



University of  
Massachusetts  
Amherst

## Lecture 9–Digital Camera

ECE 197SA – Systems Appreciation

## Lab Assignment

- Build half-adder from logic gates
  - Basic function of calculator (all operations use your gates!)
- Embedded system checks correct implementation
  - Manual calculation
  - Automated test
- What you need to do:
  - Pick up kit in Knowles 211C (available later this week)
  - Do lab (instructions provided)
  - Take picture of you and working system
  - Submit picture on Moodle



# Digital Camera

- Digital imaging technology
  - Capturing visual information in digital systems
- Today's lecture:
  - Charge-coupled device
    - » Sensor for light
  - Digital camera
    - » Storage, user interface to sensor, etc.



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# Importance of Images

- Why is "*a picture worth a thousand words*"?

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## Importance of Images

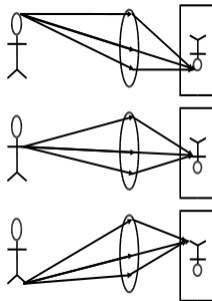
- Sight is an important human sense
  - Color and brightness
- Sight important for perception of environment
  - 2-D image used for object recognition and interpretation
  - Depth perception derived from using both eyes

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## Images as Rays of Light

- Projection of light from object onto screen
  - Convex lens gathers light from object
  - "Screen" can be retina, image sensor, cinema screen, etc.



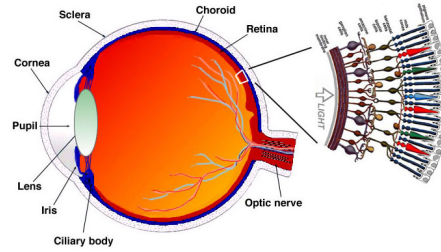
- Need to capture light and represent in electronic domain

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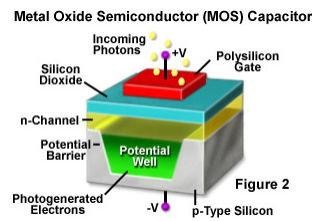
# Sensing Light

- Human eye
  - Lens project image onto retina
  - Photoreceptors in retina translate light into nerve impulses
  - Sensor types
    - » "Rod" (brightness)
    - » "Cone" (color)



From <http://webvision.med.utah.edu/sretina.html>

- Electronic sensor
  - Light becomes charge in chip
    - » Same idea as solar cell
  - Readout
    - » Charge amplifier (charge-to-voltage converter)
    - » Sampled, digitized, stored



From <http://www.microscopyu.com/articles/digitalimaging/ccdintro.html>

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# 2-D Image sensor

- How to extend sensor to capture 2-D image?

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# CCD Sensor

- Charge-coupled device (CCD)
  - Sensor to capture light
  - Clever design to move charges of pixels to amplifier
- Inventors received 2009 Nobel prize in physics



The Nobel Prize in Physics 2009  
Charles K. Kao, Willard S. Boyle, George E. Smith

The Nobel Prize in Physics 2009
Nobel Prize Award Ceremony
Charles K. Kao
Willard S. Boyle
George E. Smith



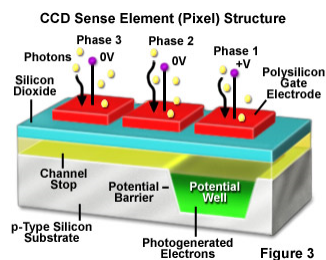
Photo: U. Montan  
 Charles Kuen Kao      Willard S. Boyle      George E. Smith

The Nobel Prize in Physics 2009 was divided, one half awarded to Charles Kuen Kao "for groundbreaking achievements concerning the transmission of light in fibers for optical communication", the other half jointly to Willard S. Boyle and George E. Smith "for the invention of an imaging semiconductor circuit – the CCD sensor".

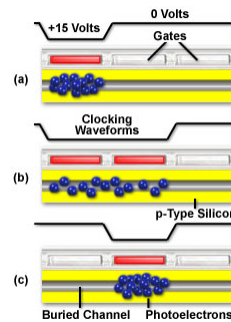
Photos: Copyright © The Nobel Foundation

# CCD Design

- Need 2-D design that can be put on CMOS chip
  - 2-D array of light sensors
  - 2-phase operation: exposure and readout
  - Readout:
    - » move charge from each pixel sequentially to edge
    - » Measure charge at edge/corner of chip



