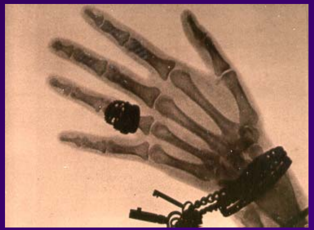
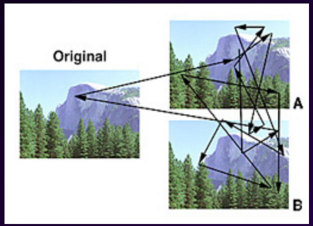
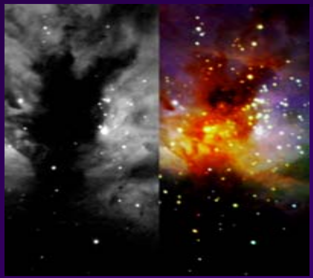
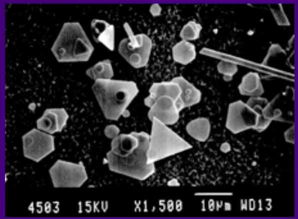


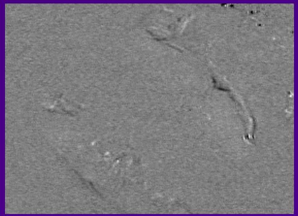











Imaging Science

and

The World Digital Imaging

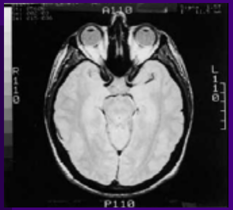
Emmett Ientilucci

Research Scientist

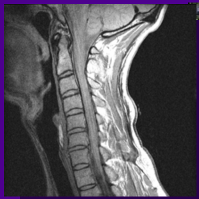
Chester F. Carlson Center for Imaging Science

emmett@cis.rit.edu

475-7778







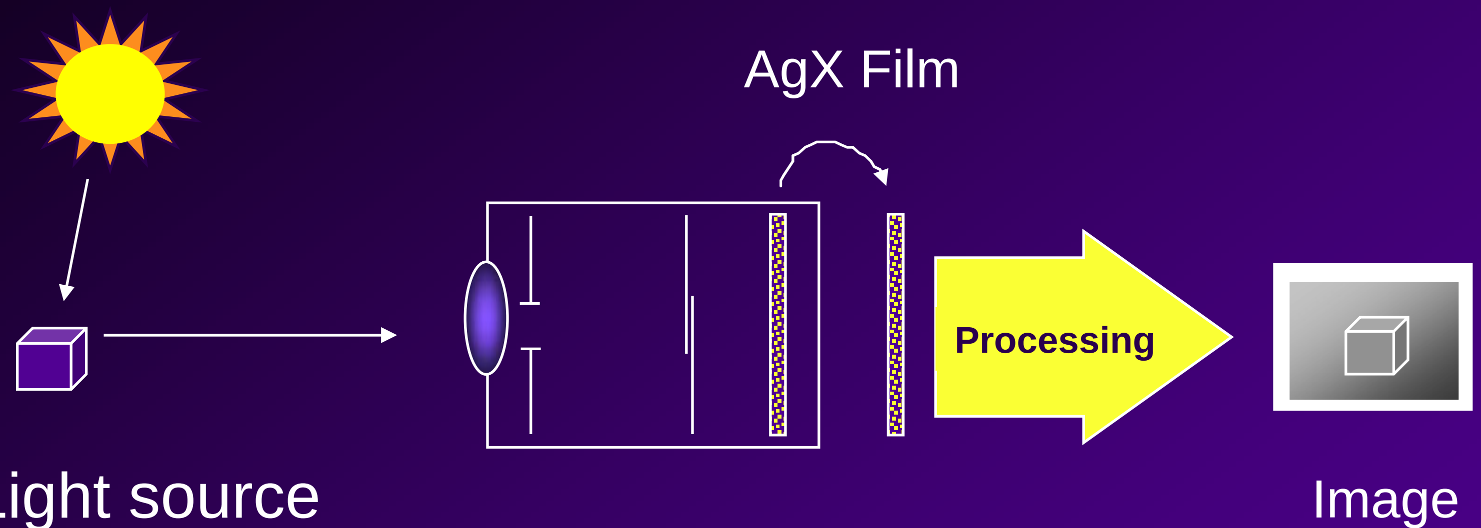

Overview

- Digital v.s. Traditional Photography
- Digital Imaging Fundamentals
    - Detector Type
    - Sampling / Quantization / Bits / Bytes
    - Color Resolution or “Color Depth”
    - Spatial Resolution
    - Color Images
    - File Size and Storage
- Applications in Imaging Science
    - Digital Imaging Processing (DIP)

Digital v.s.Traditional Photography

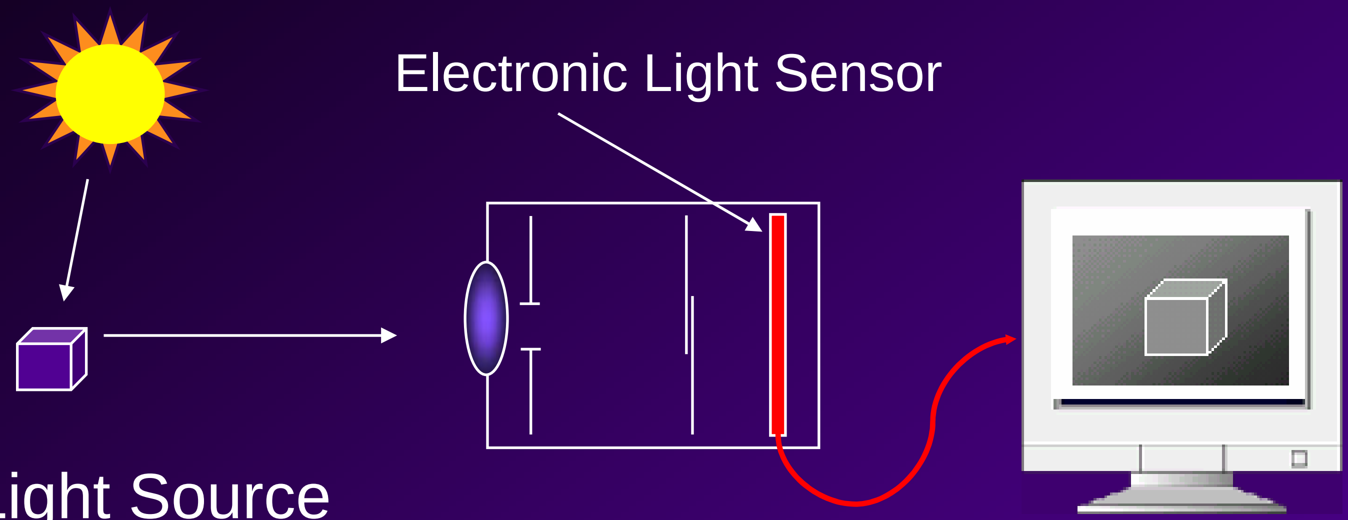
- Digital imaging relies on many of the same principles as traditional film-based photography
    - Light source
    - Object
    - Lens
    - Aperture
    - Shutter
    - “Detector”
    - “Processing”

Digital v.s.Traditional Photography



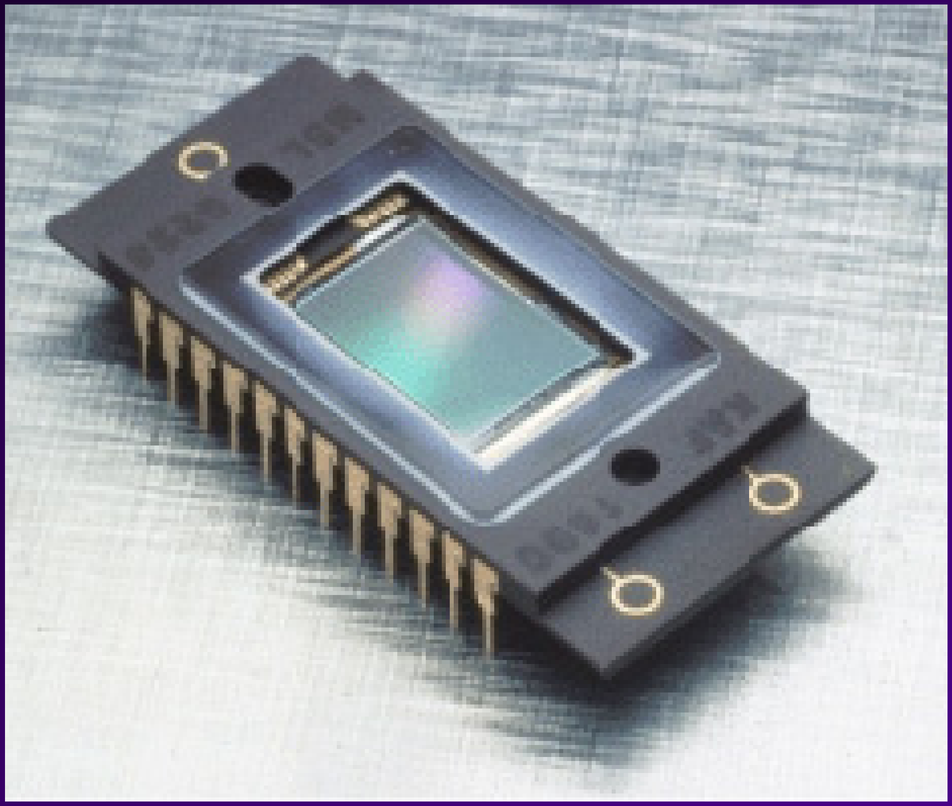
- Light source
- Object
- Lens
- Aperture
- Shutter
- Detector = Silver-Halide Film
- Processing = Wet Chemistry

Digital v.s.Traditional Photography



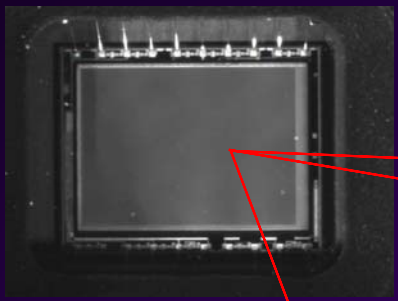
- Light Source
- Object
- Lens
- Aperture
- Shutter
- Detector = Charge Coupled Device (CCD)
- Processing = Digital Image Processing (DIP)

Charge Coupled Device (CCD)



