Chapter 2

Computer Imaging Systems

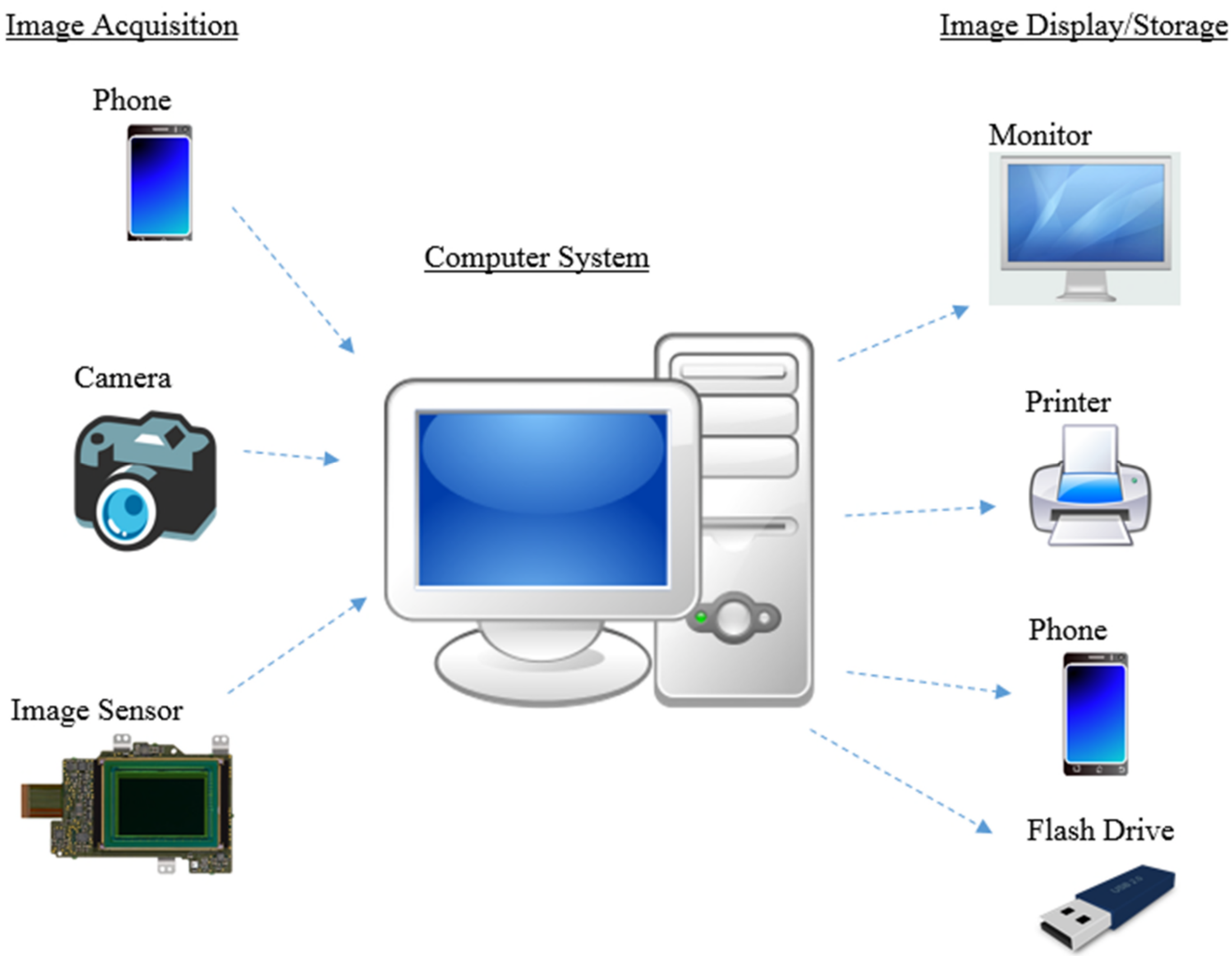
Imaging Systems Overview

- Consists of two primary component types:

- Hardware – Image acquisition system, computer, and display devices

- Software – Image manipulation, analysis, and processing

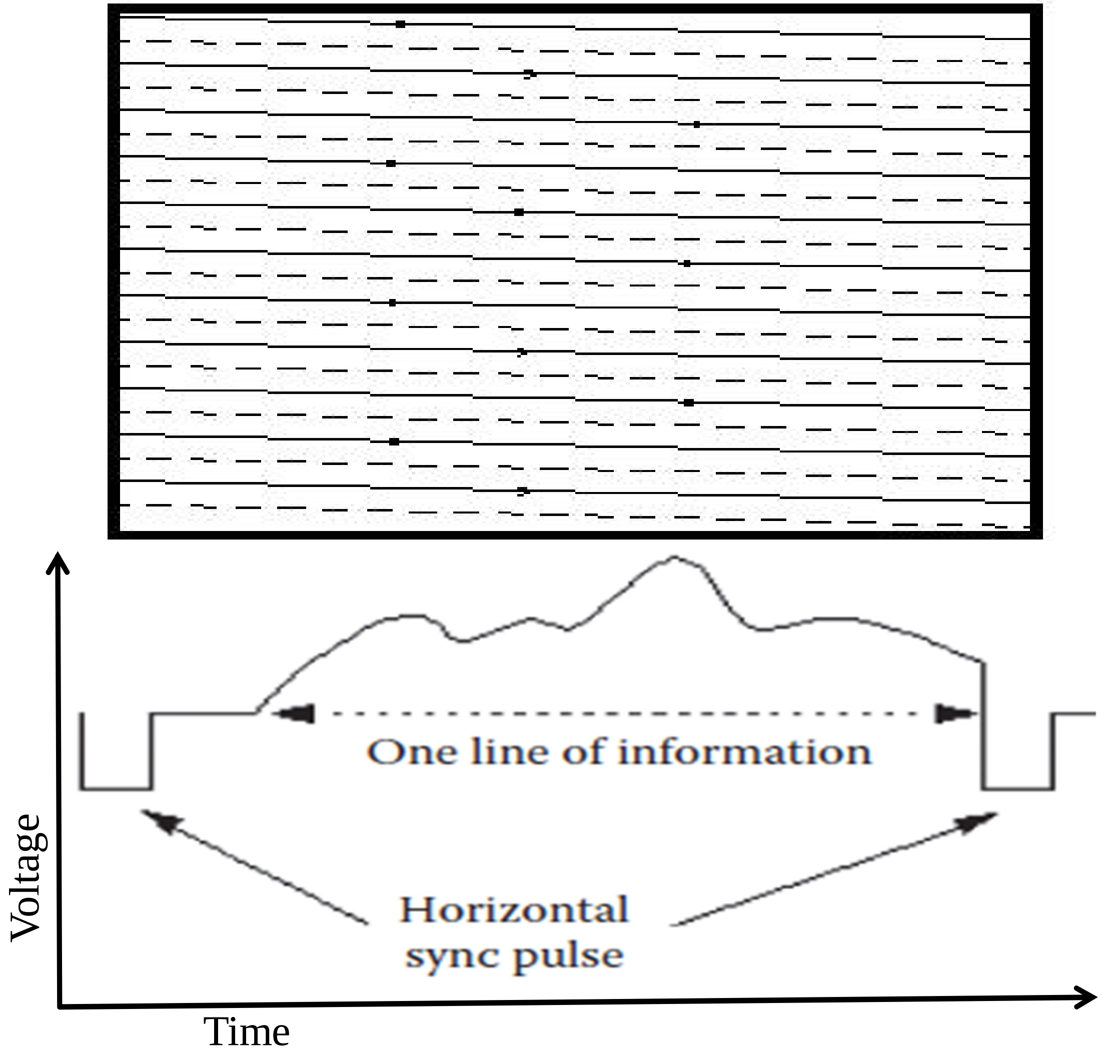
Imaging System Hardware



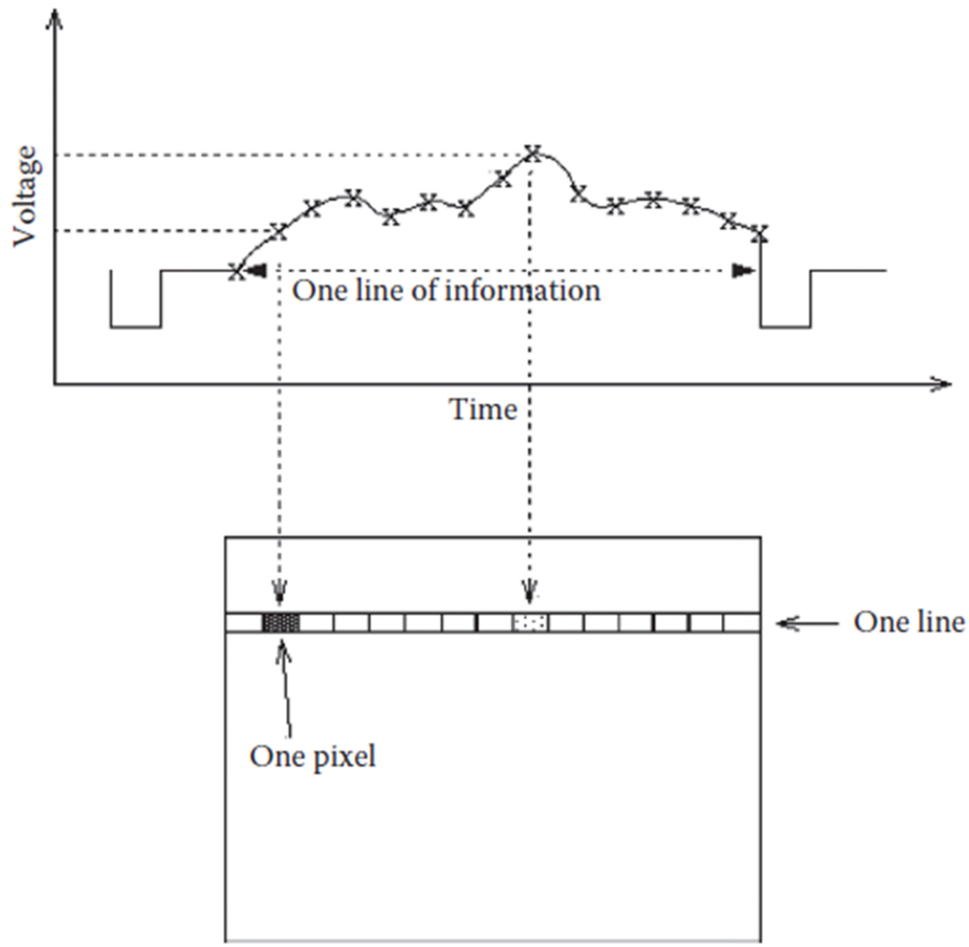
Digital Camera Interfaces

	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 (LAN)	Peer-to-peer, shared bus	Master-slave, shared bus	Point-to-point
Maximum Bandwidth for Images	~10.0 Gigabit/sec (Gbs)	~3.2 Gbs	~10 Gbs	~2.0 to 7.0 Gbs
Distance	~100 meters, no limit with switches or fiber	~4.5 meters, ~72 meters with switches, ~200 meters with fiber	~5 meters, ~30 meters with switches	~10 meters
PC Interface	Network	PCI card	PCI card	PCI frame grabber
Wireless support	Yes	No	No	No
Max # of Devices	Unlimited	63	127	1

Analog Video Signal



Digitizing (sampling) an analog video signal

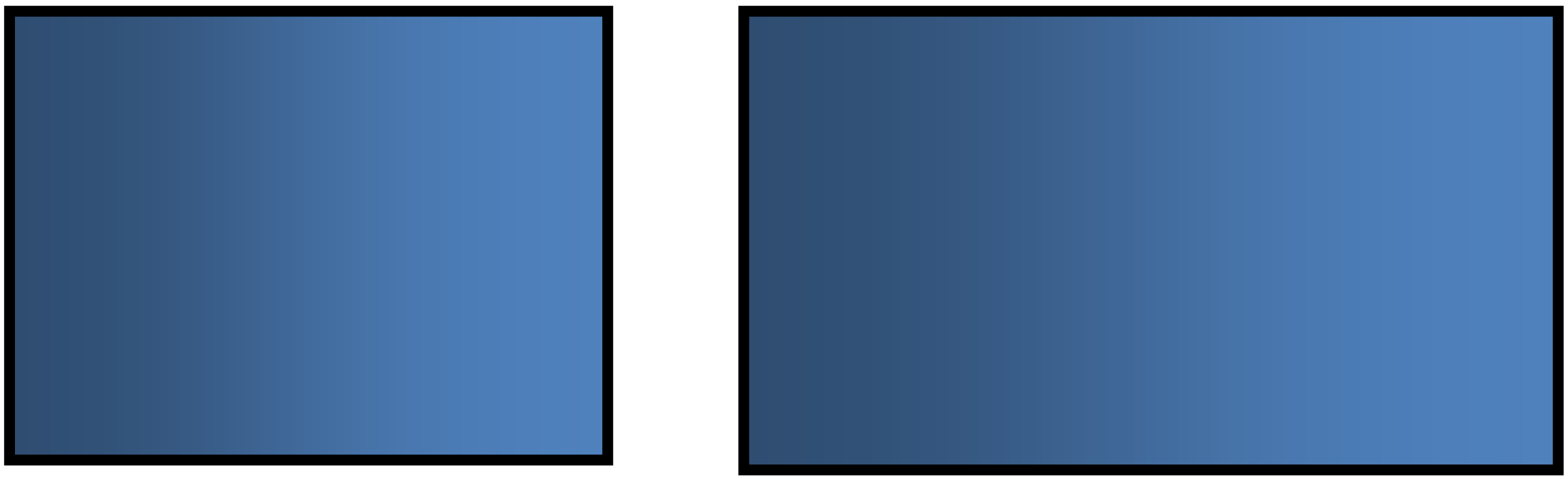


➢ Digitization: transformation of video signal into digital image

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*
- 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)

