New Directions in Imaging Sensors

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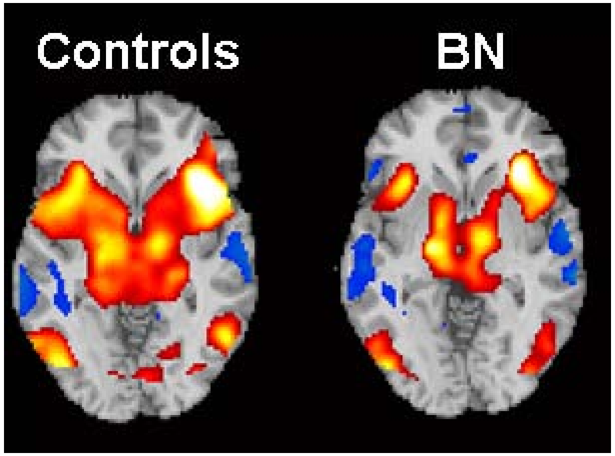
We live in xxxx age

information, biotech, nano, neurotech, quantum…

Regardless of the answer, we live in an age of *IMAGES!*



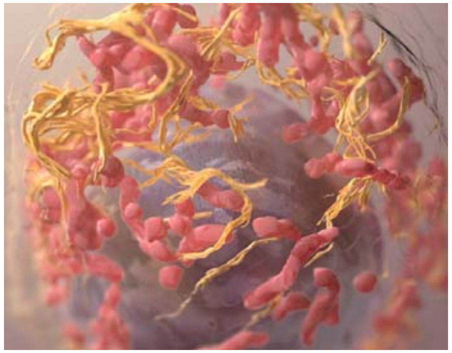


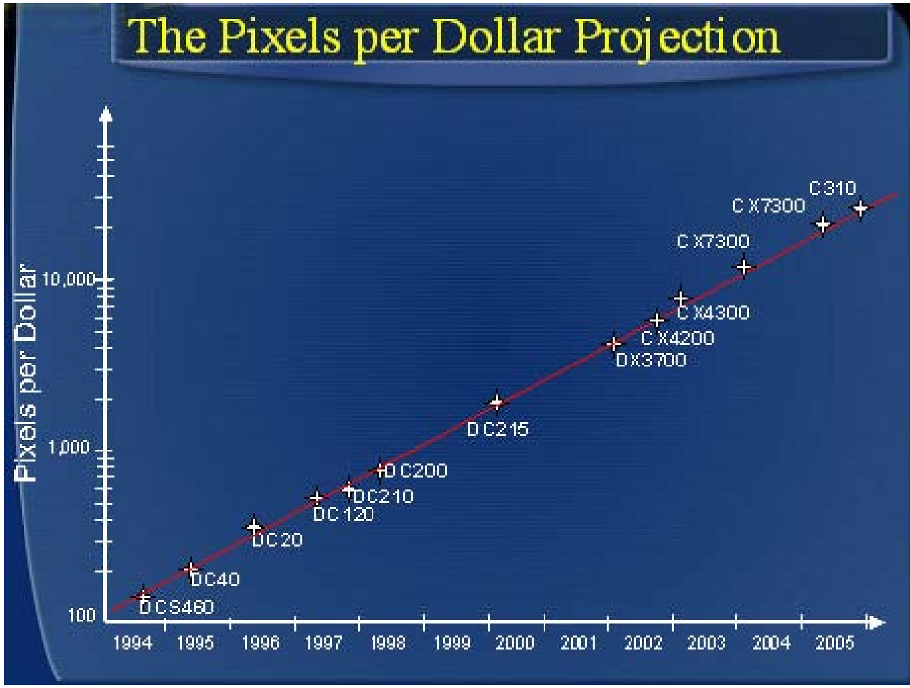
Photo removed due to copyright restrictions.
A person using his cell phone to take of photo of a fire or explosion.

Images (clockwise from upper left) from US Govt Agencies: NSA/ESA; 9-11 Commission; NIMH; NIH.