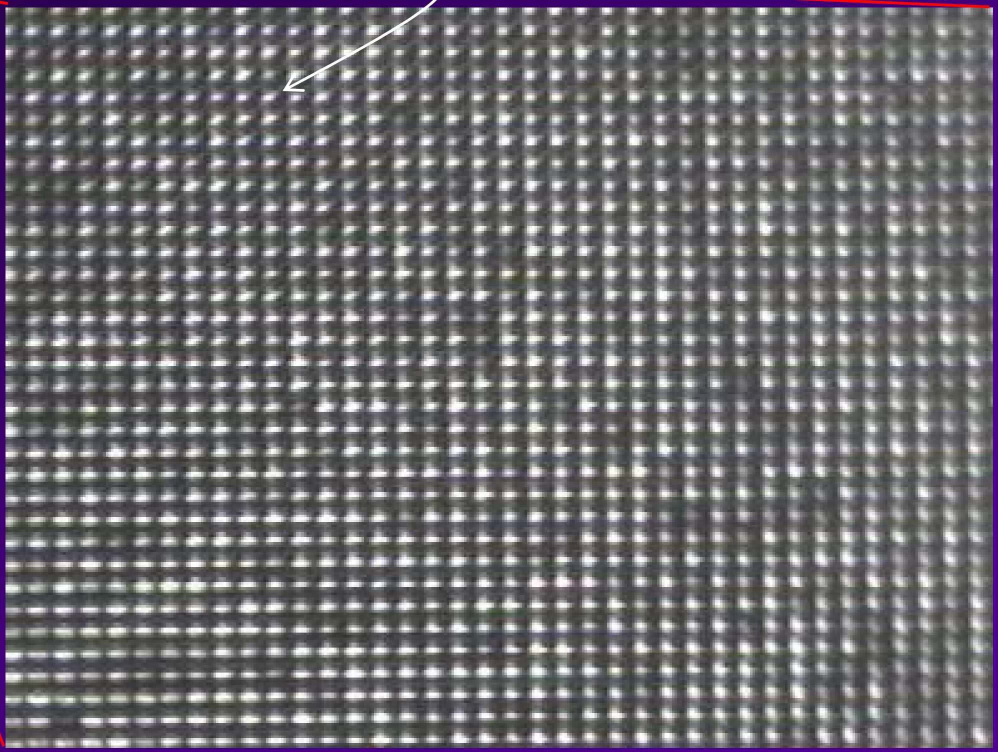
- CCD chip replaces silver halide film
- No wet chemistry processing
- Image available for immediate feedback

Magnified View of a CCD Array



CCD

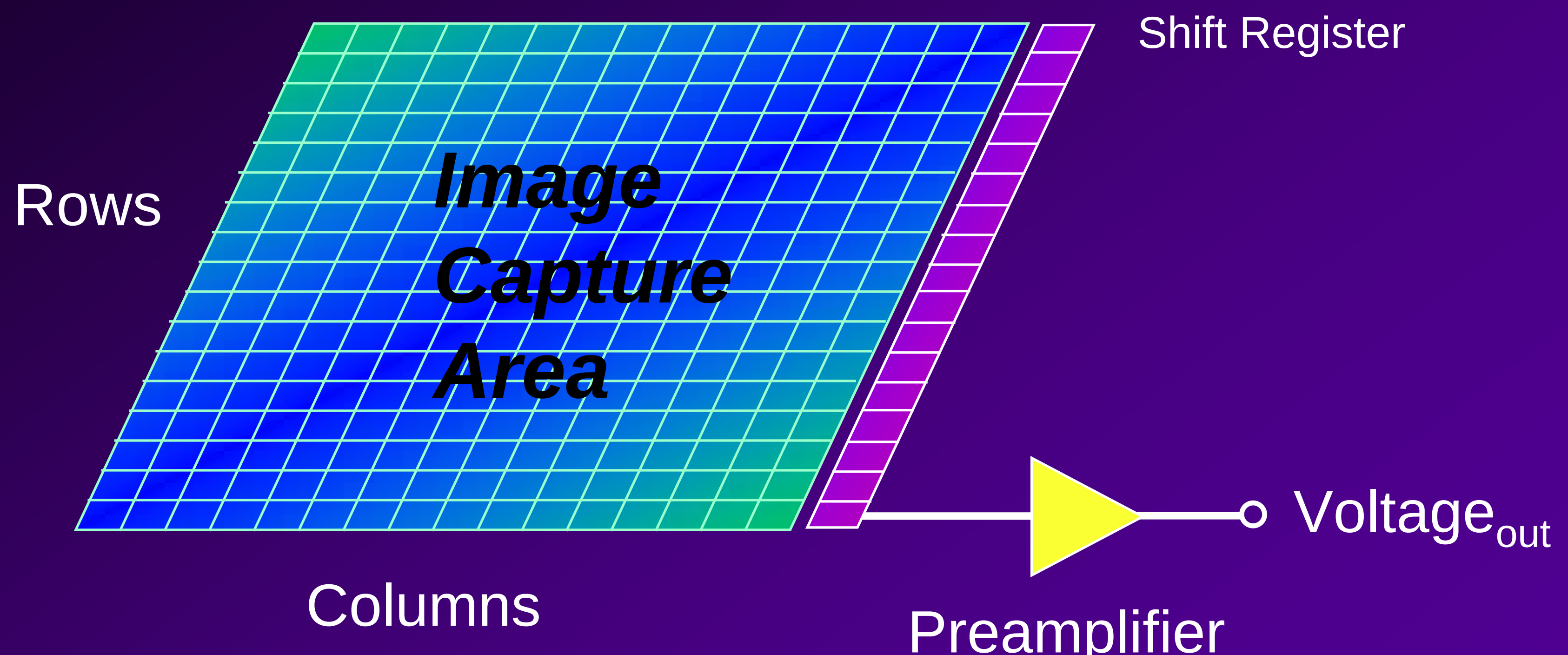
Individual picture element



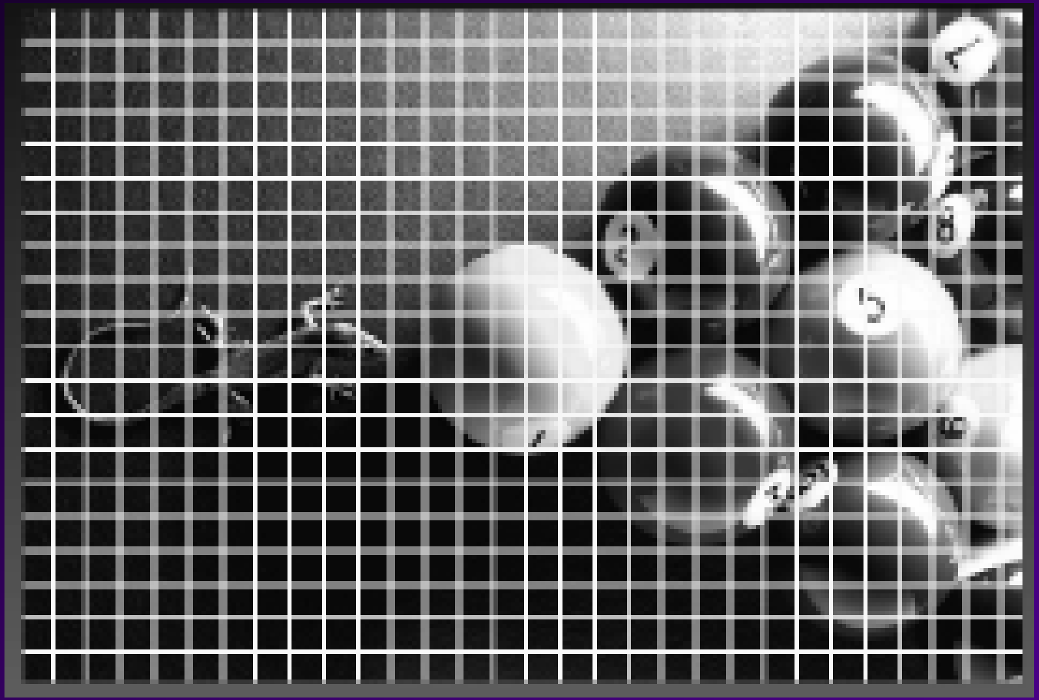
Close-up of a CCD Imaging Array

Basic structure of CCD

Divided into small elements called pixels (*picture elements*).

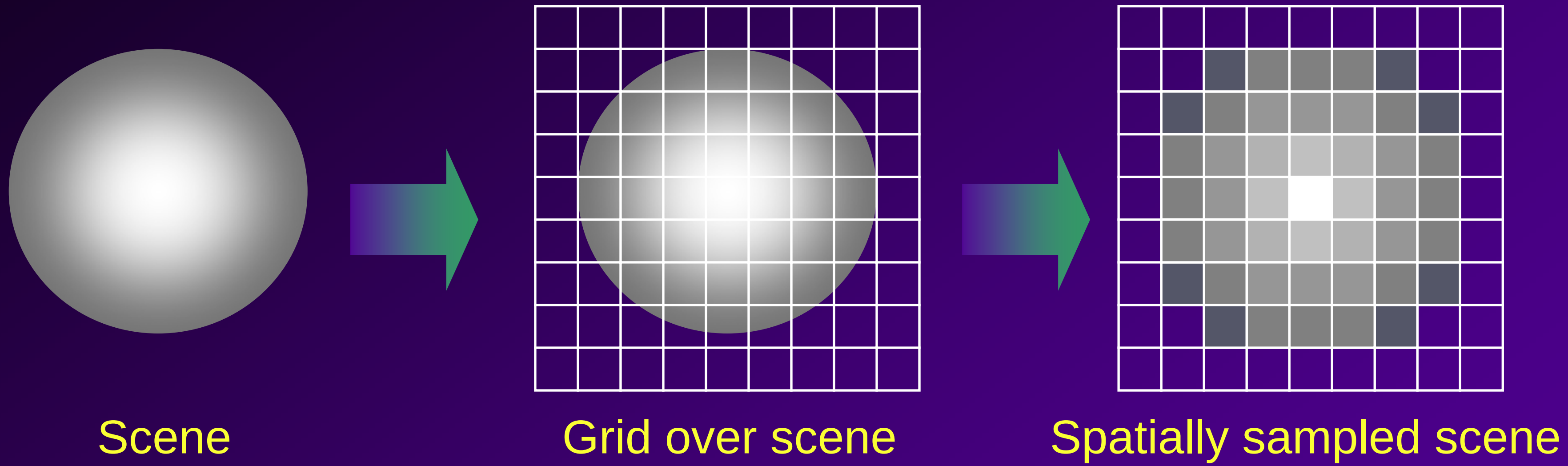


Overview of Digital Capture Process



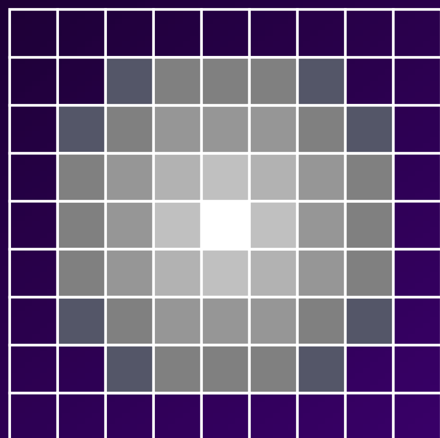
- Lens projects image onto the CCD
- CCD '*samples*' the image, creating different voltages based on the amount of light at each pixel
- Voltages are converted to digital count (DC) and stored

Spatial Sampling



- When a continuous scene is imaged on the array (grid) formed by a CCD , the continuous image is divided into discrete elements.
- The picture elements (*pixels*) thus captured represent a spatially sampled version of the image.

