Chapter 1

Digital Imaging Processing Systems

Imaging Systems Overview

- Consists of two primary components:
- Hardware – Image acquisition system, computer, and display devices
- Software – Image manipulation, analysis, and processing

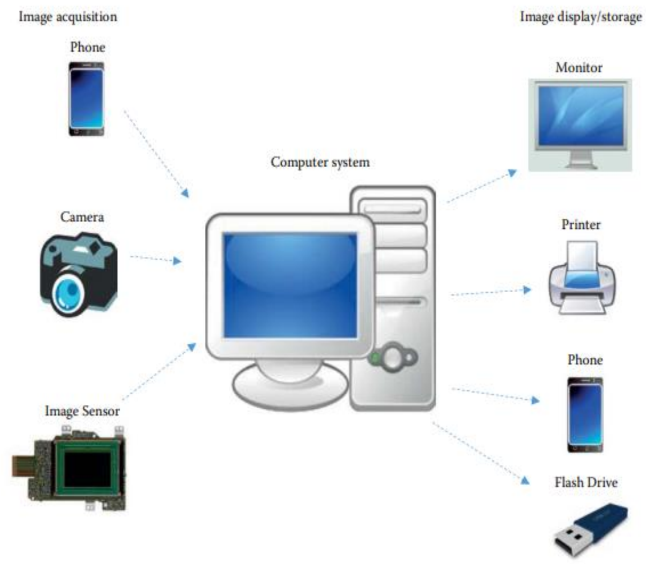


FIGURE 2.1-1
Digital Image Processing System Hardware.

Analog video standards

- CCIR – Monochrome standard - Europe

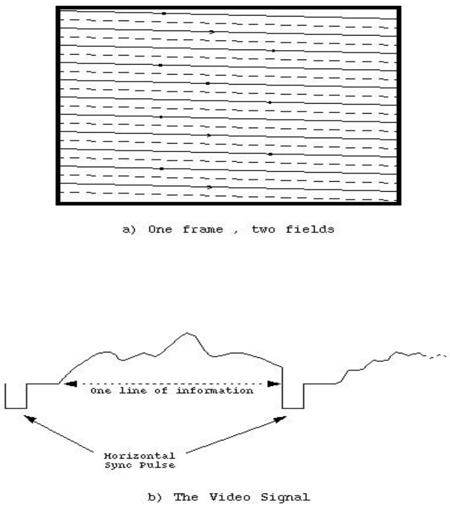
(3-Color standards)

- NTSC –North America, Japan, South America (525 lines, 30 frames/sec - 60 fields)
- PAL – North Europe (625 lines, 25 frames/sec - 50 fields)
- SECAM – France, Russia Europe (625 lines, 25 frames/sec - 50 fields)

---- 2:1 interlaced (2 fields/frame) standards----

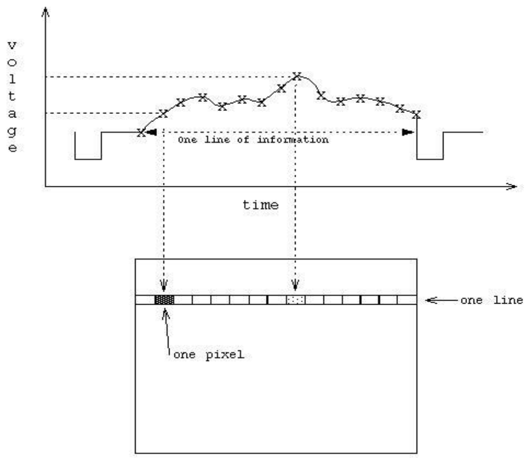
Analog Camera Signal

Figure 2.1-2: The Video Signal



- **Digitization:** Transformation of video signal into digital image

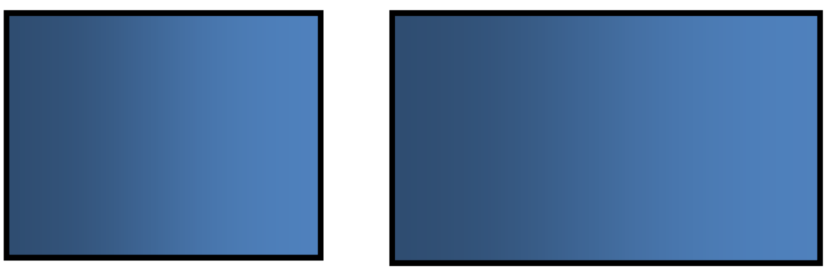
Figure 2.1-3: Digitizing (Sampling) an Analog Video Signal



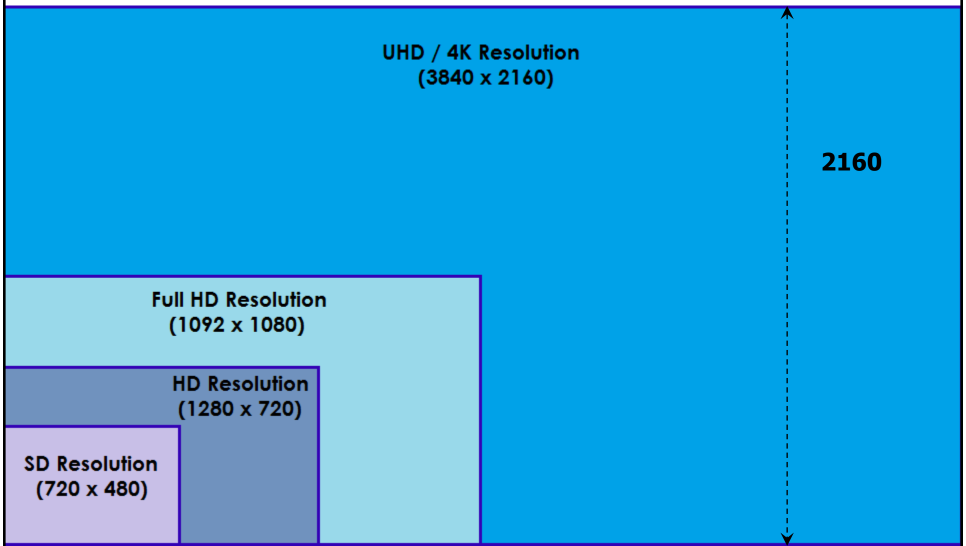
Digital Video

- Digital television (DTV) – standard definition TV (SDTV) and high definition (HDTV)
- SDTV similar to previous analog, NTSC, SECAM, PAL
- HDTV standards: 1280 columns by 720 rows (lines), in progressive scan mode, referred to as *720p*, or 1920x1080 in interlaced mode, called *1080i (lines)*
- SDTV uses a 4:3 aspect ratio, the newer HDTV standards specifies a 16:9 aspect ratio

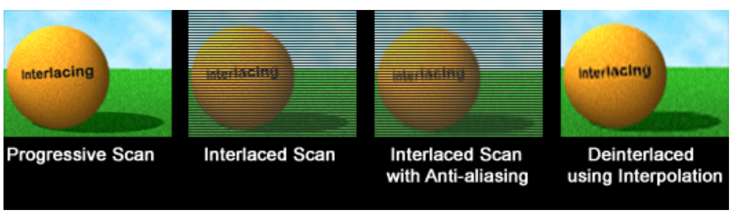
Figure 2.1-4 Aspect Ratio. The *aspect ratio* is the ratio of the image or display width (columns) to the image or display height (rows or lines). a) The aspect ratio is 4:3 for standard definition television (SDTV), and is, b) 16:9 for high definition television (HDTV).

