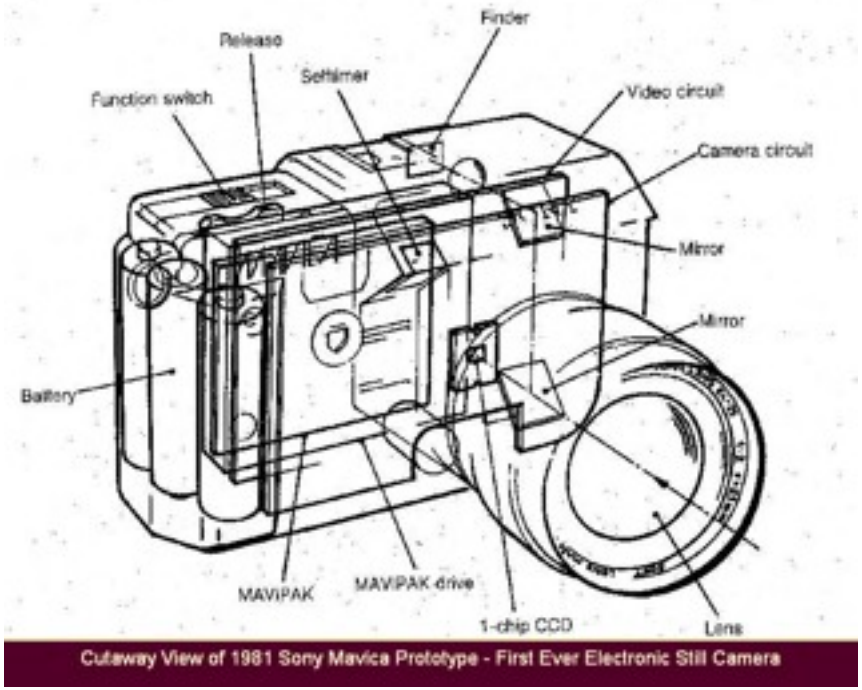
First digital camera?

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

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**

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