Quantization



Spatially sampled scene

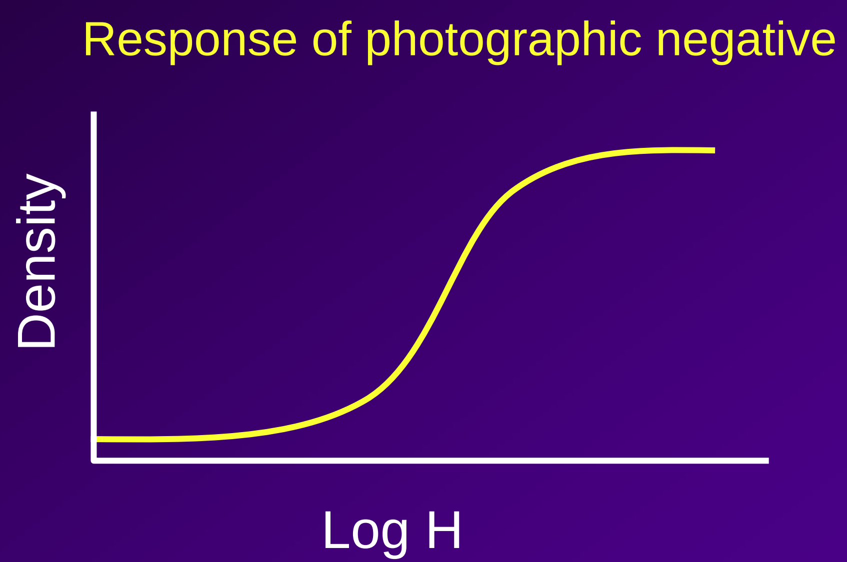
0	0	0	0	0	0	0	0	0
0	0	25	40	40	40	25	0	0
0	25	40	64	64	64	40	25	0
0	40	64	97	97	97	64	40	0
0	40	64	97	150	97	64	40	0
0	40	64	97	97	97	64	40	0
0	25	40	64	64	64	40	25	0
0	0	25	40	40	40	25	0	0
0	0	0	0	0	0	0	0	0

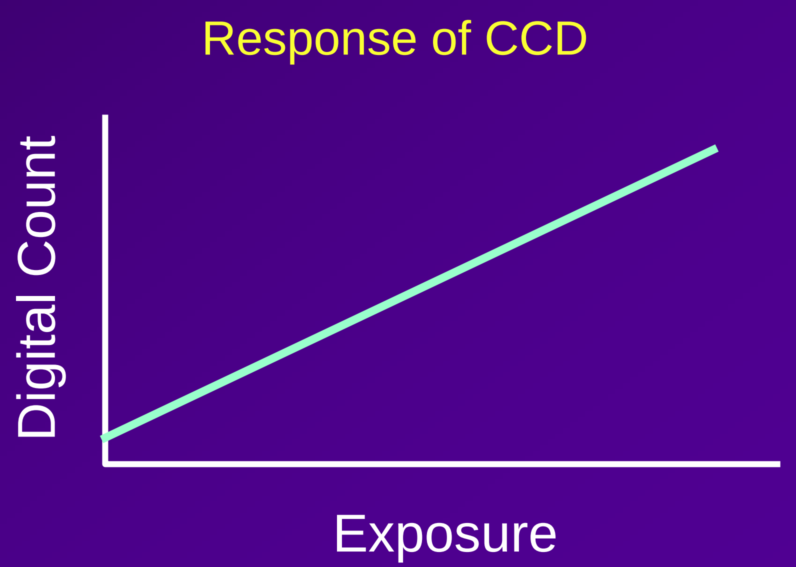
Numerical representation

- Spatially sampled image can now be turned into numbers or digital counts (DC) according to the brightness of each pixel.

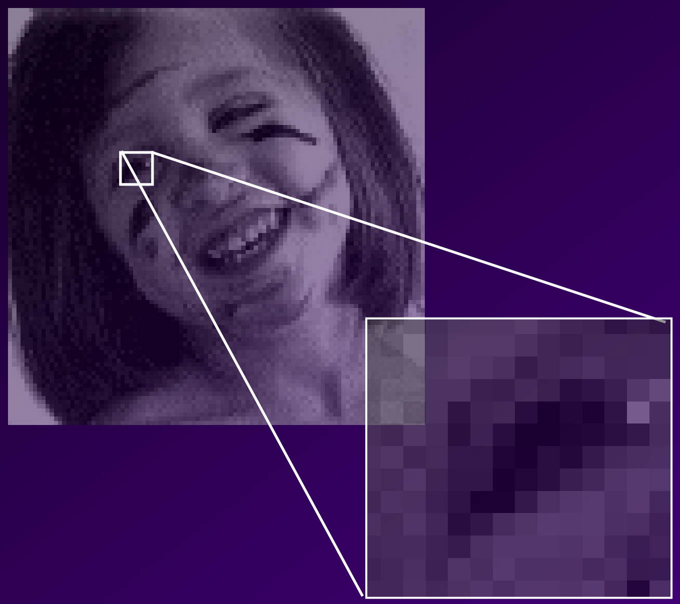
Response of CCD

- The response of a CCD is ***linear*** (*i.e.*, if 1000 captured photons corresponds to a digital count of ***4***, then 2000 photons captured yields a digital count of ***8***)
- Linearity is critical for scientific uses of CCD





So What is a Digital Image?



50	44	23	31	38	52	75	52
29	09	15	08	38	98	53	52
08	07	12	15	24	30	51	52
10	31	14	38	32	36	53	67
14	33	38	45	53	70	69	40
36	44	58	63	47	53	35	26
68	76	74	76	55	47	38	35
69	68	63	74	50	42	35	32

- Just an array of numbers!

Image Quality Factors

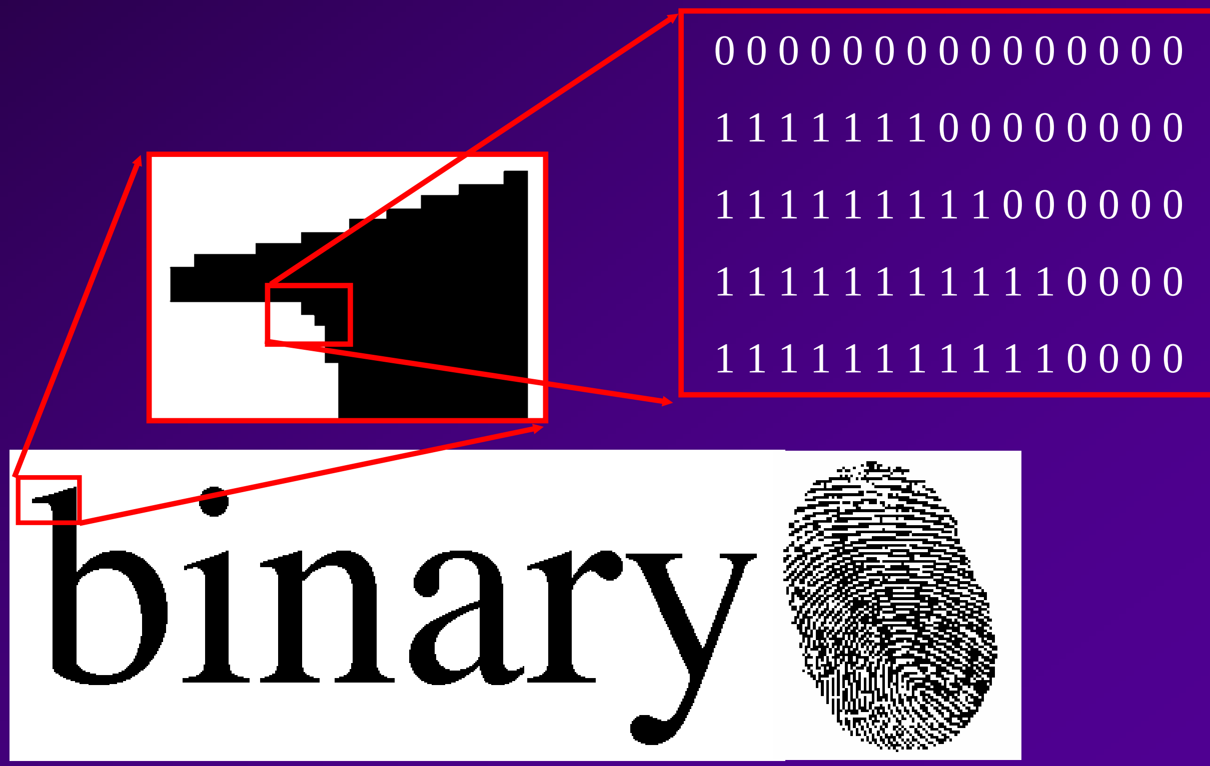
- Two major factors which determine image quality are:
  - *Color depth --* Controlled by the number of colors or grey levels allocated for each pixel
  - *Spatial resolution --* Controlled by spatial sampling
- Increasing either of these factors results in a larger image file size, which requires more storage space and more processing/display time.

Binary Images

- The simplest kind of digital image is known as a “binary image” because the image contains only two ‘colors’ - white and black. Therefore, we can encode the image using just two numbers

0 = black

1 = white



Color Resolution (Bit Depth)

- The smallest unit of measurement in a computer is the binary digit or 'bit' - 0 or 1
- *1 bit* is the amount of storage needed to store *1 pixel* of a binary image because each pixel can only be black or white.

Color Resolution (Bit Depth)

- If we want an image that has more than two gray levels, we have to increase the number of *'bits per pixel'*

Binary: two shades of gray (black and white)

Grayscale: many shades of gray

Color Resolution (Bit Depth)

$\frac{\text{1 bit}}{\text{pixel}}$

0

1

2 “states” or gray levels

$\frac{\text{2 bits}}{\text{pixel}}$

0 0

1 0

0 1

1 1

4 gray levels

Color Resolution (Bit Depth)

3 bits/pixel: 8 gray levels

000
↓
111

4 bits/pixel: 16 gray levels

0000
↓
1111

Color Resolution (Bit Depth)