Exponential Growth in Camera Technology

Stand-alone digital cameras:
1991: Kodak DCS-100,
1280x1024 pixels, $30,000
2008: Kodak Easyshare V1003,
10 Megapixel, $170
Total Digital Camera Volume > 150 million

Cellphone cameras:
1997: First baby birth recorded on
cell phone camera (VGA res)
2008: Samsung SCH-B600, 10 Megapixel,
30% of cell phone contain cameras
Total cell phone volume to reach 1 billion



Courtesy of Barry Hendry (Wikipedia)

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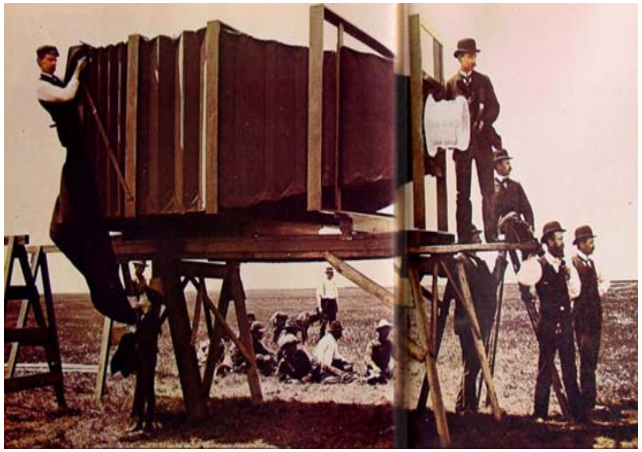
Mammoth Camera: 1900



In 1900, George R. Lawrence built this mammoth 900 lb. camera, then the world's largest, for $5,000 (enough to purchase a large house at that time!) It took 15 men to move and operate the gigantic camera. The photographer was commissioned by the Chicago & Alton Railway to make the largest photograph (the plate was 8 x 4.5 ft in size!) of its train for the company's pamphlet "The Largest Photograph in the World of the Handsomest Train in the World."

World's Smallest Cameras: 2006

http://www.letsgodigital.org/en/8687/omnivision_camerachip_ov6920/

http://www.medigus.com/CAMERA_1_8_mm/Camera.aspx

OmniVision OV6920 sensor, 2.1 x 2.3 mm; PillCam

Medigus Introspicio Camera 1.8 mm, 326x382 pixels

Medigus Corp. Israeli medical imaging company

1.8 mm Endoscope

But….basic Camera Architecture Remained Unchanged over 100 years

Other Observations:

- **Detector arrays in visible wavelength scaling up very rapidly**
  - **100 Mpixel available**
  - **Gigapixel possible (1.2 micron pixel over 35 mm sq array)**
- **Conventional imaging optics (wide FOV, high resolution) scales very poorly (heavy, bulky, expensive)**
- **Governing principles**
  - **Maximum sample rate for all parameters everywhere**
  - **Fixed resource allocation**
  - ***Measure everything then process***
- **Information unevenly distributed => most of the mega pixels contain very little to no information**
- **Large data volume (Multi GB/frame) overwhelming processing and communications.**

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What is the nature of the problem?

- Coming of data tsunami…..
  - Storing, moving, processing data
  - IDC report…. Data storage technology falling behind data generation (primarily driven by still images and video)
- Worsening pixel-pupil ratio….
  - <20% of images get looked at (this is an optimistic number)
- We are in an era that is "pixel rich – information poor"
- One solution:
  - Invoke Moore's Law to make problems go away
- Other approach:
  - Change our basic notions about imaging

Imaging Sensors: Back to Basics

- **Questions we ask:**

Who / What | **Where** | **When** | **How** | **Why**

Sensing | **Analysis Exploitation**

- **Two primary sensing modes:**

Photo courtesy of D Sharon Pruitt on Flickr.

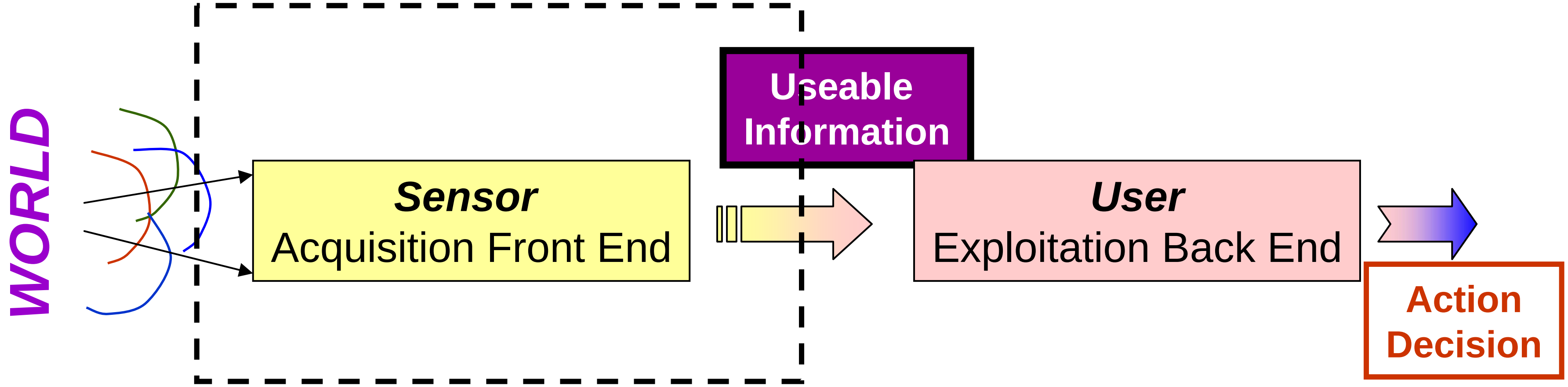
Proximate

Photo courtesy of anjamation on Flickr.

