Digital Photography and Geometry Capture

NBA 6120

Donald P. Greenberg

September 11, 2015

Lecture #5

Required Reading

- Bilger, Burkhard. "Has the Self-Driving Car Arrived at Last?" *The New Yorker*. N.p., 25 Nov. 2013. Web. 10 Sept. 2015.
  - http://www.newyorker.com/magazine/2013/11/25/auto-correct

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

William E. Strapp, "Technology of the Por

History of Photography (continued)

1880 — 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

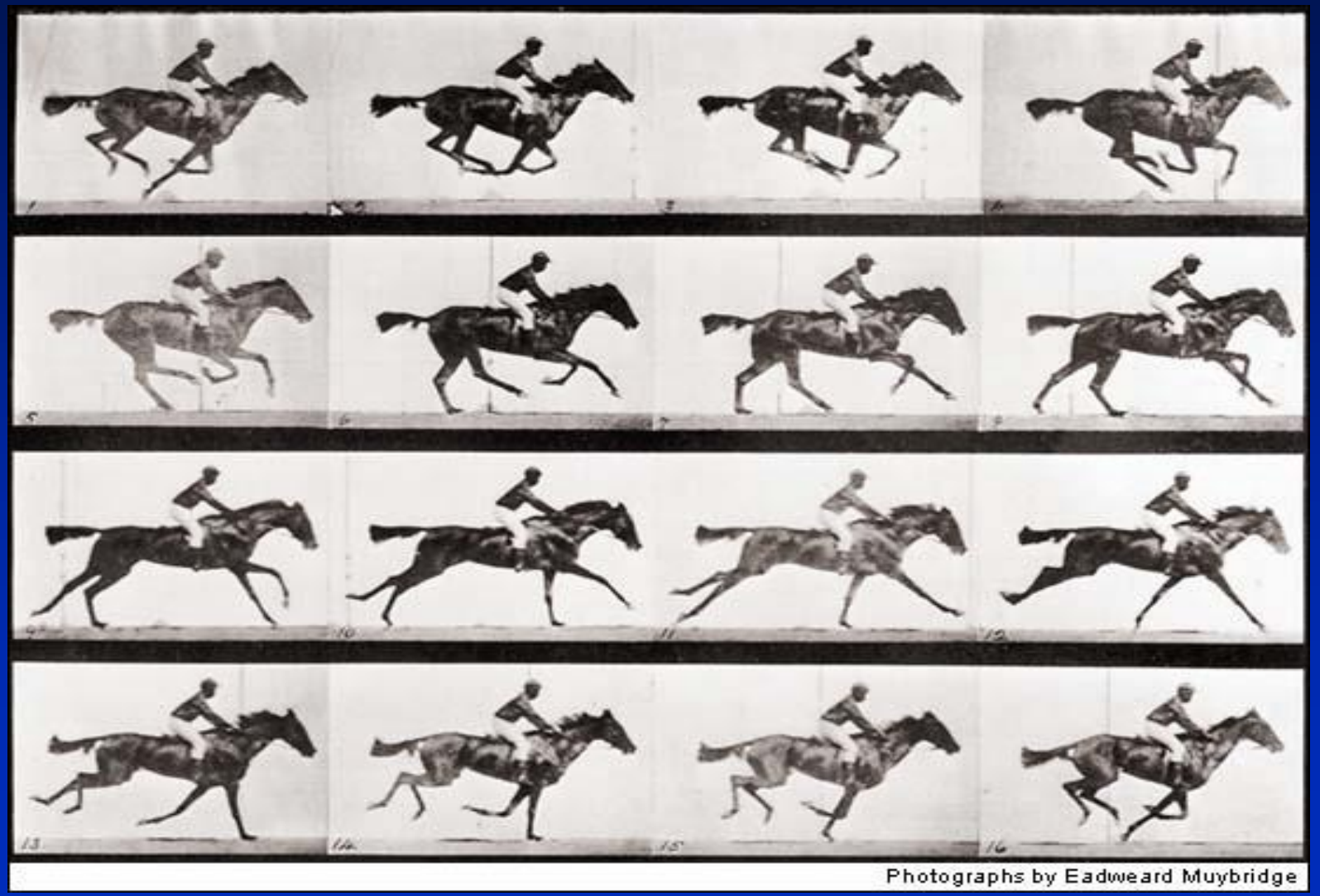
1931 — Strobe Photography – Harold Edgerton of MIT

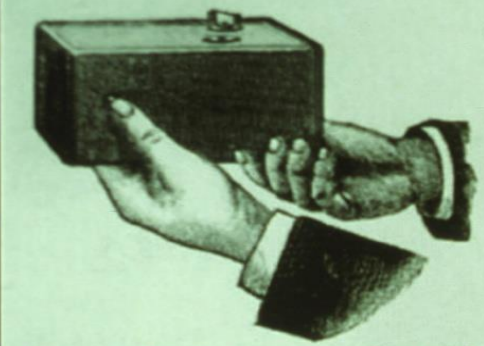
1934 — Mannes & Godowsky – developed full color Kodachrome film

Civil War

Mathew Brady

Eadweard Muybridge - Galloping Horse 1878

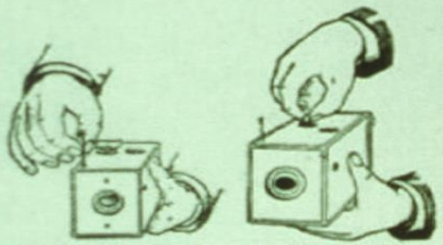




THE KODAK CAMERA.

Silver Medal at Minneapolis Convention P. A. of A. for most important invention of the year.

PHOTOGRAPHY REDUCED TO THREE MOTIONS.



1. *Pull the Cord.* 2. *Turn the Key.* 3. *Press the Button.*

And so on for 100 Pictures.

ANYBODY CAN USE IT.

Size of Camera, 3¼ x 3¼ x 6½ inches.

Weight, 1 lb. 10 oz.

Size of Picture, 2½ in. diameter.

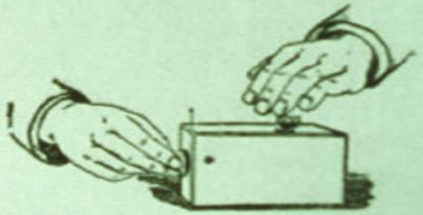
PRICE, - - - $25.00

Price includes hand-sewed sole leather Carrying Case, with shoulder strap and film for 100 exposures.

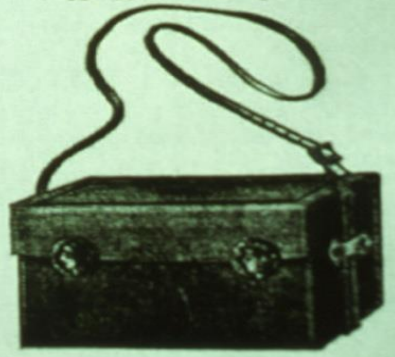
Amateurs can finish their own negatives or send the roll of exposed films to the factory by mail to have them developed and printed.

Price for developing, printing and mounting 100 Pictures, including spool 100 films for reloading Camera, - - - - - $10 00

Spool for reloading only, - - - - 2 00



Uncapping for Time Exposures.



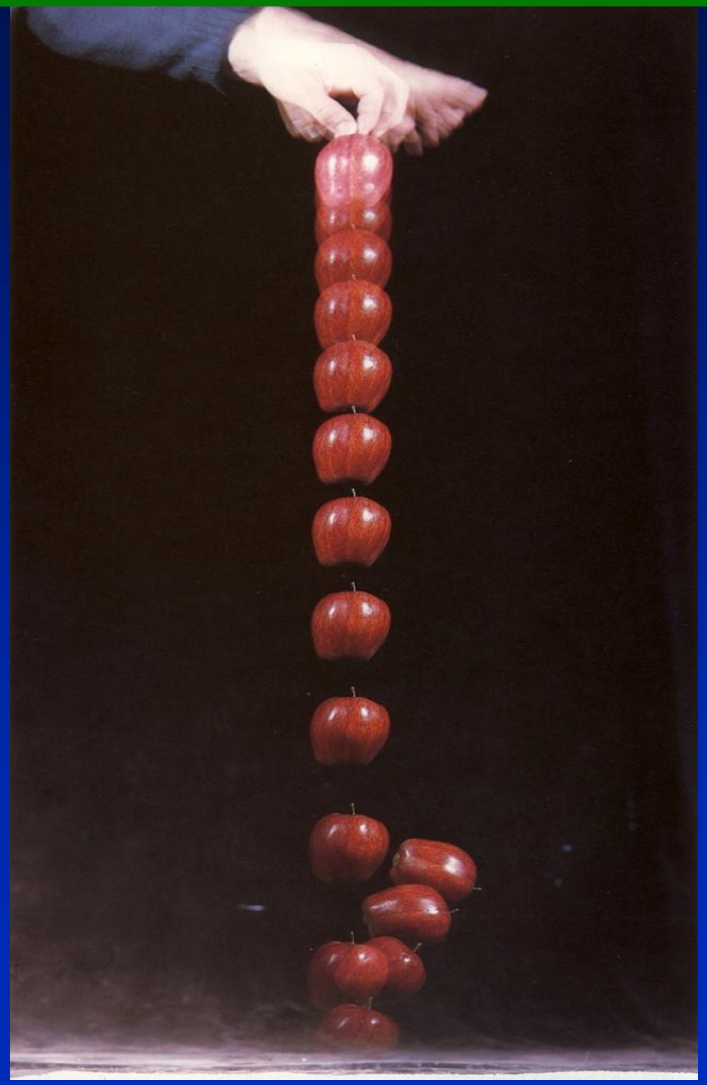
THE EASTMAN DRY PLATE AND FILM CO.,

15 Oxford Street, London. | **ROCHESTER, N. Y.**

Send for Descriptive Circulars.