5 bits/pixel: 32 gray levels

00000

↓

11111

8 bits/pixel: 256 gray levels

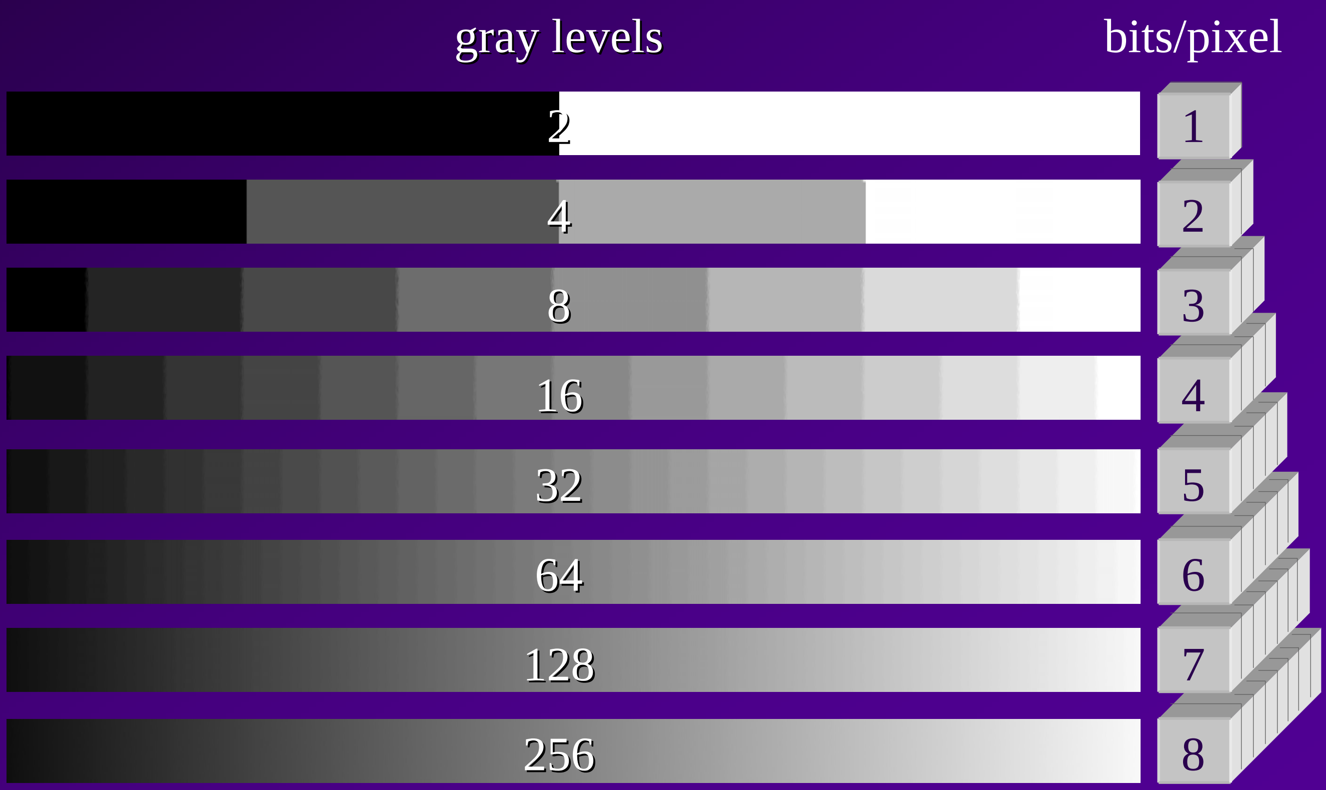
00000000

↓

11111111

Color Resolution (Bit Depth)

- The number of possible gray levels is controlled by the number of bits/pixel, or the *'bit depth'* of the image



$GL = 2^{bit/pix}$

e.g.
$2^8 = 256$ levels

Computer Memory & Storage

- Because of the internal design of early computers, 8 bits were grouped together and called a ‘byte’

$$\boxed{8 \text{ bits} \equiv 1 \text{ byte}}$$

- An image with 1 byte per pixel (common for grayscale images) can have one of 256 different gray levels at each pixel location

Computer Memory & Storage

- 1 bit ('binary digit')
- 1 byte = 8 bits
- 1 kilobyte (KB) = 1,024 bytes

  ($2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 2^{10} = 1024$)
- 1 megabyte (MB) = 1,048,576 bytes (2^{20})
- 1 gigabyte (GB) = 1,073,741,824 bytes (2^{30})

Image Resolution

- The quality of a digital image depends on many factors in addition to the number of gray levels you can show at each pixel. Most important is the level of detail the digital system can record and display.

- The number of pixels in each image is the simplest measure of this '*spatial or image resolution*'