Stand-off

- **Stand-off sensing involves wave propagation which…**
  - **carries energy and information over distance without material transport**
  - **scrambles spatial organization of signals**
- **Two aspects to processing**
  - **Source coding: how object information is encoded in wavefront**
  - **Channel distortion**

Taking pictures => Scene interrogation



- Useable information is the key concept dependent on the user
  - Break from the past paradigm:
    - Generic front end sensor generating a 2D pixel map
    - Application-specific tasks performed in backend computation

- Useable information for navigation task is different from target recognition task

- Acquiring 3D spatial, spectral, polarization, temporal information that is *relevant to task at hand* in the most resource efficient manner is the primary goal.

Future Directions for Imaging sensors

"Cameras will also change form. Today, they are basically *film cameras without the film*, which makes about as much sense as automobiles circa 1910, which were horse-drawn carriages without the horse. A car owner of that time would be pretty shocked by what's in a showroom now. Camera stores of the future will surprise us just as much."

- ***Nathan Myhrvold, former chief technology officer of Microsoft and a co-founder of Intellectual Ventures,***

  NY Times, 5 June 2006

Where are imaging sensors headed:
Extending the Automotive Analogy

Horse-drawn Carriage

Horse-*less* Carriage

Images (clockwise from upper left): DARPA, US Army, USDA, NASA.

Courtesy of M Skaffari on Flickr.

Film Cameras

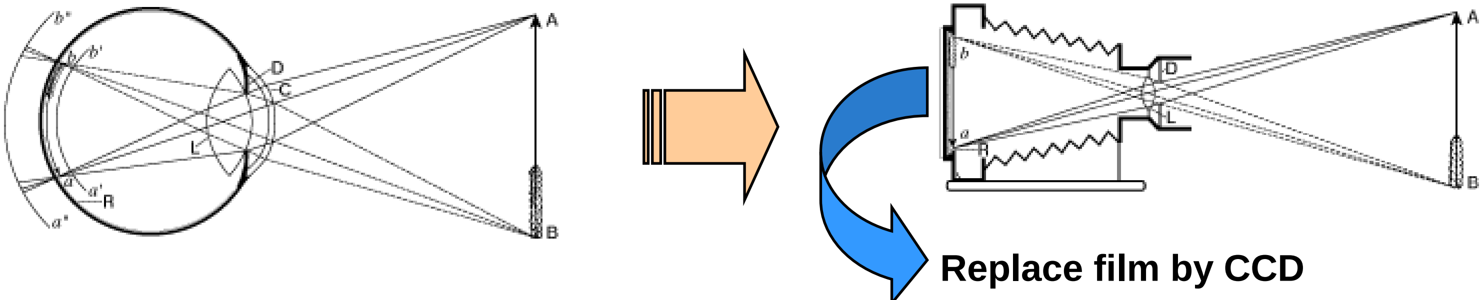
Courtesy of digitpedia on Flickr.

Film-*less* Cameras

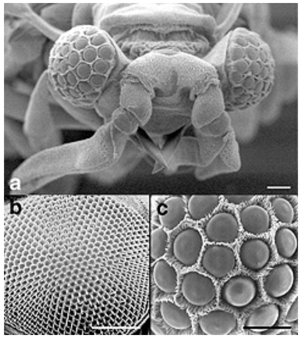
Specialization?
Autonomy?

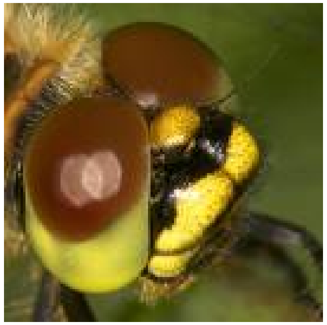
Reworking Biological Inspiration:

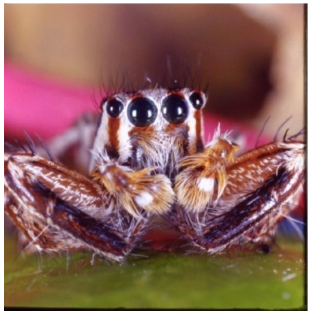
Human Eye and the Camera



- Made sense when cameras were used by *exclusively* humans
- Does it make sense for autonomous and semi-autonomous systems?