from The Story of Kodak, Douglas Co

Newton’s Apple, 1970



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

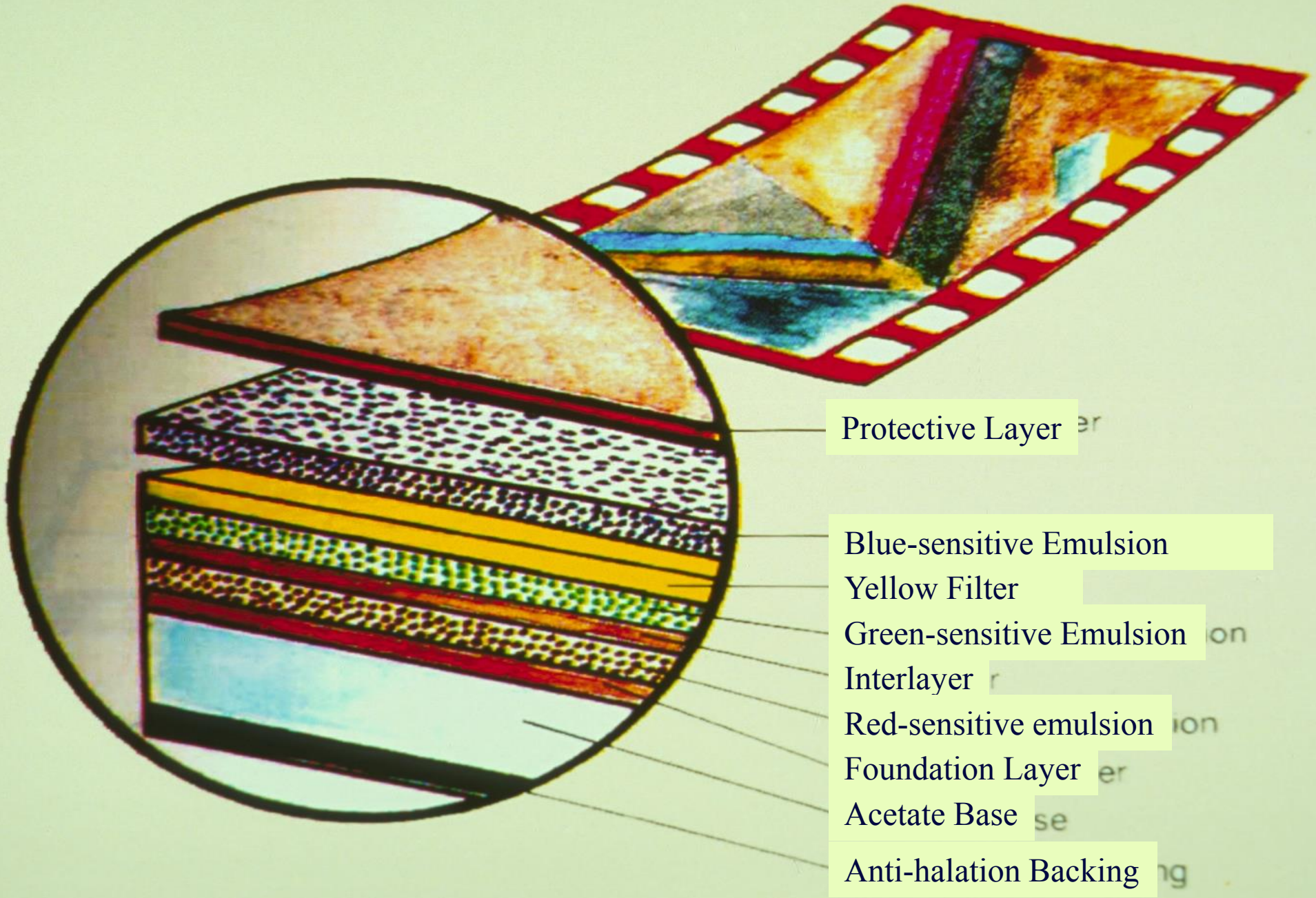
Color Film Paradigm Shift

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

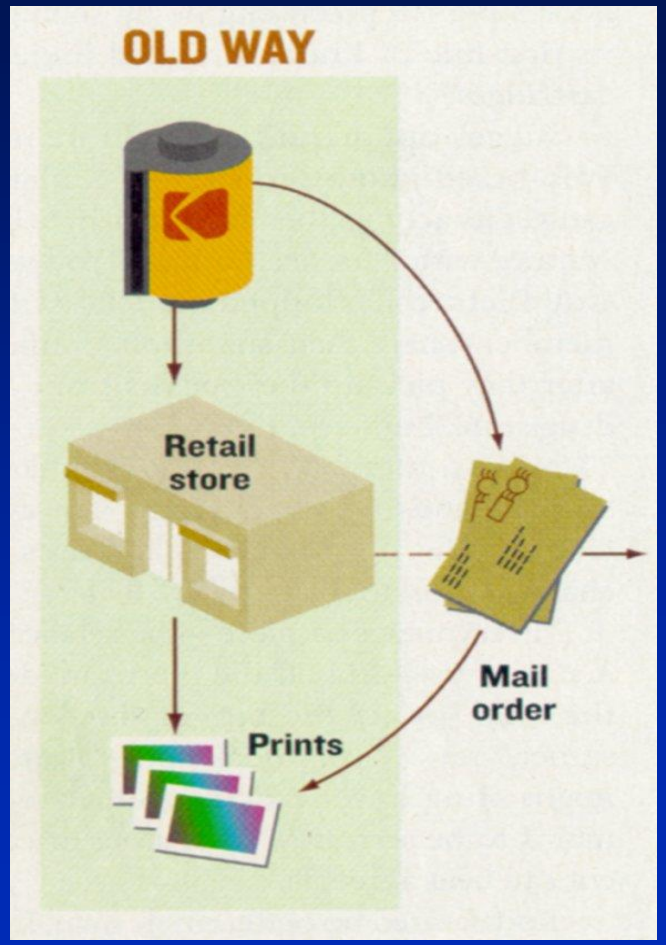
Mannes & Godowsky
1920's

(The Story of Kodak, Douglas Collin



(fig. 1.6, Color Photography, Robert Hirsch

Old Days - You Dropped Off Your Roll And Got Prints Back



Polaroid Land Camera

CCD Technology

- 1969 George Smith & Willard Boyle invented the CCD image sensor at Bell Labs. They 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

Photo-detector Technology

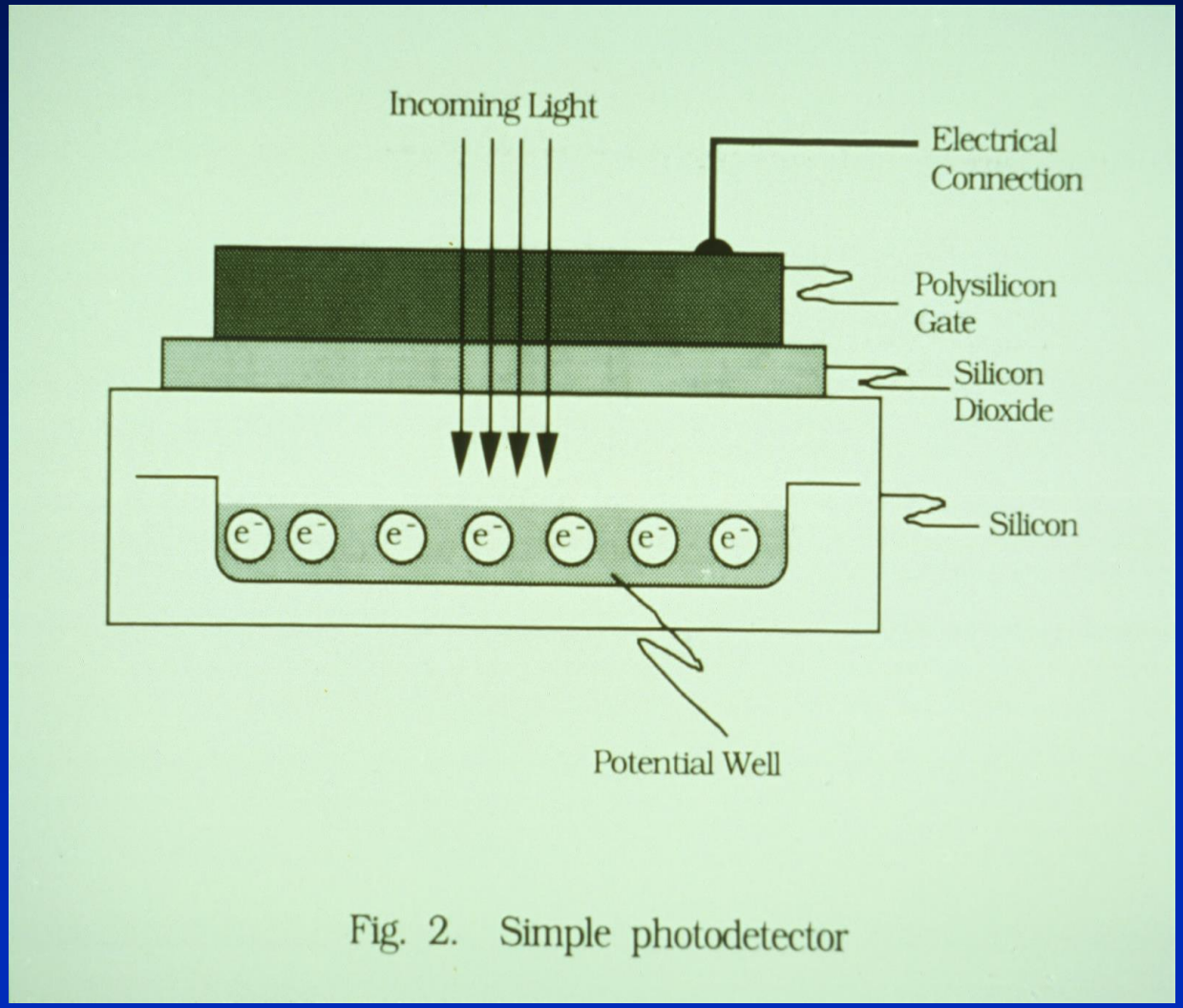


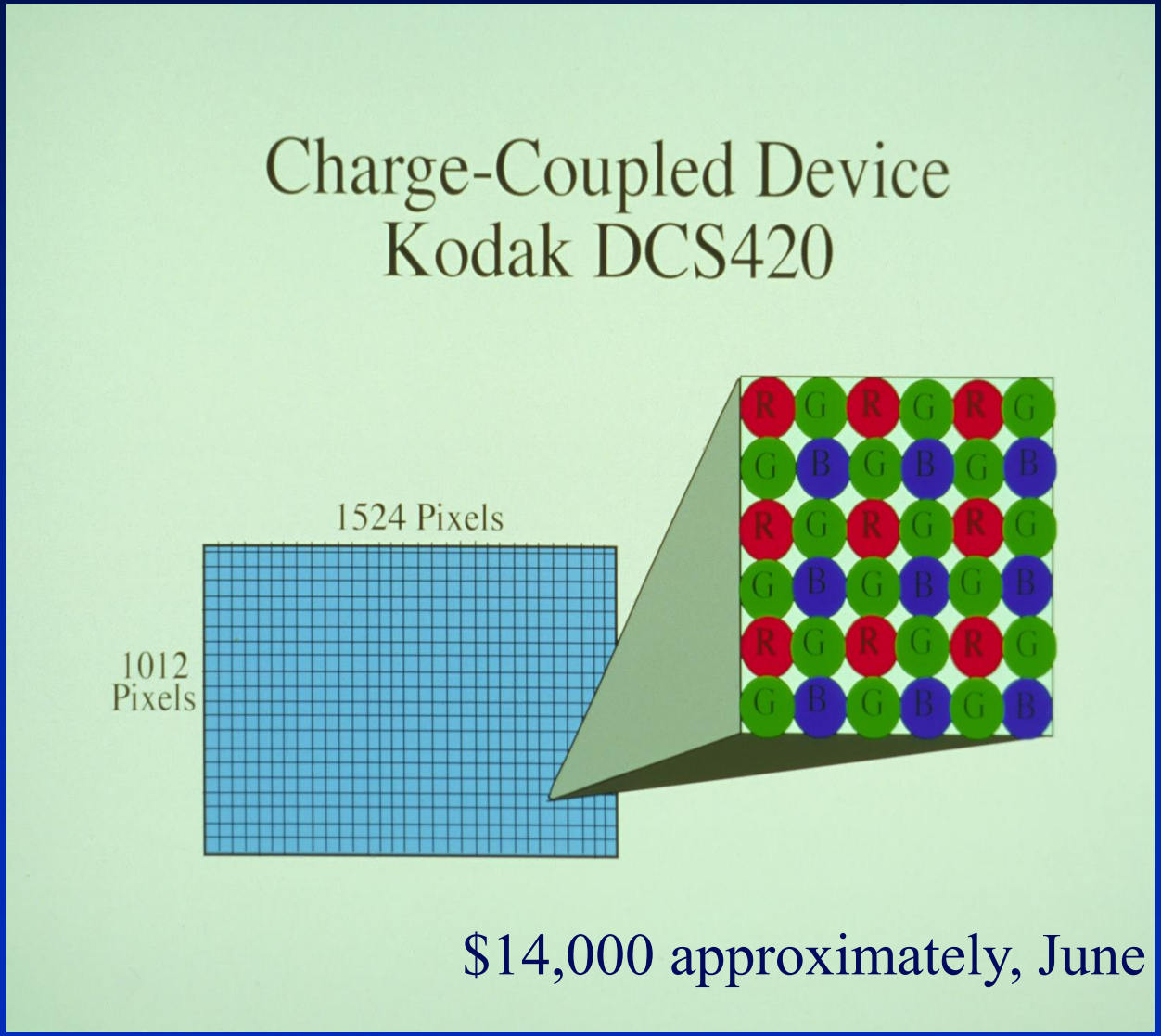
Fig. 2. Simple photodetector

(Charge-Coupled Devices for Quantitative Electronic Imaging, 19

CMOS Technology

- Complementary metal oxide semiconductor
- Cheaper manufacturing technology than CCD's
  - Follows the semiconductor industry cost curves
  - Reduces the number of chips/camera required
- Processing (which is "free") can perform calculations on each pixel within frame time (e.g. correct for lighting, motion blur, etc.).