Image Resolution: 4 x 3 Pixels

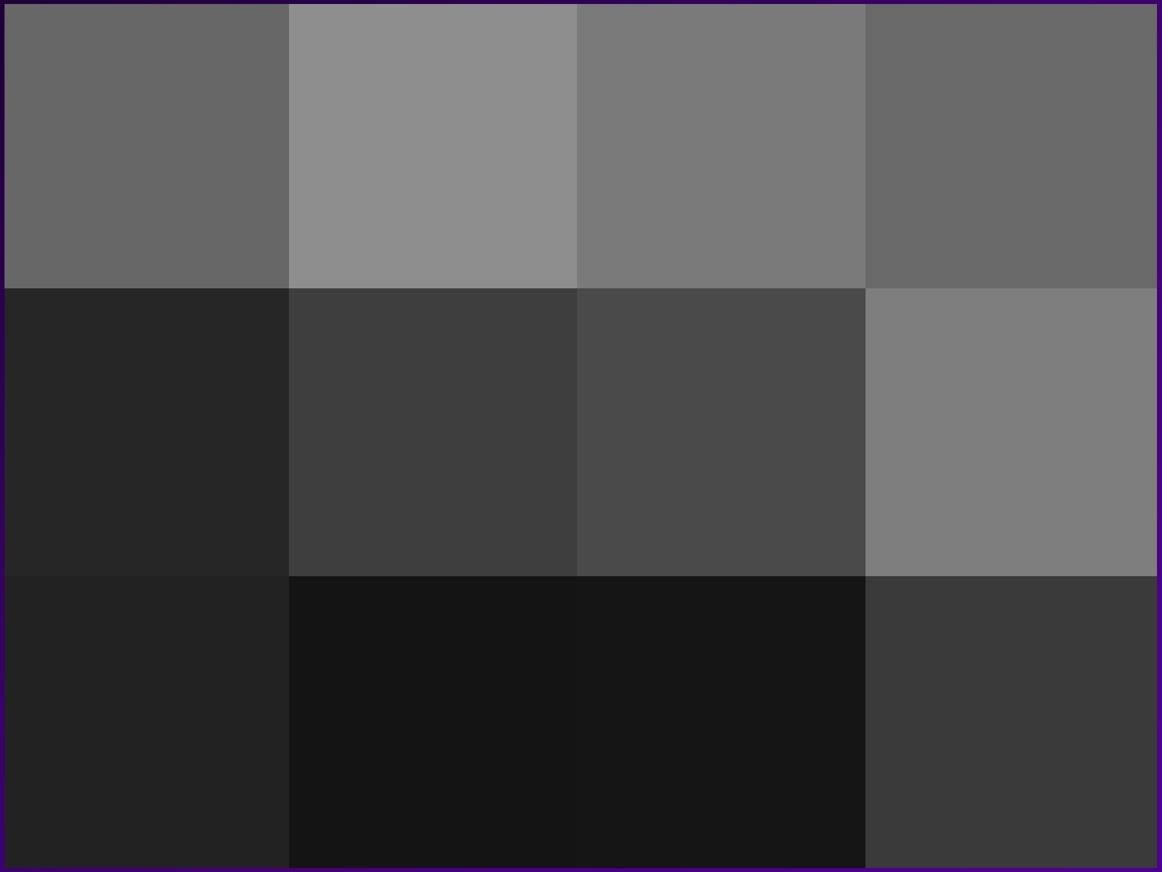


Image Resolution: 8 x 6 Pixels

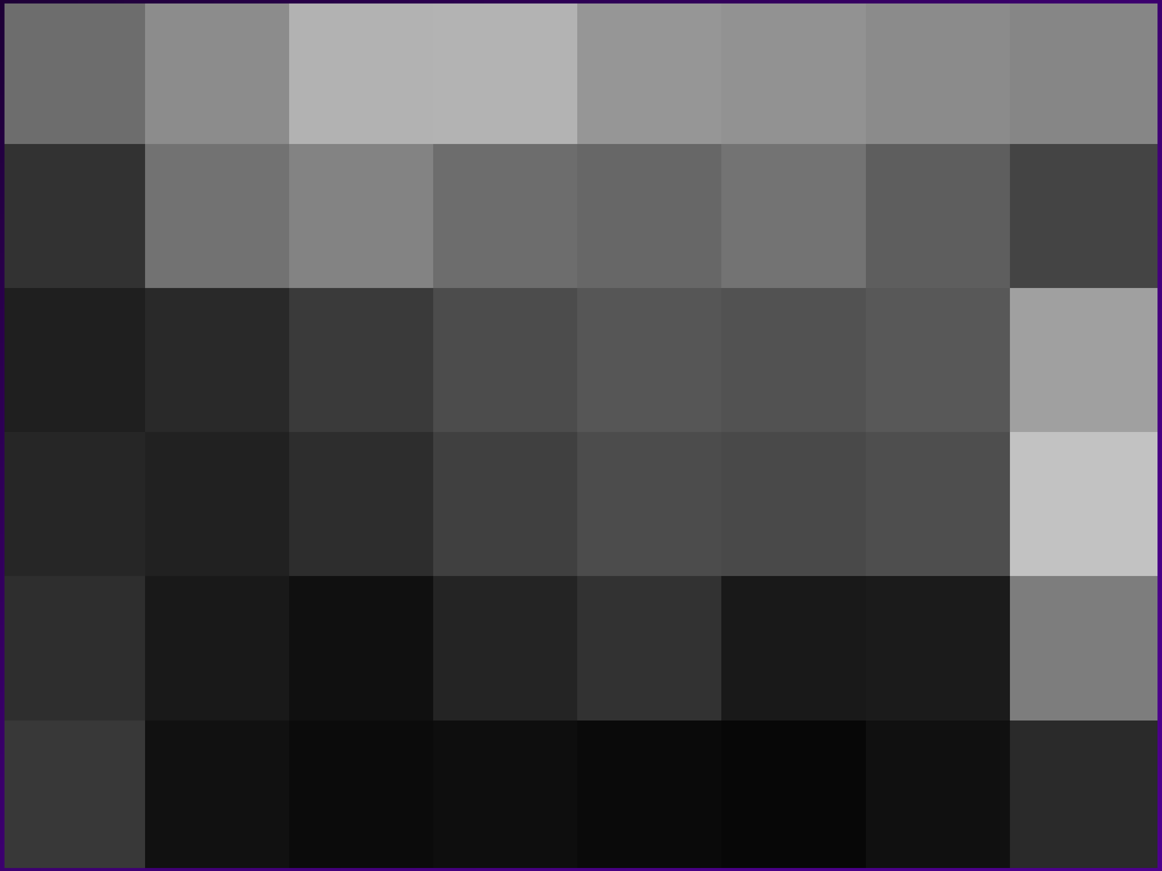


Image Resolution: 16 x 12 Pixels

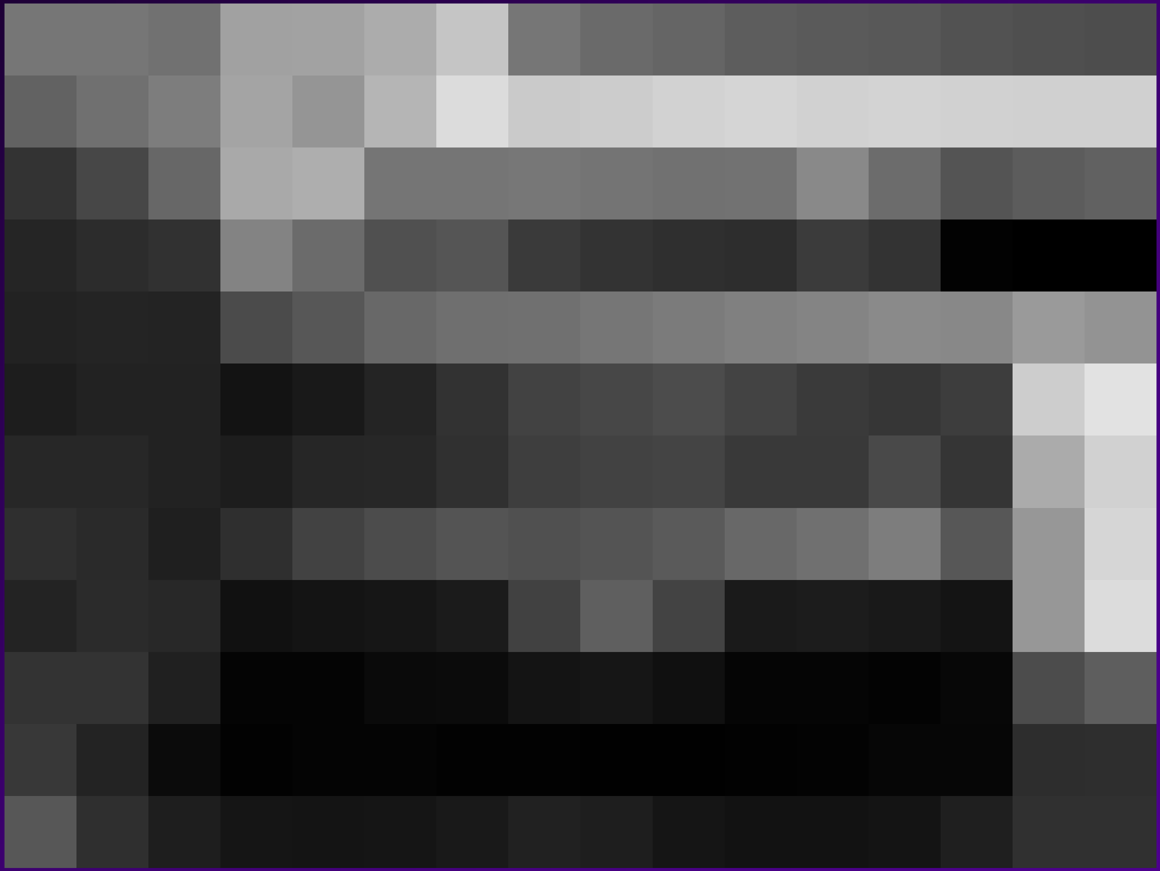


Image Resolution: 32 x 24 Pixels

Image Resolution: 64 x 48 Pixels

Image Resolution: 128 x 96 Pixels

Image Resolution: 160 x 120 Pixels

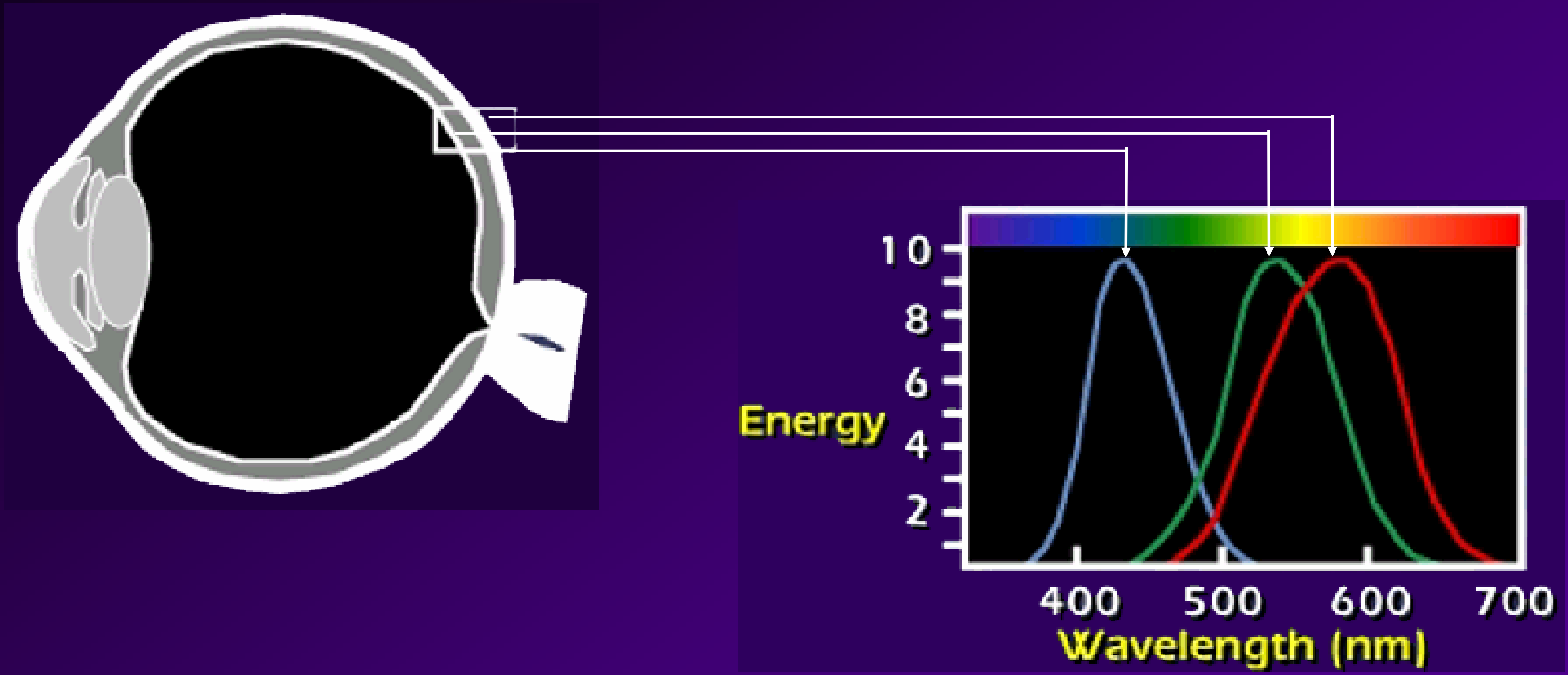
Image Resolution: 320 x 240 Pixels

Image Resolution: 640 x 480 Pixels

Color Images

- In most cases, we also want to capture color information
- The way that we capture, store, view, and print color digital images is based on the way that humans perceive color

Color Perception



- The eyes have three different kinds of color receptors ('cones'); one type each for blue, green, and red light.
- Color perception is based on how much light is detected by each of the three 'primary' cone types (red, green, and blue)

RGB Color Images

- The most straightforward way to capture a color image is to capture three images; one to record how much red is at each point, another for the green, and a third for the blue.

- Each one of the color images ('planes') is like a grayscale image, but is displayed in R, G, or B

RGB Color Images

- To capture a color image we record how much red, green, and blue light there is at each pixel.
- To view the image, we use a display (monitor or print) to reproduce the color mixture we captured.

Q) How many different colors can a display produce?

A) It depends on how many bits per pixel we have.

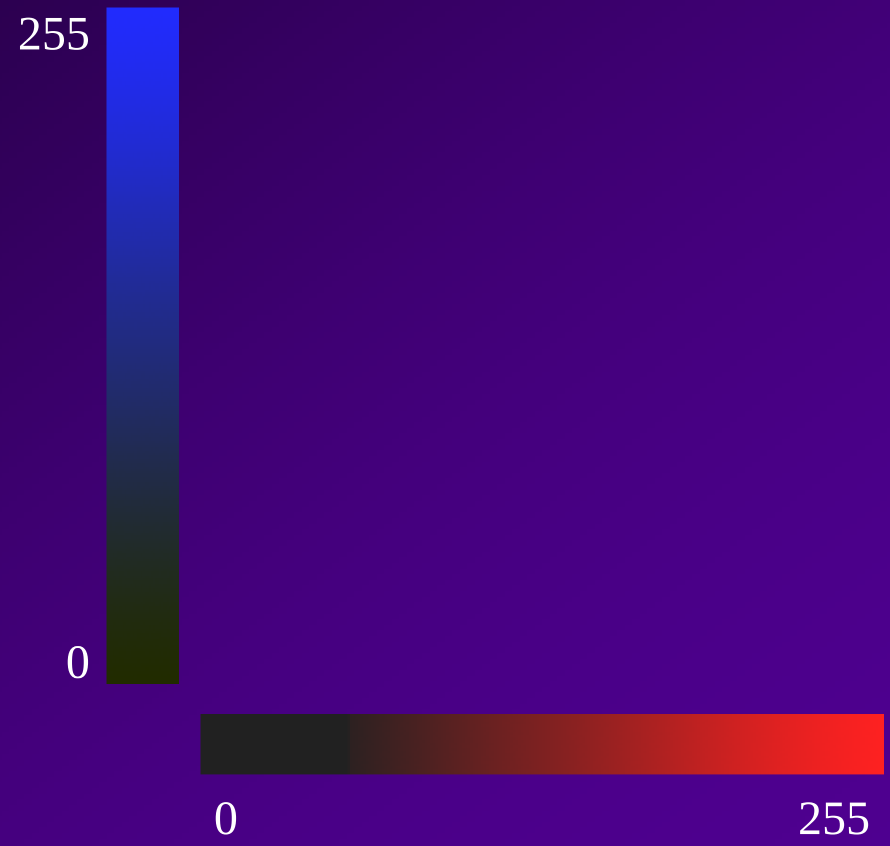
For a system with 8 bits/pixel in each of the red, green, and blue (a ‘24-bit image’)......

