Dr. Md. Al Mamun

Digital Image Processing

First Lecture

Image & Imaging

Human Eye Structure

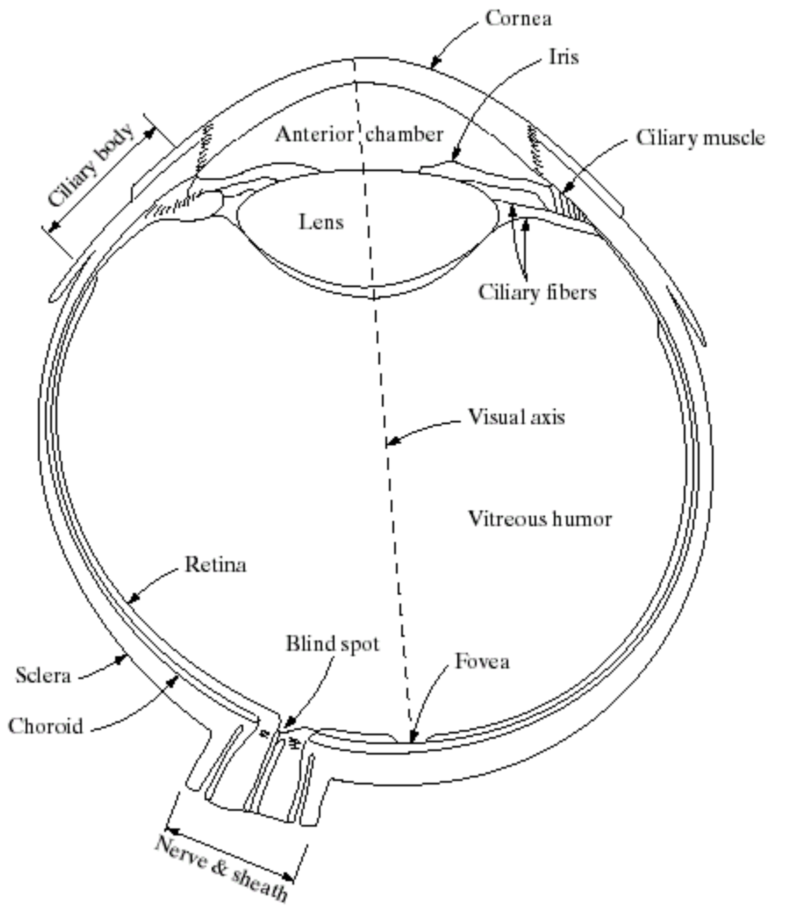
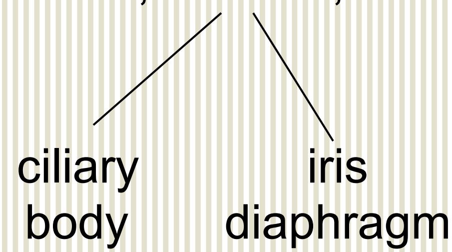


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

Three membranes enclose the eye:
Cornea and sclera, Choroid, Retina



Pupil size: 2-8mm

Eye color: melanin (pigment) in iris

http://en.wikipedia.org/wiki/Evolution_of_the_eye

Retina

- When the eye is properly focused, light from an outside object is imaged on the retina
- Two classes of receptors are located over the surface of retina: cones and rods
  – Cone: 6-7 million in each eye, central part of retina (fovea) and highly sensitive to color
  – Rod: 75-150 million, all over the retina surface and sensitive to low levels of illumination