Bayer Pattern



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

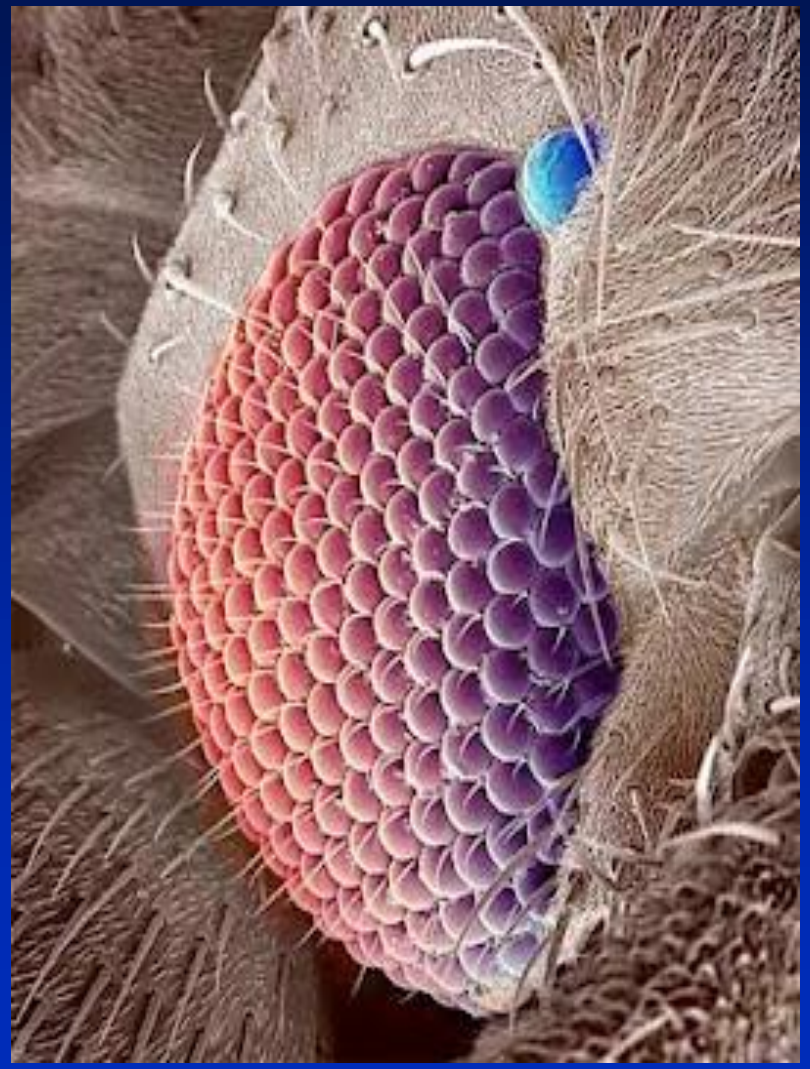
Canon EOS 5DSR
50.6 MegaPixels
$3,899

Nikon Digital SLR
16.2 MegaPixels
$5,999

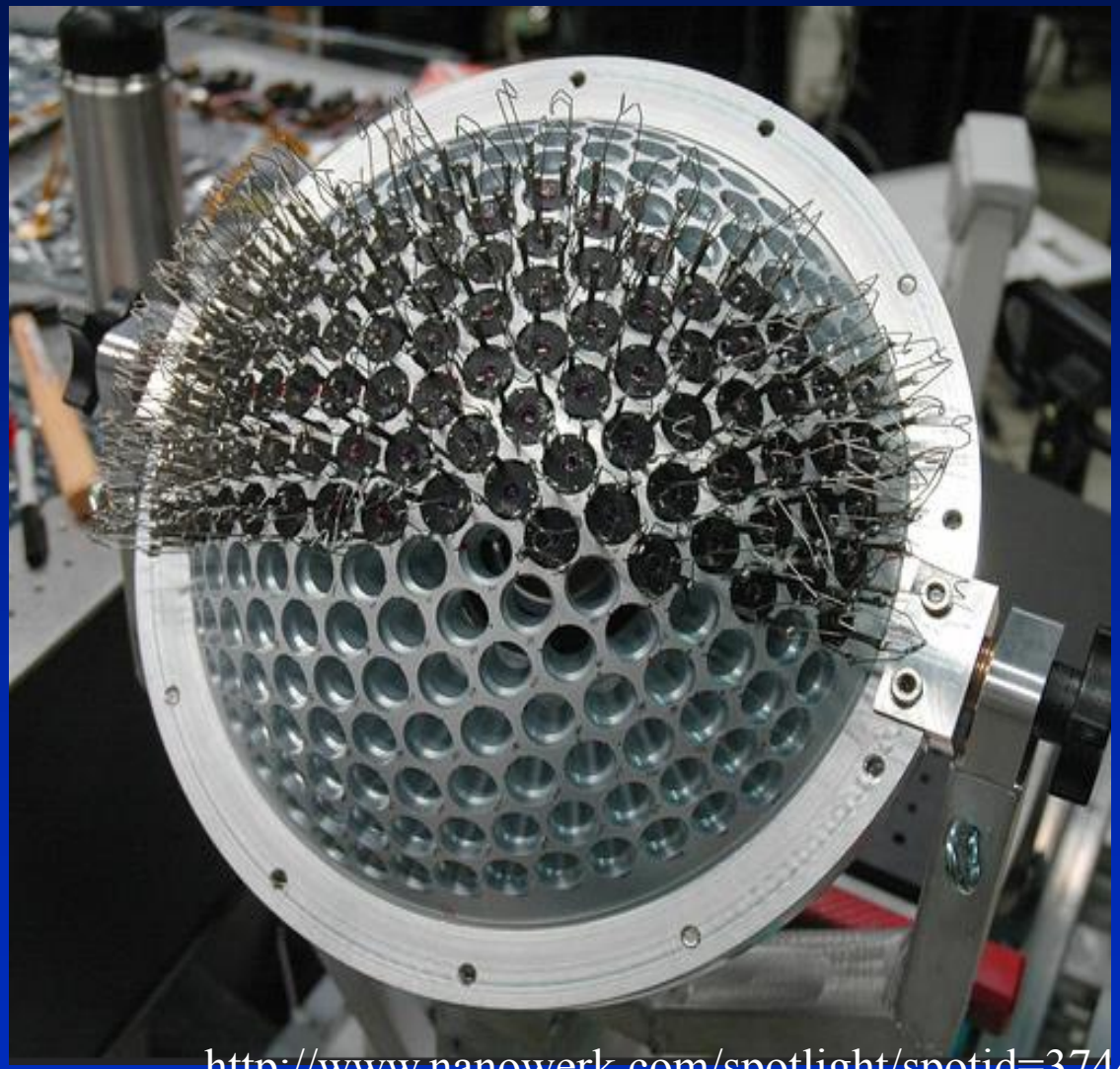
iPhone 6S Camera – 12 MPixels

Nokia Lumia 1020 – 41 MPixels

Eye of a Fly

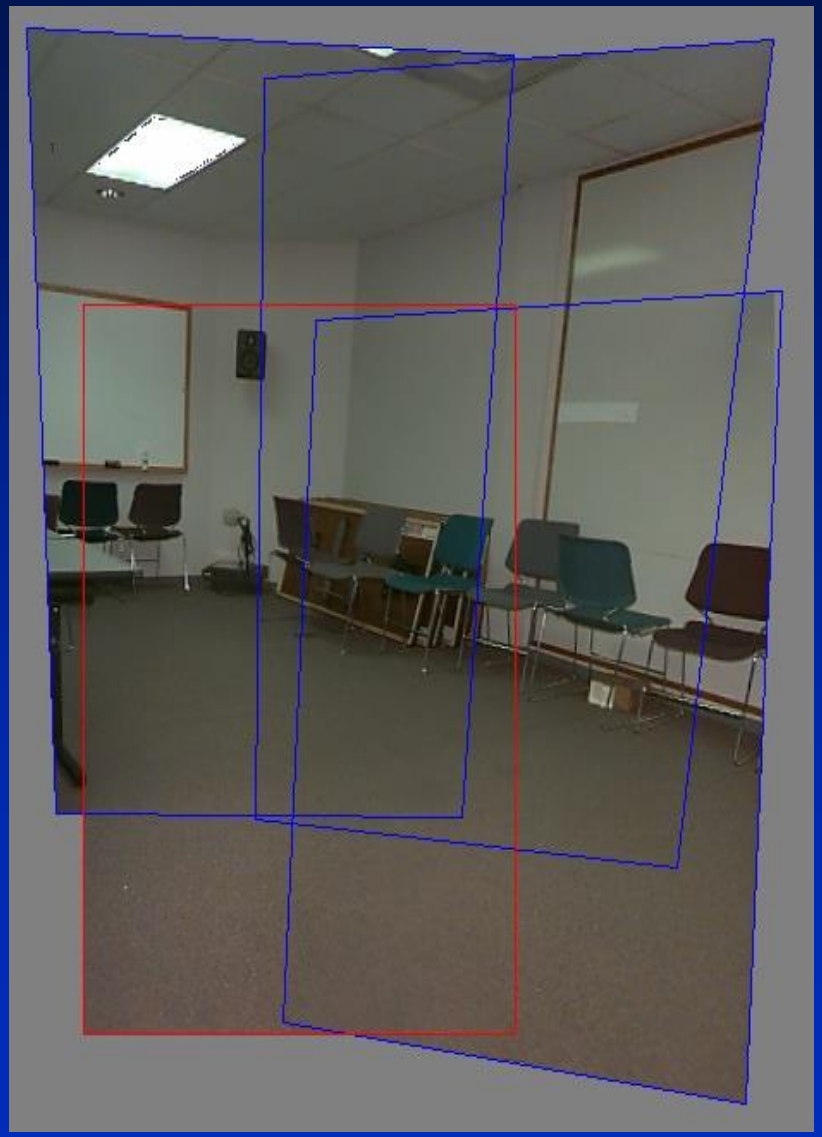


AWARE-2 Duke University



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

Creating Full View Panoramic Image Mosaics and Environment Maps



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

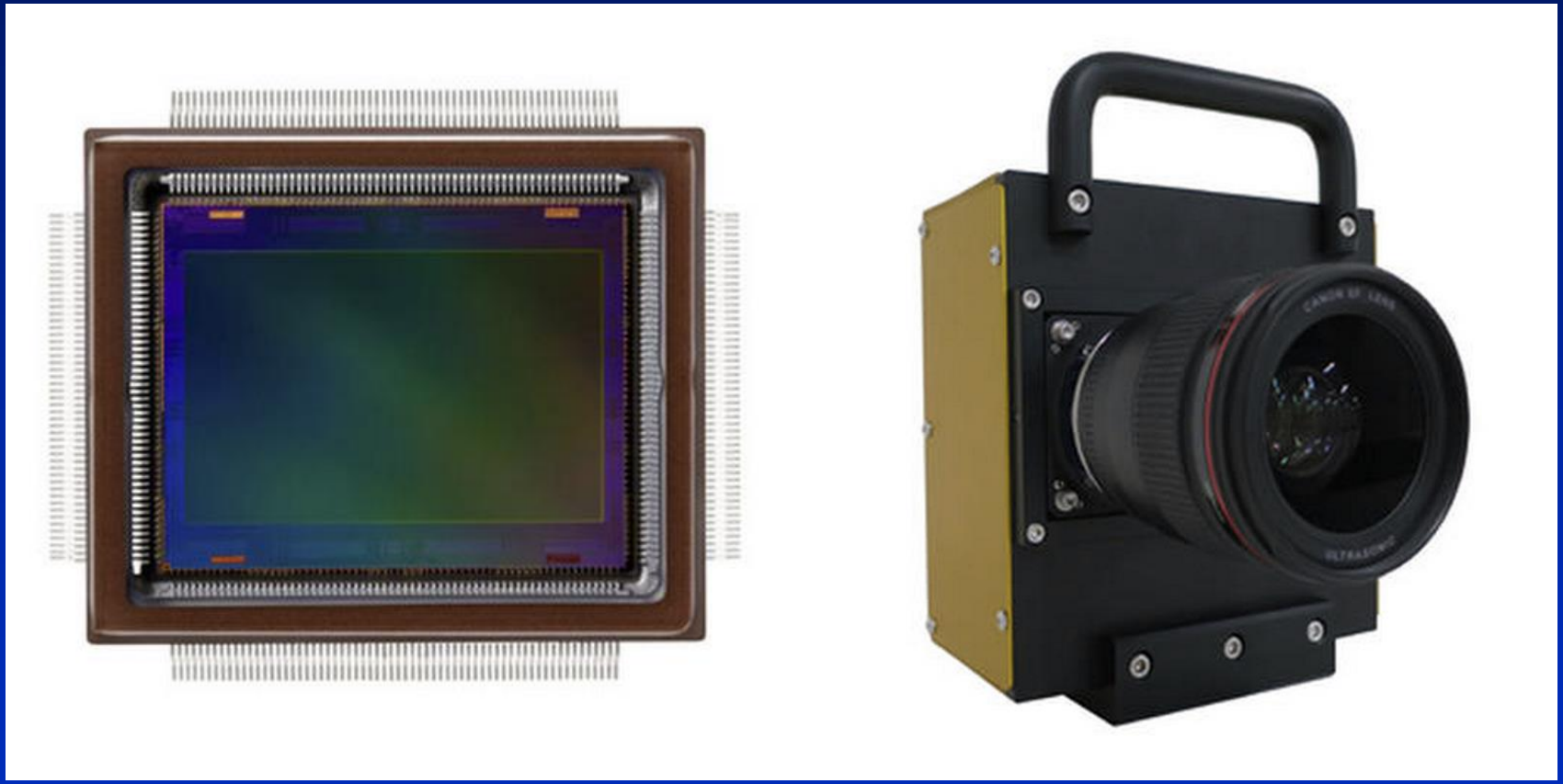
Szeliski, R., Shum, H.-Y. (1997) *SIGGRAPH.*

Professor Pedro Sander

- http://gigapan.com/gigapans/58857

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

- Can read letters 11 miles away!



Depth Imaging

Original Goals:

- Face recognition
- Gait analysis
- Skeletonization

Uses for:

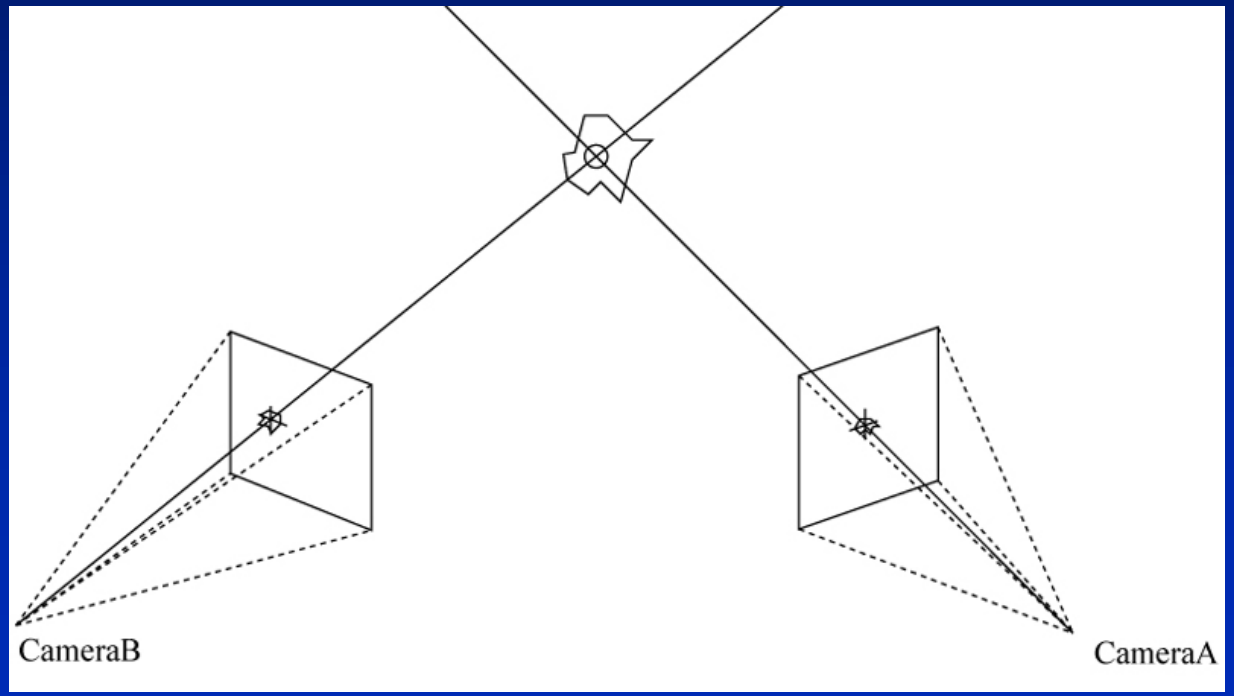
- Military + Defense
- Security and surveillance
- Gestural Interfaces
- Motion capture
- Bio-metrics
- Manipulating 3D models

Digital Geometry Capture

- Photographic methods
- Laser scanning
- Pattern projection methods
- Time of Flight