RGB Color Images: 24-bit color

- Every pixel in each of the three 8-bit color planes can have 256 different values (0-255)
- If we start with just the blue image plane, we can make 256 different "colors of blue"

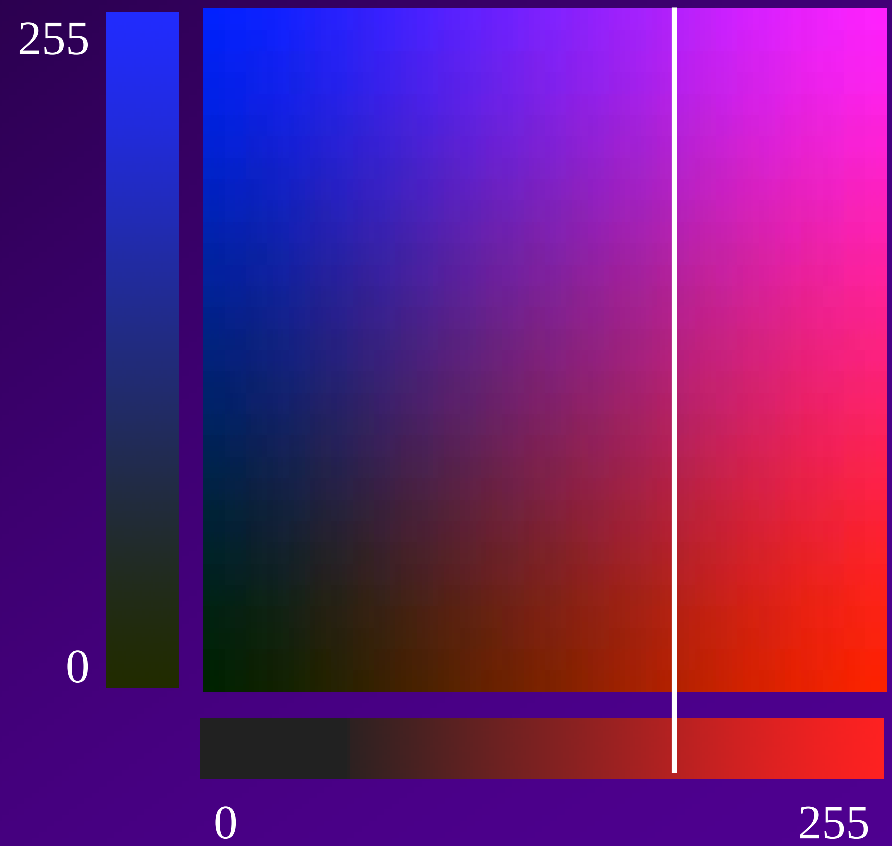
RGB Color Images: 24-bit color

- Every pixel in each of the three 8-bit color planes can have 256 different values (0-255)
- If we start with just the blue image plane, we can make 256 different “colors of blue”
- If we add red (which alone gives us 256 different reds):



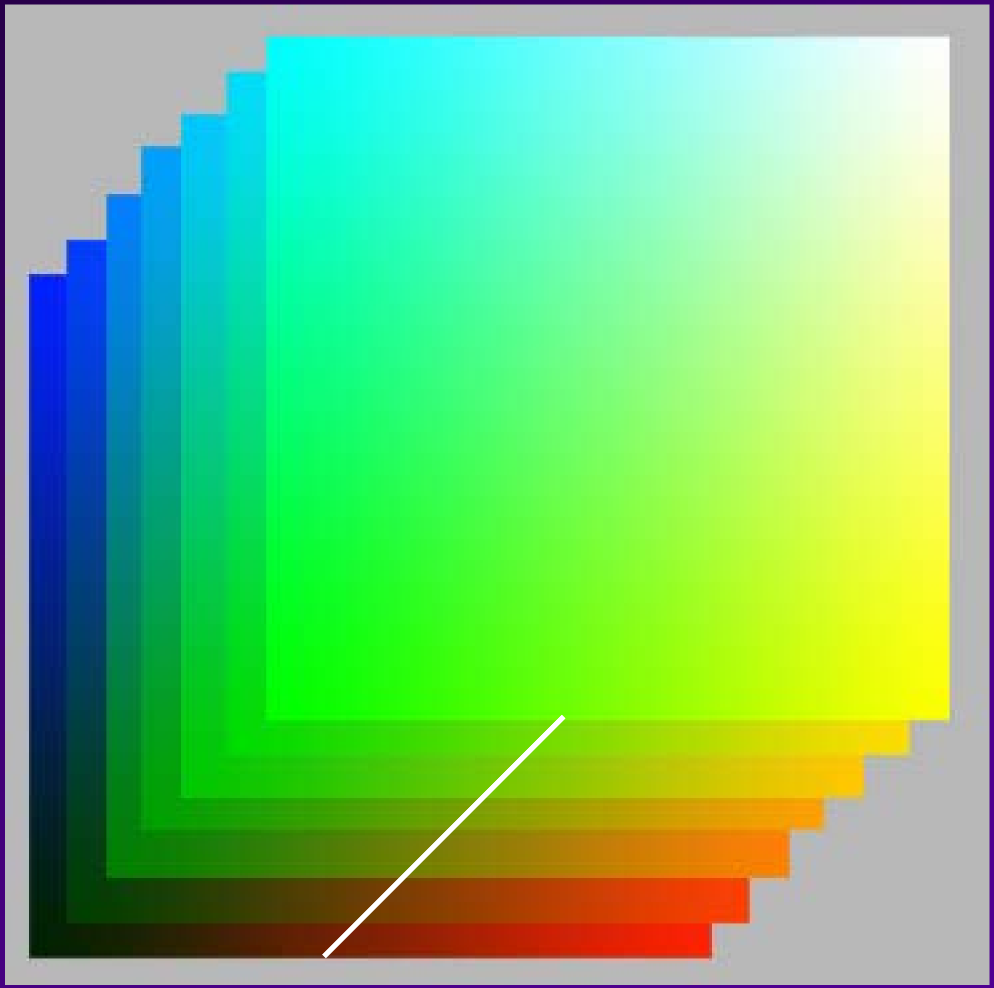
RGB Color Images: 24-bit color

- Every pixel in each of the three 8-bit color planes can have 256 different values (0-255)
- If we start with just the blue image plane, we can make 256 different "colors of blue"
- If we add red (which alone gives us 256 different reds):
- We can make 256 x 256 = 65,536 combination colors because for every one of the 256 reds, we can have 256 blues.



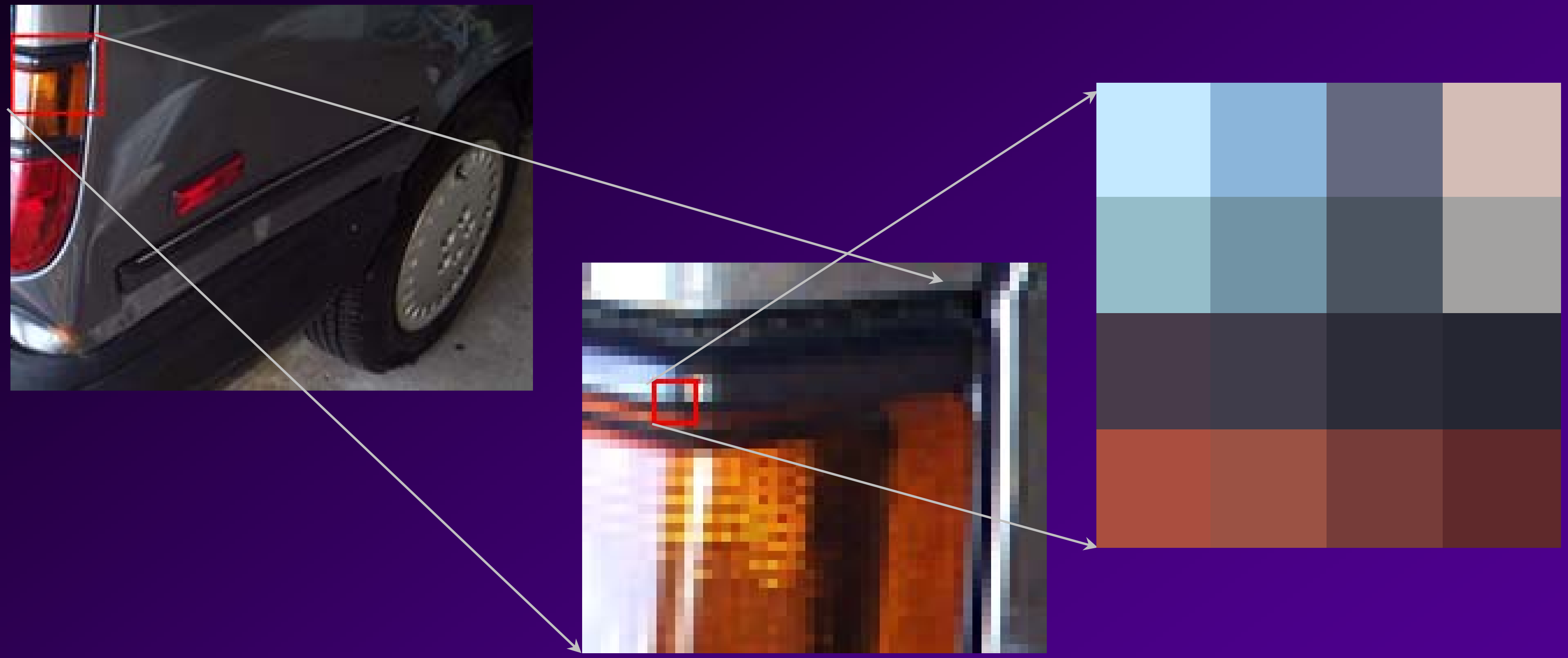
RGB Color Images: 24-bit color

- When we have all three colors together, there are 256 possible values of green <u>for each one</u> of the 65,536 combinations of red and blue:



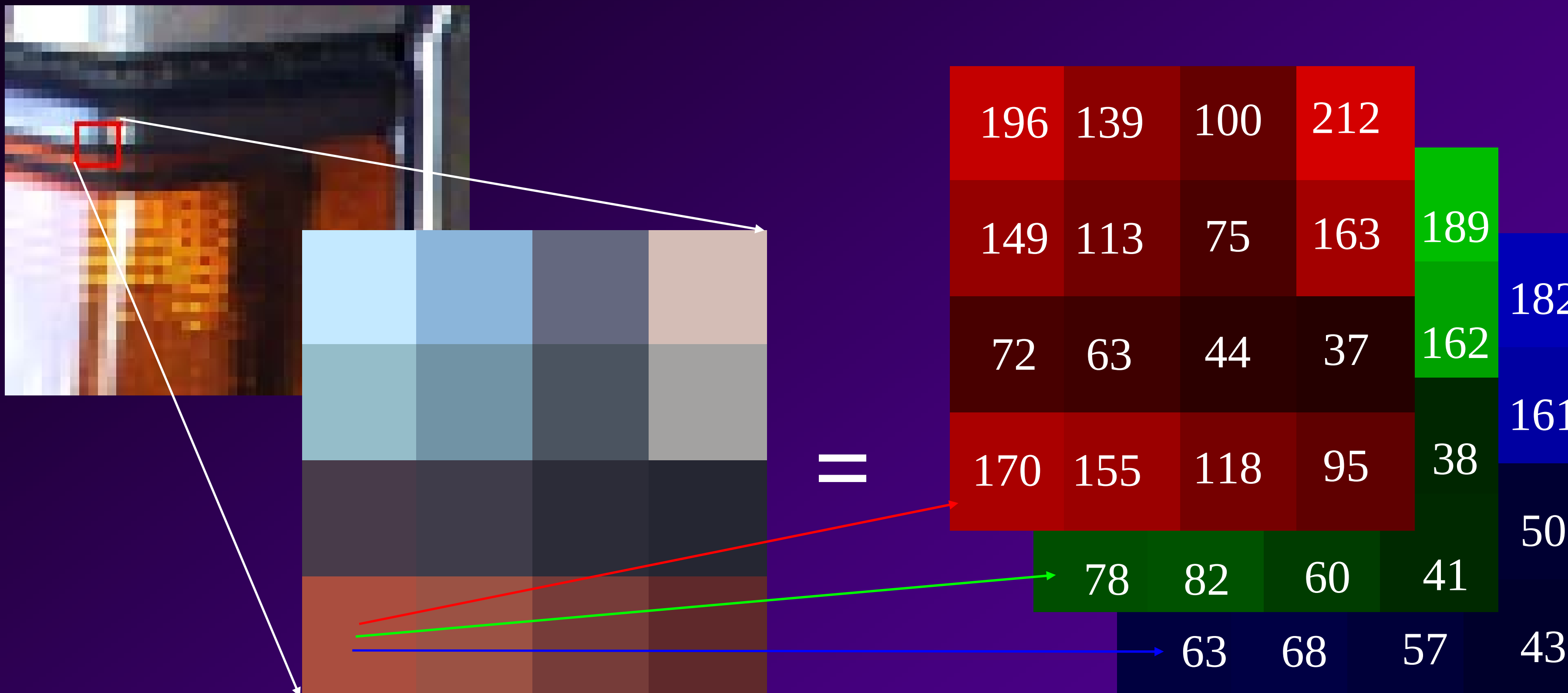
- 256 x 256 x 256 = 16,777,216 (> 16.7 million colors)