Rods and Cones in Retina

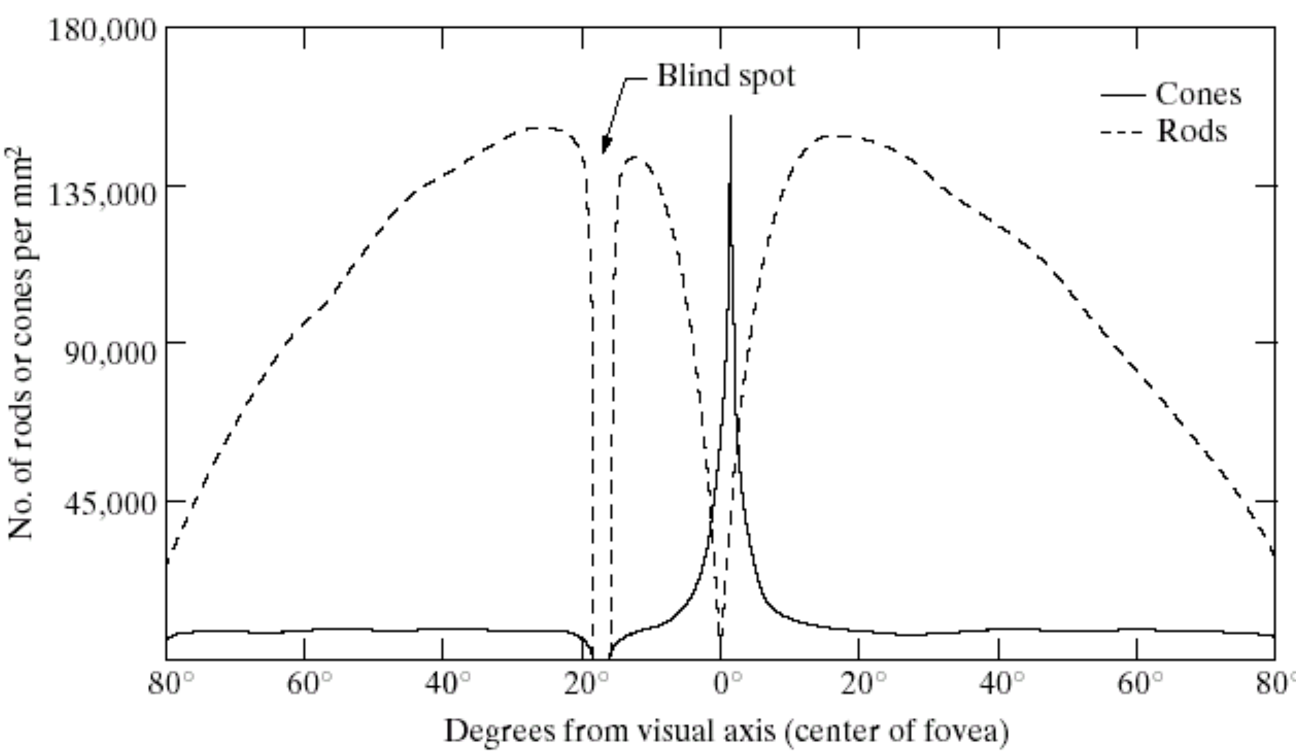
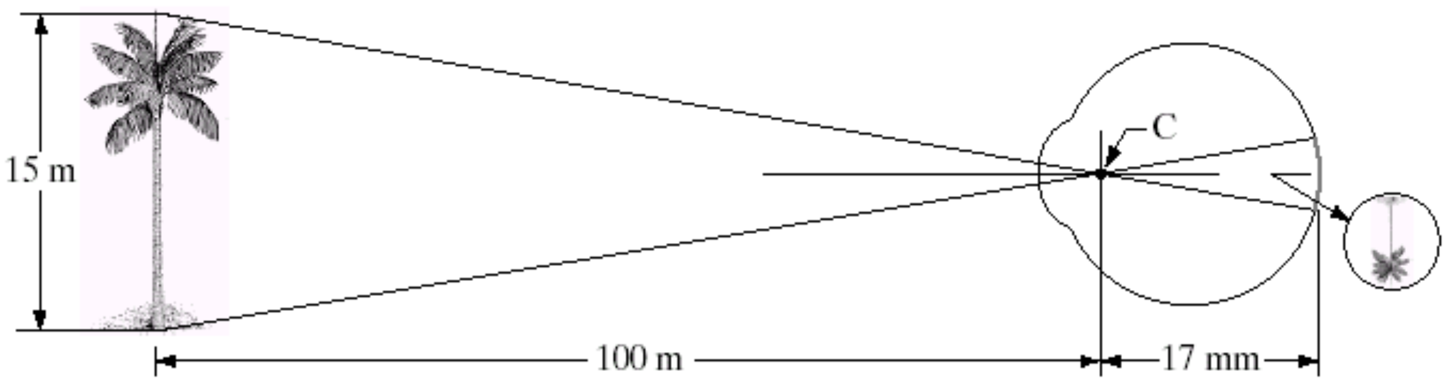


FIGURE 2.2 Distribution of rods and cones in the retina.

Q: Can you see a traffic light turn green while looking away from it?

Image Formation in the Eye

FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.