- 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

The Hierarchical Image Pyramid

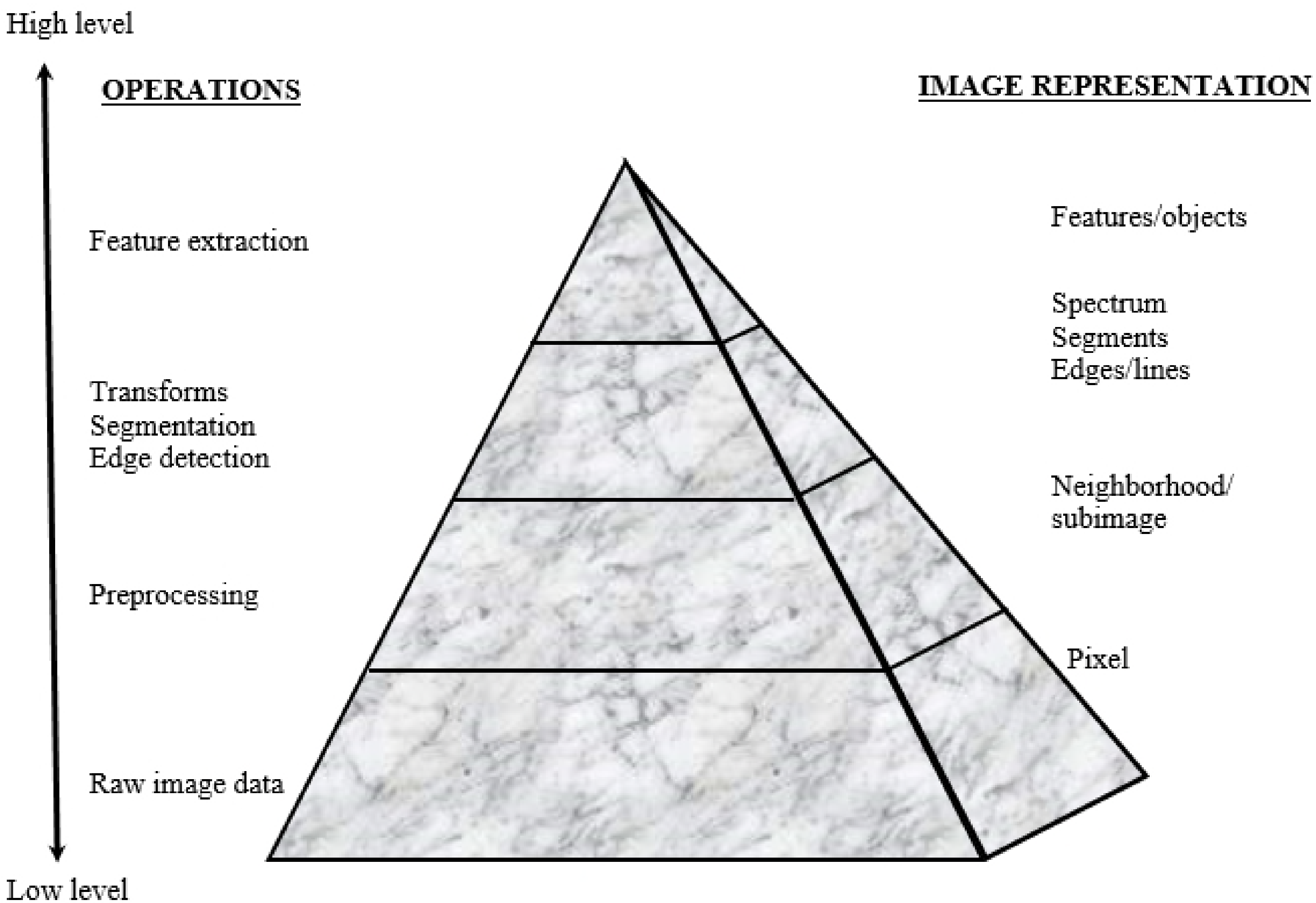
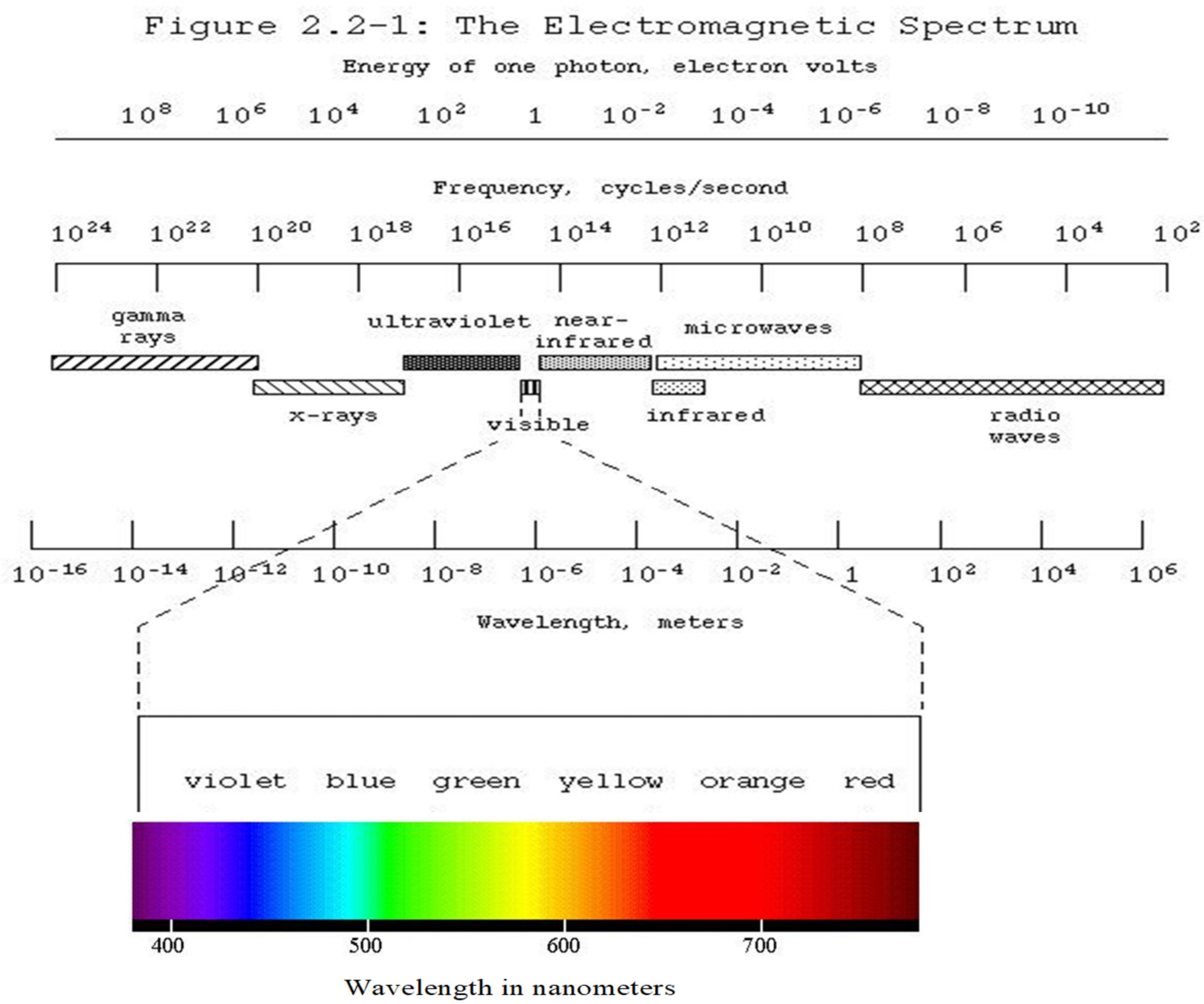


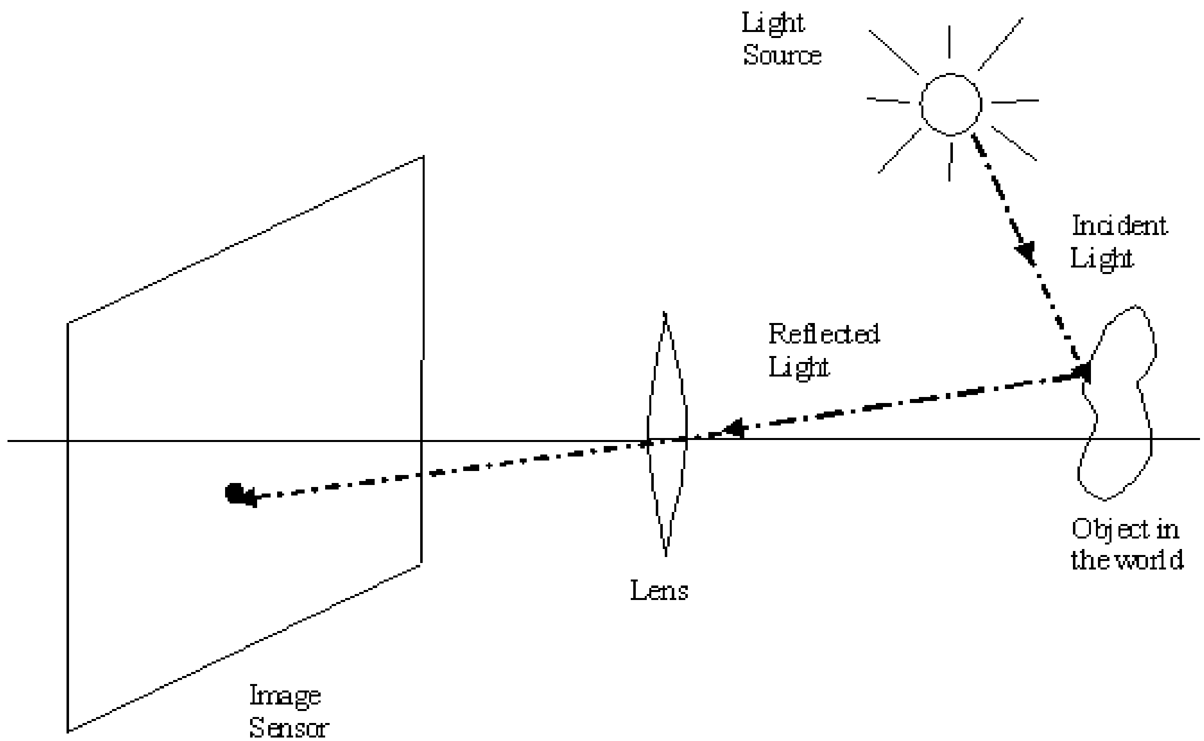
Image Formation and Sensing



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

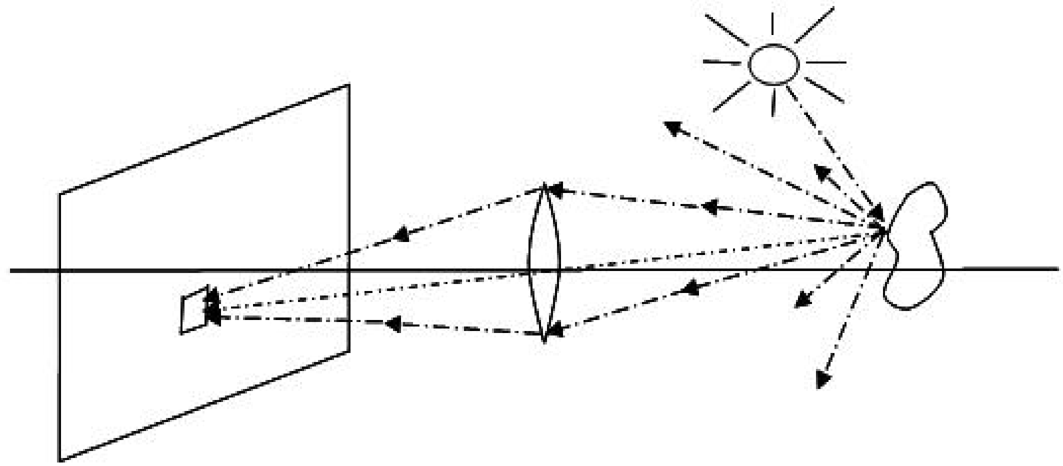


- Reflectance function determines manner in which objects reflect light

The Reflectance Function

- Reflectance function determines an object's appearance
- Texture by light scattering and color by wavelengths reflected and absorbed

