Photography - From the Beginning to the 21st Century

- An Introduction to Digital Photography -

Karsten Heeger
heeger@wisc.edu
the world's first photograph.
France in 1826: Joseph Niepce took the world's first photograph. It's a photograph of some farm buildings and the sky. It took an exposure time of ~8 hours.
the world's first photograph.
France in 1826: Joseph Niepce took the world's first photograph. It's a photo of some farm buildings and the sky. It took an exposure time of 8 hours.
FIG. 131.—How Light and a Pinhole Form an Image.
Daguerreotype Camera Example

- produced silver iodide by exposing silver-coated copper plates to iodine
- exposed them to light for several minutes. coated the plate with mercury vapor heated to 75° Celsius, to amalgate the mercury with the silver, finally fixing the image in salt water
The oldest known color photograph was taken by Louis Ducos du Hauron in 1872. The photo is of a view of Angouleme in Southern France.
Jennings, William N.
American (b. England, 1860-1946)

First Photograph of Lightning

ca. 1885
Elements of a Camera: Lens
Elements of a Camera: Aperture & Exposure

large aperture = small f number

small aperture = larger f number

\[
f/ = \frac{f}{\text{diameter}}
\]

**Figure 5.10.**

- I increases by factors of 2
- Less light on film
- BUT: increasing depth of field

- I increases by factors of 2
- Less light on film
- BUT: captures movement better
The Inverse Square Law

THE INVERSE SQUARE LAW
AN OBJECT TWICE THE DISTANCE FROM THE LIGHT SOURCE WILL RECEIVE A QUARTER OF THE AMOUNT OF ILLUMINATION

distance x 2 ⇒ 1/4 illumination

important for flash photography
Reciprocity

Interchange of shutter speed and aperture

– 1/125 at f8 *same exposure as* 1/250th at f5.6

• reciprocity failure in film:
  – color film suffer reciprocity failure when exposed for longer than a few seconds
  – 3 layers of film respond slightly differently light
  – reciprocity failure can also be a problem with b&w film. in this case just make longer exposure

*is not a problem with digital cameras.... but noise can be..*
CCD - Charged Coupled Device

- CCD receives charge via the photoelectric effect
- was invented in 1969 by Willard Boyle and George E. Smith at AT&T Bell Labs.

- CCDs commonly respond to 70% of the incident light (meaning a quantum efficiency of about 70%)
- photographic film captures only about 2% of the incident light

⇒ CCDs were rapidly adopted by astronomers
Recording Light Intensity (Brightness)

- metering cell measures the light coming through the lens -> sets the aperture and shutter speed

- when shutter opens, each pixel on the image sensor records the brightness of the light that falls on it by accumulating an electrical charge.

- the more light that hits a pixel, the higher the charge it records.

- pixels on an image sensor can only capture brightness, not color.
- record only the gray scale-a series of 256 increasingly darker tones ranging from pure white to pure black.
Pixels and Resolution of Cameras

number of pixels and the maximum resolution don't quite compute!

**Example:**
A 2.1-megapixel camera can produce images with a resolution of 1600x1200, or 1,920,000 pixels.

2.1 megapixel = 2,100,000 pixels ⇒ why do we only get 1,920,000 pixels?

CCD includes circuitry for the ADC to measure the charge. This circuitry is dyed black so that it doesn't absorb light and distort the image.
Spectral Sensitivity of Human Eyes and CCDs

The human visual system can detect the range of light spectrum from about 400 nanometers (violet) to about 700 nanometers (red).
Infrared Sensitivity of CCDs

• **CCDs are typically sensitive to infrared light**, which allows infrared photography, night-vision devices, and zero lux (or near zero lux) video-recording/photography.

• Because of their sensitivity to infrared, CCDs used in astronomy are usually cooled to liquid nitrogen temperatures, because infrared black body radiation is emitted from room-temperature sources.
Infrared Sensitivity of CCDs
Color Photographs

1860s: James Clerk Maxwell's discovered that color photographs could be created using black and white film and red, blue, and green filters.

- Thomas Sutton photographed a tartan ribbon three times, each time with a different color filter over the lens.
- three black and white images were then projected onto a screen with three different projectors, each equipped with the same color filter used to take the image being projected.
- when brought into register, the three images formed a full color photograph.

http://static.howstuffworks.com/flash/digital-camera-colors.swf
Color Pixels in Digital Cameras

• digital color cameras generally use a Bayer mask over the CCD.

• each square of four pixels has one filtered red, one blue, and two green.

• the human eye is more sensitive to green than either red or blue.

• colored filters cover each photosite on the image sensor.