RGB Color Images: 24-bit color



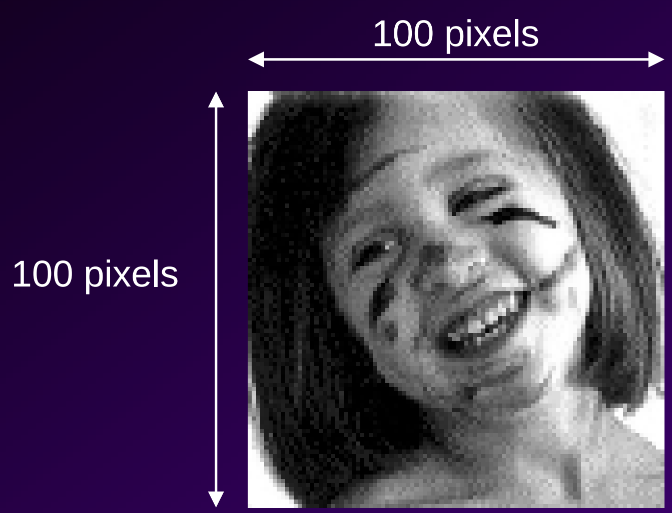
- The numbers stored for each pixel in a color image contain the color of that pixel

Color Image = Red + Green + Blue



- In a 24-bit image, each pixel has R, G, & B values
- When viewed on a color display, the three images are combined to make the color image.

File Size Calculation



Bit depth = 8 bits per pixel (256 gray levels)

- How much memory is necessary to store an image that is 100 x 100 pixels with 8 bits/pixel?

$$\boxed{\text{File size (in bits)} = \text{Height} \times \text{Width} \times \text{Bit Depth}}$$

100 x 100 x 8 bits/pixel = 80,000 bits/image

80,000 bits = 10,000 bytes = 9.8 KB

File Size Calculation

1280 pixels

960 pixels

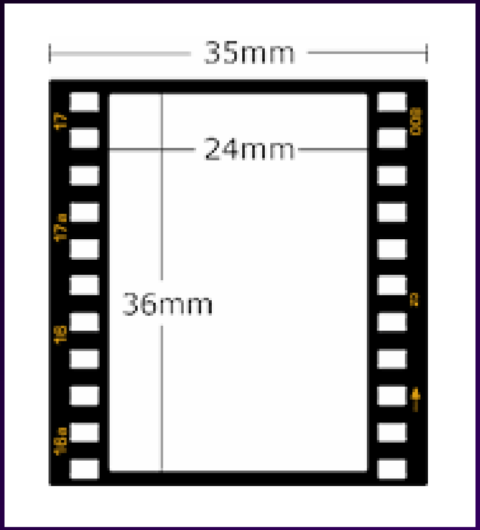
Bit depth = 24 bits per pixel (RGB color)

- How much memory is necessary to store an image that is 1280 x 960 pixels with 24 bits/pixel?

960 x 1280 x 24 bits/pixel = 29,491,200 bits/image

29,491,200 bits = 3,686,400 bytes = 3.5 MB

Bytes needed to Capture 35mm Format



- The grain size diameter for a typical negative is approximately 0.7μm (assuming ISO 100 speed film), while the effective pixel size is about 10μm, due to optical scattering.
- We will assume the approximate equivalent bit depth for today's B&W emulsions is about 8 bits.

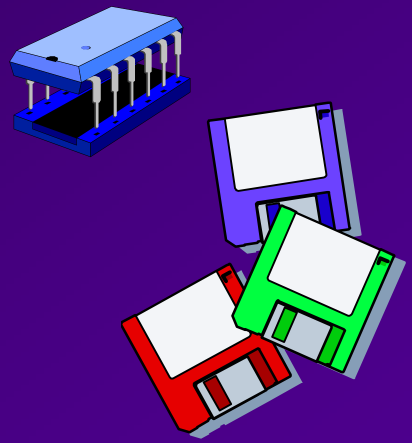
$$\frac{36\text{ mm}}{10\mu\text{m}} \times \frac{24\text{ mm}}{10\mu\text{m}} \times 8\text{ bits/pixel} = 69{,}120{,}000\text{ bits/image}$$

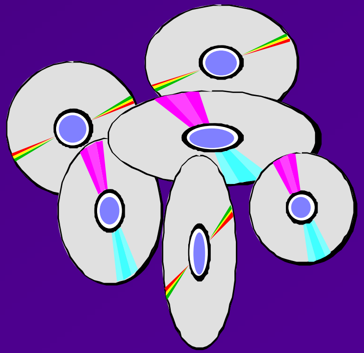
69,120,000 bits = 8,640,000 bytes = 8.2 MB: FOR B&W

8.2 MB x (3 channels) = 24.7 MB: FOR 24BIT COLOR

Storage

- The digital images must be stored to be retrieved later.
- Some storage options:
  - On-site (Short term) storage
    - On board memory (RAM)
    - Floppy disk
    - Memory flash cards
    - Hard drives
  - Archiving (Long term) storage
    - CD-recordable (CD-ROM, PhotoCD™, etc)
    - Tape drives





Archeology / Conservation

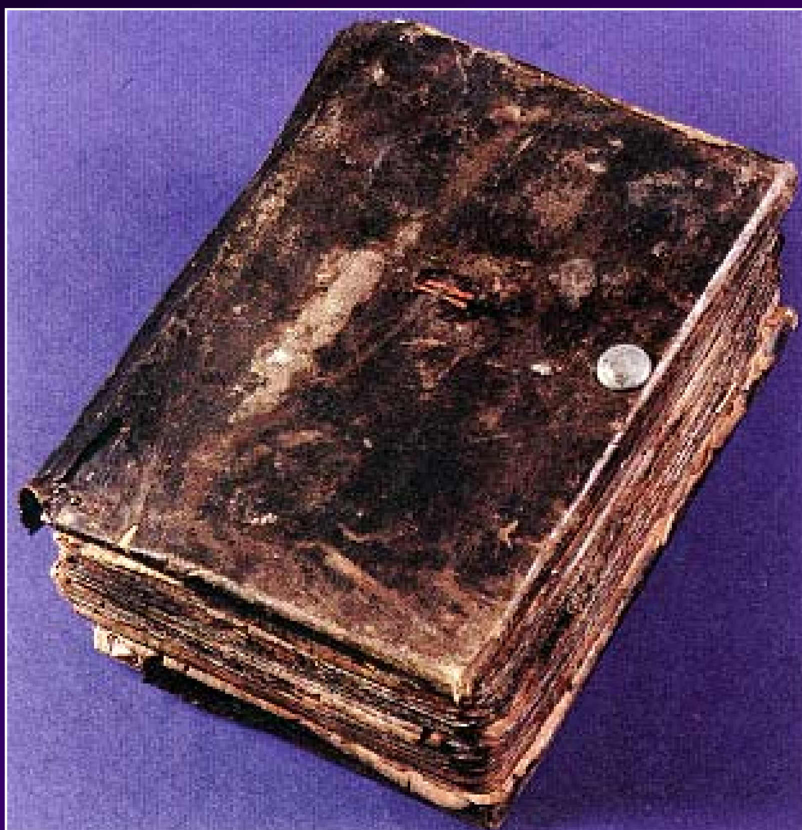
Portion of a dead sea scroll, one of the oldest written documents (2,000 yr. old)

Original document is almost illegible from thousands of years of storage / stains and fading

Can be made legible by digital image processing (DIP) techniques.

Ancient Document Restoration

Archiemedes notes underneath the text in a prayer book (287-212 BC)