- Brightness:



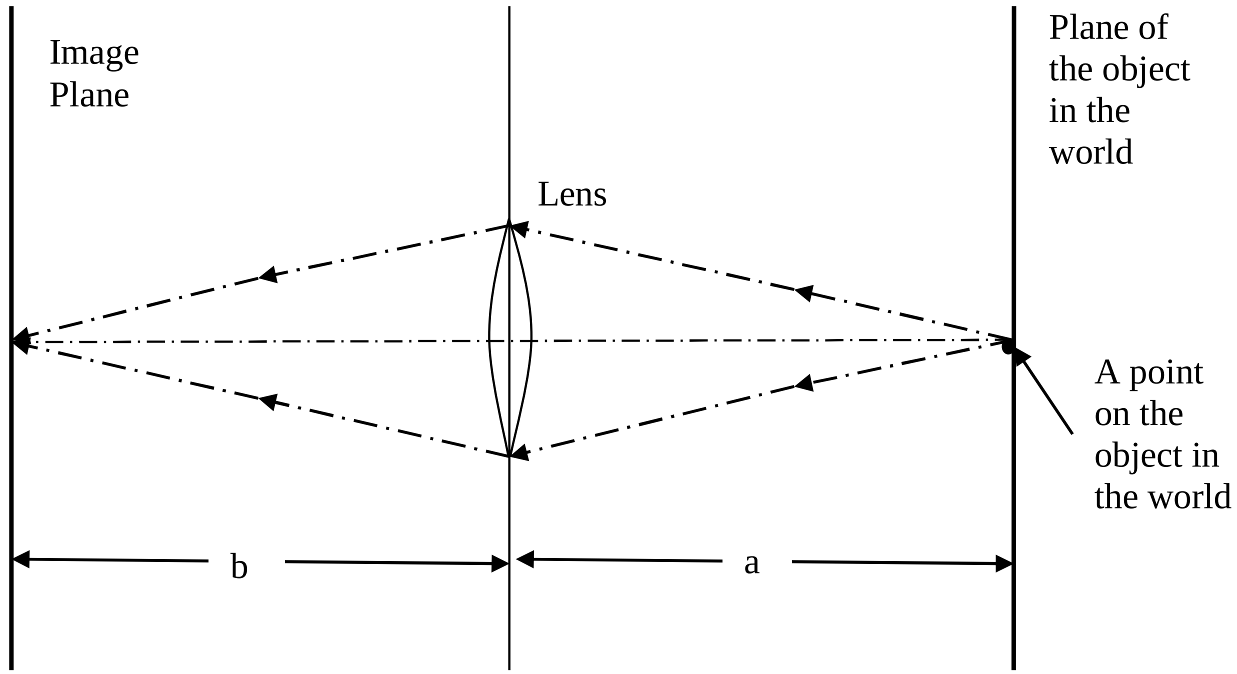
- <u>Irradiance</u> (Image brightness): Amount of light falling on surface, measured by a sensor

  Irradiance = Power / Area

- <u>Radiance</u> (Scene brightness): Amount of light emitted from a surface into a unit solid angle

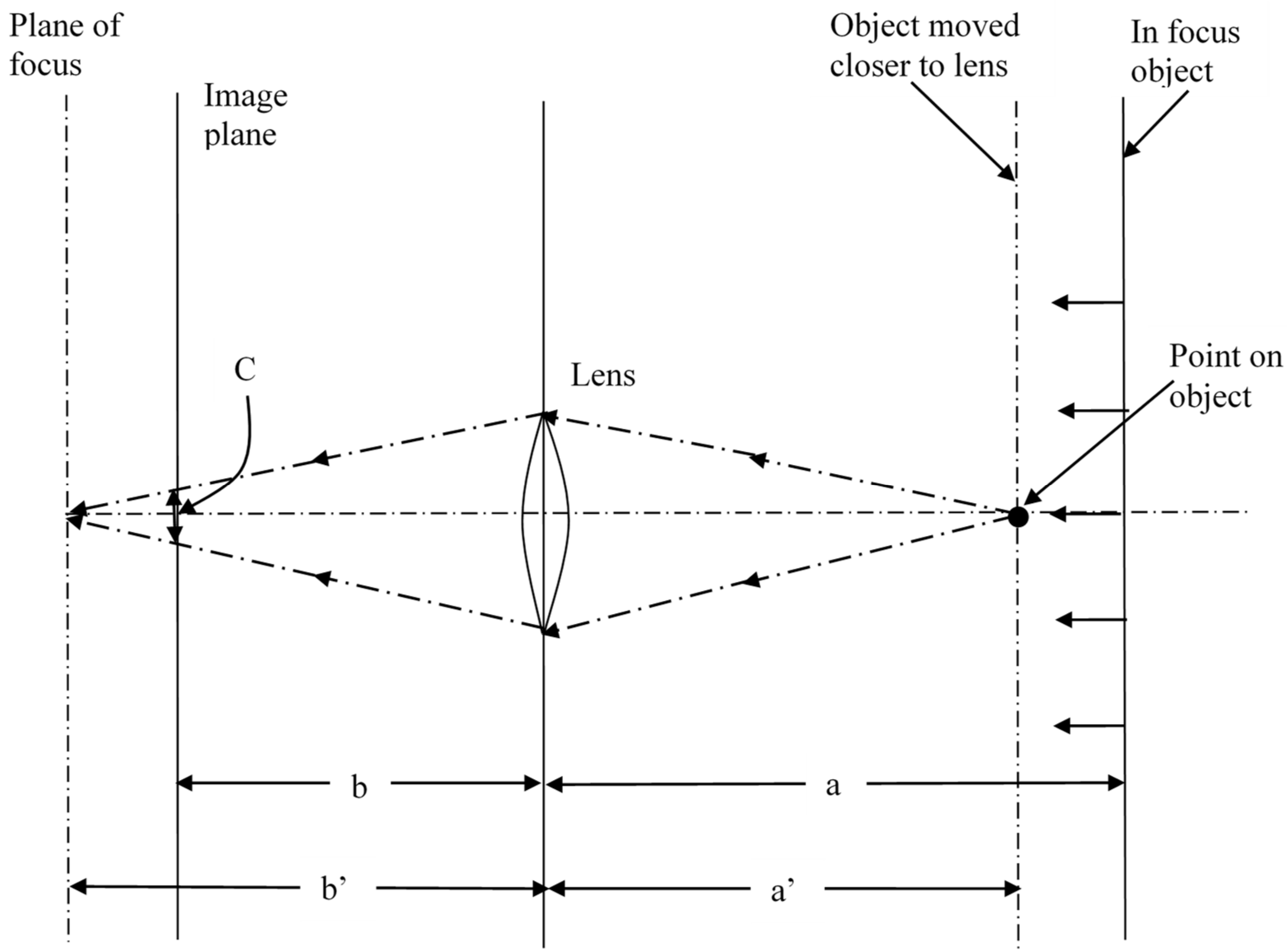
  Radiance = Power/(Area * Solid Angle)

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



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

- Blur equation: $c = (d/b')|b' - b|$



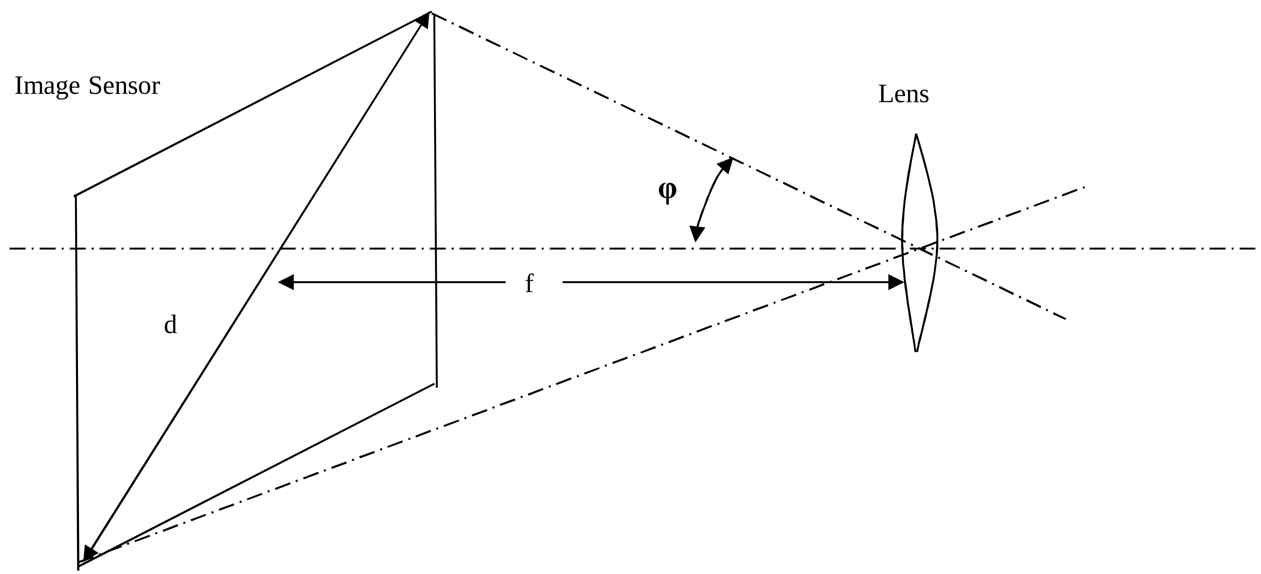
- Depth of field (Depth of focus): Range of distances over which objects are focused sufficiently well (blur circle equal or smaller than device resolution)

  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

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

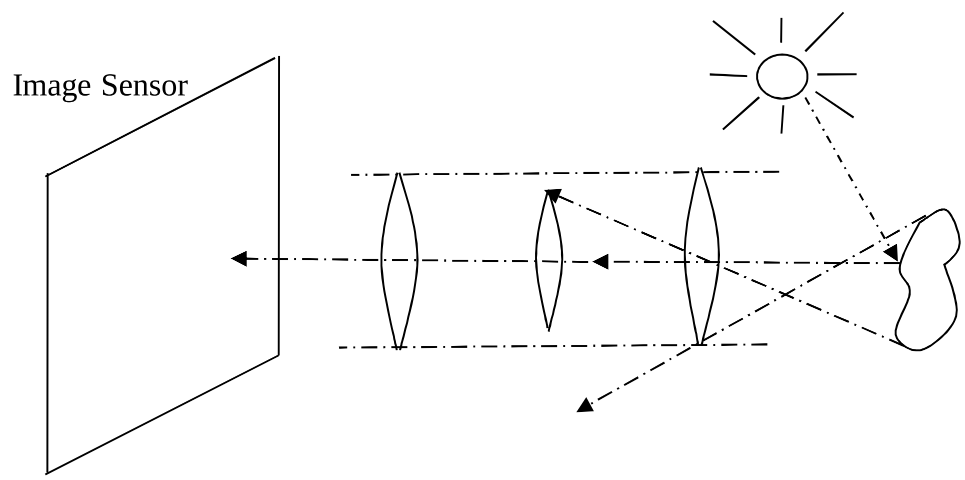


FOV = 2Ø, where Ø = $\tan^{-1}$((d/2)/f)

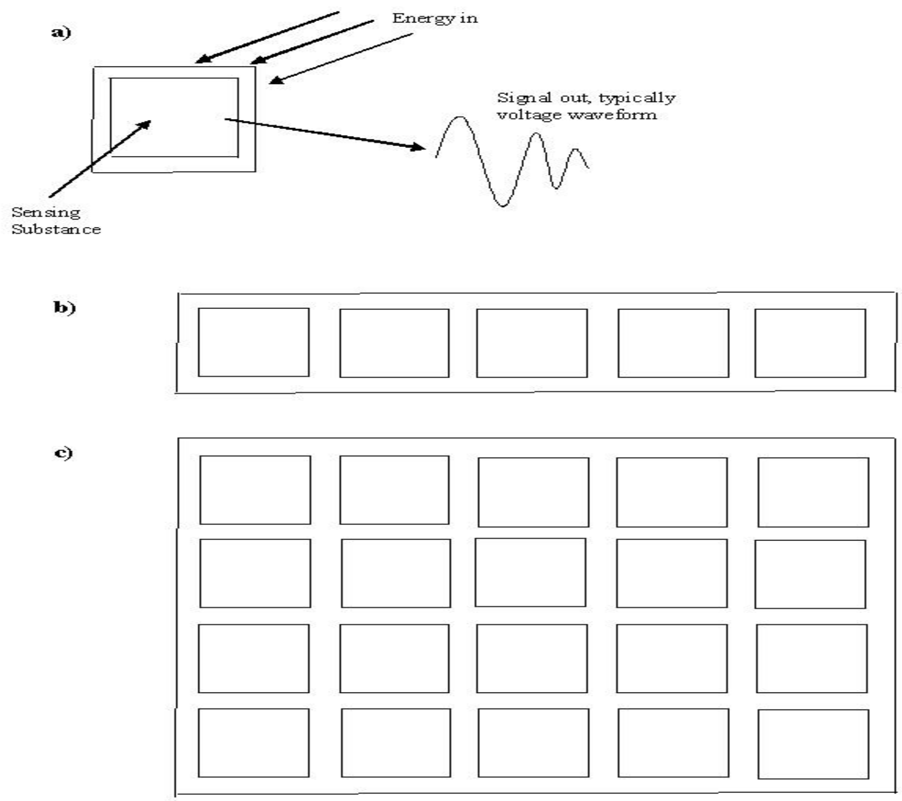
Depends upon focal length of the lens and size of image sensor