Simple case

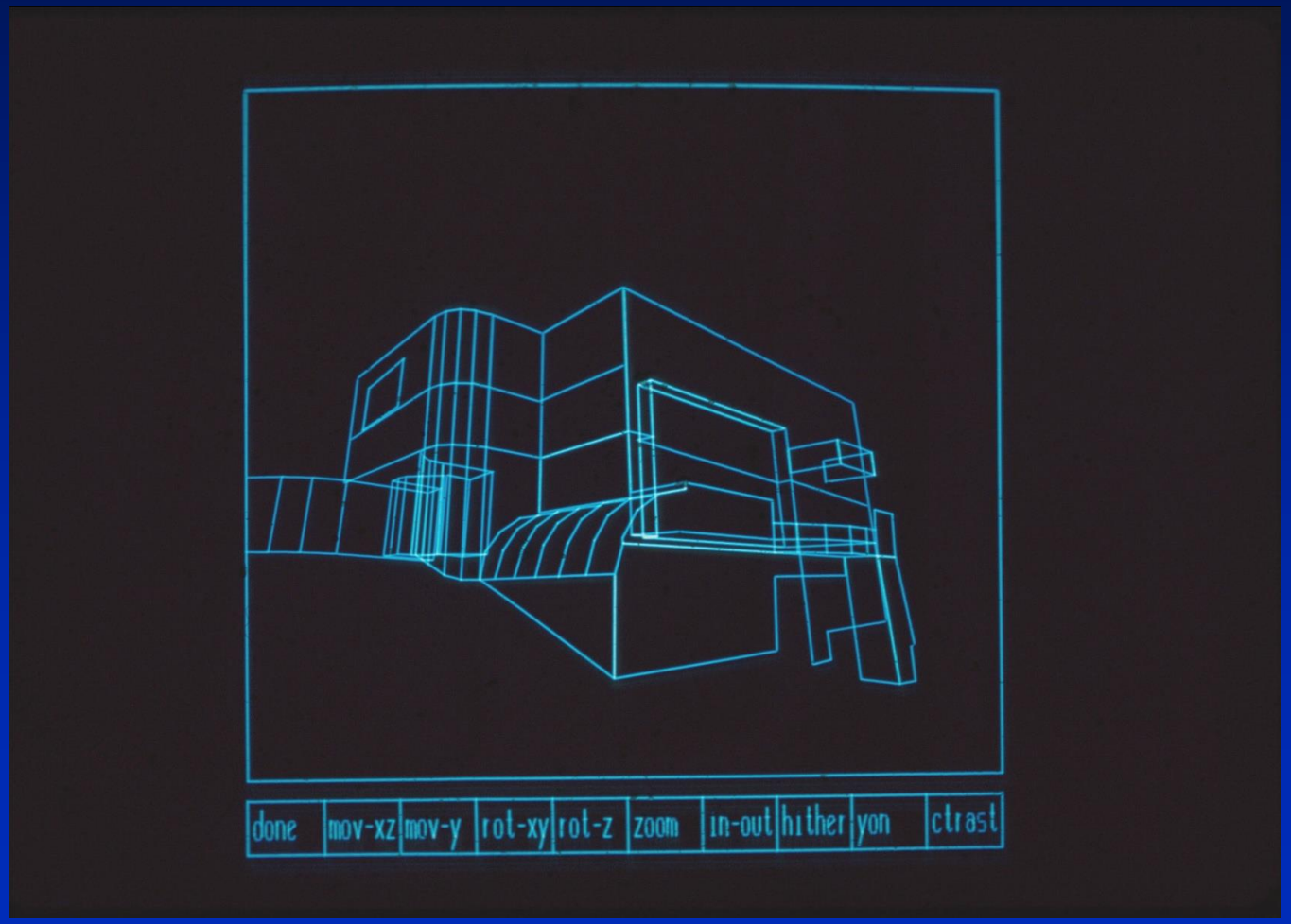
Known camera positions (x_e, y_e, z_e) , camera optics, known corresponding points each image.



Jeremiah Fairbank. View dependent perspective images. Master's thesis, Cornell University, August 2005.

Early Work - 1975

Sagan House



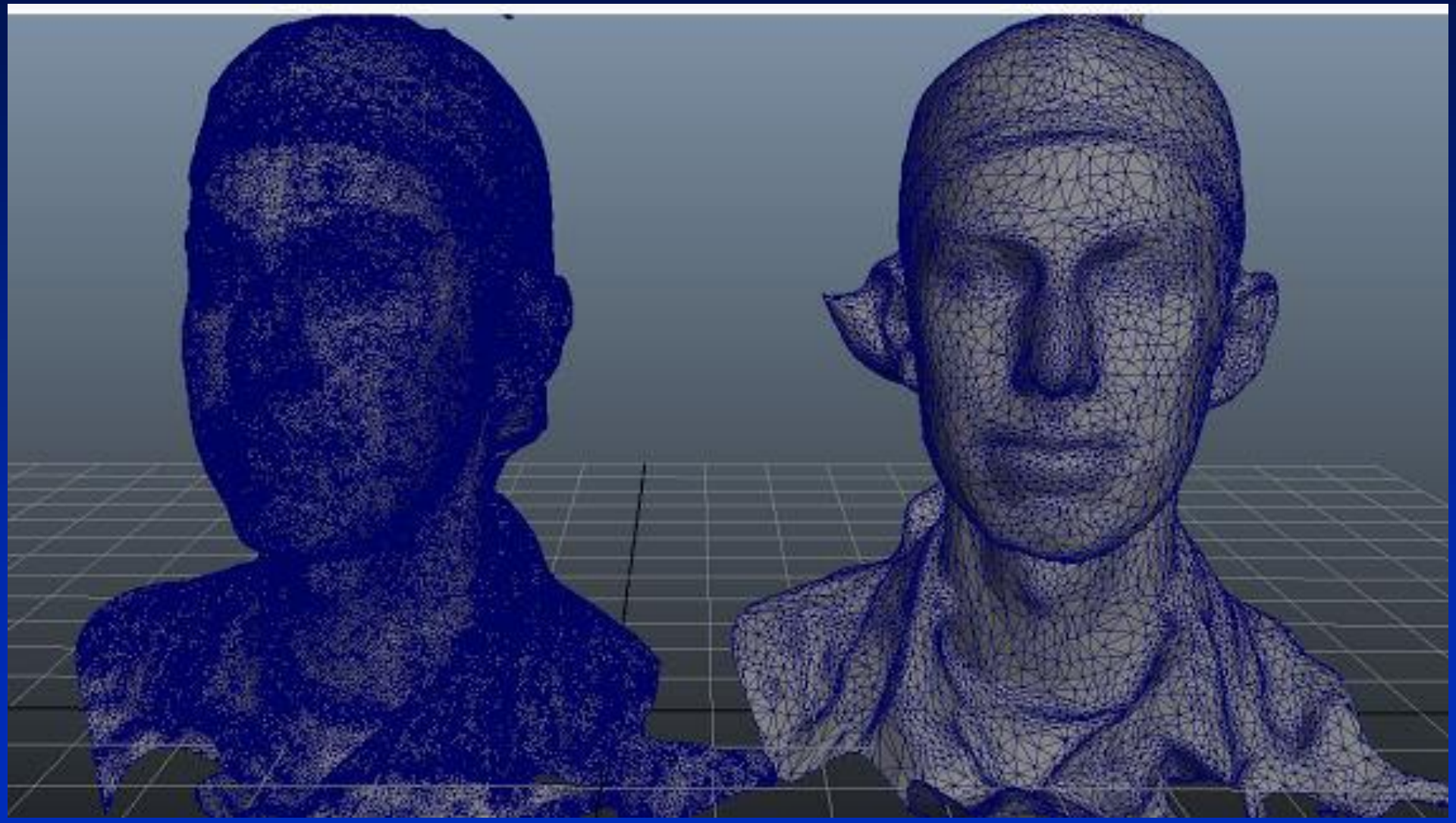
Autodesk 123 Catch

1 2 3 Catch

Autodesk

1 2 3 Catch

Autodesk



Capturing Geometry from Photographs

Can we reconstruct the 3D geometry from an arbitrary set of photographs?

Reconstructing Rome[1]

- "The advent of digital photography and the recent growth of photo-sharing websites (flickr) have brought about the seismic change in photography and the use of photo collections."[1]
- A search for the word "Rome" on flickr returns two million photos.
- This collection, or others like it, capture every popular site, facade, statue, fountain, interior, café, etc.

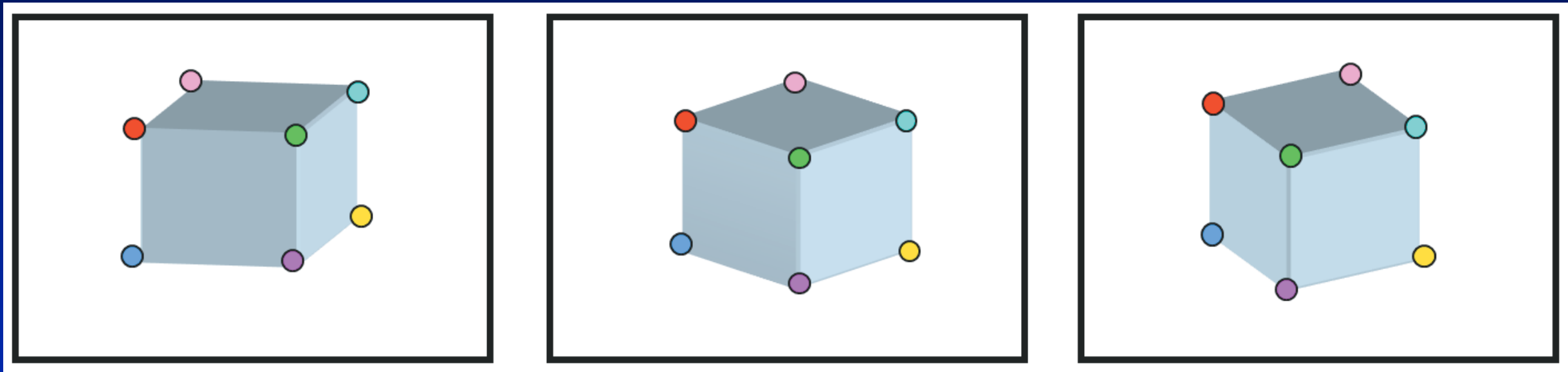
Characteristics of Typical Photo Sets

- The photos are unstructured
  - No particular order or distribution of camera viewpoints
- The photos are uncalibrated
  - Nothing is known about the camera settings (exposure, focal length, etc.)
- The scale is enormous
  - (millions, not thousands of photos)

and

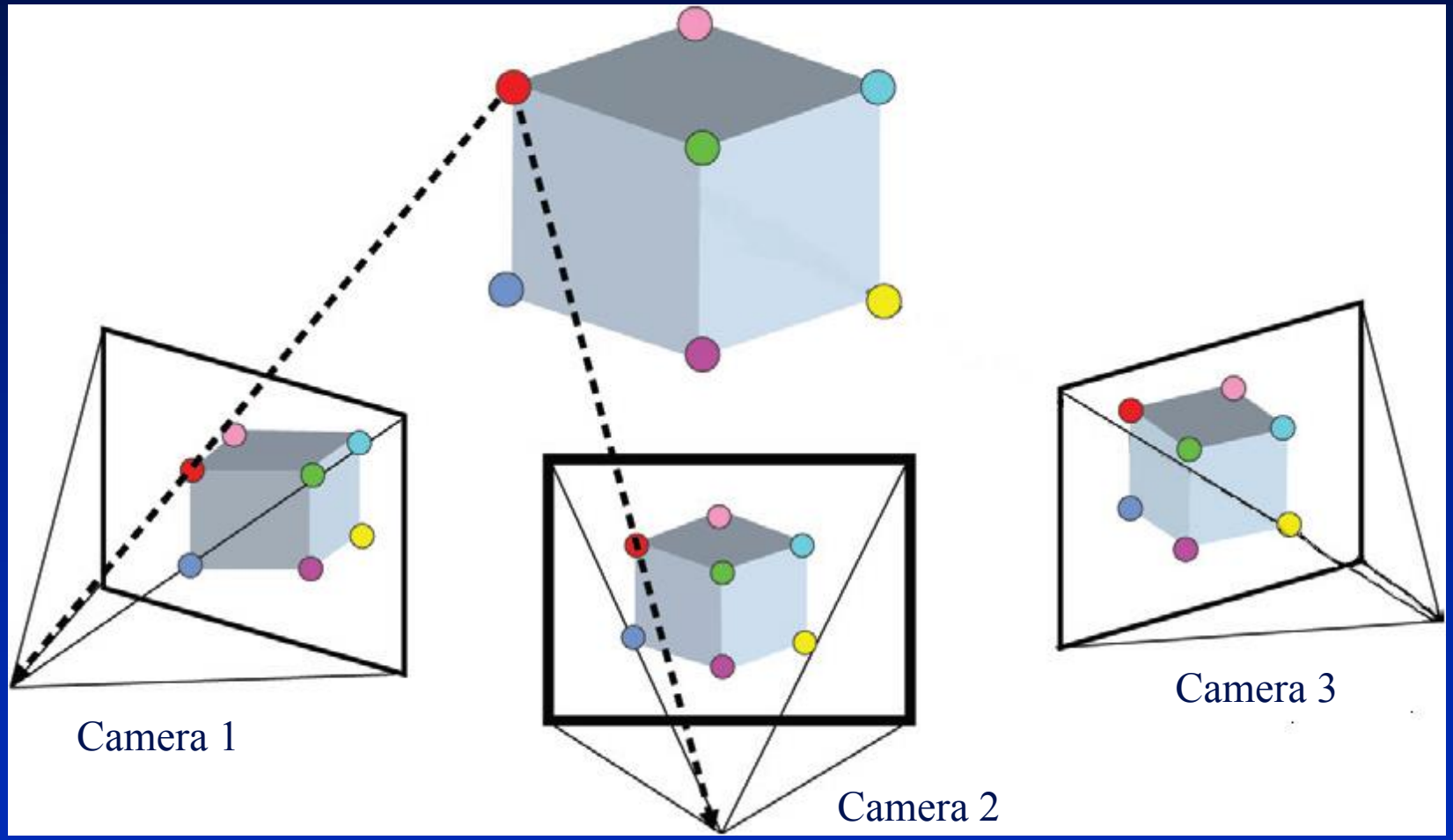
We need to do this fast!