- Animal world shows a far greater diversity of imaging sensor designs
- Co-evolution of eye-brain-locomotion
  - Task-specific sensor design
  - Efficient use of resources

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SOME EXAMPLES OF NEW CAMERA DESIGNS AND OPERATION

Prototype camera

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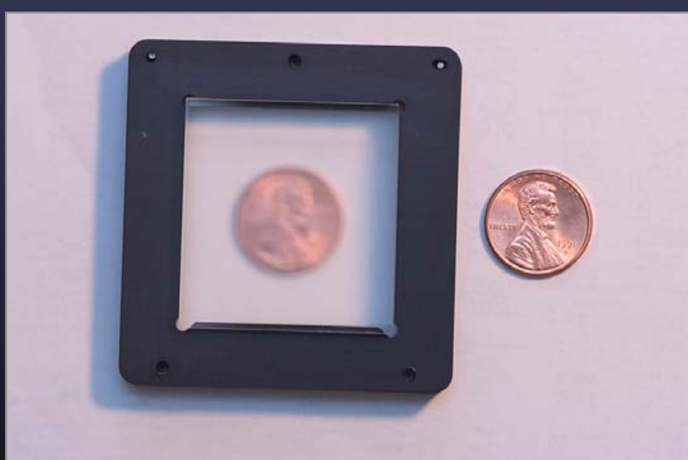
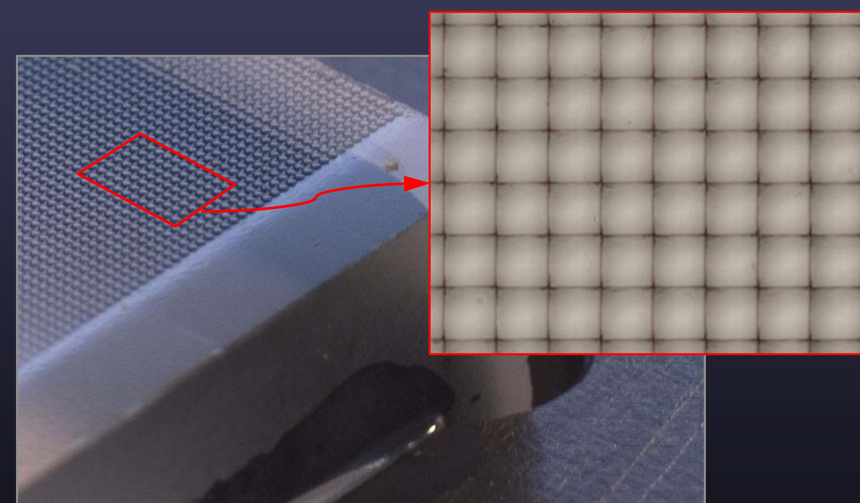
Contax medium format camera