- Types of Lenses:
  - <u>Wide Angle lens</u>: Short focal length, FOV greater than 45°
  - <u>Normal lens</u>: Medium focal length, FOV from 25° to 45°
  - <u>Telephoto lens</u>: 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



- Sensors : Converts light energy into electrical energy



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

- ➢ CCD: 9kx9k 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

SMALL CAMERAS

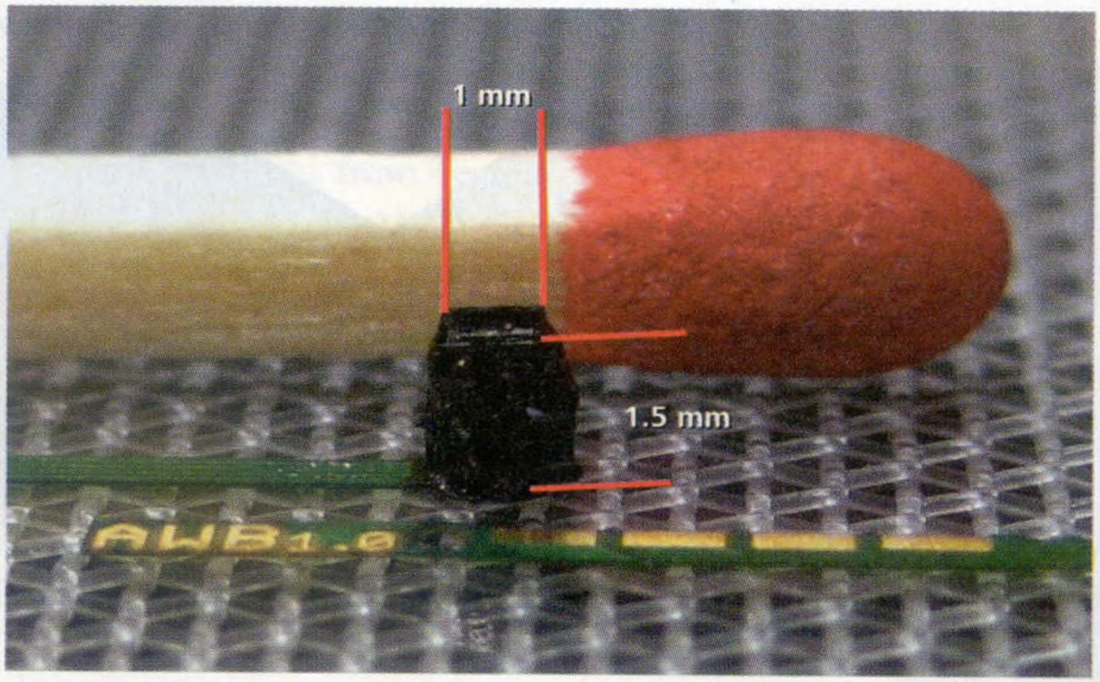
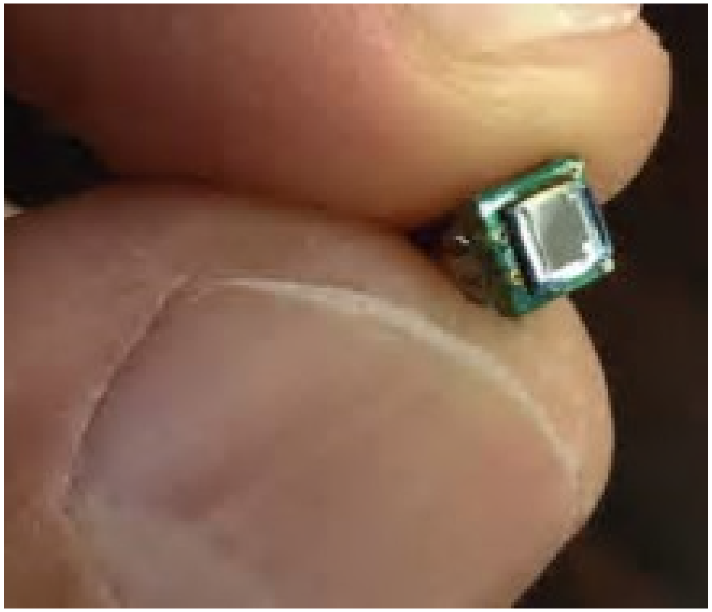


FIGURE 1. In the development of Awaiba's NanEye miniature camera, individual lenses, sensors, and readout electronics are fabricated at the wafer level and then bonded to form a single camera.

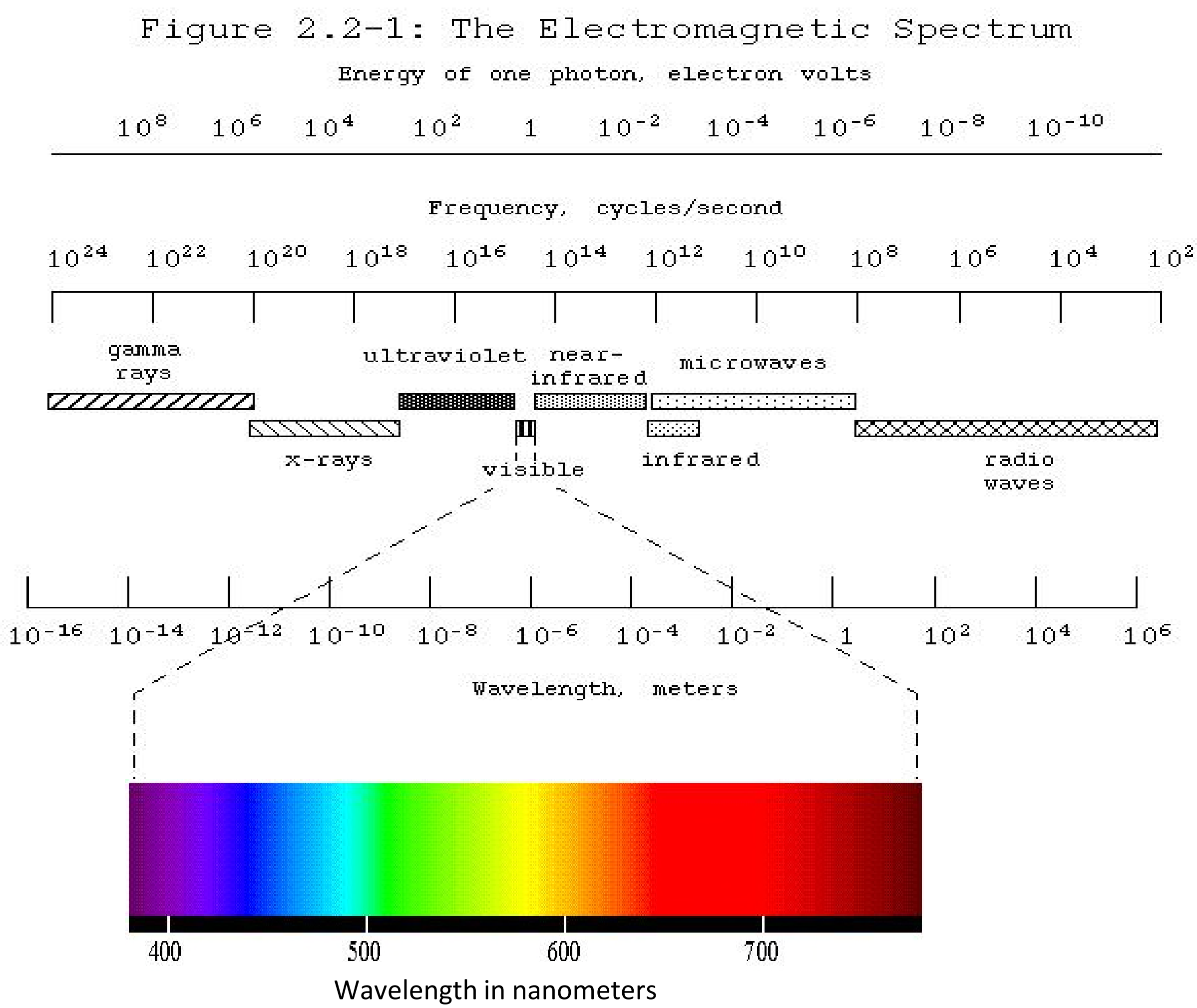
- Source: <u>VISION SYSTEMS DESIGN,</u> November 2010, "Color Camera Cubes", p. 17

Multispectral Sensor Chip

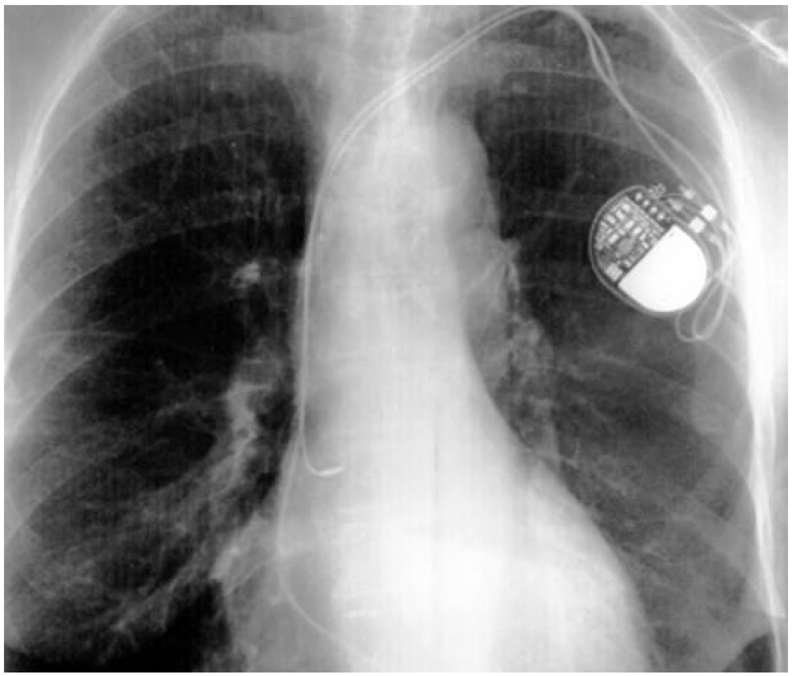


- 2.7×2.7×1.1 mm in size
- Two versions: 1) 385-900 nm, 2) 775-1065 nm
- Manufactured by Viavi Solutions
- Development kit available
- Photonics Spectra, June 2017, p. 36