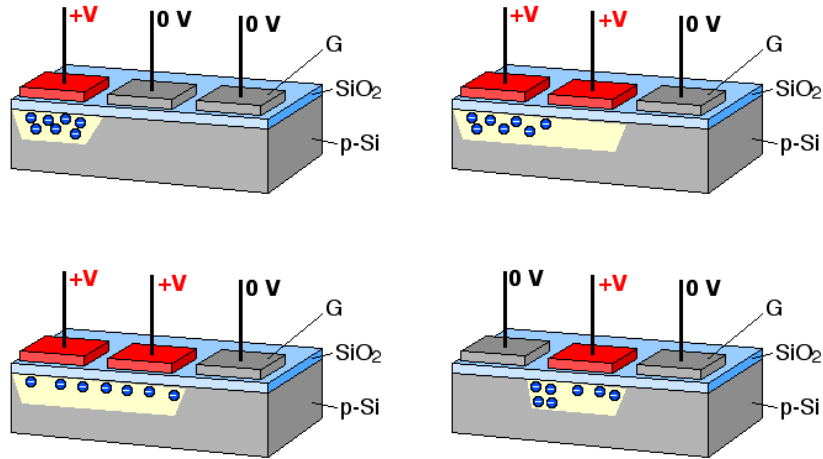
Three Phase CCD Clocking Scheme



From <http://www.microscopyu.com/articles/digitalimaging/ccdintro.html>

# CCD Design

- Moving charge:

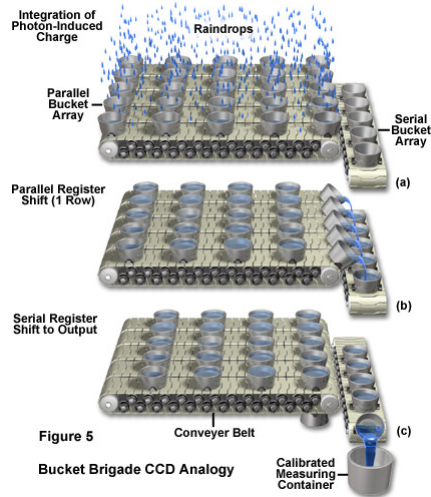


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# CCD Operation

- 2-D operation to move charge to corner of chip
  - Single amplifier/A-to-D converter



From <http://www.microscopyu.com/articles/digitalimaging/ccdintro.html>

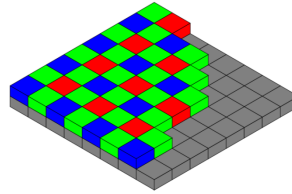
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# Colors

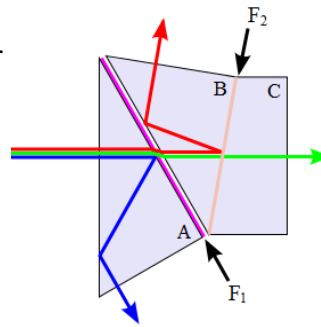
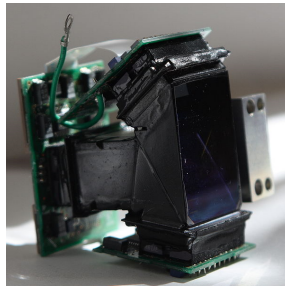
- Separate light by different colors
- Bayer filter

- Single CCD sensor
- Different pixels sense different colors



- 3CCD separates colors

- Tricentric prism assembly
- One CCD sensors per color



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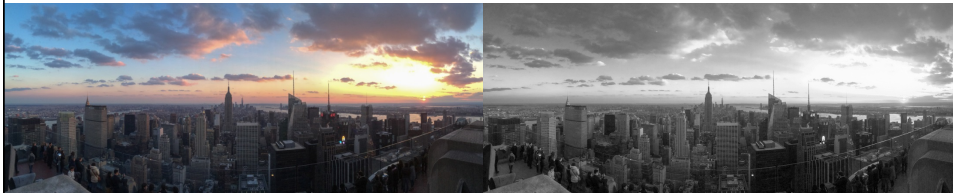
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# RGB Decomposition

- Intensity of red, green, and blue channel:

original

red



green

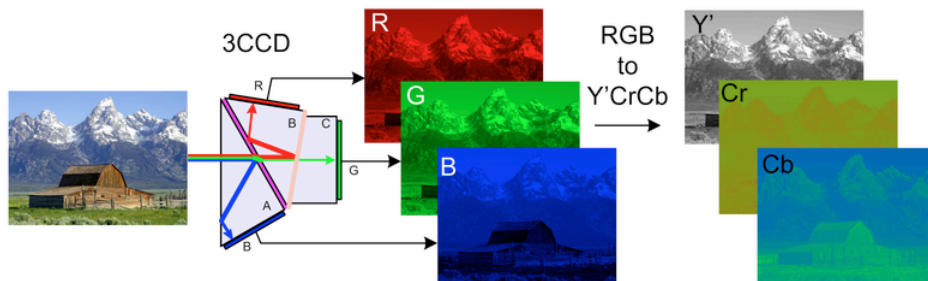
blue

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# Color Spaces

- RGB is not the only color space
  - Example: YCbCr
    - » Luma (Y)
    - » Blue-difference chroma (Cb)
    - » Red-difference chroma (Cr)
  - Linear transformation between spaces



From wikipedia.com

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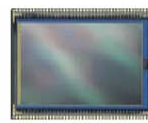
# Image Sensor Uses

- Photographic cameras
  - Scientific application: CCD
    - » CCD uses specialized fabrication process for light capture
  - Consumer cameras: CMOS imager
    - » CMOS imager has charge-to-voltage conversion per pixel
  - Different sensor sizes
- Video cameras
- Astronomic telescope
  - Large arrays of CCDs
- Microscopes
- ...