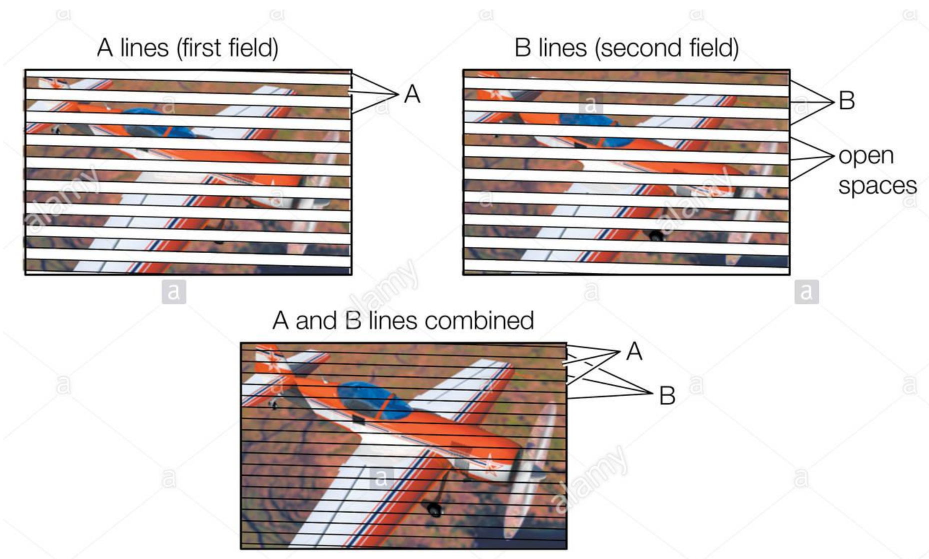


a) b)



progressive scan   interlace




A lines (first field)
A
B lines (second field)
B
open spaces
A and B lines combined
A
B


Progressive Scanning
One scan per frame
Interlaced Scanning
Scan 1 & Scan 2 are separate frames


Buzzle.com
Older generation TVs used interlaced scanning.
Modern TVs use progressive scanning.

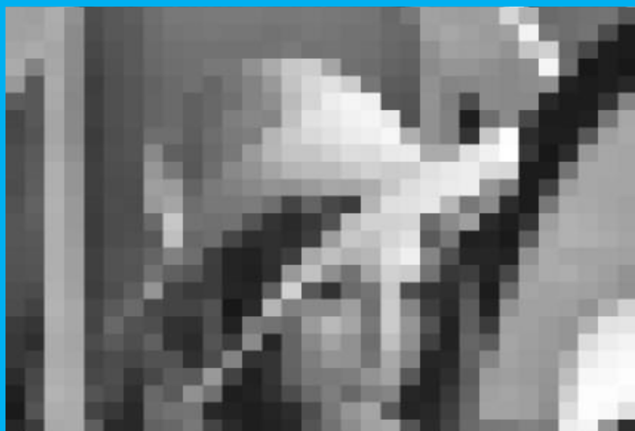
Digital Camera Interfaces

TABLE 2-1
Camera Interface Specifications

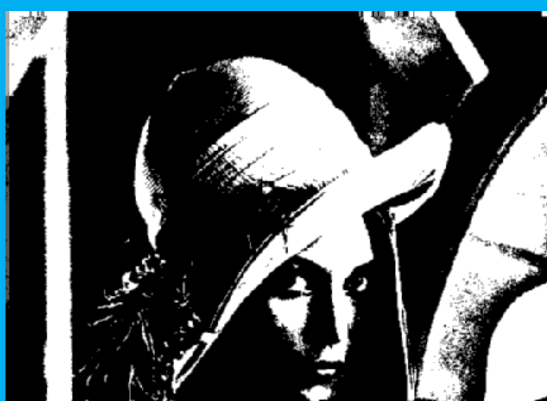
	10 Gigabit Ethernet (IEEE 802.3-2015)	FireWire S3200 (IEEE 1394)	USB 3.1	Camera Link
Type of standard	Public	Public	Public	Commercial
Connection Type	Point-to-point or Local Area Network	Peer-to-peer, shared bus	Master-slave, shared bus	Point-to-point
Maximum Bandwidth for Images	~10.0 Gbit/sec (Gbs)	~3.2 Gbs	~10 Gbs	~2.0–7.0 Gbs
Distance	~100 m, no limit with switches or fiber	~4.5 m, ~72 m with switches, ~200 m with fiber	~5 m, ~30 m with switches	~10 m
Personal Computer Interface	Network	PCI card	PCI card	PCI frame grabber
Wireless Support	Yes	No	No	No
Max # of Devices	Unlimited	63	127	1

- Image is accessed as a 2-D array of data, where each data point is referred to as a *pixel*

  Notation:
  I(r,c) = Brightness of image at the pt *(r,c)* where
  r = row, and *c* = column



Spatial Reduction 512x512 to 256x256



Original Image 256 Gray levels

Gray level Reduction 256 to 8

- Hierarchical image pyramid: Consists of levels for processing of images

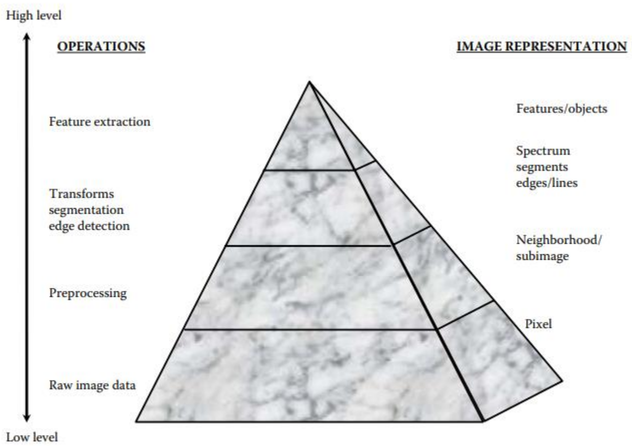


FIGURE 2.1-5
The hierarchical image pyramid. At the lowest level is the raw image data, the pixel brightness values *I*(*r*,*c*). As the image is processed by various operations, and we ascend the pyramid, the image is represented by less data and fewer objects. These are referred to as higher level representations of the image. At the highest level are the objects as the human visual system sees them.

Image Formation and Sensing

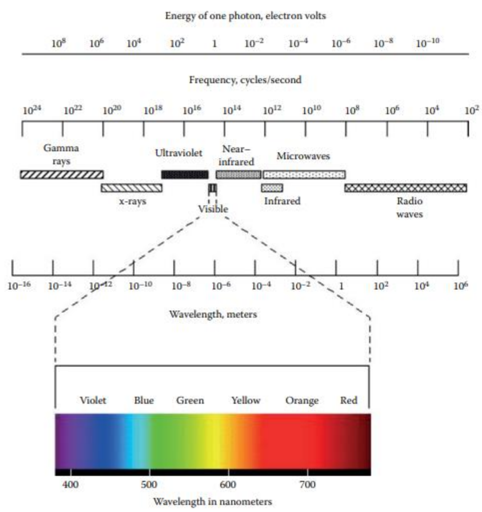
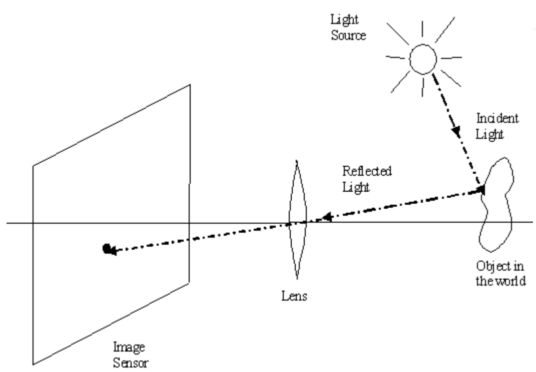


FIGURE 2.2-1
The electromagnetic (EM) spectrum. Higher frequencies have higher energy and are more dangerous. Note that the visible spectrum is only a small part of the entire EM spectrum.