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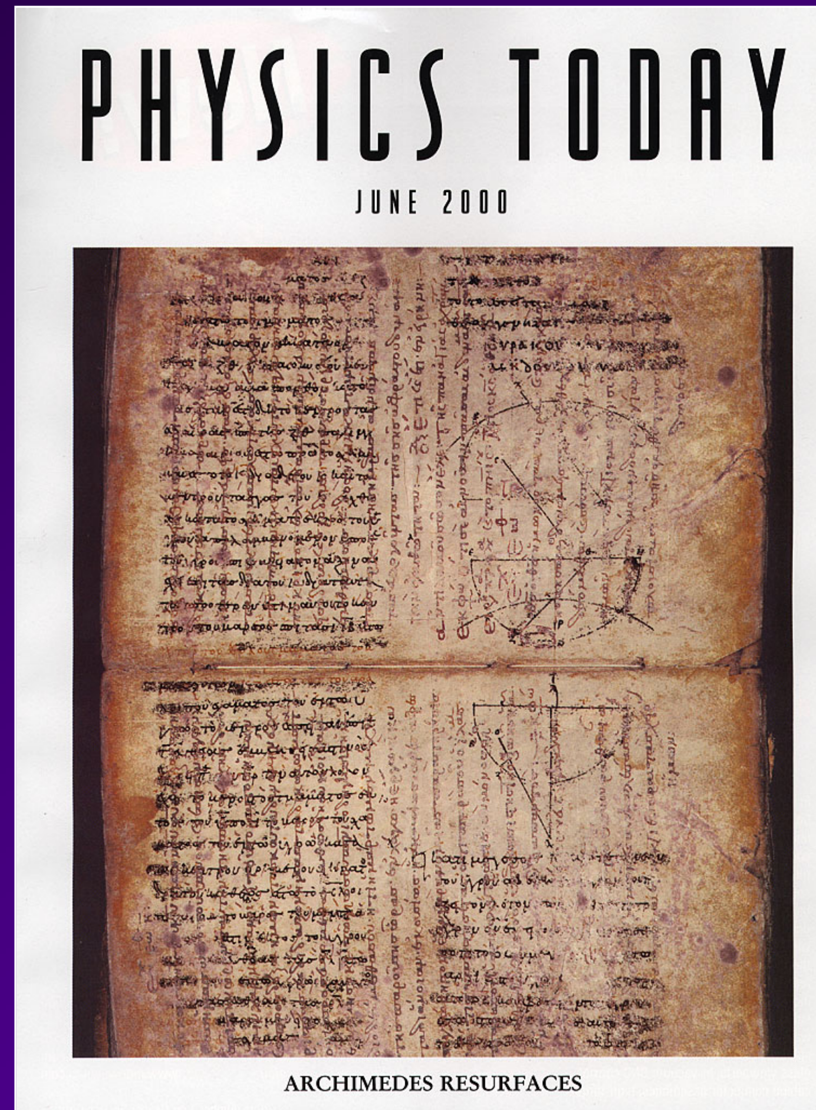
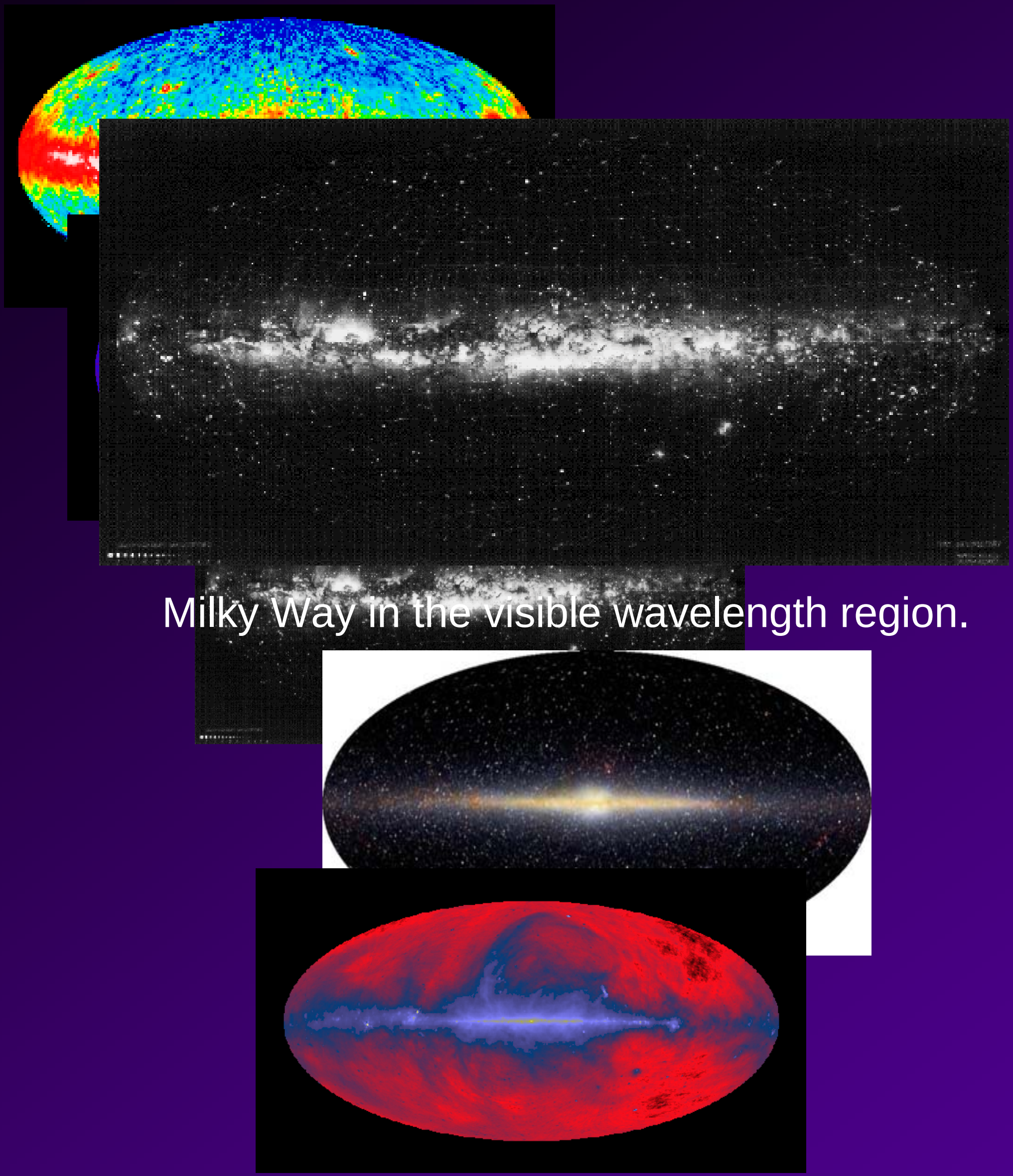


Astronomy (what is in each image?)



Milky Way in the visible wavelength region.

Radio (5×10^9nm)

- Milky Way is the galaxy where our solar system is located.
- Different regions of the electromagnetic spectrum allow astronomers to detect diverse phenomena in the universe.

Astronomy - Optics

- Astronomers can avoid the blurring and absorption of Earth's atmosphere using telescopes stationed in orbit around the Earth.

Hubble Space Telescope
before optics correction

Hubble Space Telescope
AFTER optics correction

Images from NASA

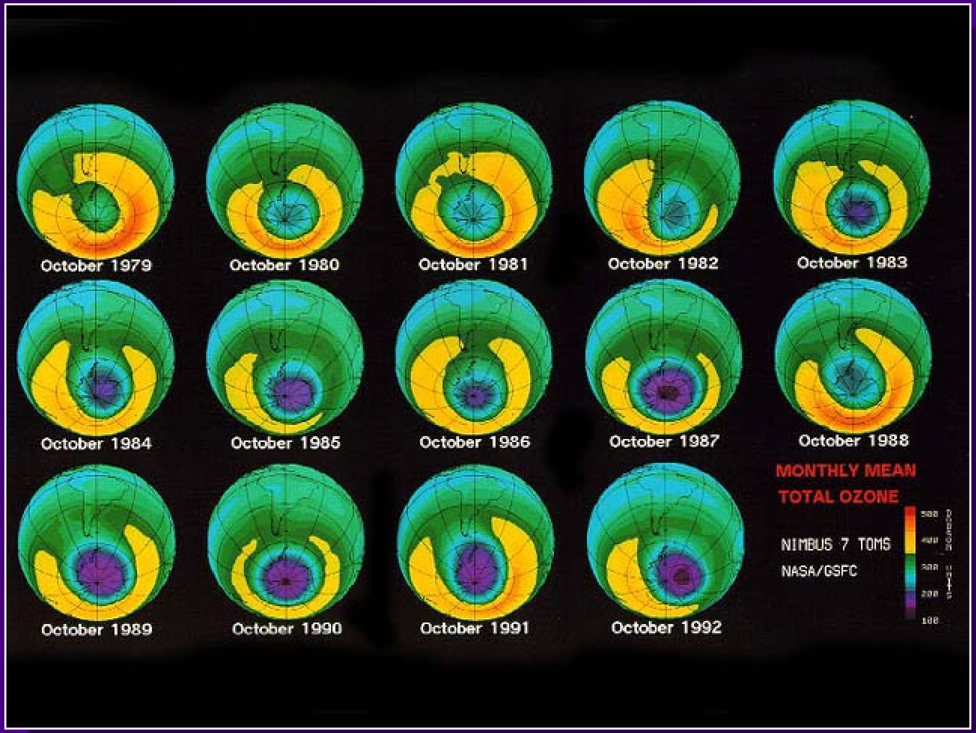
Remote Sensing - Defense

- Visible and infrared wavelengths show visual details as well as heat signatures of aircraft and other objects.

Image from Digital Globe

Remote Sensing - Environment

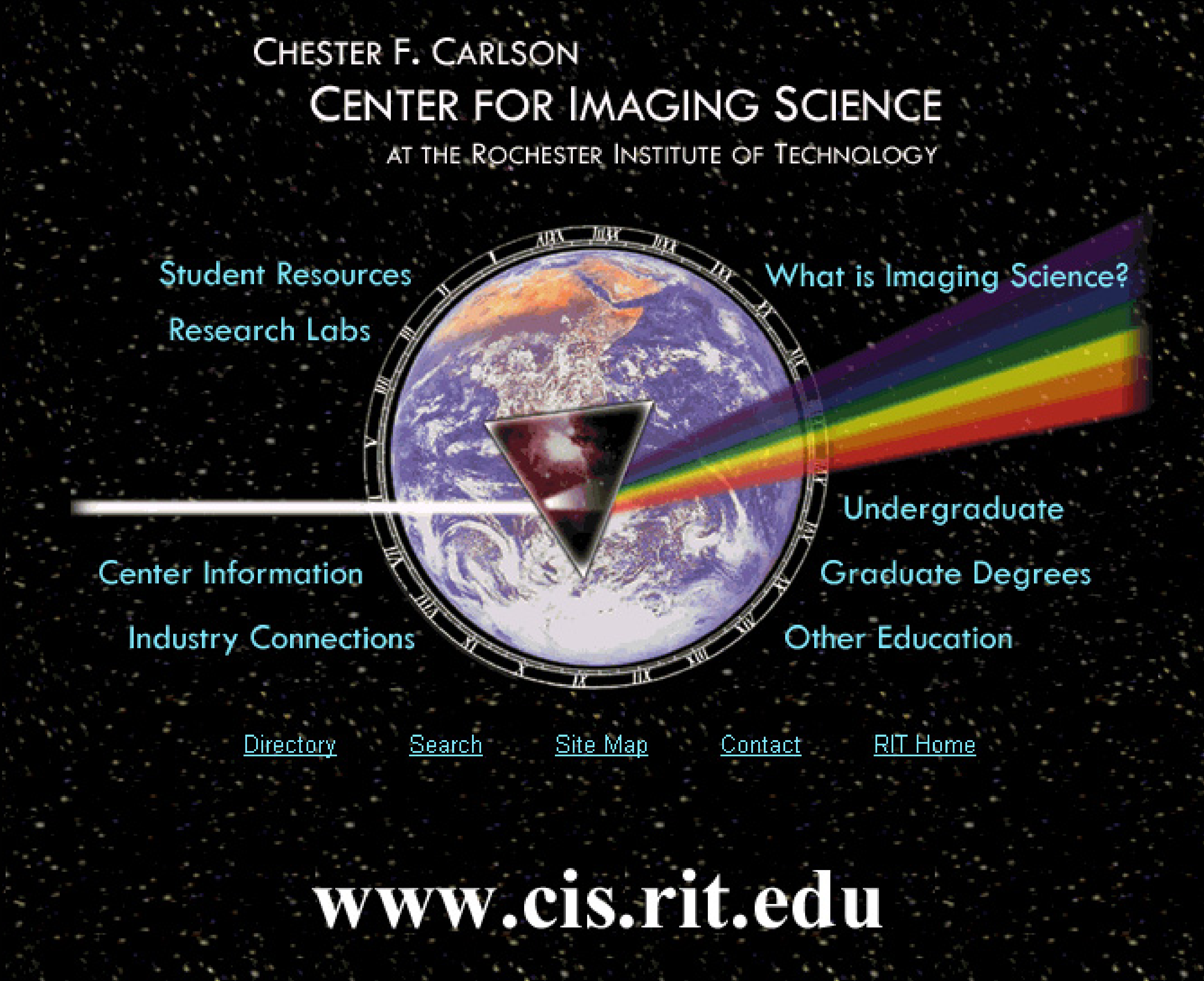
Satellites can monitor protected forests for illegal logging activities



Images from space show depletion of ozone from the south pole

Digital Globe - QuickBird Satellite

- Alt = 450 km (280 miles)
- Launch Oct, 2001
- Dynamic Range = 11 bits/pix



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