Correspondence and 3D Structure from Different Camera Positions

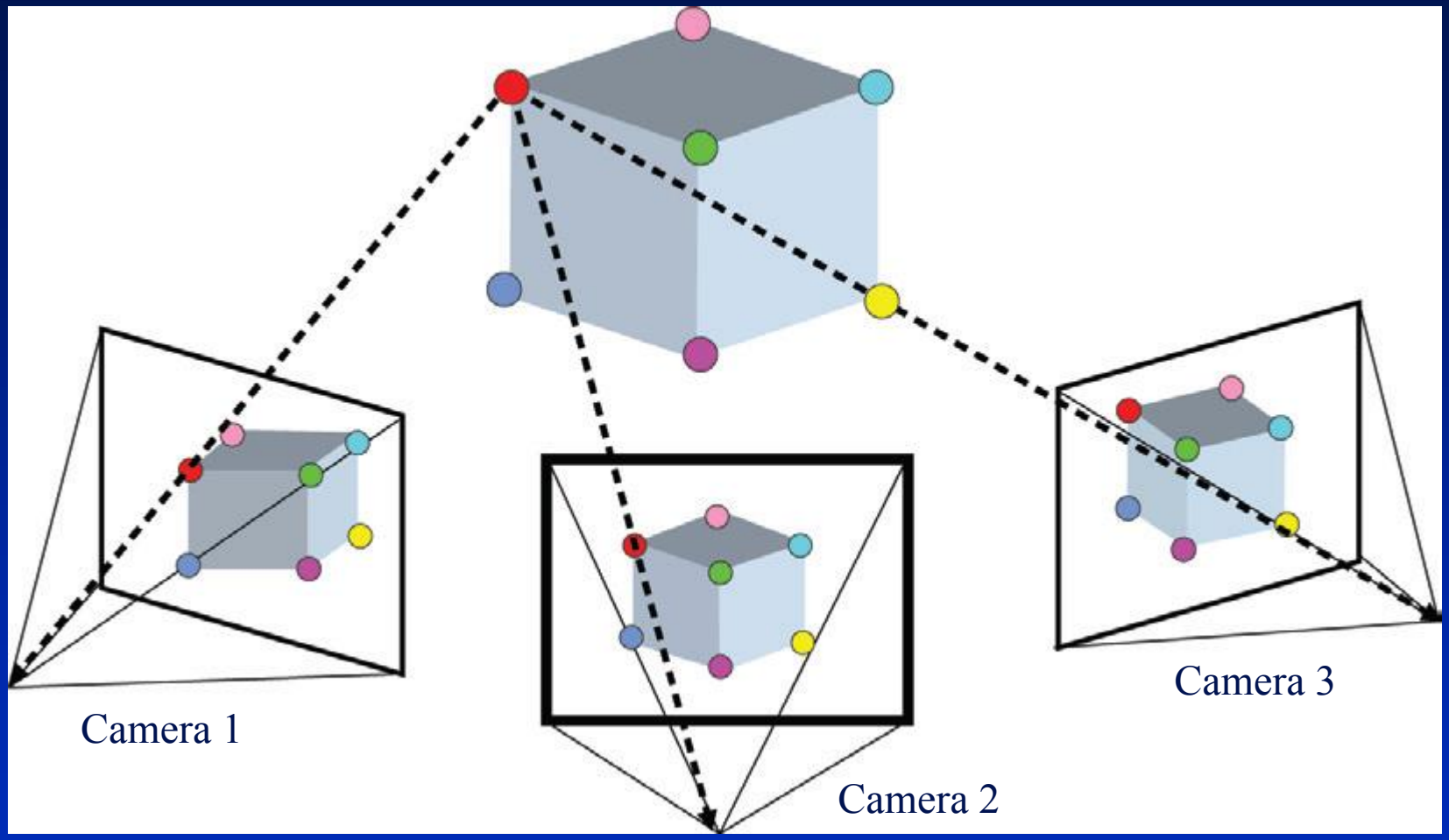


Note: The pictures are in correspondence
2D dots with same color correspond to the same 3D points.

3D Structure from Different Camera Positions



3D Structure from Different Camera Positions

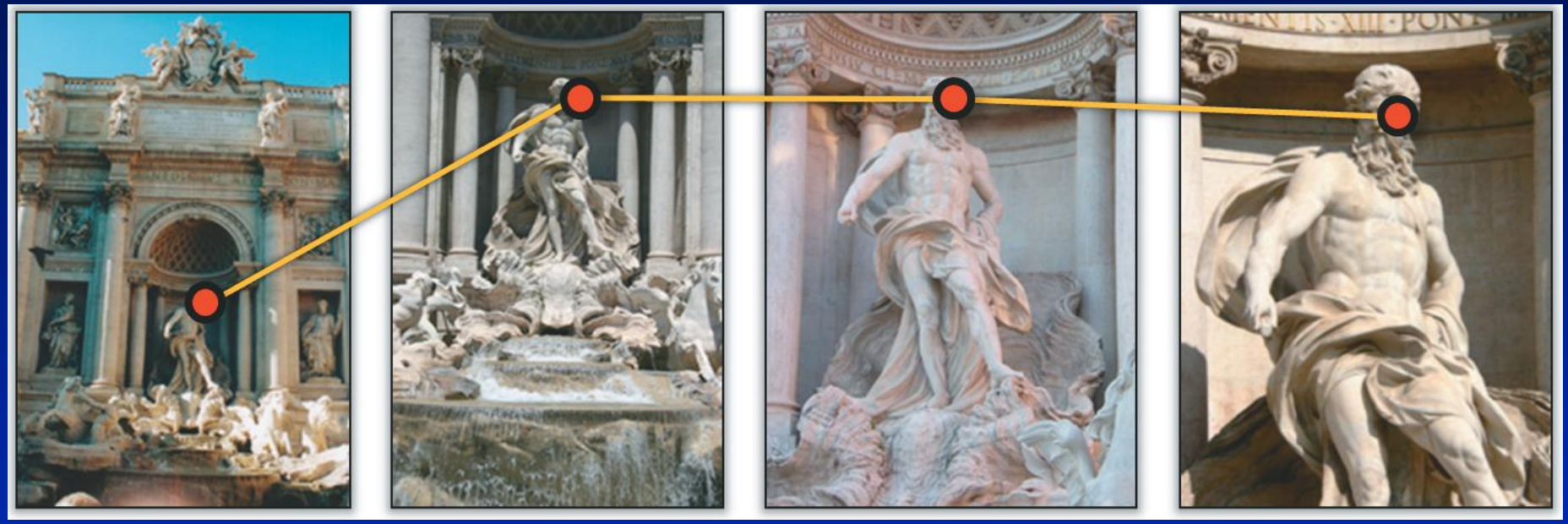


Assuming the position of the red dot is known, there is reprojection error in Camera 3.

Change the Problem to an optimization problem

- Minimize the sum of the squares of the reprojection errors.
- This non-linear least squares problem is difficult to solve due to local minima and maxima.

Feature Detection and Matching



A track corresponding to a point on the face of the central statue of Oceanus at the Trevi Fountain, the embodiment of a river encircling the world in Greek mythology.

Sameer Agarwal, Yasutaka Furukawa, Naoh Snavely, Brian Curless, Steve M. Seitz, Richard Szeliski. “Reconstructing Rome”, IEEE Computer, June 2010.

Colosseum

The Colosseum (Rome)

Reconstructed dense 3D point models. For places with many available images, reconstruction quality is very high.

Sameer Agarwal, Yasutaka Furukawa, Naoh Snavely, Brian Curless, Steve M. Seitz, Richard Szeliski. “Reconstructing Rome”, IEEE Computer, June 2010.

Cornell Campus, McGraw Hall - Noah Snavely

What is a Light Field?

- Radiance is defined as the light energy coming from a specific direction.
- A light field is defined as the radiance at a position (x, y), and a direction (θ, φ).
- Thus, the light field is a 4-dimensional space.

Light Field

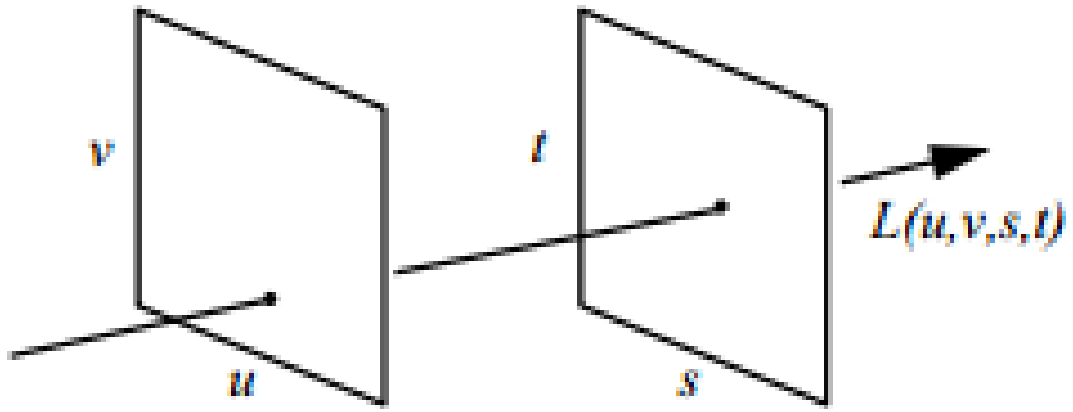
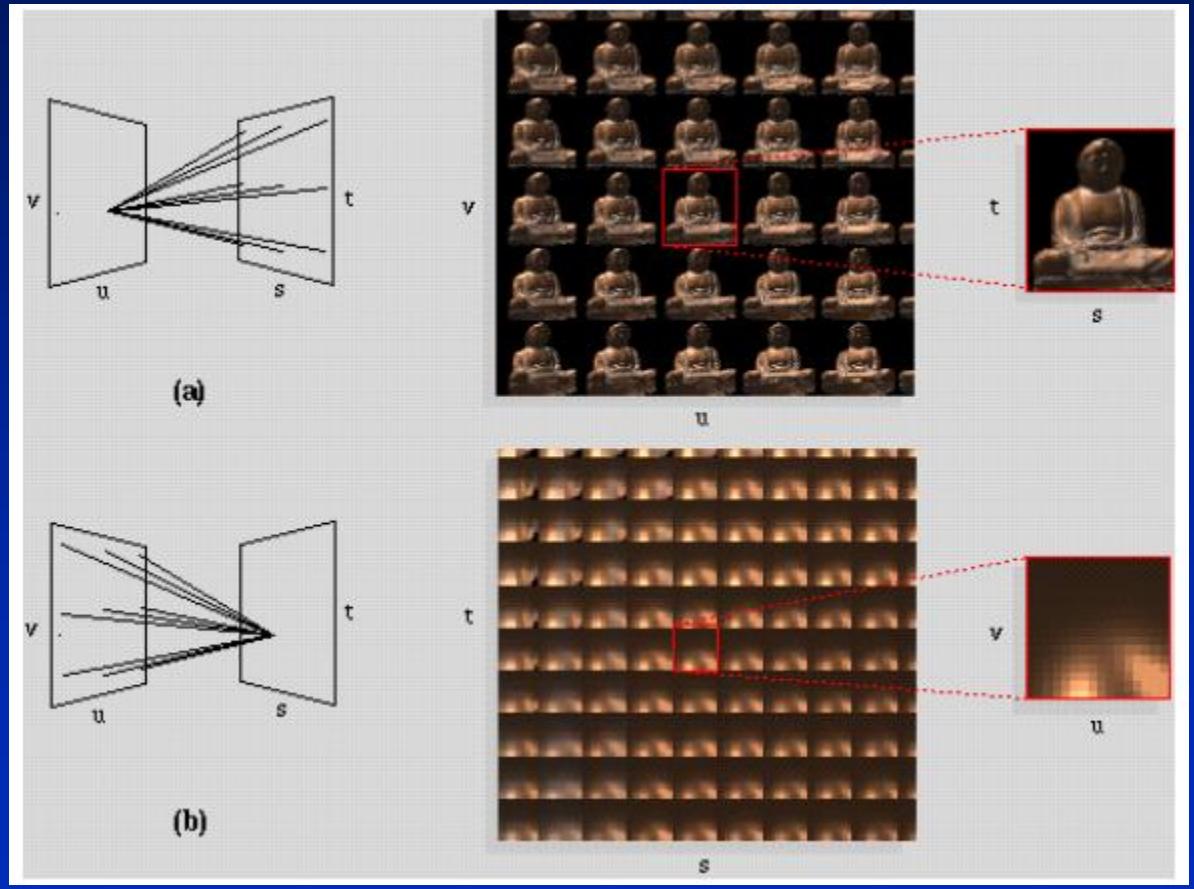
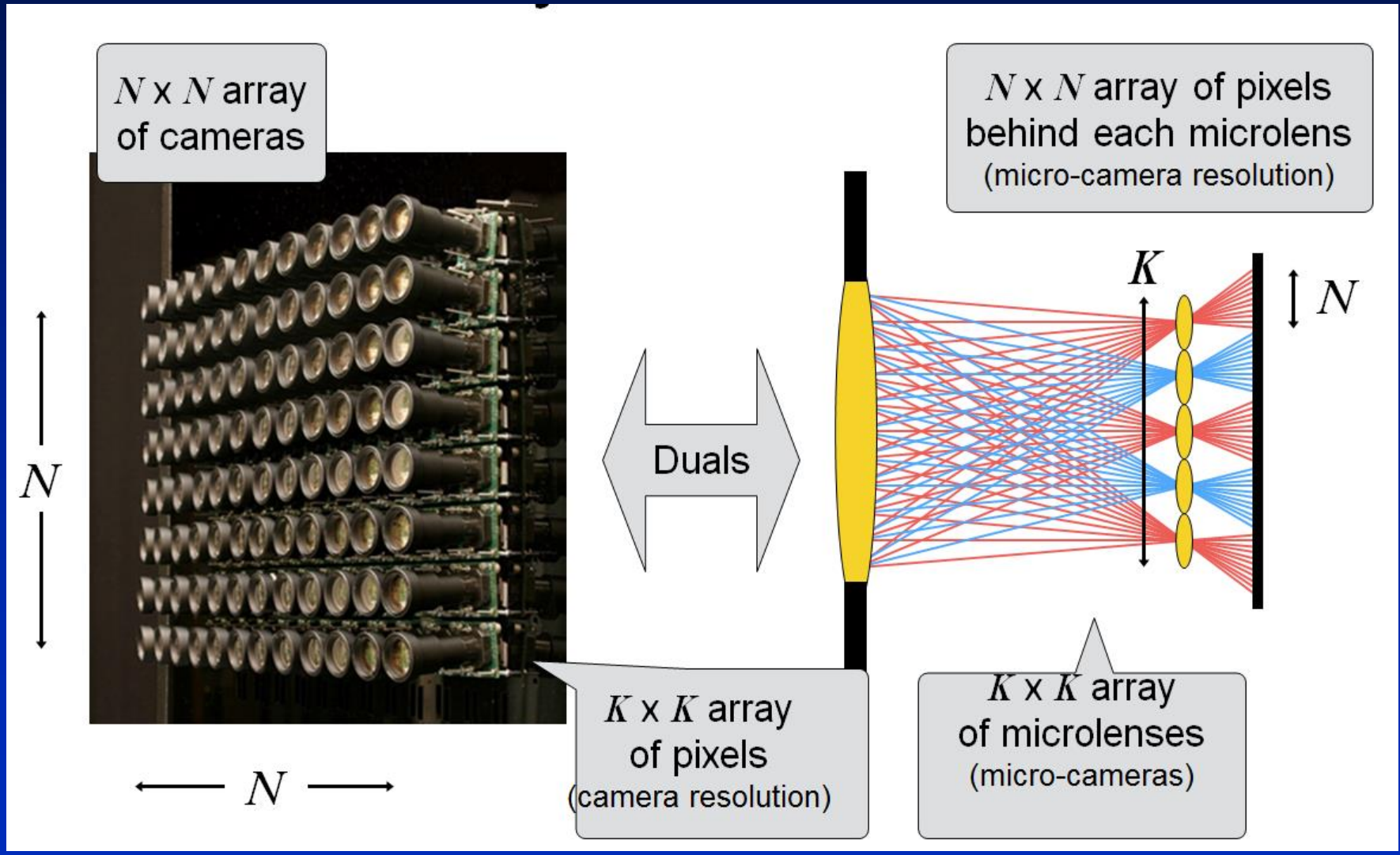