Key components of image formation

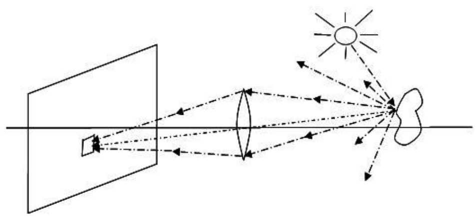
- Where will the image point appear?
  - Determined by lenses and the physics of light, the science of *optics*
- Value, or brightness, of that point?
  - Sensor and electronic technology

Visible Light Imaging



- Reflectance function determines manner in which objects reflect light
  - Related to Color and Texture

- Brightness:



- ✓ Irradiance (Image brightness): Amount of light falling on surface, measured by a sensor

  Irradiance = Power / Area
- ✓ Radiance (Scene brightness): Amount of light reflected/emitted from an object/surface into a unit solid angle
- ✓ Radiance = Power/(Area * Solid Angle)

Brightness:

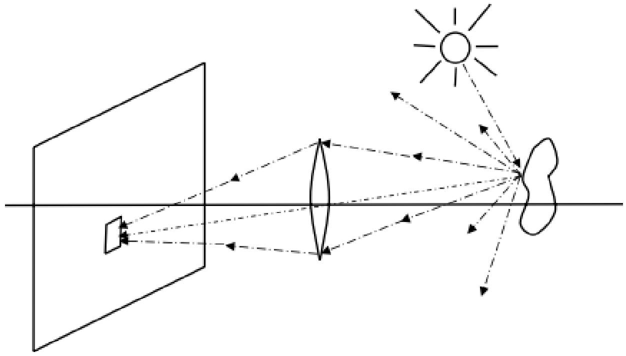
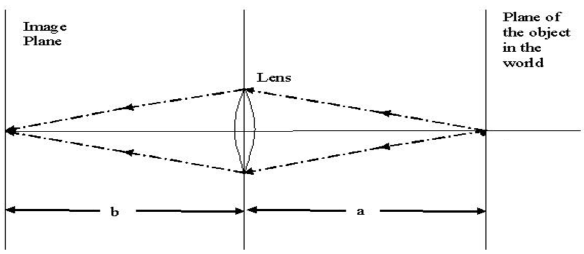


FIGURE 2.2-4
Irradiance and radiance. Irradiance is the measured light falling on the image plane. It is measured in power per unit area. Radiance is the power reflected or emitted per unit area into a directional cone having a unit of solid angle. Note that all the reflected light is not captured by the lens.

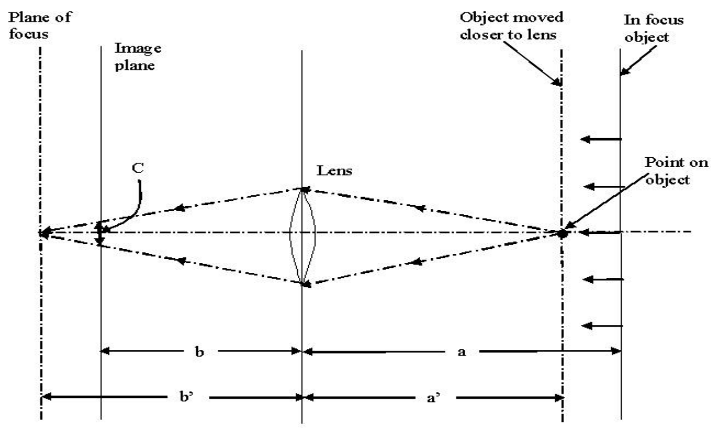
- Lens equation: 1/a + 1/b = 1/f



➢ *f* is the focal length and is an intrinsic property of the lens

- Blur equation: $c = (d|b - \bar{b}|) \div \bar{b}$

$\frac{d}{\bar{b}}|\bar{b}' - b|$

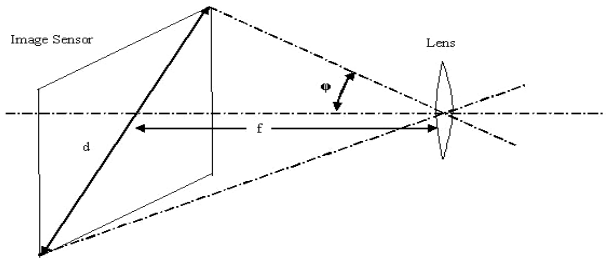


- Depth of field (Depth of focus): Range of distances over which objects are focused sufficiently well (blur circle equal or smaller than device resolution)
  - Depth of field can be controlled by adjusting the diaphragm

- f-number (f-stop): Ratio of the focal length to the lens diameter
  - Depth of field is directly proportional to f-number

Diaphragm Example:

- Field of view (FOV) : Angle of cone of directions from which the device will create the image

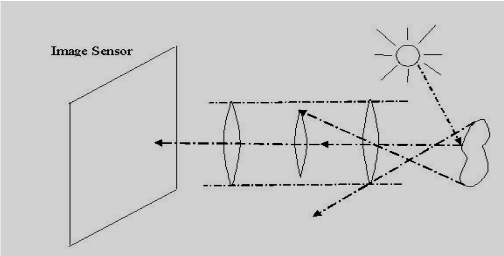


FOV = 2Ø, where Ø = $\tan^{-1}((d/2)/f)$

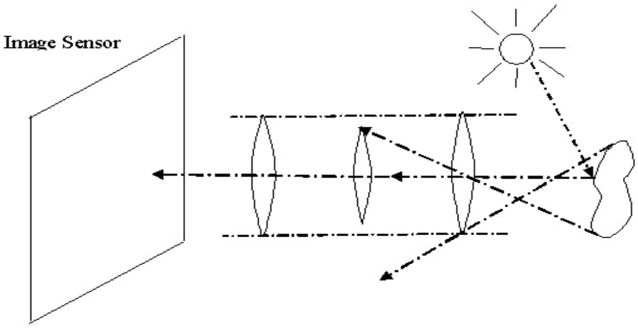
Depends upon focal length of the lens and size of image sensor

- Types of Lenses:
  - ✓ Wide Angle lens: Short focal length, FOV greater than 45°
  - ✓ Normal lens: Medium focal length, FOV from 25° to 45°
  - ✓ Telephoto lens: Long focal length, FOV less than 25°
- Real lens consists of multiple lenses, as single lens may contain aberrations

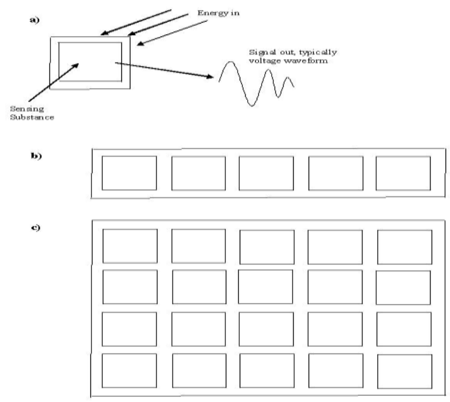
- Vignetting effect:
  - ✓ Negative effects of compound lens
  - ✓ Decreases the amount of energy to the image plane passing through the lens, as we move farther away from the center of the lens
  - ✓ Can be avoided by using center portion of the lens



- Vignetting effect:



- Sensors : Converts light energy into electrical energy



a) Single imaging sensor ; b) Linear (line) sensor ; c) 2-D or array sensor

- CCD: 4kx4k CMOS: less power, cheaper, image quality not as good as CCD

- Sensor equation: Calculates the approximate number of electrons (N) liberated in a sensor

  $N = \delta A \delta t \int b(\lambda) q(\lambda) d\lambda$

  δA is the area; δt is the time interval;

  $q(\lambda)$ is the *quantum efficiency* – the ratio of electron flux produced to the incident photon flux;

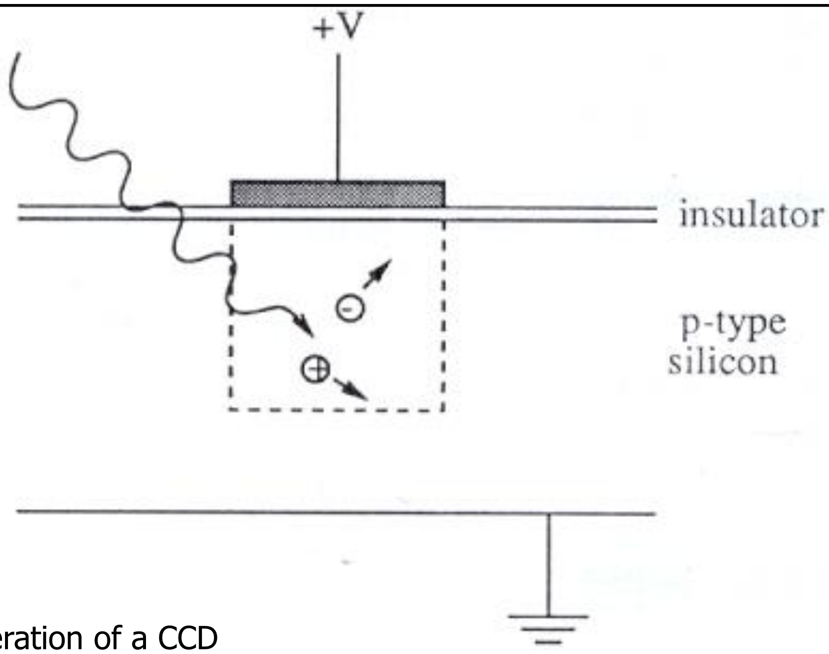
  $b(\lambda)$ is incident photon flux (irradiation)