Imaging Outside the Visible Range of the EM Spectrum



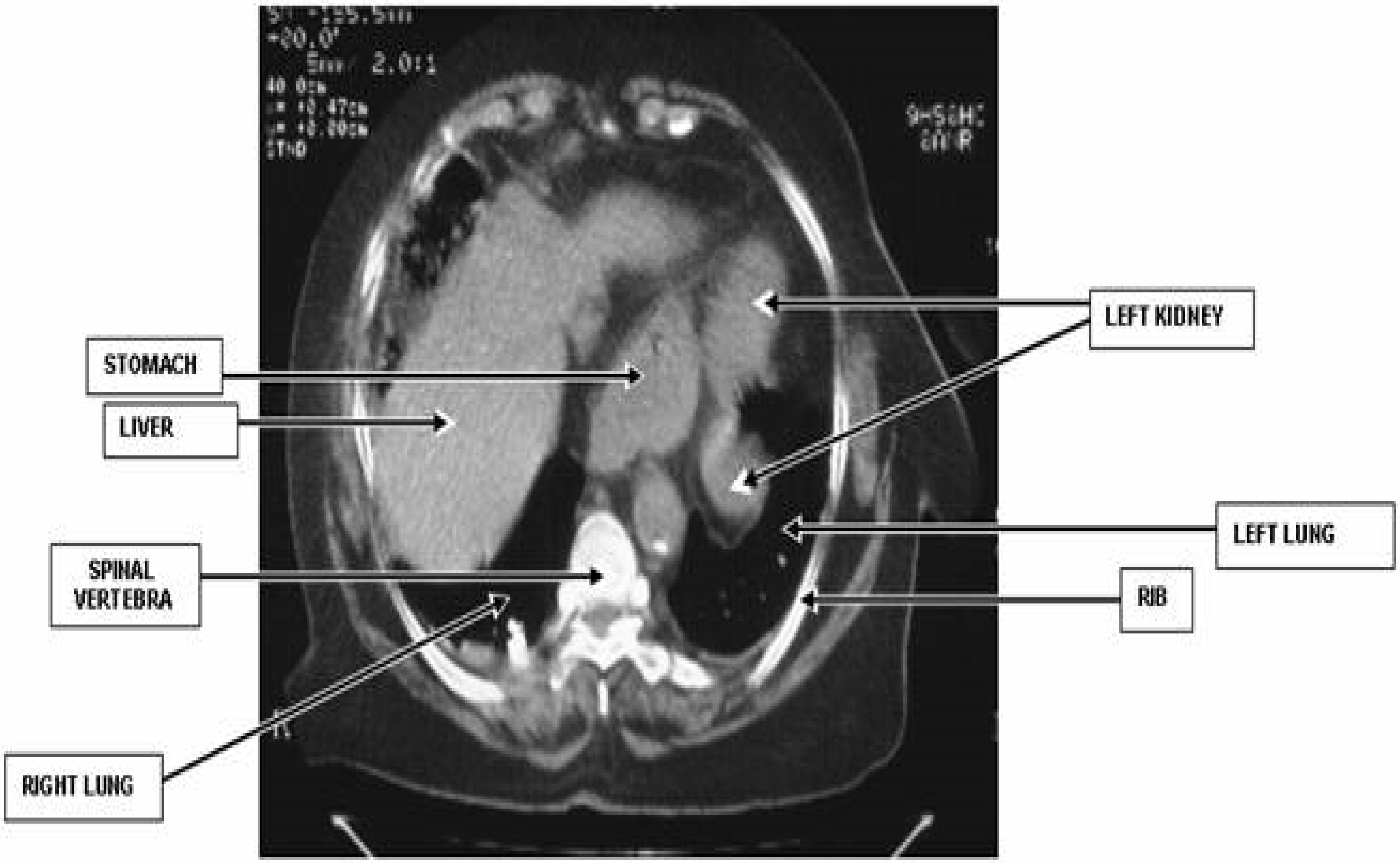
- X-Rays: Used in medical diagnostics and computerized tomography (CT)