Kodak 16-megapixel sensor



Adaptive Optics microlens array

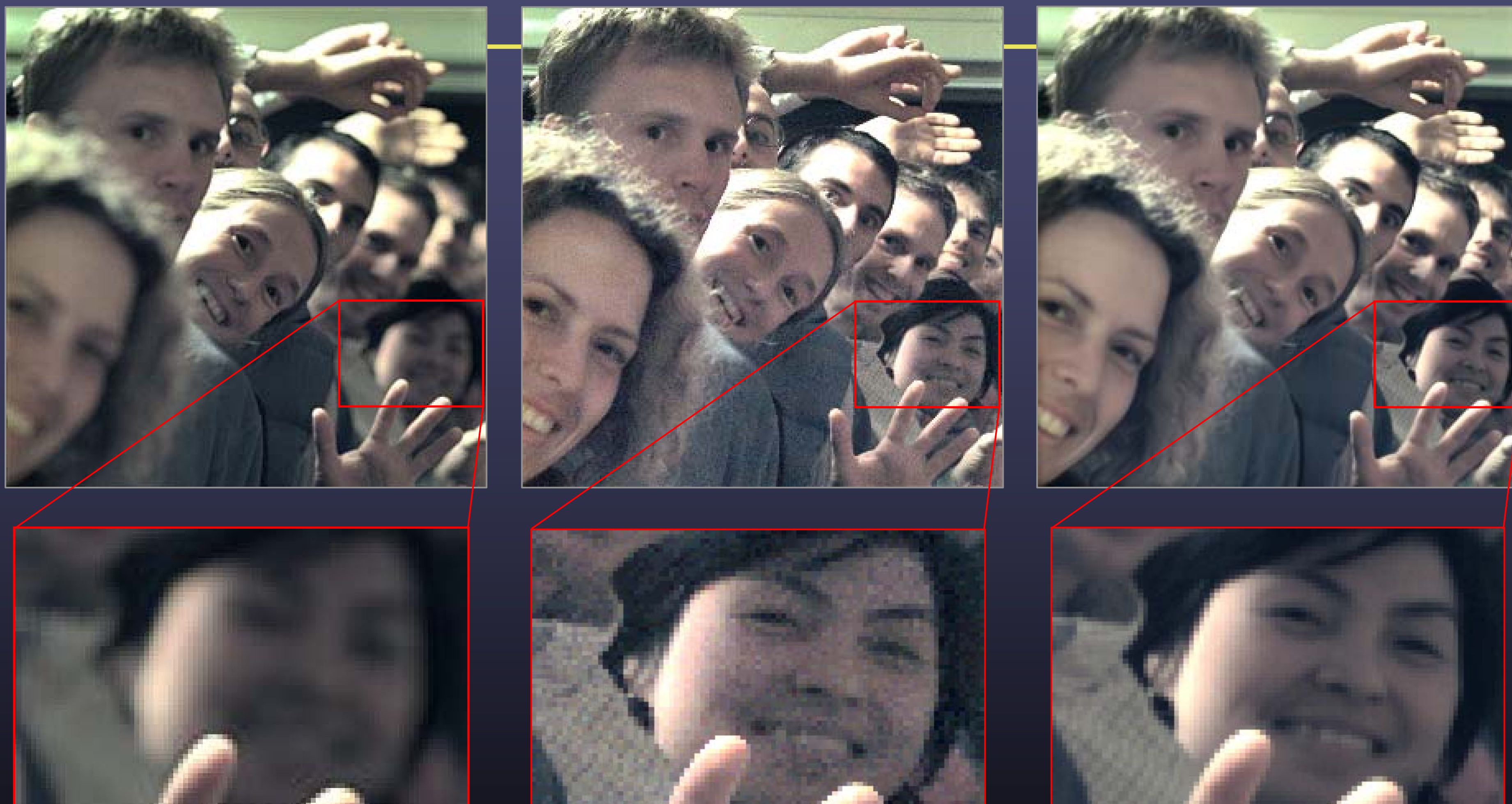


125μ square-sided microlenses

4000 × 4000 pixels ÷ 292 × 292 lenses = 14 × 14 pixels per lens

Stanford U

Extending the depth of field



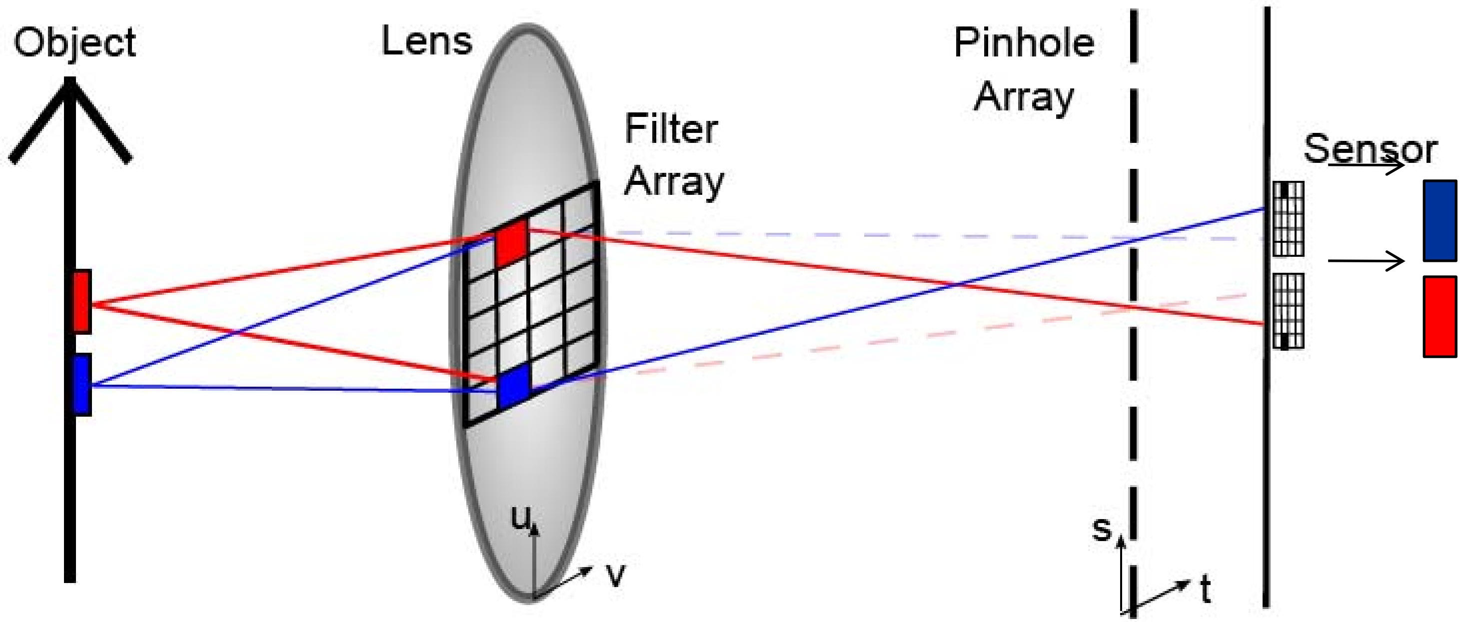
conventional photograph, main lens at f / 4