• lenses on top of each pixel are used to collect light and make the sensor more sensitive.

• luminance information is collected at every pixel.

• color resolution is lower than the luminance resolution.

Bayer mask over CCD in digital camera

Figure from Fuji corp.
Natural Color from Interpolation

• with filters in place, each pixel can record only the brightness of the light that matches its filter

• other colors are blocked.

• use “interpolation” between colors of neighboring pixels to calculate the two colors that the pixel didn't record directly.

• combining interpolated colors with the color measured by the site directly, the full color of the pixel can be calculated.

*example:* painter creating a color by mixing varying amounts of other colors on his palette.
Demosaicing Algorithms

raw color pixels of CCD

http://static.howstuffworks.com/flash/digital-camera-demosaicing.swf
Digital Image Pixels

A Feature of Digital Photography

true (natural) color pixels after processing in camera
3CCD Cameras

• better color separation can be reached by three-CCD devices (3CCD) and a beam splitter prism,
• splits the image into red, green and blue components.
• each of the three CCDs is arranged to respond to a particular color.
Grainy Photographs .... Noise in Digital Cameras

- High-sensitivity films produce grainy pictures because of grain size of emulsion
- Long exposures on digital cameras can produce visible noise, which looks a bit like the grain you see in a fast film image.
- Sensor has trouble reading the scene properly and pixels of random color are thrown into the picture.

Grain most obvious in parts of the picture which are fairly plain, such as the sky or the roof line. Effect even more obvious in pictures taken in lower light levels.
Bits (binary digit) and Bytes

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbr.</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilo</td>
<td>K</td>
<td>$2^{10} = 1,024$</td>
</tr>
<tr>
<td>Mega</td>
<td>M</td>
<td>$2^{20} = 1,048,576$</td>
</tr>
<tr>
<td>Giga</td>
<td>G</td>
<td>$2^{30} = 1,073,741,824$</td>
</tr>
<tr>
<td>Tera</td>
<td>T</td>
<td>$2^{40} = 1,099,511,627,776$</td>
</tr>
<tr>
<td>Peta</td>
<td>P</td>
<td>$2^{50} = 1,125,899,906,842,624$</td>
</tr>
<tr>
<td>Exa</td>
<td>E</td>
<td>$2^{60} = 1,152,921,504,606,846,976$</td>
</tr>
<tr>
<td>Zetta</td>
<td>Z</td>
<td>$2^{70} = 1,180,591,620,717,411,303,424$</td>
</tr>
<tr>
<td>Yotta</td>
<td>Y</td>
<td>$2^{80} = 1,208,925,819,614,629,174,706,176$</td>
</tr>
</tbody>
</table>

0 = 0
1 = 1
2 = 10
3 = 11
4 = 100
5 = 101
6 = 110
7 = 111
8 = 1000
9 = 1001
10 = 1010
11 = 1011
12 = 1100
13 = 1101
14 = 1110
15 = 1111
16 = 10000
17 = 10001
18 = 10010
19 = 10011
Storing Binary Data on CDs and DVDs

![Diagram of CD and DVD structure]

- **CD**:
  - 1.6 μm spacing
  - 0.83 μm minimum

- **DVD**:
  - 0.74 μm spacing
  - 0.40 μm minimum

---

**Legend**:
- Label
- Lacquer
- Aluminum
- Polycarbonate plastic
- Gold or silicon
- UV cure plastic
- Aluminum
- Glue
- Polycarbonate plastic

---

Karsten Heeger

Physics in the Arts - 109, Spring 2007
The Digital Image Process

1. **CCD produces charge** from light

2. CCD transports the charge across the chip and reads it at one corner of the array.

3. The analog to digital converter (ADC) measures the charge at each photosite and creates a digital signal (binary form) that represents the values of the charge at each pixel.

4. A processor interpolates the data from the different pixels to create natural color. On many cameras, it is possible to see the output on the LCD at this stage.

5. **Image is stored in binary form** on memory card or disk.
Photograph as a Document

- **Questions to Ask About a Documentary Photographs:**
  - Who took the photograph?
  - Why and for whom was the photograph taken?
  - How was the photograph taken?
  - What can companion photographs tell us?

- **Documentary Photographs**
  - World view
  - A social conscience
  - Social Record
  - A scientific record, etc.
The Age of Digital Image Alterations...
• Photographs as a document...

Digital imaging as a tool ....
  - science
  - art
  - fun
  - etc.
References

http://www.usa.canon.com

http://www.geofflawrence.com/

http://www.howstuffworks.com


“How things work”, L. Bloomfield