Chest X-ray

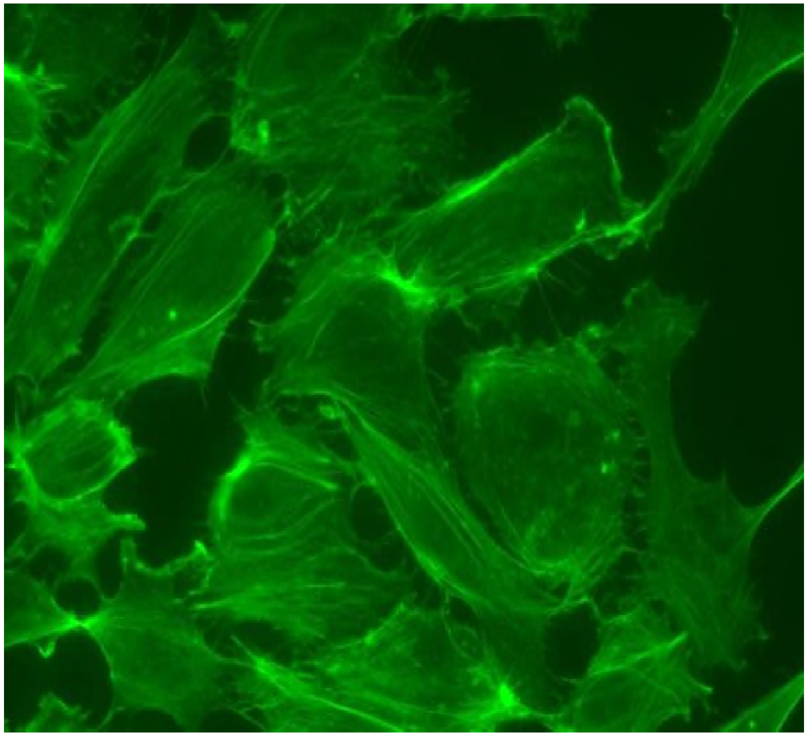
Dental X-ray

➢ Computerized Tomography

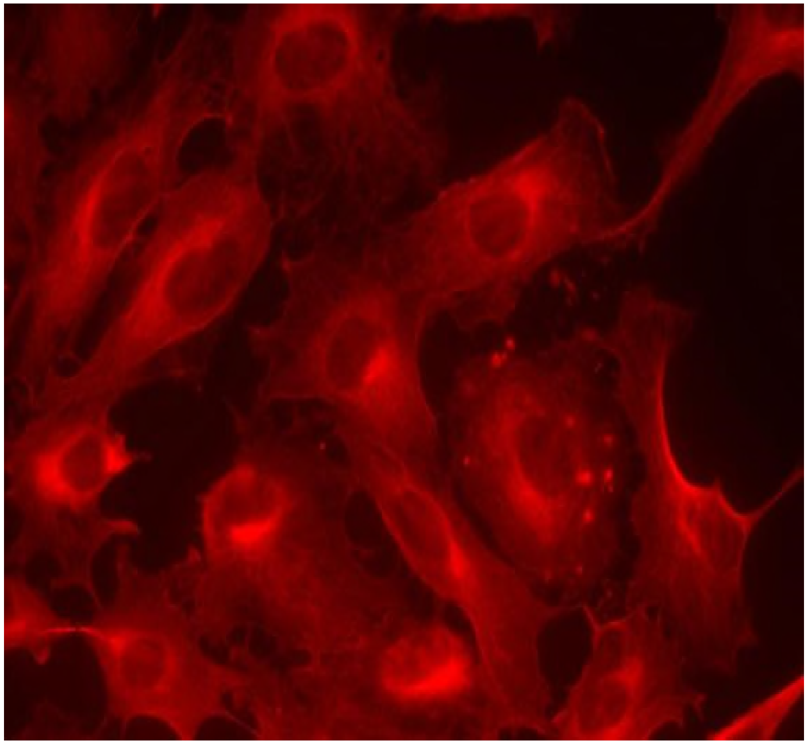


One slice of CT of patient’s abdomen

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

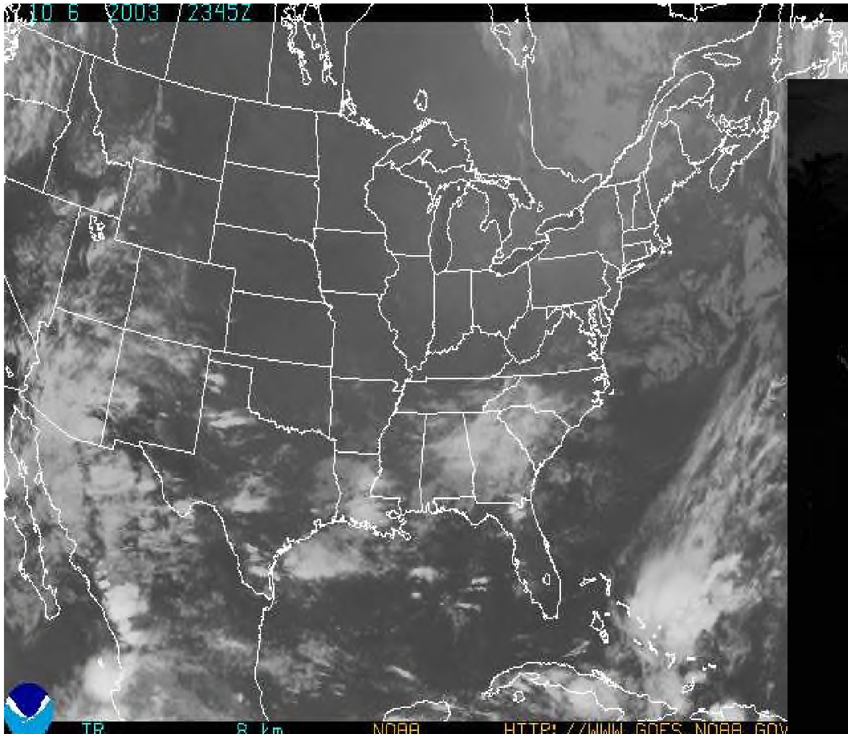


Fluorescence microscopy of cells

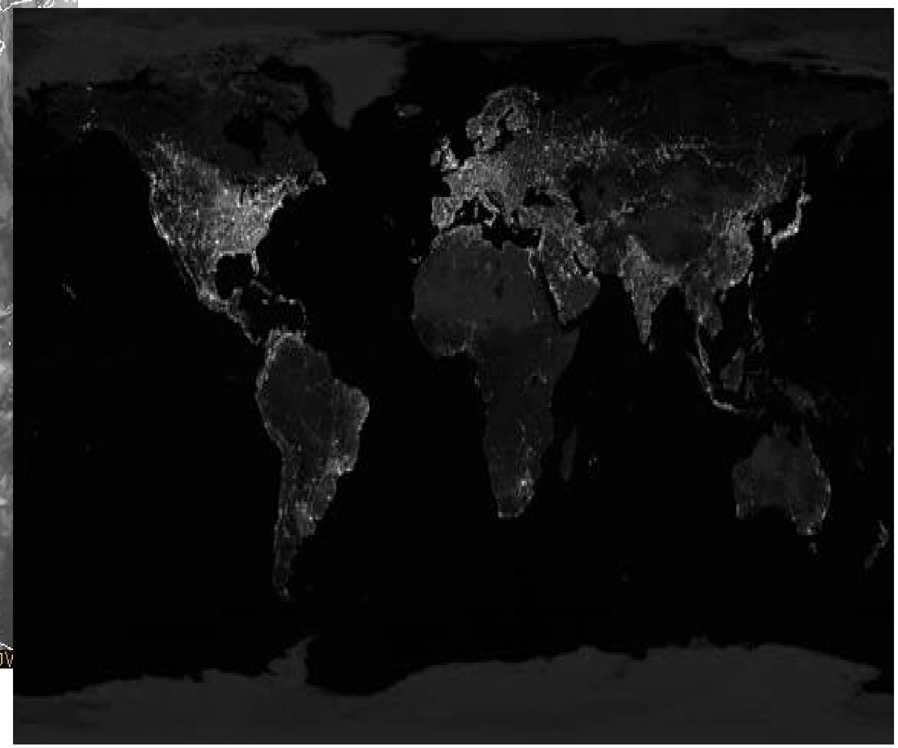


Fluorescence microscopy of cells

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

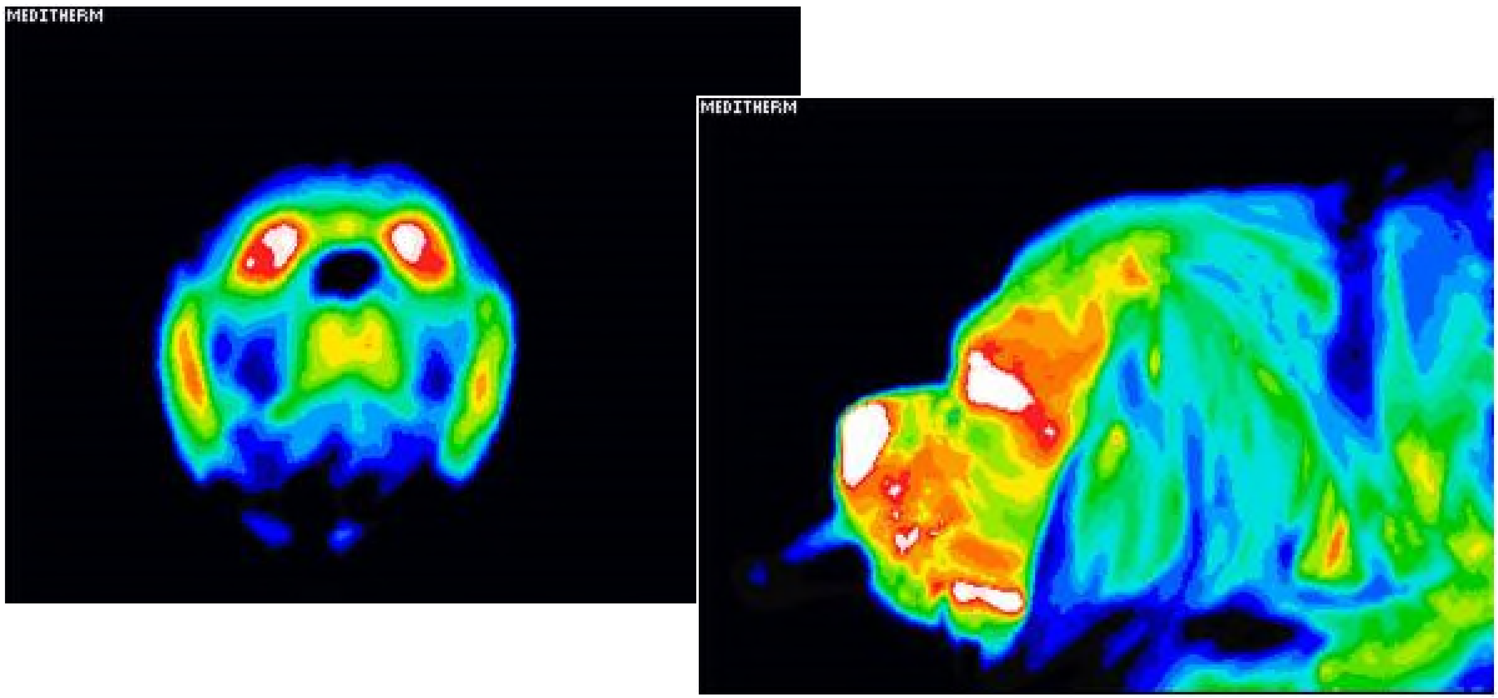


Satellite image showing water vapor



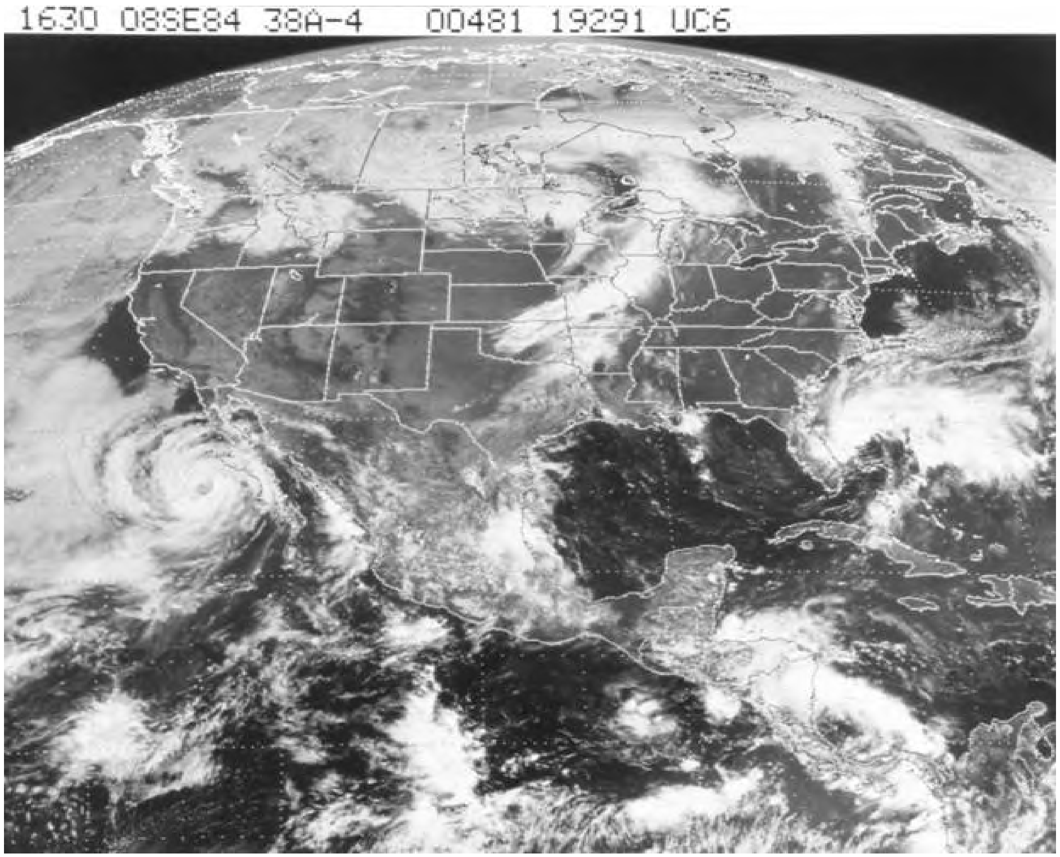
Infrared satellite imagery in the near infrared band

➢<u>Infrared imaging</u> (800nm+): Used in satellite imaging, law enforcement, medical diagnosis and fire detection



Thermographic images used in research for the diagnosis of Chiari malformation, a brain disease, in dogs

➢ Multispectral imaging: Used in weather analysis



GOES image of North America
(Multispectral Geostationary Operational Environment Satellite)

- Microwave images: Used in radar applications, to acquire info through obstacles in any light conditions

- 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

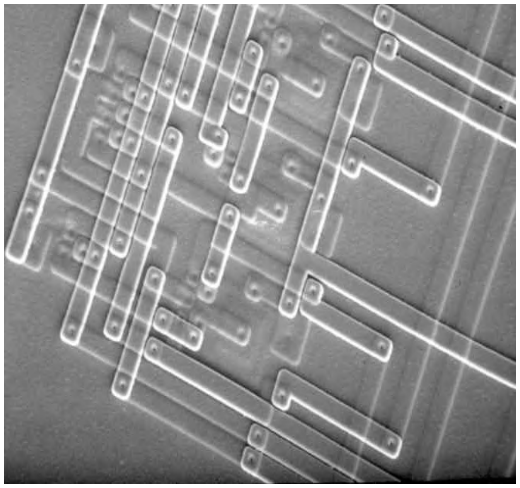
Conventional ultrasound

3-D Ultrasound

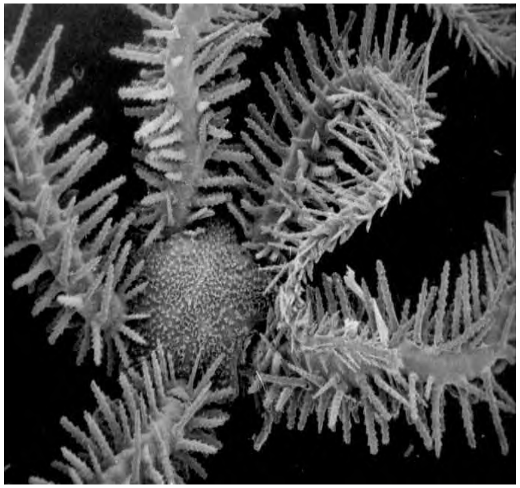
Electron Imaging

- 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



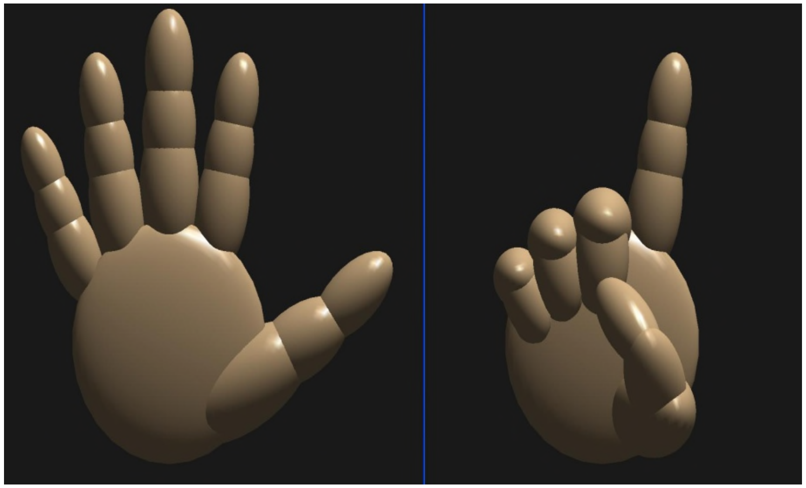
Brittlestar

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 access to 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

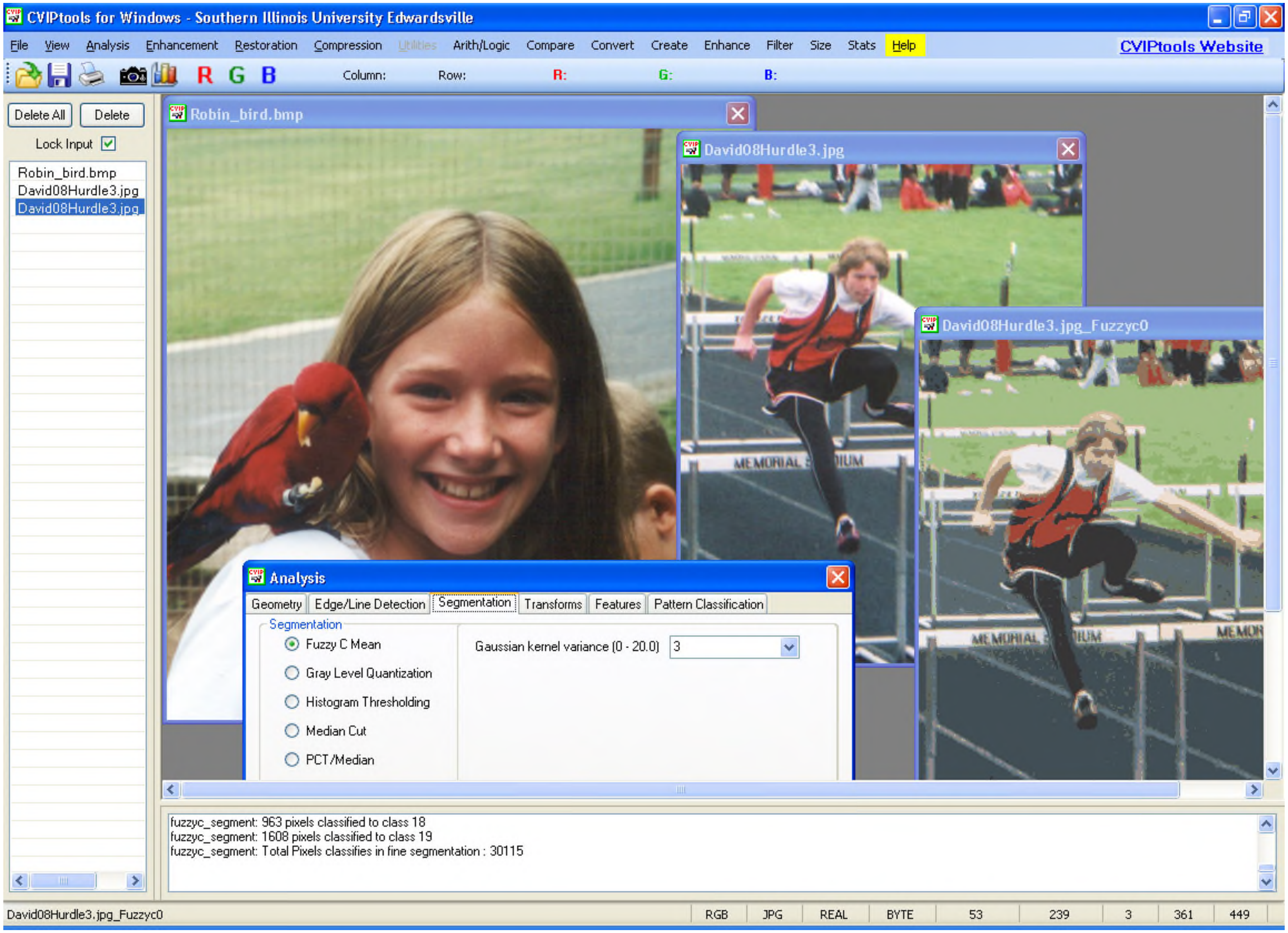
- Loading an image requires clicking on the standard file open icon in the upper left of the main window
- The image is read into the memory and its name appears in the image queue and is displayed in the main window
- Image information shown in the status bar at the bottom of the main window

Image Viewer

- The loaded image is the 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

Viewer Commands

DRAW, MARK, SELECT	Shift key-drag left mouse button	Select rectangular area of image, used in crop, etc
	Control key-drag left mouse button	Select irregular shaped area of image, used in *Utilities->Create->Border Mask* and *Border Image* and *crop*, etc
	Control key-click left mouse button	Select *Original Image* for *Analysis->Features*
	Control-A	Select entire image for copy/paste
	Control-C	If image has area currently selected, copy area to clipboard – this is used for copying images into documents Else, if image has current mesh (from *Restoration->Geometric Transforms)*, copy mesh to clipboard
	Control-V	If mesh (from *Restoration->Geometric Transforms)* is available on clipboard, paste mesh to image
	Alt key-click left mouse button	Mark mesh points for *Restoration->Geometric Transforms* for *Enter a new mesh file*; select *Segmented Image* for *Analysis->Features*; select *Second Image* for the *Utility->Arith/Logic* operations; select Green band image for *Utility->Create->Assemble Bands*
	Shift key-click left mouse button	Select Blue band image for *Utility->Create->Assemble Bands*
	Alt key-click left mouse button drag	After a mesh is entered in *Restoration->Geometric Transforms*, this will allow the user to move mesh points
	Right mouse button on image	Mesh display select box (followed by left button to select) Copy/Paste current mesh
	Middle mouse button on image	Removes drawn boxes and borders

Viewer Commands (cont')