Figure 1: The light slab representation.

Light Field

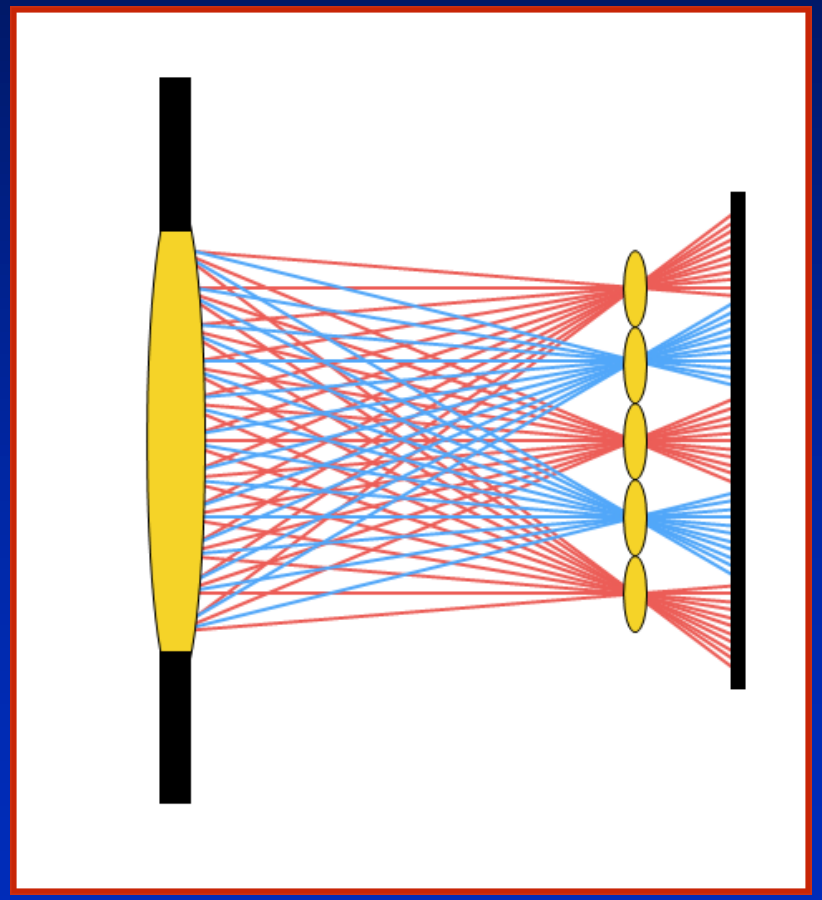


Multi-camera array and LF camera are duals

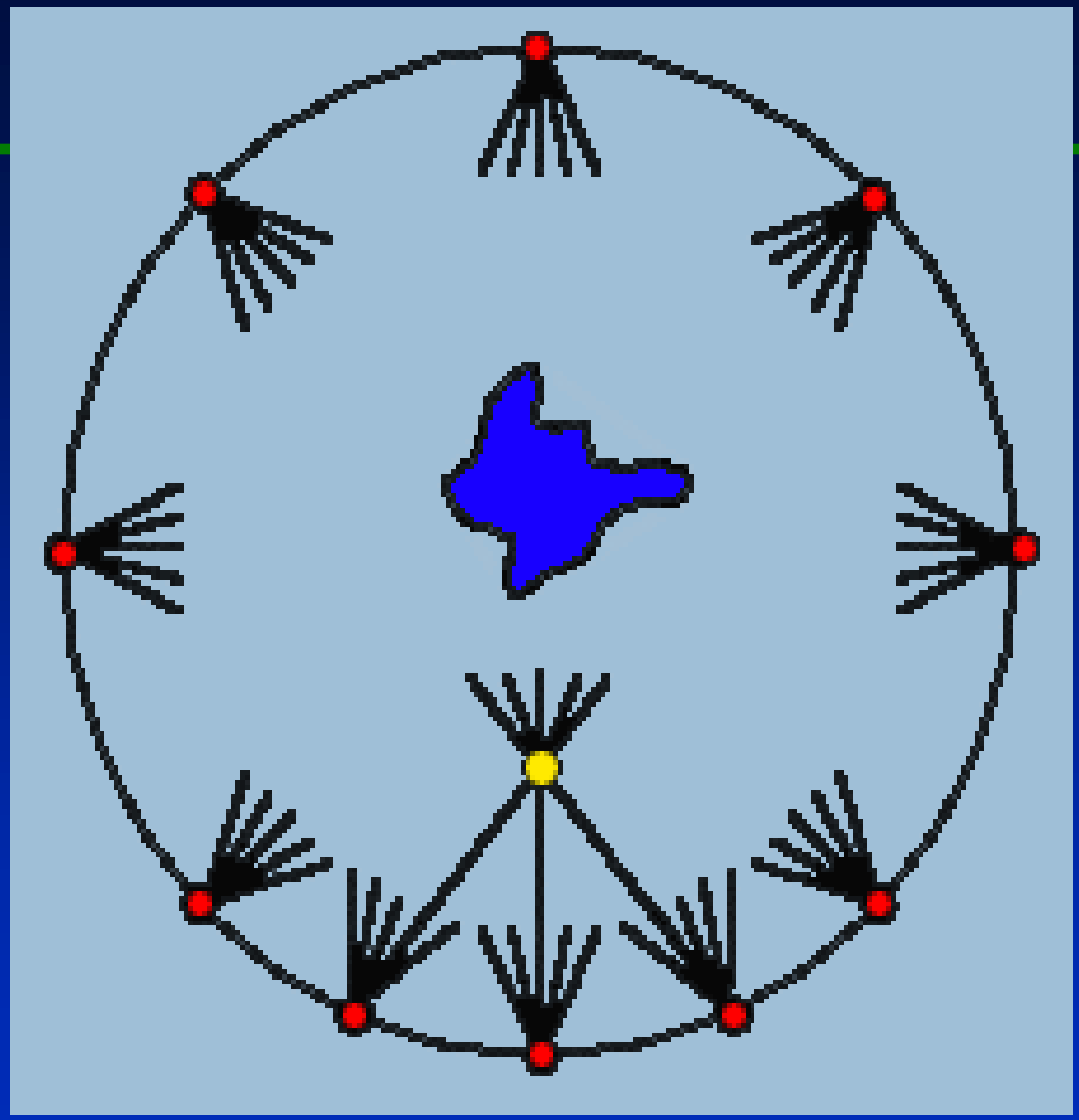


Key LF-camera advantage: a single lens

- (more familiar, reduces complexity, simplifies calibration, …)