Focal length: 14-17mm　　　Length of tree image≅2.55mm

For distant objects (>3m), lens exhibits the least refractive power (flattened)

For nearby objects (<1m), lens is most strongly refractive (curved)

Q: What if the image is focused in one eye but not the other (i.e., lazy eye)?

http://en.wikipedia.org/wiki/Amblyopia

Lightness Perception: Objective Quantities

- *Luminance* is the amount of visible light that comes to the eye from a surface.
- *Illuminance* is the amount of light incident on a surface.
- *Reflectance* (also called *albedo*) is the proportion of incident light that is reflected from a surface.
  - varies from 0% to 100% where 0% is ideal black and 100% is ideal white. In practice, typical black paint is about 5% and typical white paint about 85%.

http://www-bcs.mit.edu/people/adelson

Image Formation Model

$$f(x,y)=i(x,y)r(x,y)$$

$0<f(x,y)<\infty$	luminance – proportional to energy radiated by a physical source
$0<i(x,y)<\infty$	Illumination/shading
$0<r(x,y)<1$	reflectance (“intrinsic images”)

Example

f(x,y) r(x,y) i(x,y)

Q: How to separate r(x,y) and i(x,y) from f(x,y)? (Google “intrinsic images”)

Introduction to Grayscale and Color Images

- Image acquisition
  - Light and Electromagnetic spectrum
  - Charge-Coupled Device (CCD) imaging and Bayer Pattern (the most popular color-filter-array)
  - Sampling and Quantization
- Image representation
  - Spatial resolution
  - Bit-depth resolution
  - Local neighborhood
  - Block decomposition

Electromagnetic spectrum

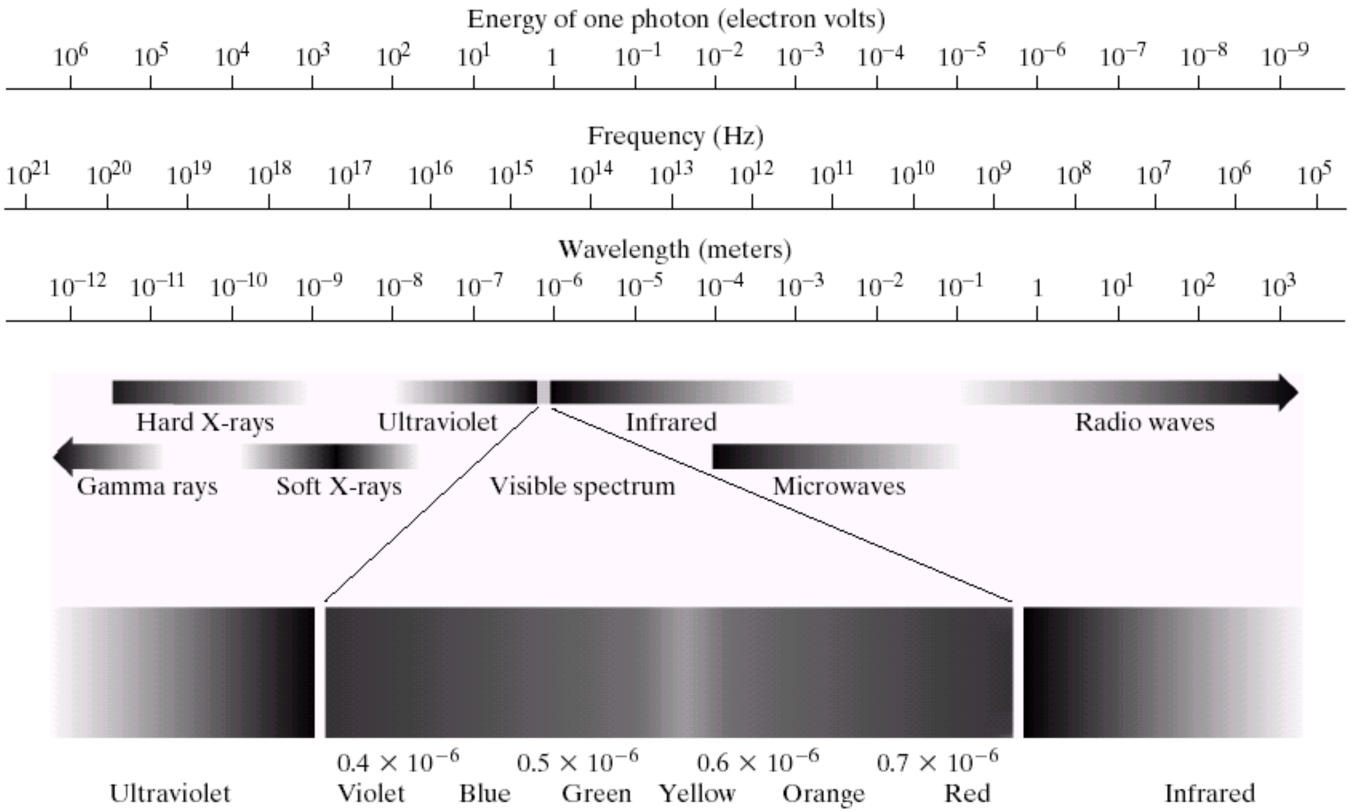


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Light: the Visible Spectrum

- Visible range: 0.43μm(violet)-0.78μm(red)
- Six bands: violet, blue, green, yellow, orange, red
- The color of an object is determined by the nature of the light *reflected* by the object
- Monochromatic light (gray level)
- Three elements measuring chromatic light
  - Radiance, luminance and brightness