- Tube devices are 5% quantum efficient and solid state devices are 60% to 95% quantum efficient

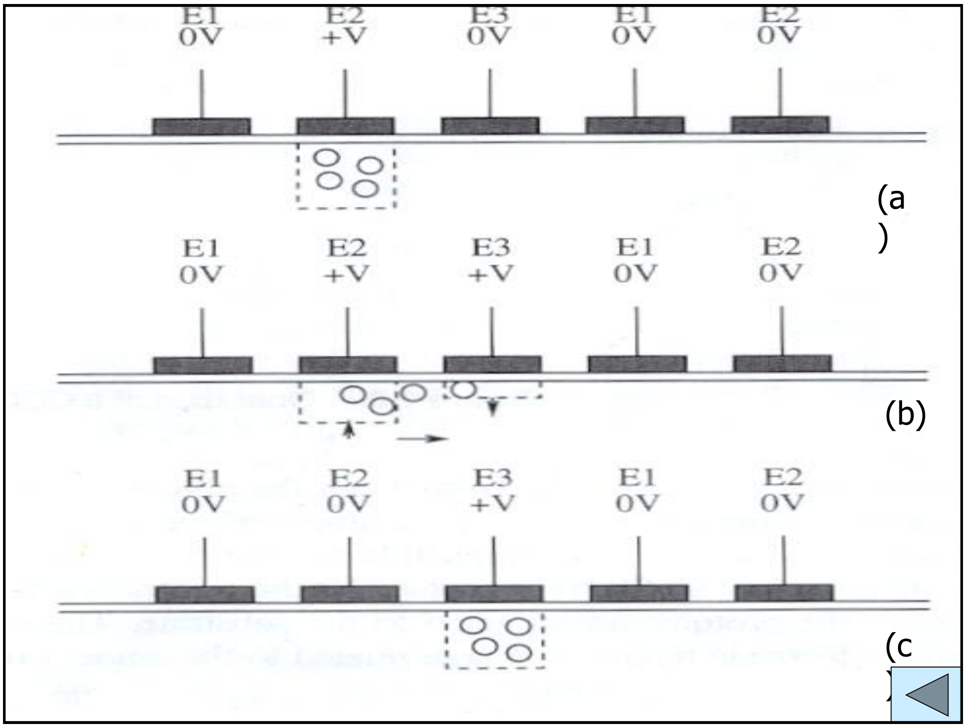
Charged Coupled Device (CCD)

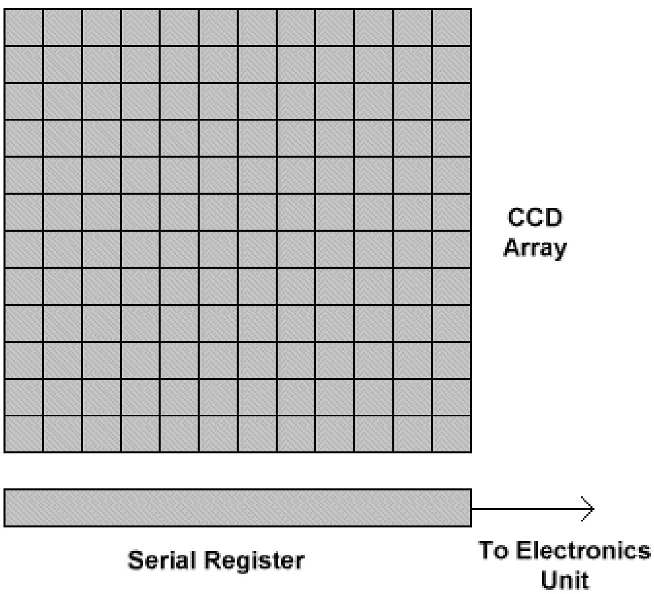
- It's a solid-state circuit that can be used to record images much as vidicon would.

- CCD consists of an electrode attached to an insulator, behind which is a block of semiconducting silicon. The electrode is connected to the positive terminal of a power supply, the silicon to negative. The insulator prevent electron to remove, so no current flows.

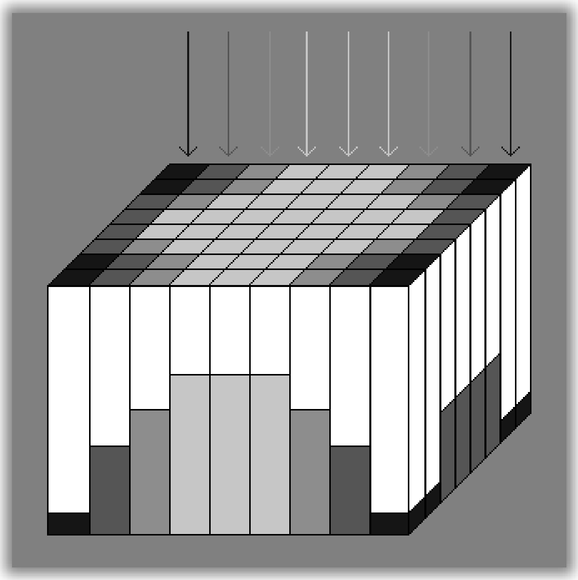


Operation of a CCD

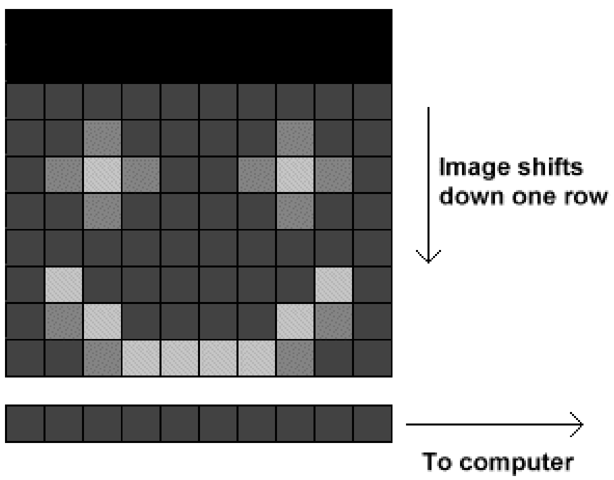




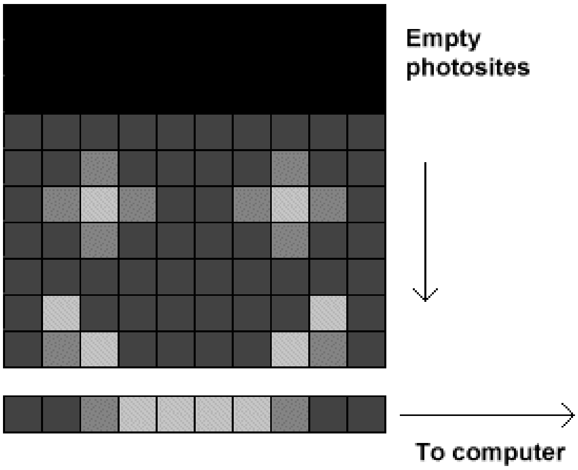
Above: *A CCD chip consists of an array of photosites (squares) and a serial register for reading out the image data.*