conventional photograph, main lens at f / 22

light field, main lens at f / 4, after all-focus algorithm [Agarwala 2004]

Our Modification of Light Field Camera: Flexible Modality Imaging

- **A light field architecture facilitates placing multidimensional diversity in the camera's pupil plane:**

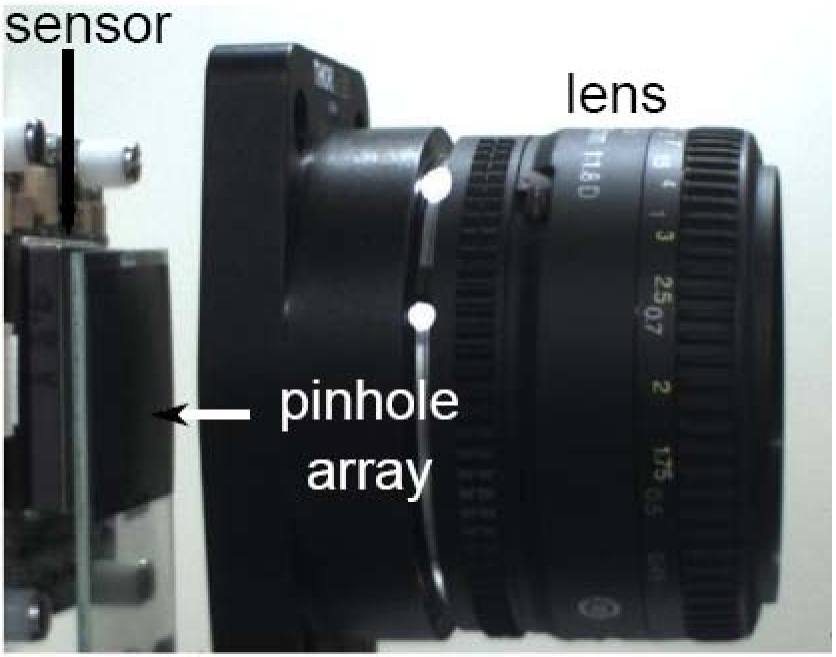


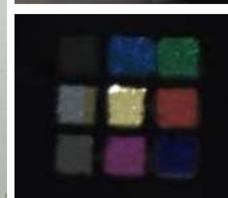
- **Color information (e.g.) is available at each spatial location in *(s,t)* from each filter array image**
- **Spatial resolution from pinholes, filter resolution from # filters**

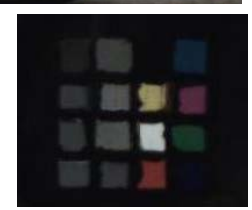
Ref: Horstmeyer, R., G.W. Euliss, R.A. Athale, and M. Levoy. "Flexible Multimodal Camera Using a Light Field Architecture." *Proceedings of IEEE ICCP, 2009.*

Experimental Results

- **Use conventional Nikon 50mm f/1.8 lens, 10Mpix 9µ CCD**
- **Pinhole arrays printed on transparencies, varying size + pitch**
- **Filters cut and arranged on laser-cut plastic holders, placed inside lens over aperture stop**







Left and lower center images © 2009 IEEE. Courtesy of IEEE. Used with permission.
Source: Horstmeyer, R., G.W. Euliss, R.A. Athale, and M. Levoy. "Flexible Multimodal Camera Using a Light Field Architecture." Proceedings of IEEE ICCP, 2009.