A Light-Field of Michelangelo's Statue of Night




yberware

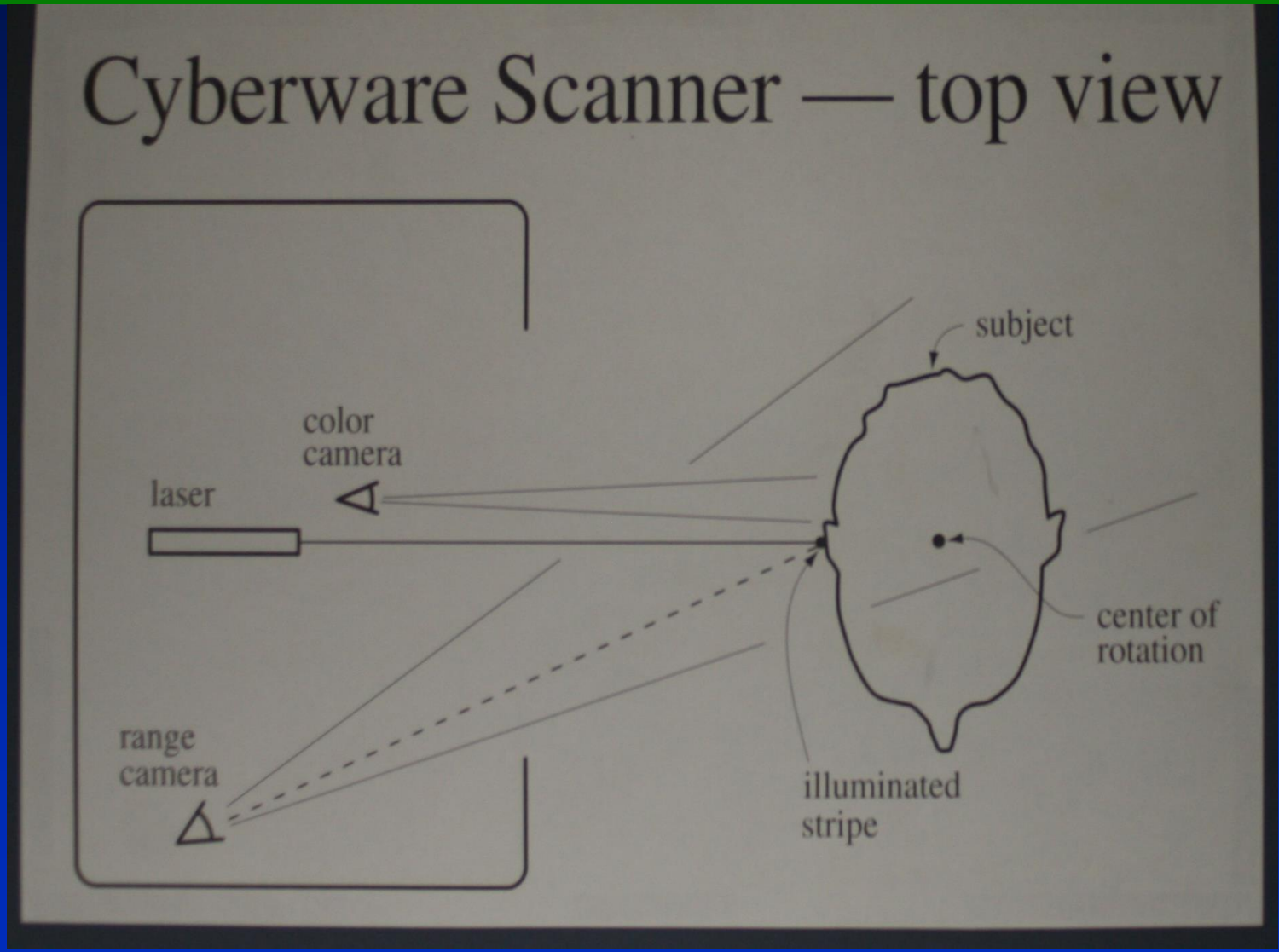
Lytro Camera

Key LF-camera advantage: a single lens

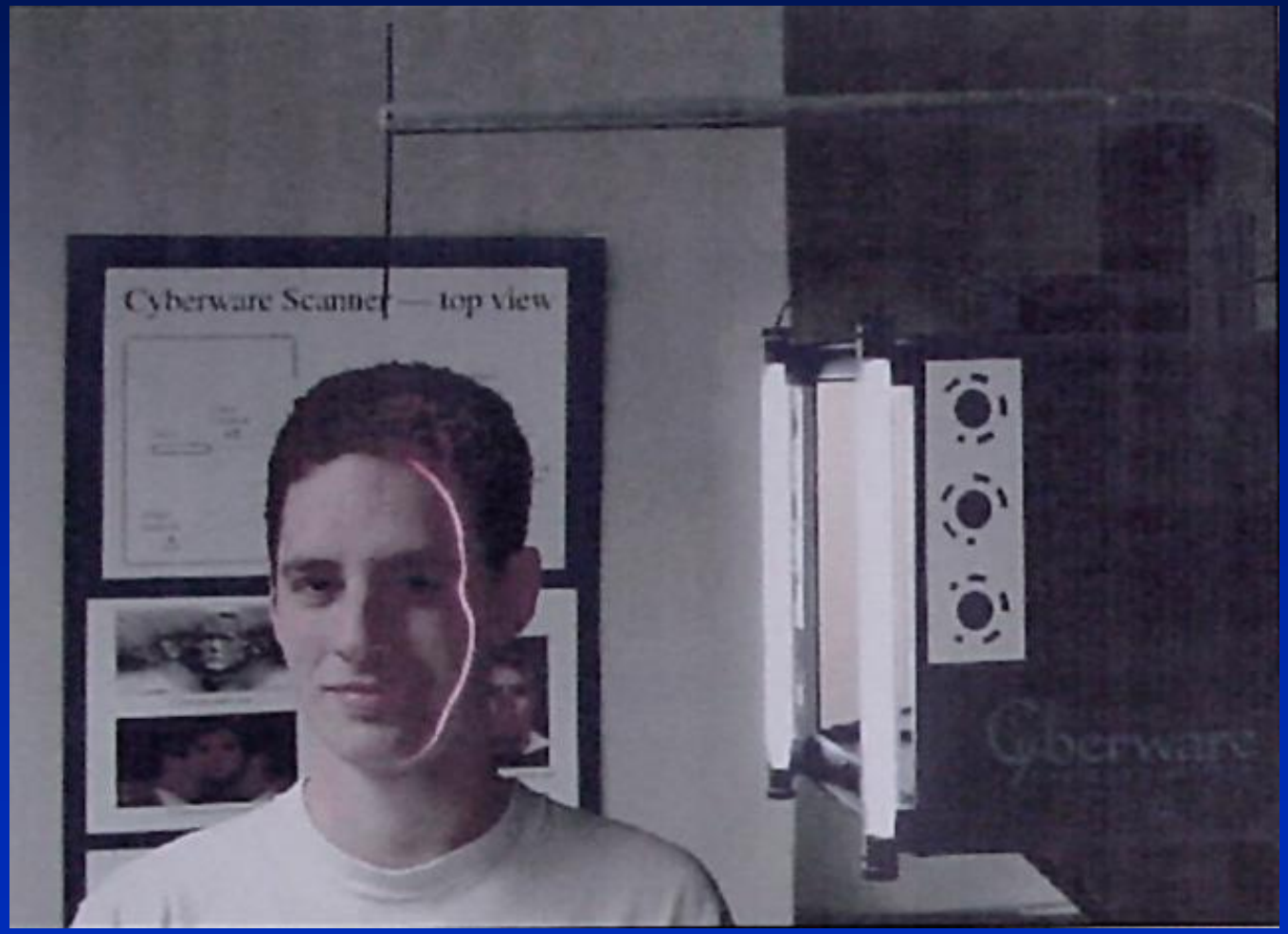
- (more familiar, reduces complexity, simplifies calibration, …)

Cyberware Scanner

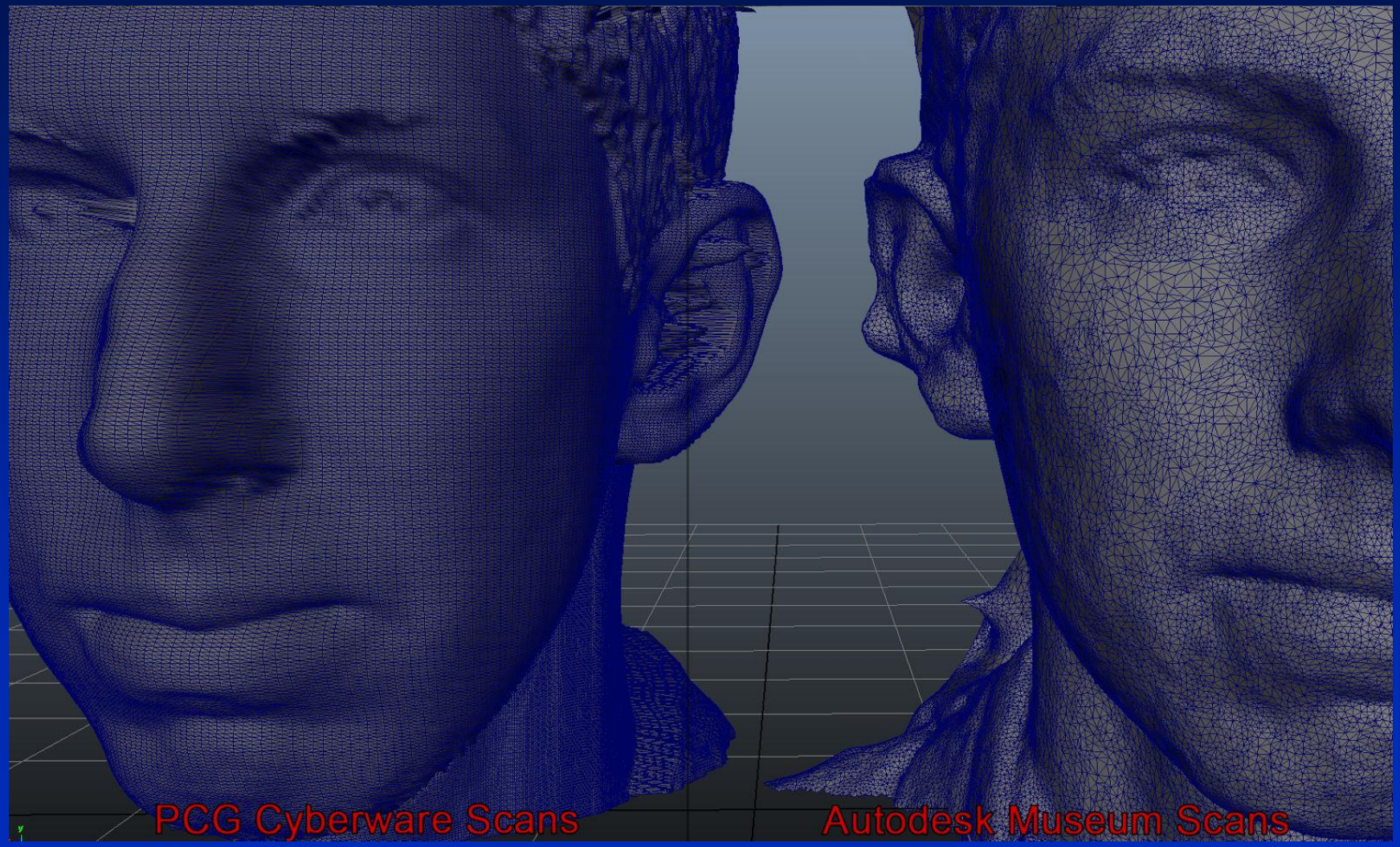
Cyberware Scanner Diagram



Cyberware Scanner



Cyberware vs. 1 2 3 Catch

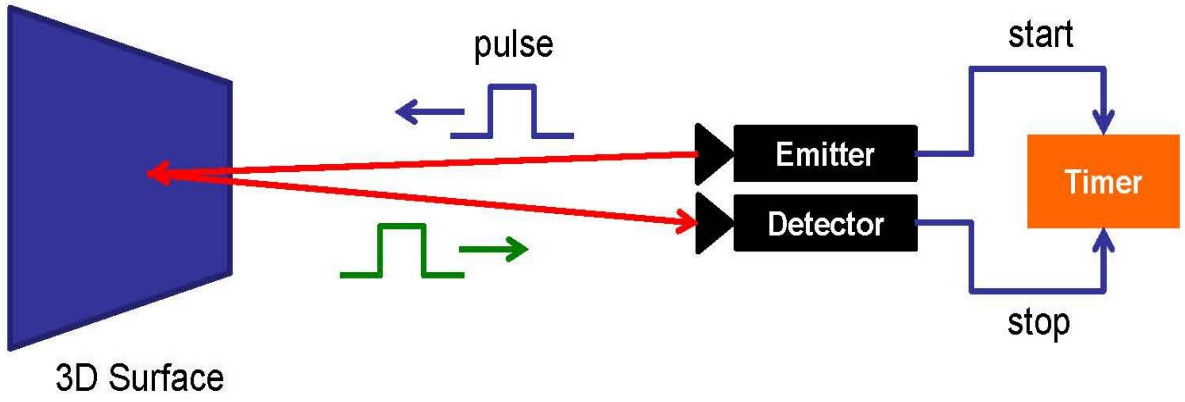


Microsoft's Kinect

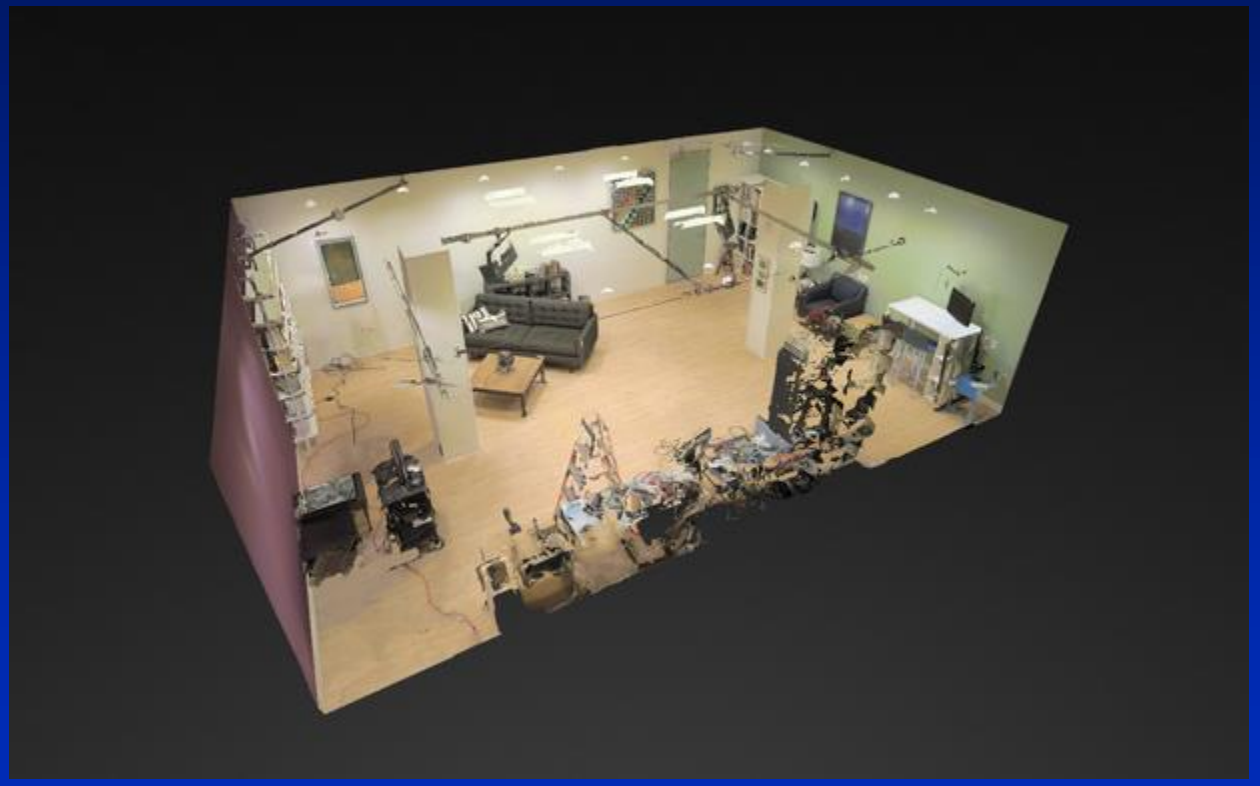
Kinect: Depth Image and Real Image

Pulsed Modulation

- Measure distance to a 3D object by measuring the absolute time a light pulse needs to travel from a source into the 3D scene and back, after reflection
- Speed of light is constant and known, $c = 3 \cdot 10^8 m/s$