Above: *The photosites (squares on top) collect light and convert it to electric charge. The "wells" begin to fill with charge. Brighter areas (light grey) fill faster than dark areas (dark grey and black).*



Above: *Each row is shifted down to the next row of photosites. The bottom row is transferred to the serial register and sent to the computer.*



Above: *The process continues until all the photosites have been read out.*

CCD's Imperfections (Cont …)

•Most common distortion is due to imperfect optics

•Damage can occur to very tiny pixel arrays, causing data jam

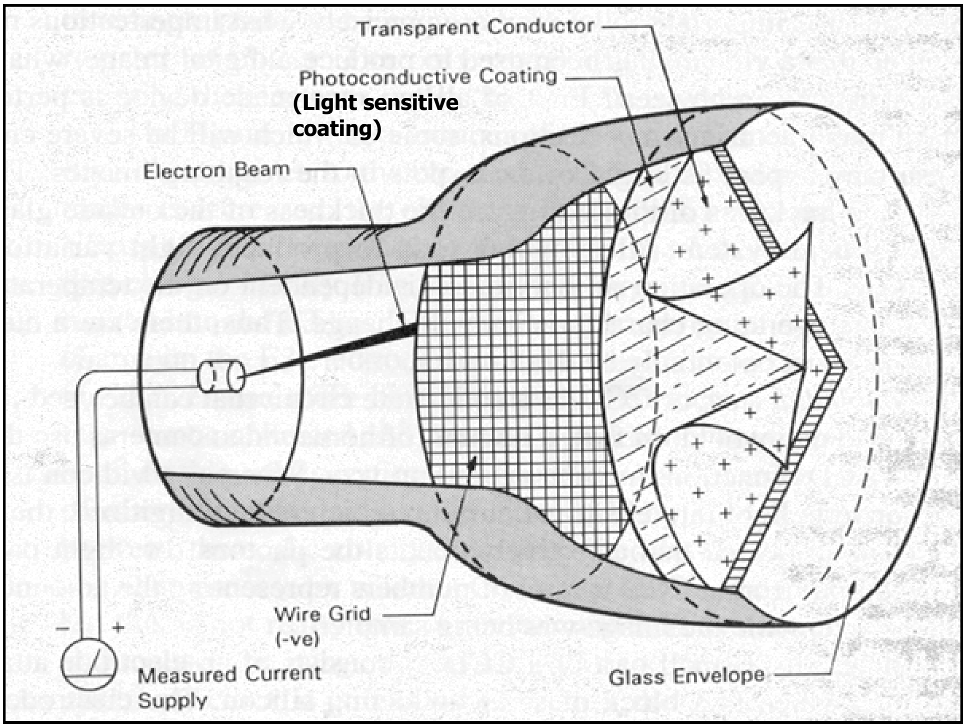
•A defective electrode can cause a break in the charge-coupling arrangements that stops any pixel above that point from being transferred down the column. This is called blocked column, resulted in a dark line of pixels

•Finally charge bleeding occurs when, because of long exposure of a bright object, the electrons fill up some of the bins and overflow into neighbor bins. This effect is seen as a very bright line extending from bright object

•Vidicon: found in many TV cameras, converts a scene into electronic form in real time.

•A vacuum tube containing a light-sensitive coating on one end sandwiched b/w a transparent conductor (+ve) and a wire mesh (-ve). An optical system focuses an image of the scene onto this coating, which conduct electric current when illuminated.

•At the opposite end of the tube is an electron source (gun) and a system to focus these electrons onto the coating.

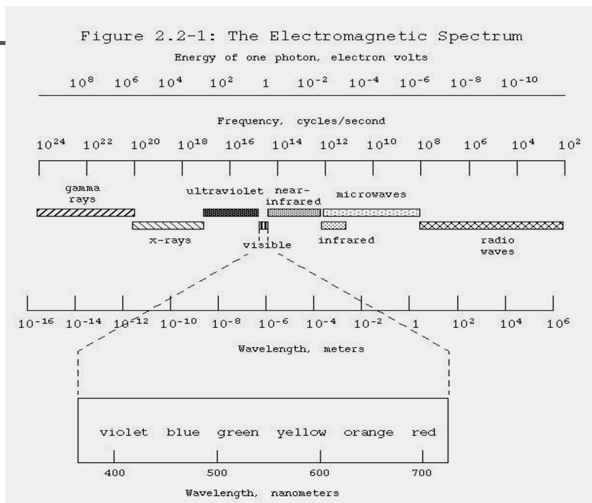


Vidicon cont…

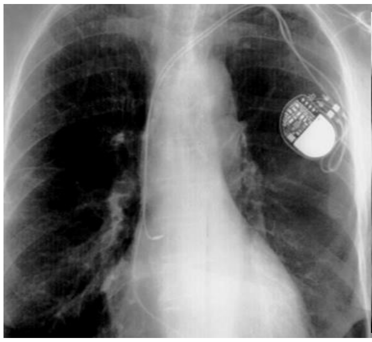
Device Imperfections: No man made device is perfect.

- manufacturing imperfections - bright or dark spots
- variations in the thickness of the coating- slight variations over regions of the image
- temperature dependent - operation characteristics will change with time

Imaging Outside the Visible Range of the EM Spectrum



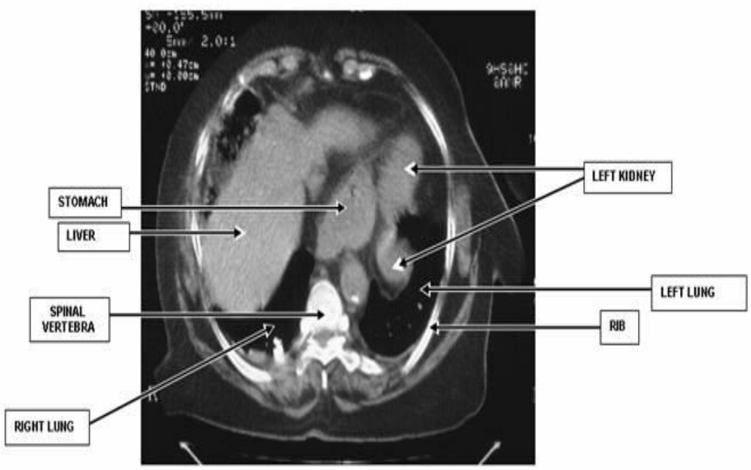
➢ X-Rays: Used in medical diagnostics and computerized tomography (CT)



Chest X-ray

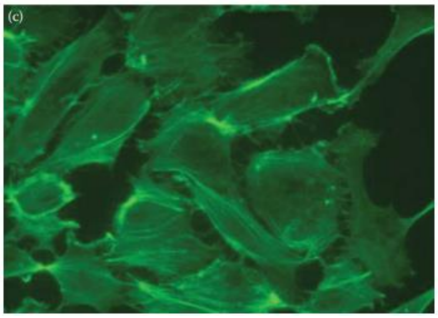
Dental X-ray

➢ Computerized Tomography

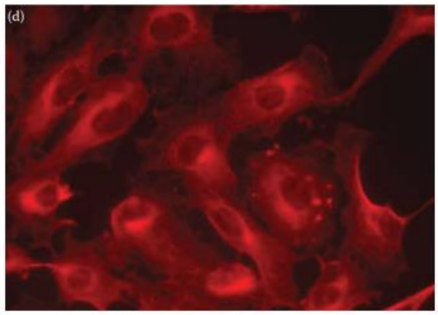


One slice of CT of patient's abdomen

- Ultraviolet imaging (300nm): Used in industrial applications, law enforcement, microscopy and astronomy