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

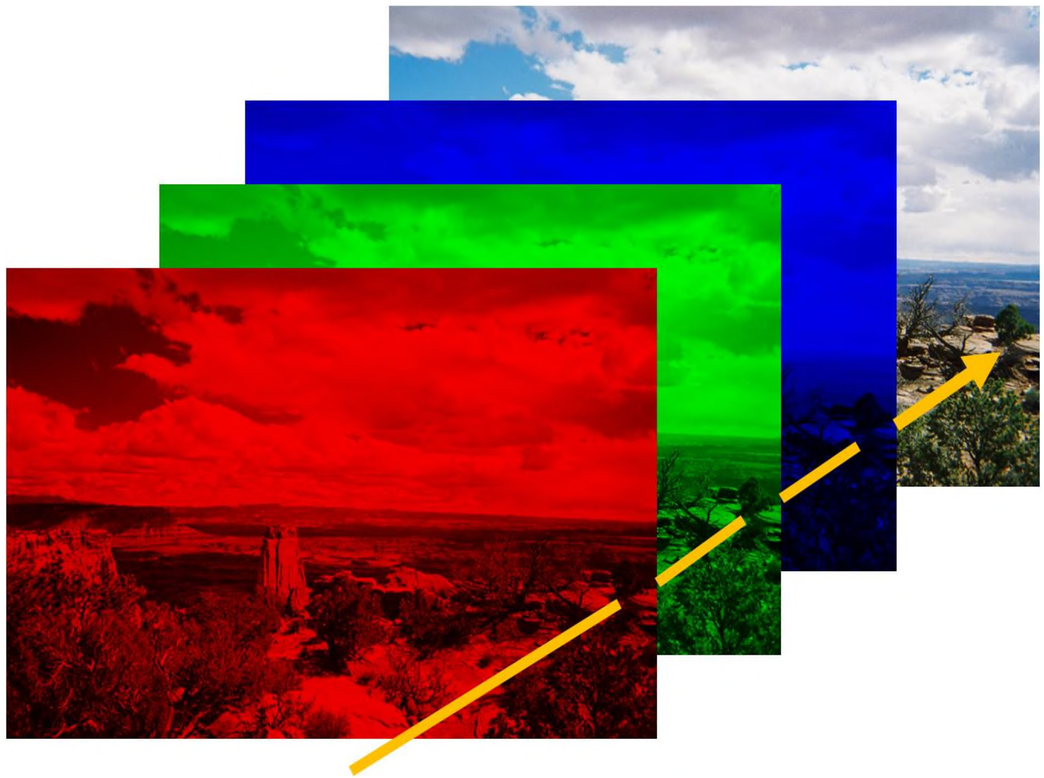
Image Representation

- <u>Optical image</u>: Collection of spatially distributed light energy measured by an image sensor to generate $I(r,c)$
- <u>Matrix</u>: 2-D array corresponding to the image model, $I(r,c)$
- <u>Vector</u>: 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 contain only brightness information and no color information
- Color images: 3 band monochrome images, where each band corresponds to a different color, typically red, green and blue or RGB

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



- Multispectral Images: Images of many bands, which may contain 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), Hue/Saturation/Value (HSV) and Hue/Saturation/Intensity (HSI) Color Transforms:

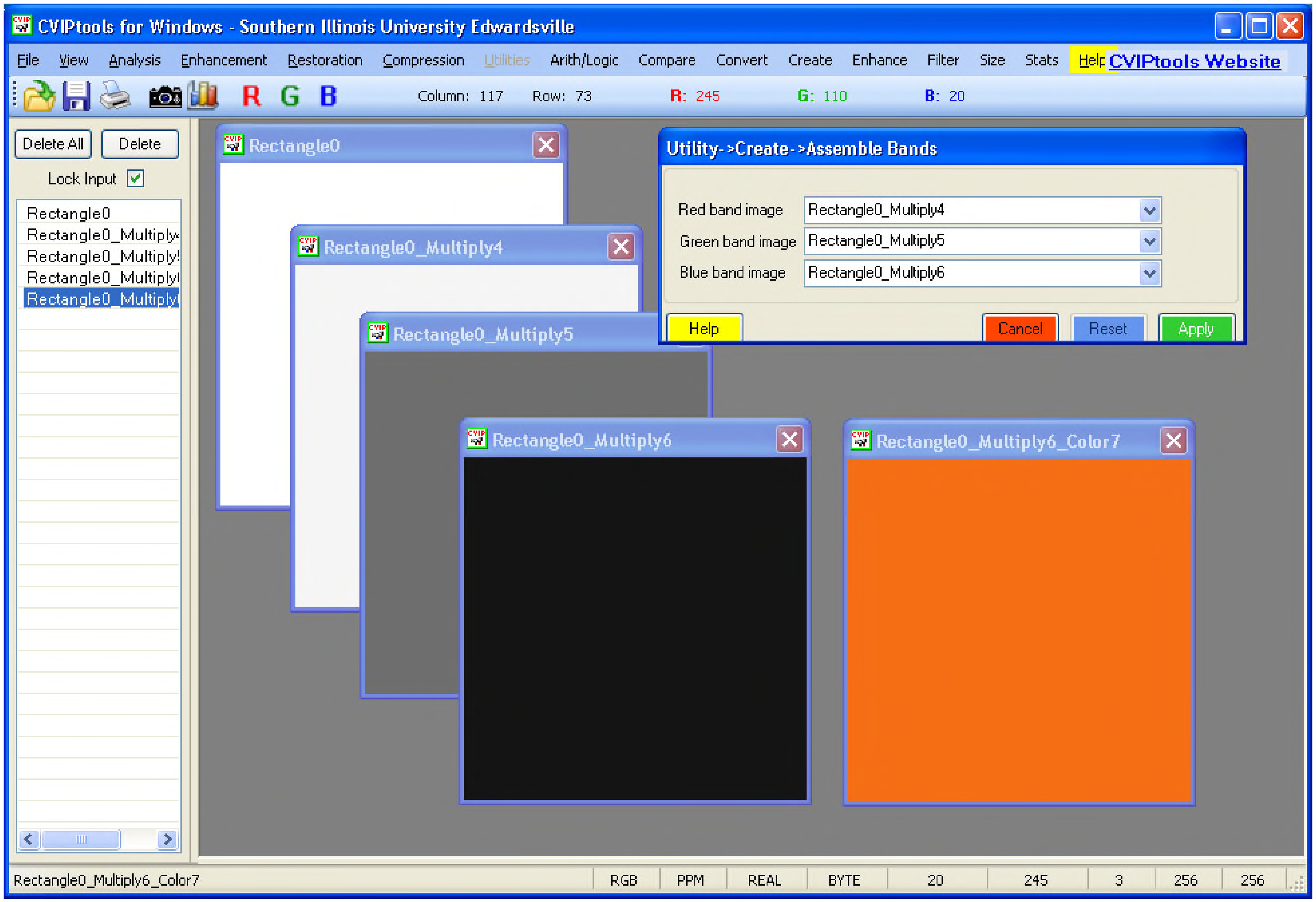
✓ Describes colors in terms that we can more readily understand

- ***Hue*** corresponds to color, ***saturation*** corresponds to the amount of white in color, and ***lightness, intensity*** or ***value*** is the brightness

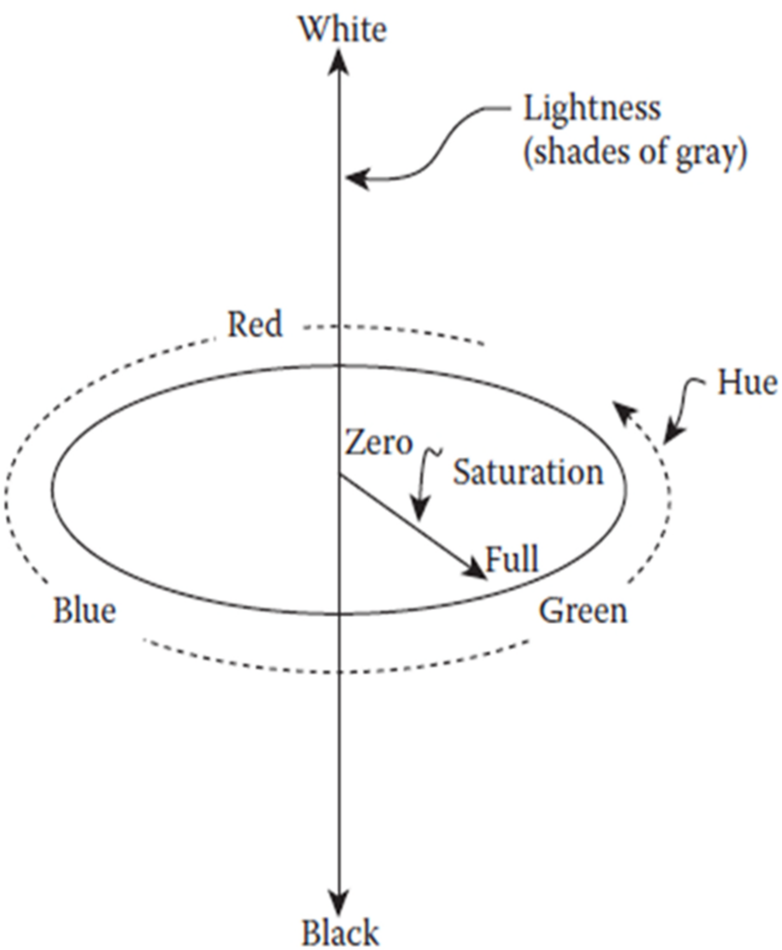
- For example: *a **deep, bright orange*** color would have a large **lightness/intensity/value** (bright), a **hue** of "orange", and a high value of **saturation** ("deep")

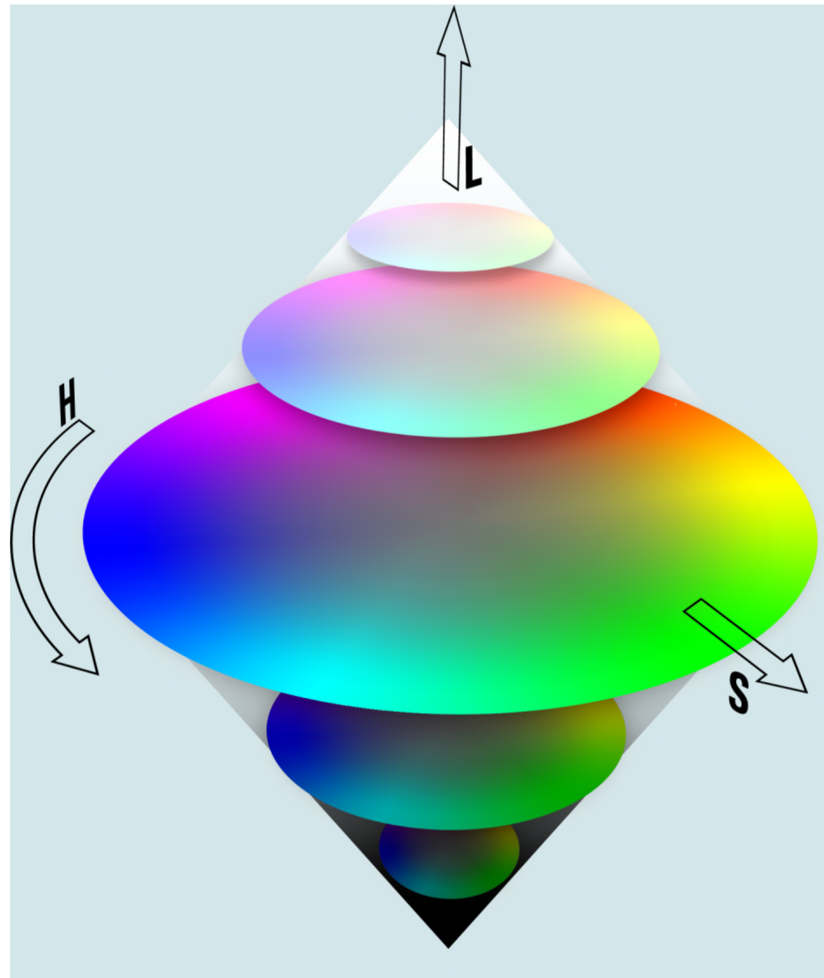
  But in terms of RGB components, this color would have the values as R=245, G=110, and B=20