Experimental Results

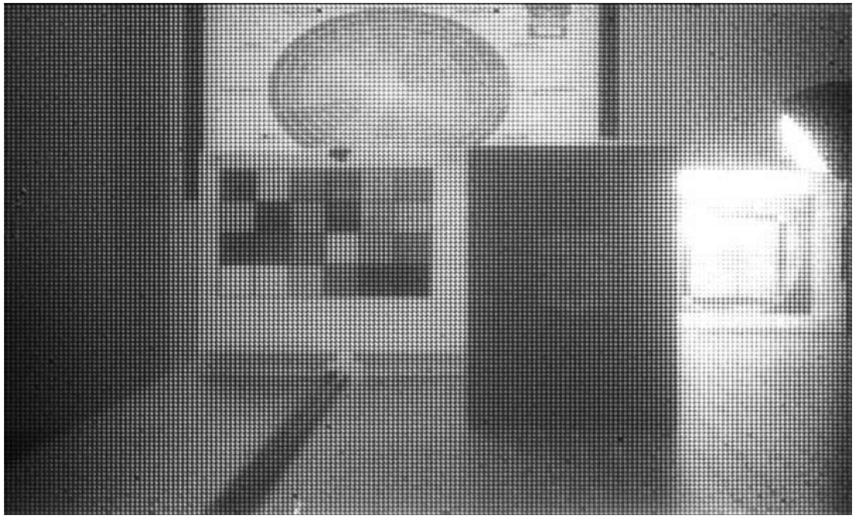
- **<u>Nine filters</u>:**

Color =R, G, B, Y, C,

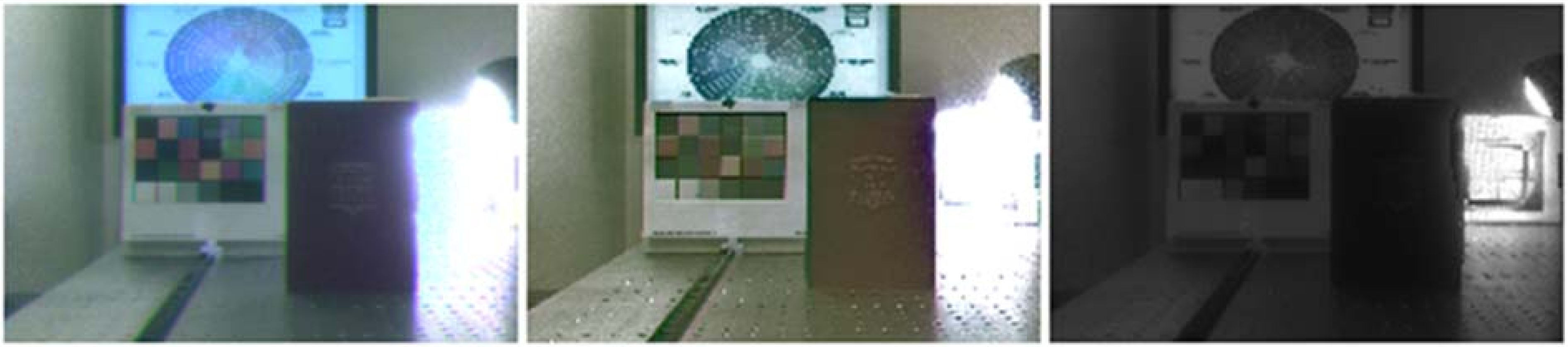
Neutral Density = .4, .6, 1

pinhole r = 25µ, pitch = 250µ

- **Use 3 ND filters to extend dynamic range (CMYK with density filter, HDR)**



RGB **CMYK** **HDR**



Images courtesy of SPIE. Used with permission. Source: Horstemeyer, R., R. A. Athale, and G. Euliss. "Light Field Architecture for Reconfigurable Multimode Imaging." *Proc. of SPIE* 7468, August 2009. doi: 10.1117/12.828653

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Experimental Results

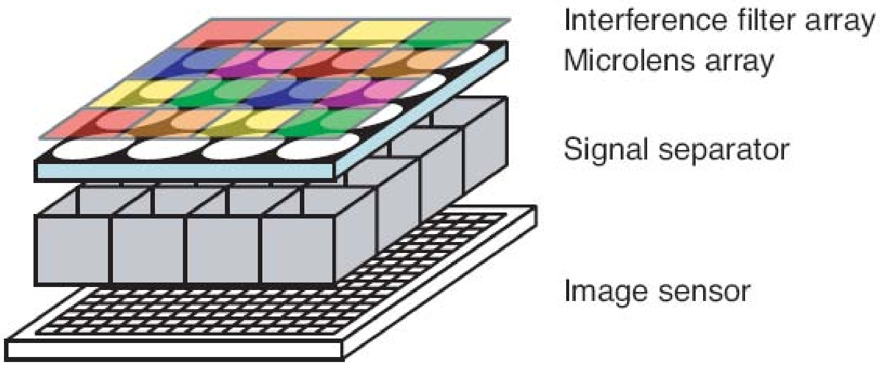
- **Sixteen filters**:

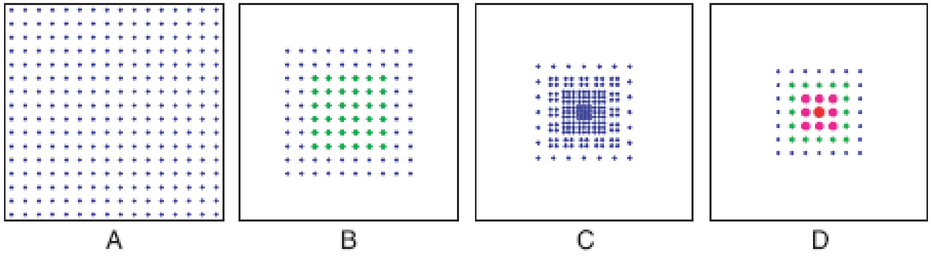
layout

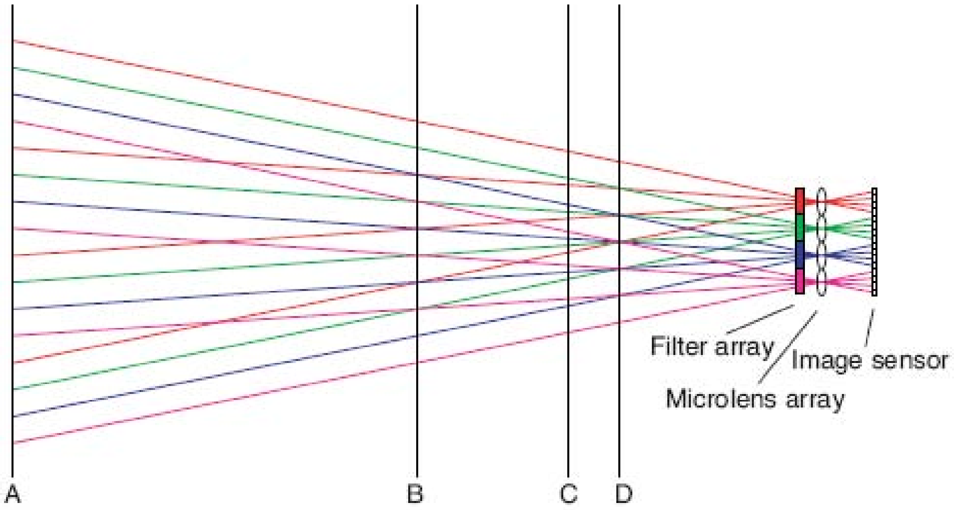
B	G	M	C
R	No Filter	Y	IR
0°	RC	0.4	0.6
45°	135°	90°	1

Image © 2009 IEEE. Courtesy of IEEE. Used with permission.
Source: Horstmeyer, R., G.W. Euliss, R.A. Athale, and M. Levoy. "Flexible Multimodal Camera Using a Light Field Architecture." Proceedings of IEEE ICCP, 2009.

Thin observation module bound by optics (TOMBO)







- Compound image is collected via microlens array
- High-resolution image is reconstructed from sub-images
- Architecture enables reduction in size and weight

See Tanida, et. al., Applied Optics 40, 1806-1813 (2001)

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Examples of Scene Interrogation systems:

Same Scaling Analysis Doesn't Apply

Adobe

Photo of Adobe Lightfield camera array (2008). See http://www.notcot.com/archives/2008/02/adobe-lightfiel.php

Mesa Imaging SR 3100 3D camera. See http://www.flickr.com/photos/81381691@N00/3720851779/

Pixim D2500 'Orca' chipset for wide dynamic range video (e.g. surveillance).
See http://www.pixim.com/products-and-technology/pixim-orca-chipsets

Light-field cameras

Time-of-flight imaging

Active pixel sensors

Images removed due to copyright restrictions.

Image of demonstration.

Nova Sensors

Foveation

Final Thought….

- **A Personal Imaging Assistant (PIA) for:**
  - Health care:
    - Checking for sun burns, status of superficial wounds, ear infections….
  - Appearance:
    - Wardrobe matching (color and styles) while getting dressed or shopping
    - Make up assistance (skin color analysis)
  - Hygiene:
    - Cleanliness of surroundings (presence of bacteria), water, food safety, quality
  - Relationships:
    - Remembering people, names, likes/dislikes, family details
    - Discerning moods (boredom, deceit, amorous intents…)
  - and of course taking pictures and videos without manual intervention based on user preferences learned over time
- **How?**
  - Multi-spectral, polarimetric, day/night, active/passive illuminations, powerful processing
  - Unobtrusive (almost covert) form factor
  - Part of getting dressed