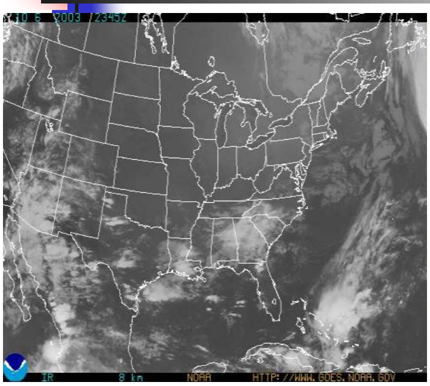


Fluorescence microscopy of cells



Fluorescence microscopy of cells

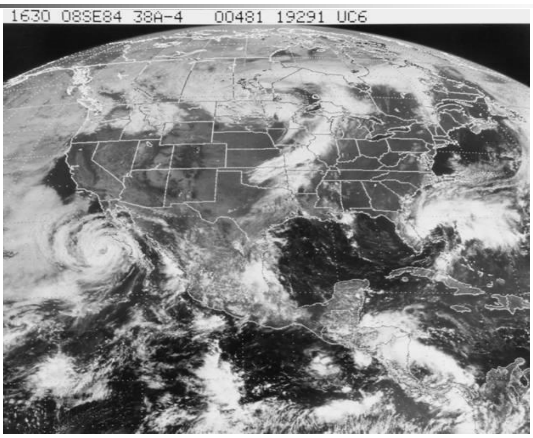
- Infrared imaging (800nm+): Used in satellite imaging, law enforcement, and fire detection



Satellite image showing water vapor

Infrared satellite imagery in the near infrared band

- Multispectral imaging: Used in weather analysis



GOES image of North America

- Microwave images: Used in radar applications
- Radio waves: Used in astronomy and medicine (MRI)

MRI of patient's shoulder

Acoustic Imaging

- Works by sending out sound waves at various frequencies and then measuring the reflected waves
- Used in biological and man-made systems, geological systems, and medicine


Head and spine of baby

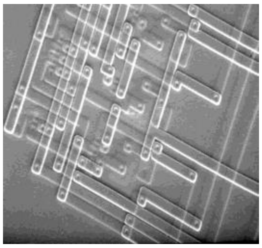

Baby sucking its thumb

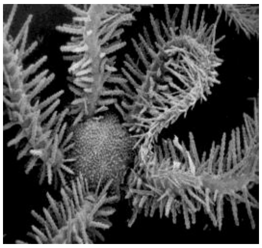

Baby smiling

Electron Imaging

- Uses a focused beam of electrons
- Provides high magnification (200 thousand times)
- Two types: SEM (scan) and TEM (xmit)


SEM image of mosquito


Logic gate in microchip

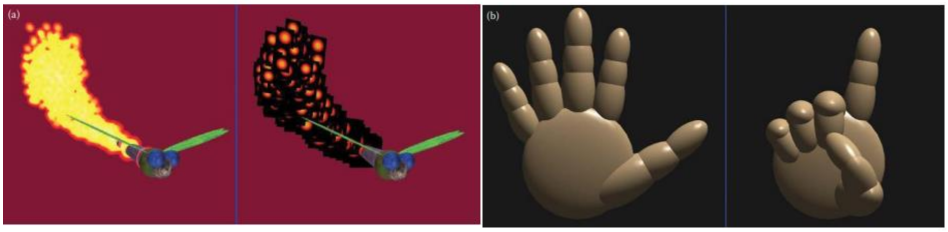

Brittlestar

Laser Imaging

- *LASER* = *L*ight *A*mplification by *S*timulated *E*mission of *R*adiation
- Produces narrow beam of light in visible, IR, or UV range of EM spectrum
- Generates coherent light, highly intense and monochromatic
- Used to create *range images*, referred to as *depth maps*

Computer Generated Images

- Computers are used to generate images, they are not *sensed* from the real world
- Used in engineering (CAD), medicine, education, arts, games, aviation



The CVIPtools Software

- Developed at SIUE
- Provides the user to access a wide variety of computer imaging operations and to explore these operations by varying all the parameters and observing the results in real time
- Continually under development in the university environment, so that newly developed algorithms are available for exploration and research

Image Viewer

- Loading an image requires clicking on the standard file open icon in the upper left of the main window
- The image is read into the memory and its name appears in the image queue, along with the image being displayed in the main window, and image information being displayed in the status bar at the bottom of the main window

- The loaded image is an active image, which can be changed at anytime either by clicking on the image name in the queue or the image itself
- The image viewer allows the user to perform standard image geometry as well as image enhancement operations via histogram equalization
- These operations affect only the image that is displayed, and not the images in the CVIPtools image queue

Main Window with images in queue

TABLE 2-2 CVIPtools Image Viewer Keyboard and Mouse Commands		
DRAW	shift key -left mouse button	Draw a box on an image, used in crop, etc
	control key-left mouse button	Draw border for *Utilities-> Create-> Border Mask* and *Border Image* and *crop*, etc
	Alt key-left mouse button	Mark mesh points for geometric transforms
	Right mouse button on image	Mesh display select box (followed by left button to select)
	Middle mouse button on image	Removes drawn boxes and borders
ROTATE	t	turn 90 degrees clockwise
	T	Turn 90 degrees counter-clockwise
FLIP	h,H	horizontal flip
	v,V	vertical flip
OTHERS	N	Change back to original image, including size
	n	Change back to original image, without changing size
	q,Q	Quit – removes image from display but leaves in queue (clicking on the X in the upper right corner will remove the image from queue)
	e,E	Histogram equalization
	Right mouse button in image viewing area (workspace)	Brings up *Utilities* menu

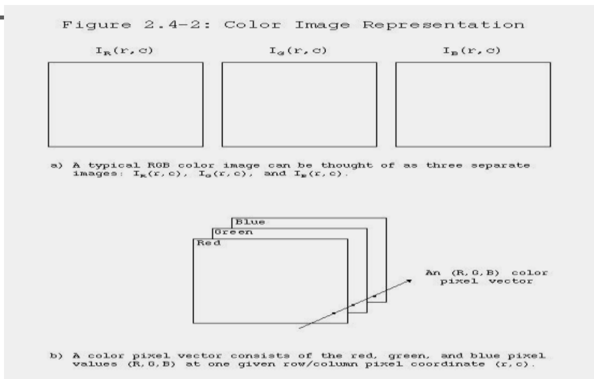
Image Representation

- Optical image: Collection of spatially distributed light energy measured by an image sensor to generate $I(r,c)$
- Matrix: 2-D array like the image model, $I(r,c)$
- Vector: One row or column in a matrix

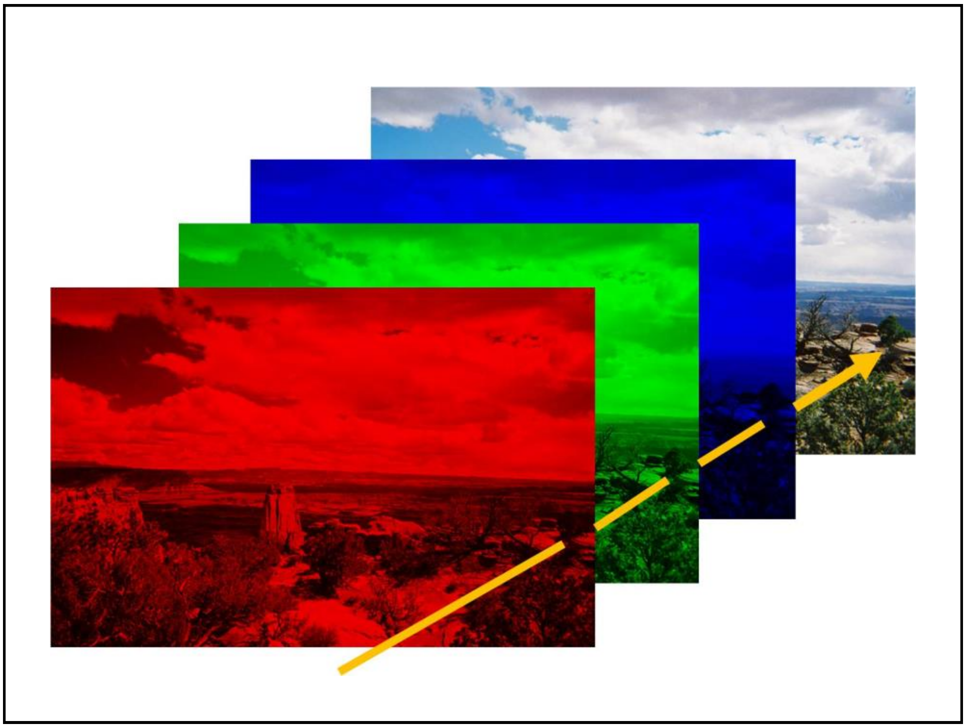
Image Types

- Binary images: Simplest type of images, which can take two values, typically black or white, or “0” or “1”
- Gray scale images: One-color or monochrome images that contains only brightness information and no color information
- Color images: 3 band monochrome images, where each band corresponds to a different color, typically red, blue and green or RGB