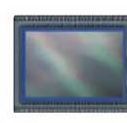
Sensor size - from Canon White Paper; © Canon



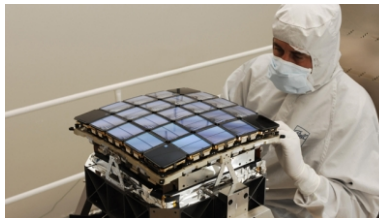
35mm full-frame sensor:  
approx. 36 x 24mm



APS-H size sensor:  
approx. 29 x 19mm



APS-C size sensor:  
approx. 22 x 15mm

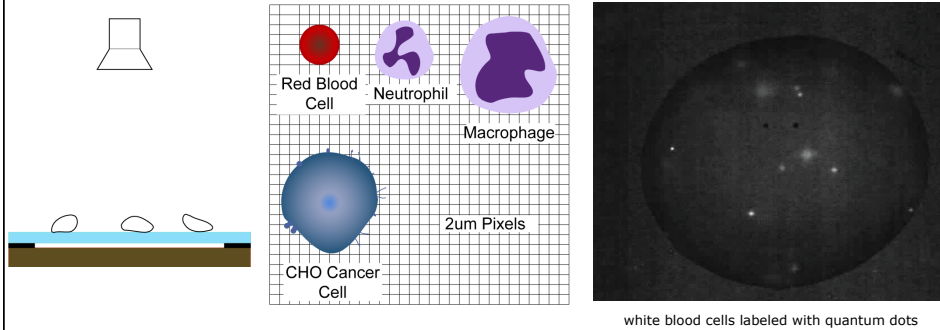


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## Interesting Uses of Image Sensors

- Lensless cellular imaging (Prof. Salthouse, ECE)
  - "Because the pixels of modern imagers are even smaller than cells, blood samples can be analyzed by flowing the sample directly on top of the imager without a microscope."

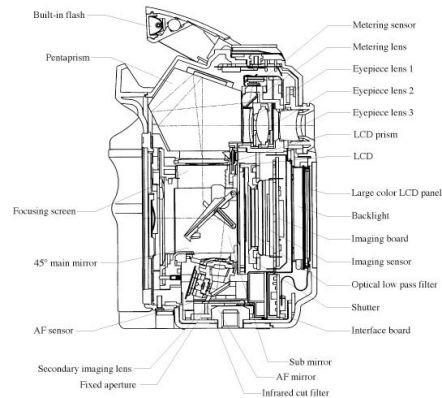
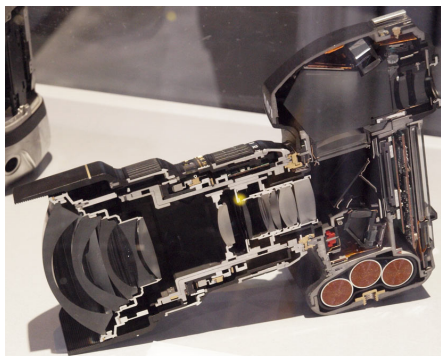


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## Digital Camera

- Camera contains optics and electronics
  - Optics project image onto sensor
  - Electronics read and process sensor information

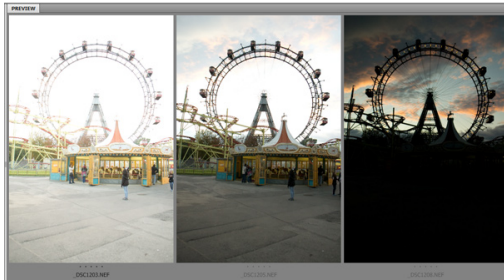


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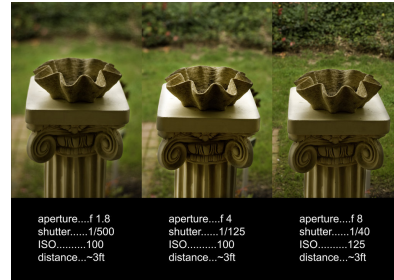
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## Digital Camera Operation

- Camera opens shutter to expose sensor to light
  - Choice: longer or shorter time of open shutter (exposure)
  - Choice: wider or smaller opening of shutter (aperture)
  - Choice: more or less sensitive readout of sensor (ISO)
- Readout: conversion into image file
  - Image file contains light intensity measurements
- Tradeoffs: contrast, depth of field, etc.



From mishes.com



From photographywisdom.com

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## Courses in ECE Curriculum

- ECE 344 – Semiconductor Devices & Materials
- ECE 572 – Optoelectronics
- ECE 597BE – Bioelectronics

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## Upcoming...

- Next week: Internet
  - Network protocols
- Moodle quiz