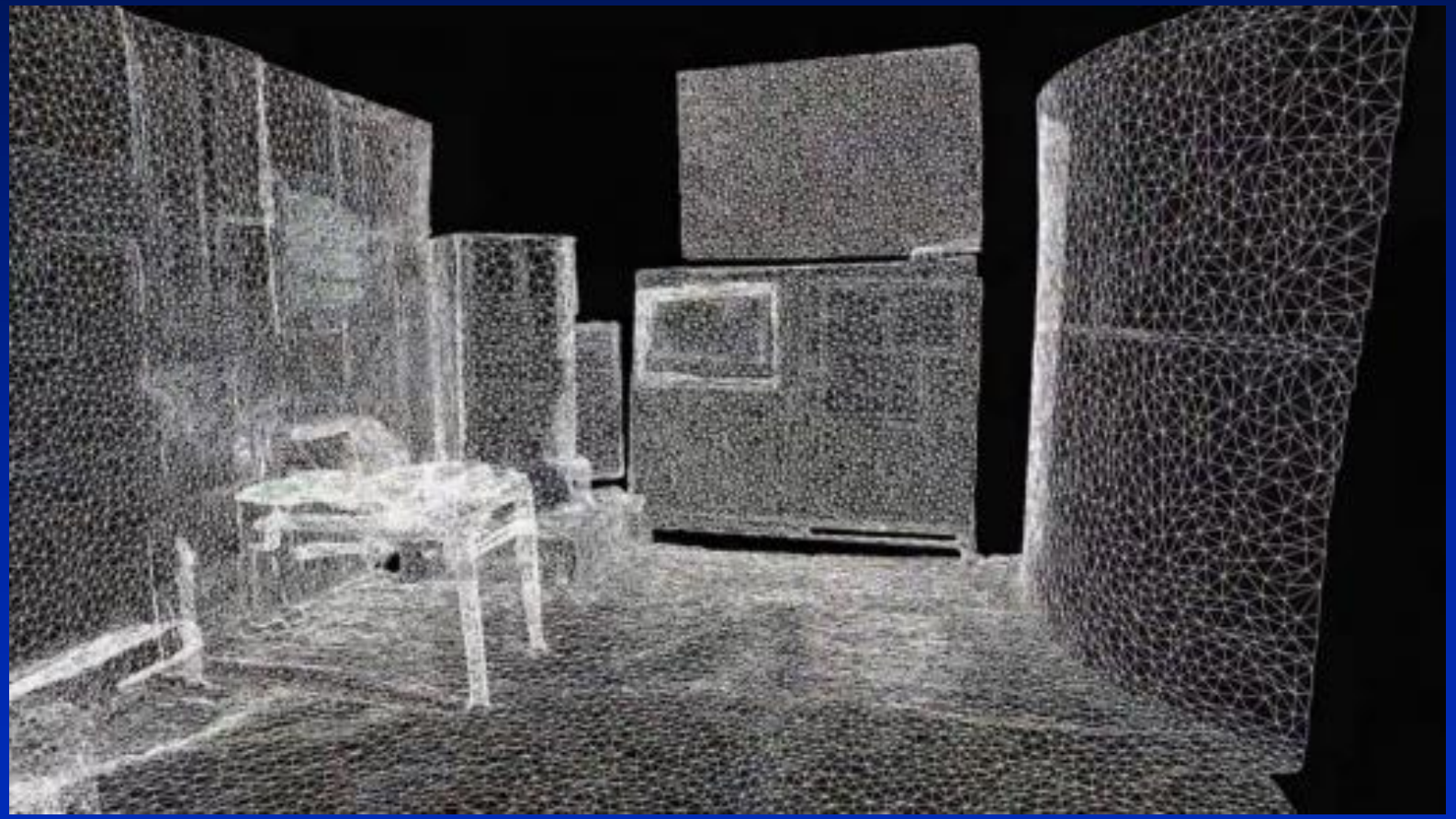


Matterport

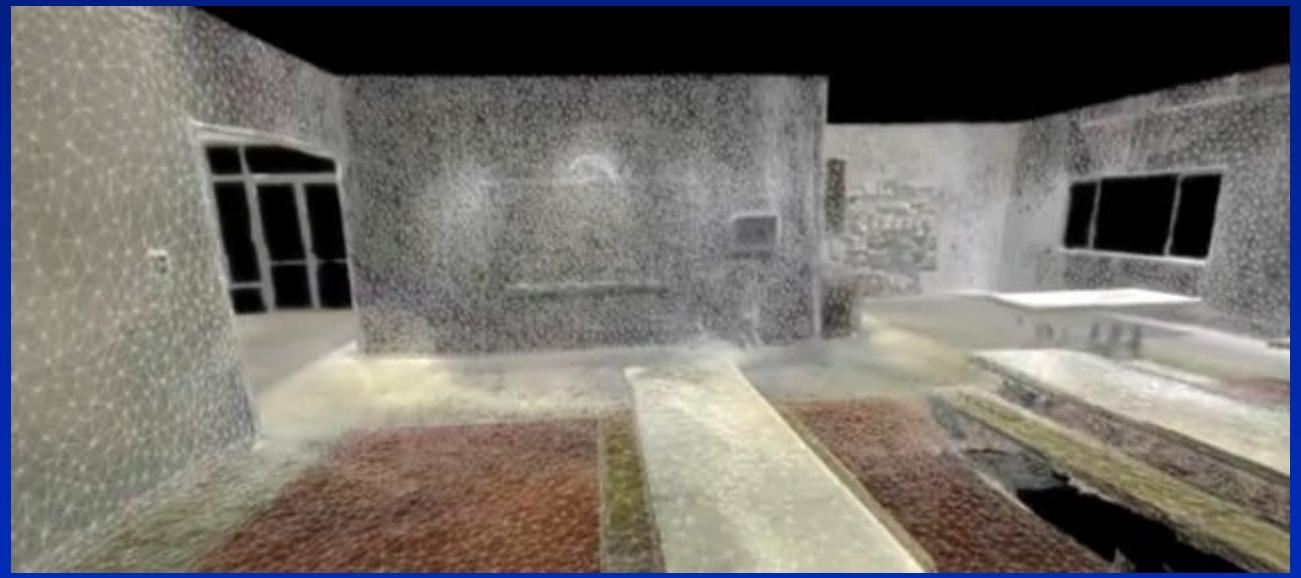


Matterport

Matterport



Matterport



Digital Geometry Capture

- Photographic methods
- Time of Flight
- Radar
- Sonar
- All of the Above

Google Street View

- The world contains roughly 50 million miles of roads, paved and unpaved, across 219 countries (ref.)
- This is equivalent to circumnavigating the globe 1250 times.
- To date, hundreds of cities in many countries across four continents have been captured.
- Google has developed several vehicular platforms and texture information in the project's seven year history.

Drafomir Anguelov, Carole Dulong, Daniel Filip, Christian Frueh, Stepheane Lafon, Richard Lyon, Abhijit Ogale, Luc Vincent, Josh Weaver. "Google Street View: Capturing The World At Street Level," IEEE Computer, June 2010.

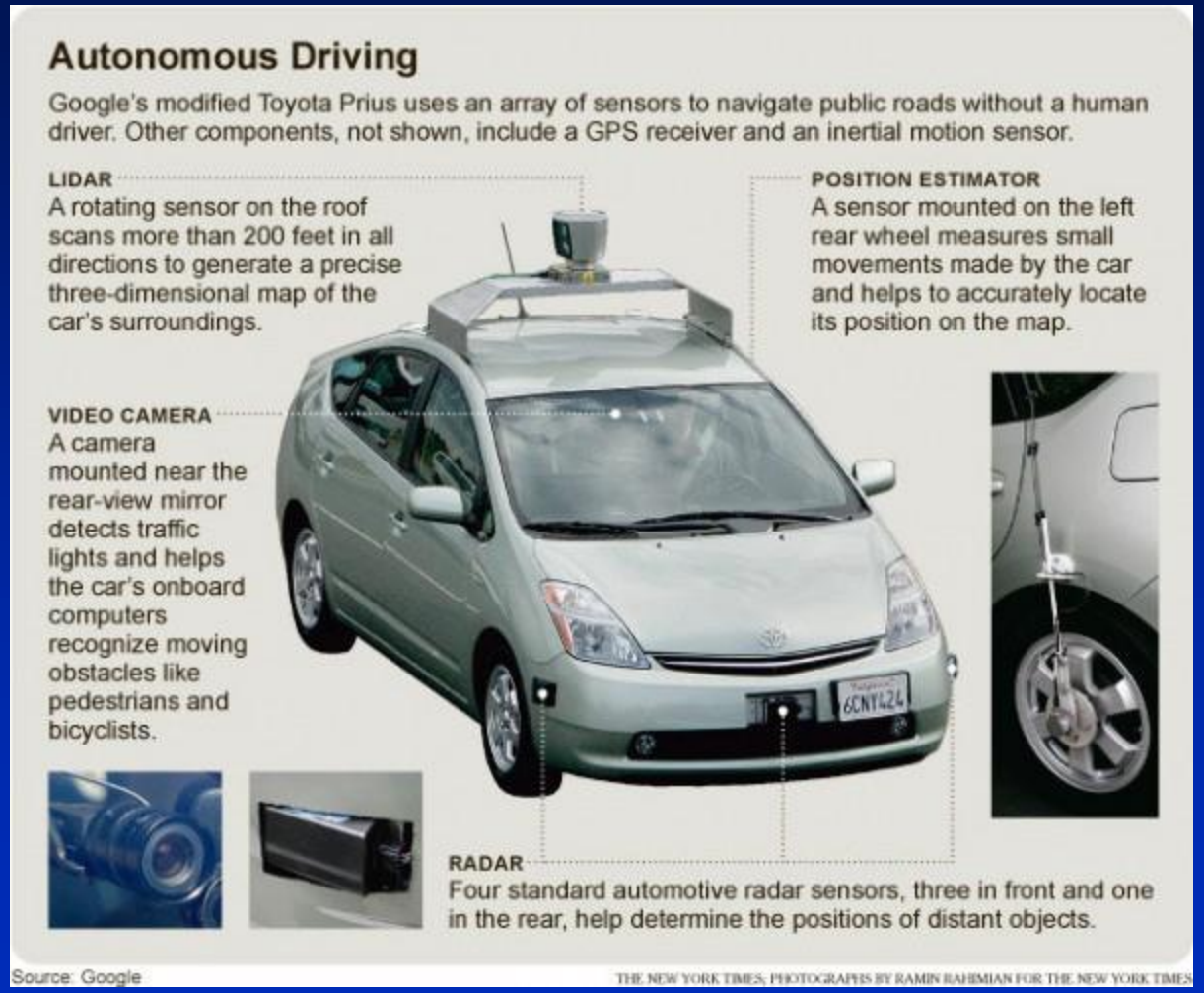
Google Street View and Google Maps 2007-2012

- In 2007, Larry Page requests Thrun and Levandowski to create a virtual map of the U.S.
- Engineers jury-rigged some vans with GPS and rooftop cameras which shot 360° panoramas for any address. They equipped 100 cars which were sent around the U.S.
- Data was put together with a program written by Marc Levoy.
- In 2011, Google announced it would start charging (large) commercial sites
- In 2012, Google allows users to post photos and reviews of locations

By October 2012, Google will have updated 250,000 miles of U.S. roads

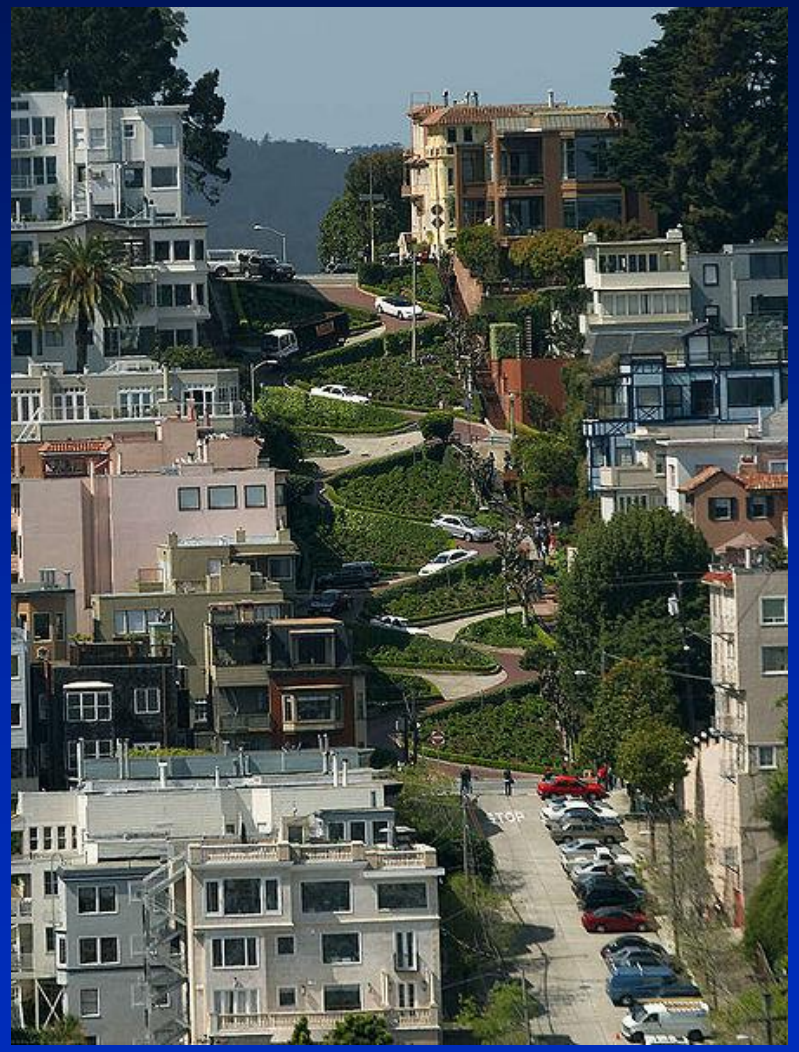
Note: They have also added Google Moon and Google Mars

Google's Autonomous Driving Vehicle



http://erictric.com/2010/10/09/google-secretly-develops-tests-automated-cars/

Lombard Street, San Francisco



Street View Vehicular Platforms

Trike

Modified Snowmobile

Drafomir Anguelov, Carole Dulong, Daniel Filip, Christian Frueh, Stepheane Lafon, Richard Lyon, Abhijit Ogale, Luc Vincent, Josh Weaver. “Google Street View: Capturing The World At Street Level,” IEEE Computer, June 2010.

Google Street View Car Fleet

October 15, 2012

Google's Autonomous Driving Vehicle 2013

- Uses multiple sensors, each with a different view of the world
- Laser
  - 64 beams @ 10 revolutions/second scanning 1.3 million points in concentric waves starting 8 feet from the car
  - It can spot a 14" object at a distance of 160 feet
- Radar
  - Has twice the range of the Laser, but much less precision
- Photography
  - Excellent at identifying road signs, turn signals, colors and lights

Google's Autonomous Driving Vehicle 2014-2015

- New laser sensors
  - 2 X range
  - 30 X resolution
  - @ 300' can spot a metal plate <2" thick
  - Size of a coffee mug
  - Cost ≈ $10,000 (less than current model @ $80,000)

End