- Color pixel vector: Single pixel’s values for a color image, (R,G,B)

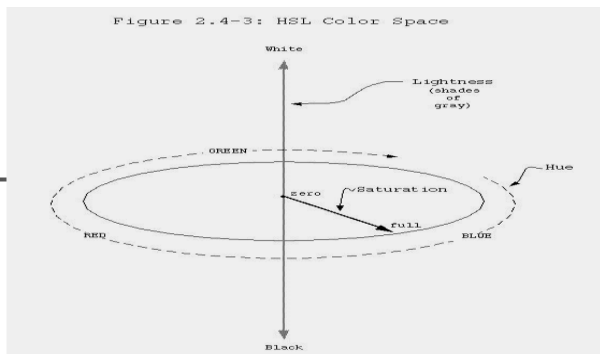


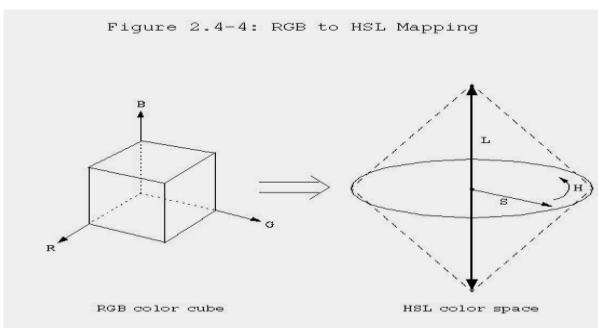
- Multispectral/Multiband Images: Images of many bands containing information outside of the visible spectrum

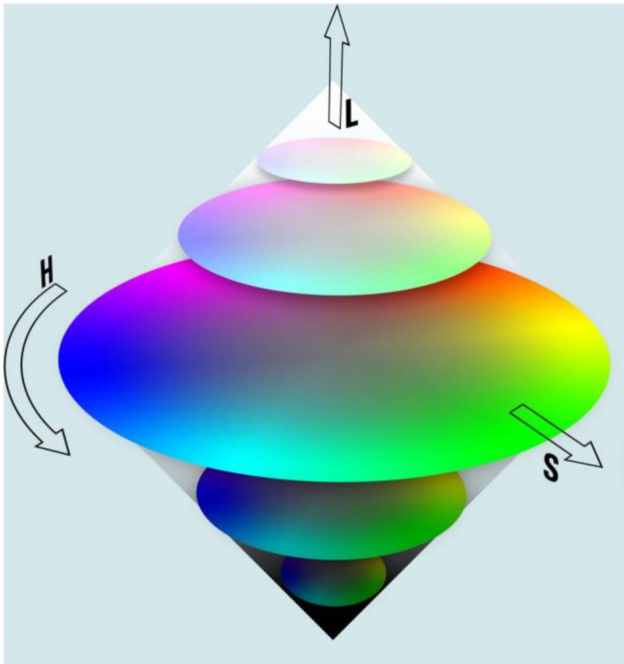


Color Transform/Color Model

- Mathematical model or algorithm to map RGB data into another color space
- Decouples brightness and color information
- Hue/Saturation/Lightness (HSL) Color Transform:
  - ✓ Describes colors in terms that we can more readily understand







- *Hue* corresponds to color, *saturation* corresponds to the amount of white in color, and *lightness* is the brightness
- For example: *a deep, bright orange* color would have a large intensity (bright), a hue of “orange” , and a high value of saturation (“deep”)

  But in terms of RGB components, this color would have the values as R =245, G= 110, and B=20

- ✓ Equations for mapping RGB to HSI are:

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases}$$

where

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2 + (R-B)(G-B)]^{1/2}} \right\}$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)]$$

$$I = \frac{(R+G+B)}{3}$$

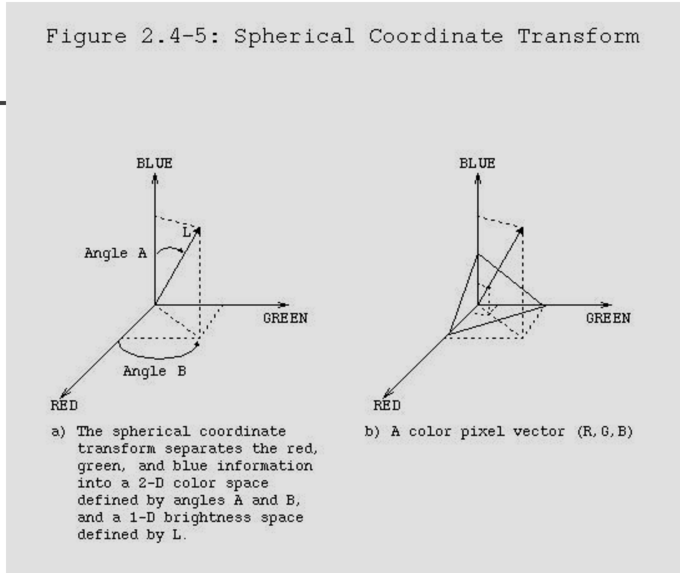
Note: See text for inverse of the equations

- ➢ Spherical Coordinate Transform (SCT):
- ✓ Maps color information into two angles (A and B), and the brightness into color vector length (L), useful for segmentation
- ✓ Equations relating SCT to RGB components are:

$$L = \sqrt{R^2 + G^2 + B^2}$$

$$\angle A = \cos^{-1}\left[\frac{B}{L}\right]$$

$$\angle B = \cos^{-1}\left[\frac{R}{L \sin(\angle A)}\right]$$



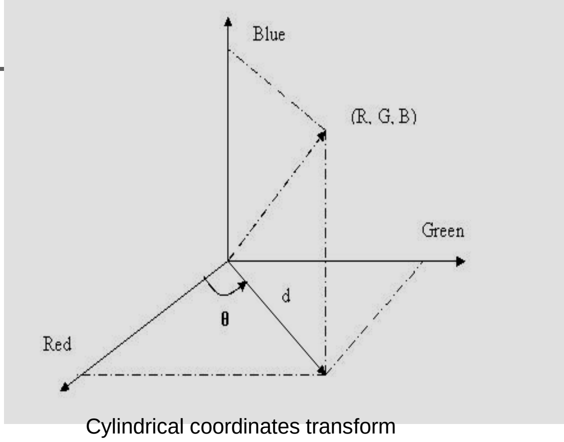
Cylindrical coordinate transform (CCT):

- Does not completely decouples brightness from color information
- Application specific
- Equations for finding CCT are:

$$z = B$$

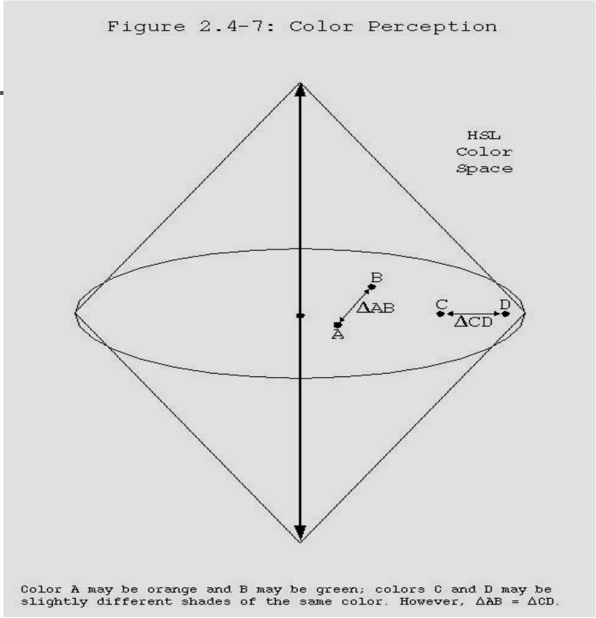
$$d = \sqrt{R^2 + G^2}$$

$$\theta = \tan^{-1}\left(\frac{G}{R}\right)$$



Cylindrical coordinates transform

➢Perceptually uniform color spaces



- Chromaticity coordinates: [defined by CIE]
- ✓ Normalizes RGB values to the sum of all three
- ✓ Chromaticity coordinates are basis:

$$r = \frac{R}{R+G+B}$$

$$g = \frac{G}{R+G+B}$$

$$b = \frac{B}{R+G+B}$$

✓CIE XYZ, Lu*v*, La*b*

- CMY (Cyan, Magenta, Yellow)/CMYK:
- Color transform based on subtractive model (from white)
- ✓ Used for color printing