Creation of Orange Image in CVIPtools

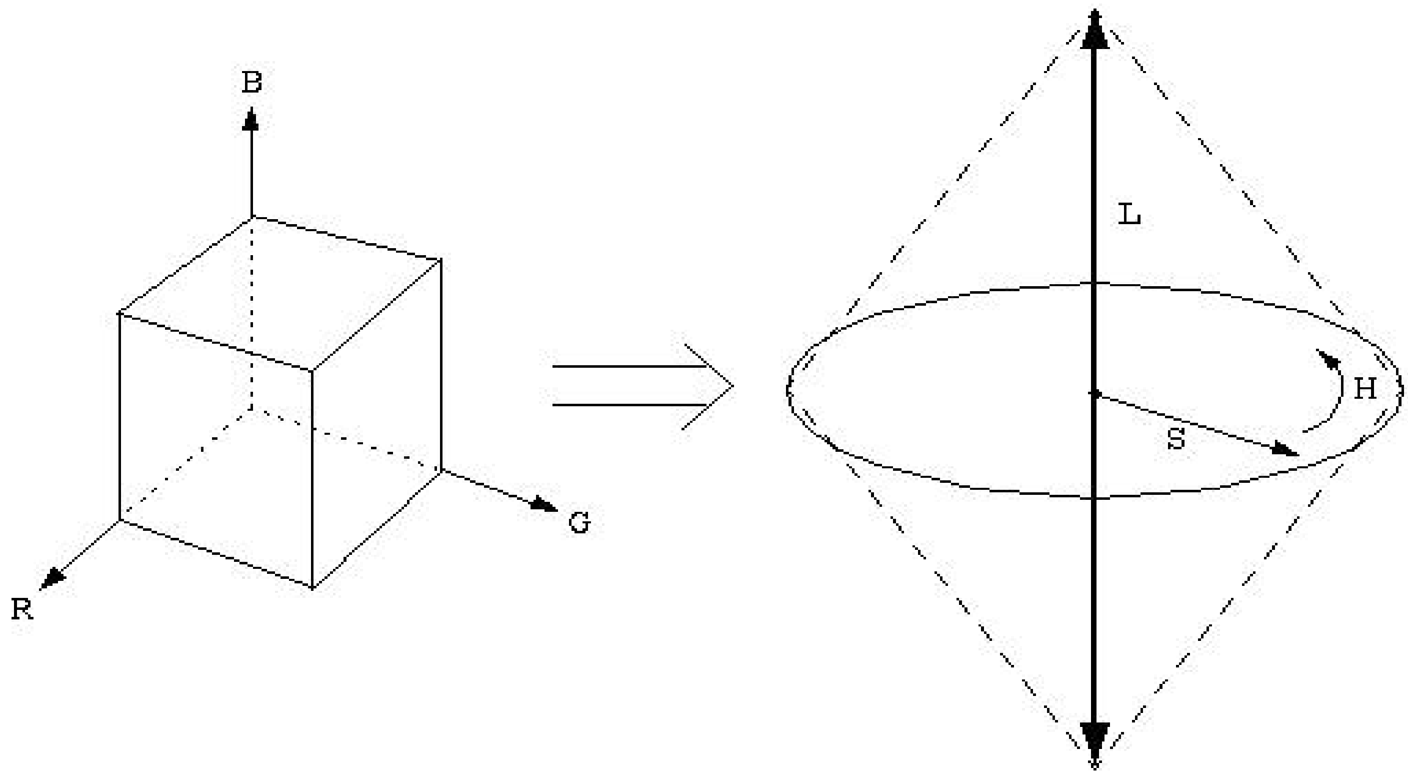


HSL Color Space





RGB to HSL Mapping



RGB color cube

HSL color space

✓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 HSL, HSV and inverse of the equations

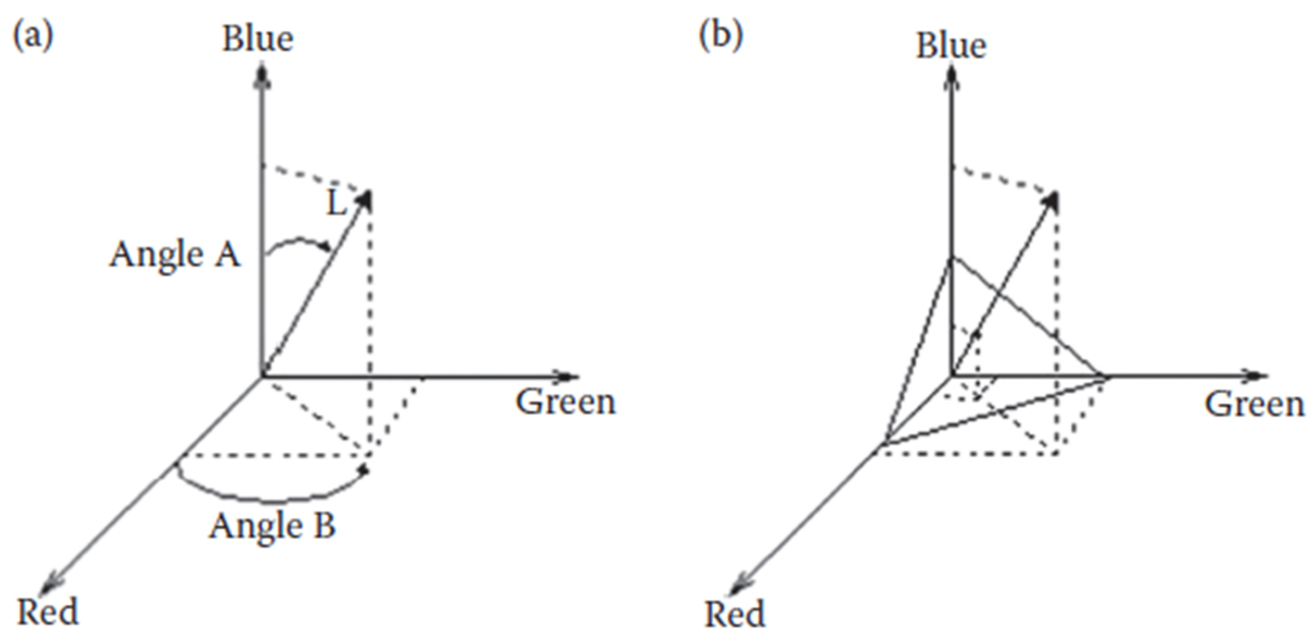
- ➢ Spherical Coordinate Transform (SCT):
- ✓ Maps color information into two angles (A and B), and the brightness into color vector length (L)
- ✓ Equations relating SCT to RGB components are:

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

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

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

Spherical Coordinate Transform



Then SCT represents a color pixel vector by two angles and the vector length

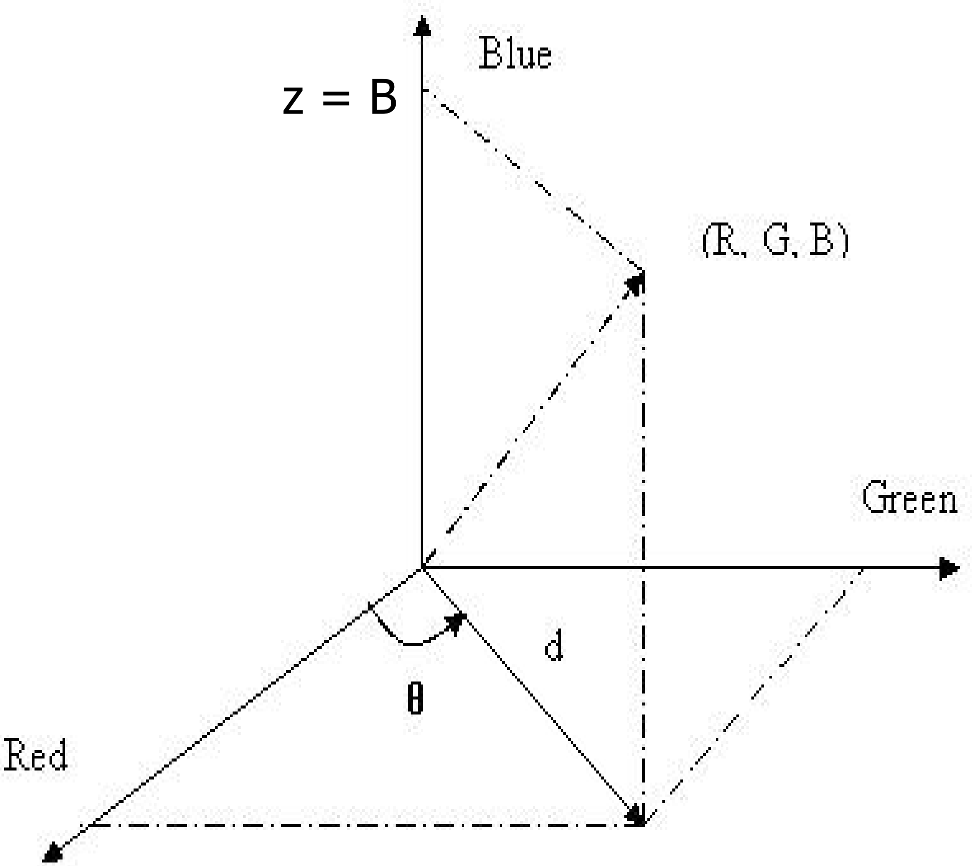
- ➢ Cylindrical coordinate transform (CCT):
- ✓ Does not completely separate brightness and color information
- ✓ Application specific
- ✓ Equations for finding CCT are:

$$z = B$$

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

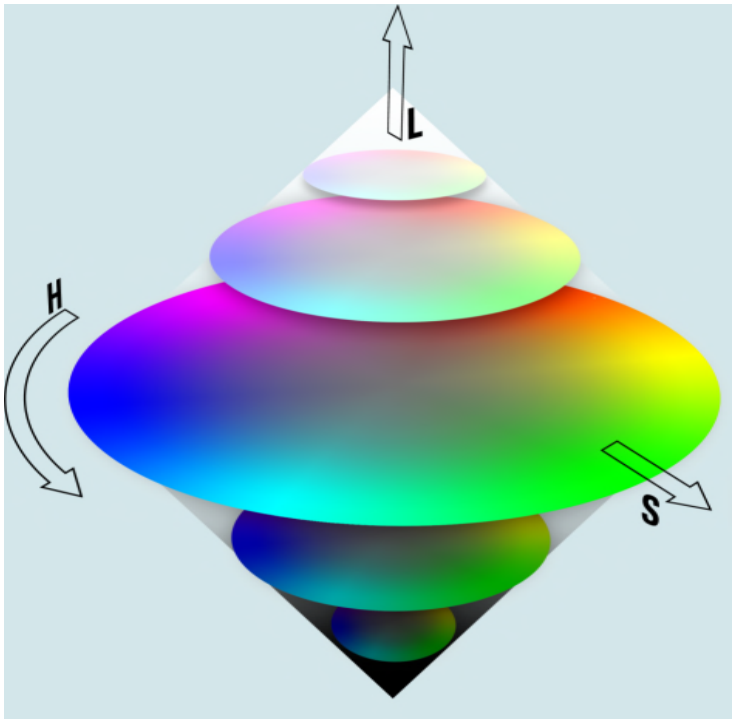
$$\theta = \tan^{-1}\left(\frac{G}{R}\right)$$

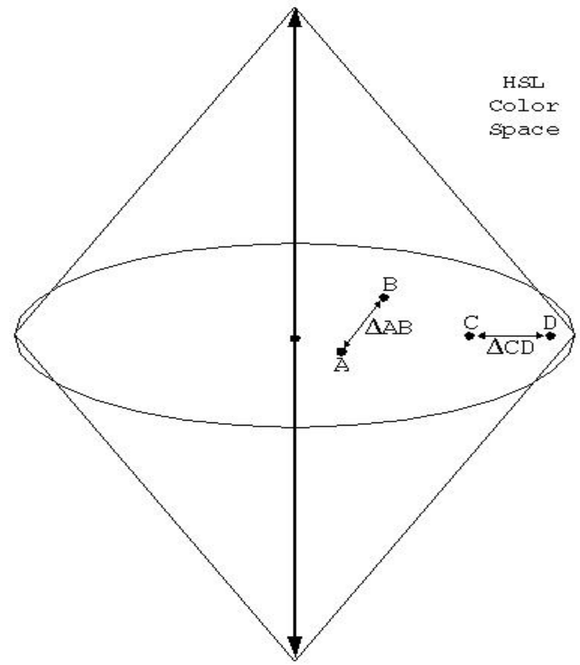
Cylindrical coordinates transform



Then CCT represents a color pixel vector by one angle and two distance measures

- Comparing colors in the previously defined color spaces are not well correlated to human visual perception





Color perception. Color A may be green and color B may be orange. Colors C and D may be slightly different shades green, but ΔCD = ΔAB.

- ➢ Chromaticity coordinates:
- ✓ Normalizes RGB values to the sum of all three
- ✓ Chromaticity coordinates are:

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

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

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

- ➢ CMY (Cyan, Magenta, Yellow)/CMYK:
  - ✓ Color transform based on subtractive model
  - ✓ Used for color printing:
    - o C = 1- R; M = 1 – G ; Y = 1 – B; K = Black
- ➢ 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*

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

- <u>Image file header</u>: 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

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

<u>8-bit Index</u>	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.

- Common image file formats are:
  - ✓ BIN, RAW
  - ✓ PPM,PBM,PGM
  - ✓ BMP
  - ✓ JPEG, JPEG2000
  - ✓ TIFF
  - ✓ GIF
  - ✓ RAS (Sun – old format)
  - ✓ SGI (Silicon Graphics – old format)
  - ✓ PNG
  - ✓ PICT (old Apple format)
  - ✓ EPS
  - ✓ VIP, VIPM

- **Remapping for display.** If data range exceeds the bounds of a standard 8-bit (per band) image, it must be remapped for display. Typically with a linear remapping process. Note that data precision will be lost.