- PCT (Principal components transform):
- ✓ Examines all RGB vectors within an image
- ✓ Finds linear transform, that aligns the coordinate axes so that most of the information is along one axis, the *principal axis*

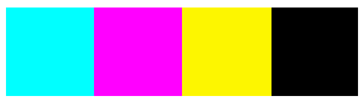
Color Models

Additive Color System
Red - Green - Blue (RGB)

Subtractive Color System
Red - Yellow - Blue

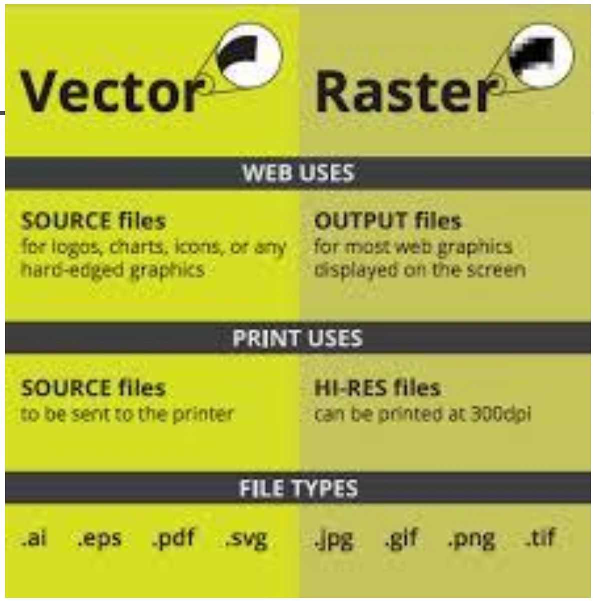
Primary Colors | Secondary Colors | Tertiary Colors

The CMYK Color System
Cyan - Magenta - Yellow - Black



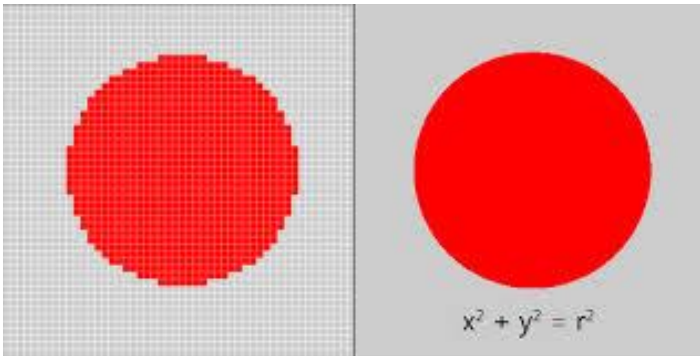
Digital Image File Formats

- *Bitmap images* (*raster images*): Images that can be represented by our image model, $I(r,c)$
- *Vector images*: Artificially generated images by storing only mathematical description of geometric shapes using *key points*
- *Rendering*: Process of turning a vector image into a bitmap image



Vector
Raster
WEB USES
SOURCE files
for logos, charts, icons, or any hard-edged graphics
OUTPUT files
for most web graphics displayed on the screen
PRINT USES
SOURCE files
to be sent to the printer
HI-RES files
can be printed at 300dpi
FILE TYPES
.ai .eps .pdf .svg
.jpg .gif .png .tif

I'm a bitmap.
I'm a vector.



- Image file header: A set of parameters found at the start of the file image and contains information regarding:
  - ✓ Number of rows (height)
  - ✓ Number of columns (width)
  - ✓ Number of bands
  - ✓ Number of bits per pixel (bpp)
  - ✓ File type

- Look-up table (LUT): Used for storing RGB values for 8-bit color images

Figure 2.4-8: Look-up Table (LUT)

8-bit Index	RED	GREEN	BLUE
0	R_0	G_0	B_0
1	R_1	G_1	B_1
2	R_2	G_2	B_2
⋮	⋮	⋮	⋮
254	R_{254}	G_{254}	B_{254}
255	R_{255}	G_{255}	B_{255}

One byte is stored for each pixel in I(r,c). When displayed, this 8-bit value is used as an index into the LUT, and the corresponding RGB values are displayed for that pixel.

DIGITAL IMAGE FORMATS

•Device specialized formats were devised for use with a specific computer or display device. The Sun raster file format, Silicon Graphics format are some examples. The main advantage is the speed at which one of these can be displayed on its appropriate host; disadvantages are many, including lack of portability, inefficiency on other devices, inadequate header information, and the tendency of these formats to change from time to time.

•Software specialized formats were designed to be used with a particular program or class of programs. Alpha is one of these; others are the MacPaint format on the Apple Macintosh computers, PI3 files for use with the Degas program on Atari computers, and so on. These formats have the same advantages and disadvantages as do the device-specialized ones.

DIGITAL IMAGE FORMATS (Cont …)

•Interchange formats are used to exchange data/images between users, usually across networks but sometimes by tape or diskette. Interchange formats are often compressed to take less space on the tape or transmission time across the network.

•Image compression:

- •image data to reduce the number of bytes needed to store or transmit an image.
- •comes at the cost of execution time needed to decompress the image. Introduce an error into the image
  - JPEG2000 (Joint Photographic Experts Group)

DIGITAL IMAGE FORMATS (Cont …)

•GIF (Graphics Interchange Format) images, for example, have been compressed. GIF is the CompuServe image transfer format.

- Must contain enough information to reconstruct the image
- Does not depend on any particular hardware and gives a certain minimum amount of other information:
  - •image size, title, number of colors.

DIGITAL IMAGE FORMATS (Cont ...)

•Tagged formats TIFF make use of special codes in the file to identify information. Tags are usually in numeric constants. A TIFF file would convey the information as

256 256
257 256

- 256 and 257 refer to the number of rows and columns
- It occupies less space, - less easy for a human to read (although it is easier to read by computer).

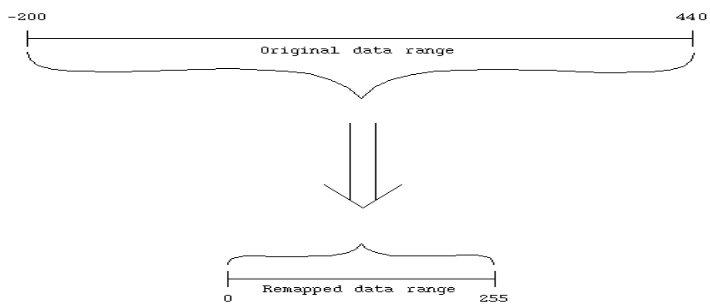
•Designed as a general format for exchanging image data and is independent of operating system or hardware. It is also extensible, so as the need arises, more kinds of header information can be included in the TIFF file.

Common image file formats are:

- ✓ BIN, RAW
- ✓ PPM,PBM,PGM
- ✓ BMP
- ✓ JPEG
- ✓ TIFF
- ✓ GIF
- ✓ RAS
- ✓ SGI
- ✓ PNG
- ✓ PICT, FPX
- ✓ EPS
- ✓ VIP

Remapping:

Figure 2.4-9: Remapping for Display



Original data ranges outside the bounds of a standard image.
It is remapped to the 8-bit range from 0 to 255.