Sensor Array: CCD Imaging

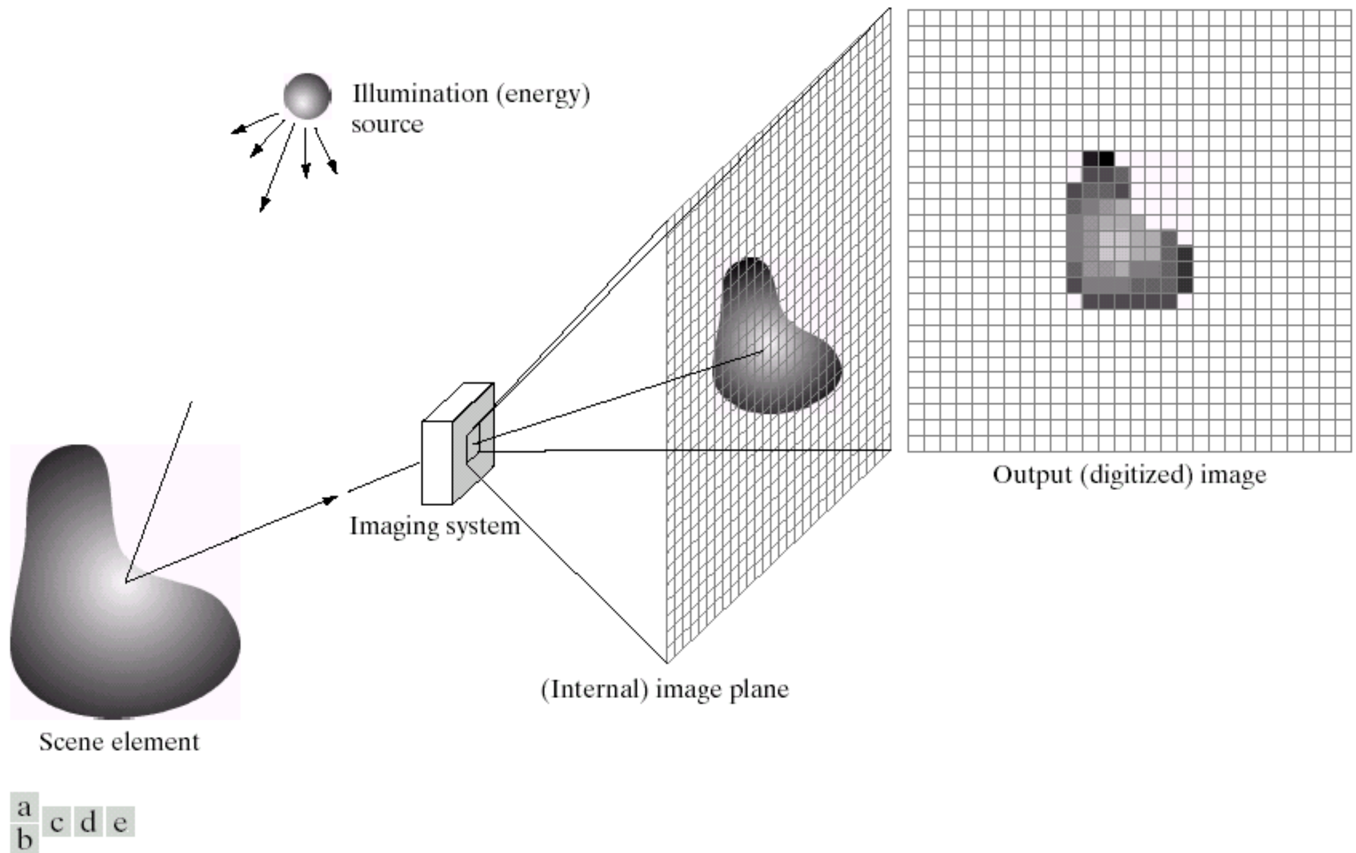
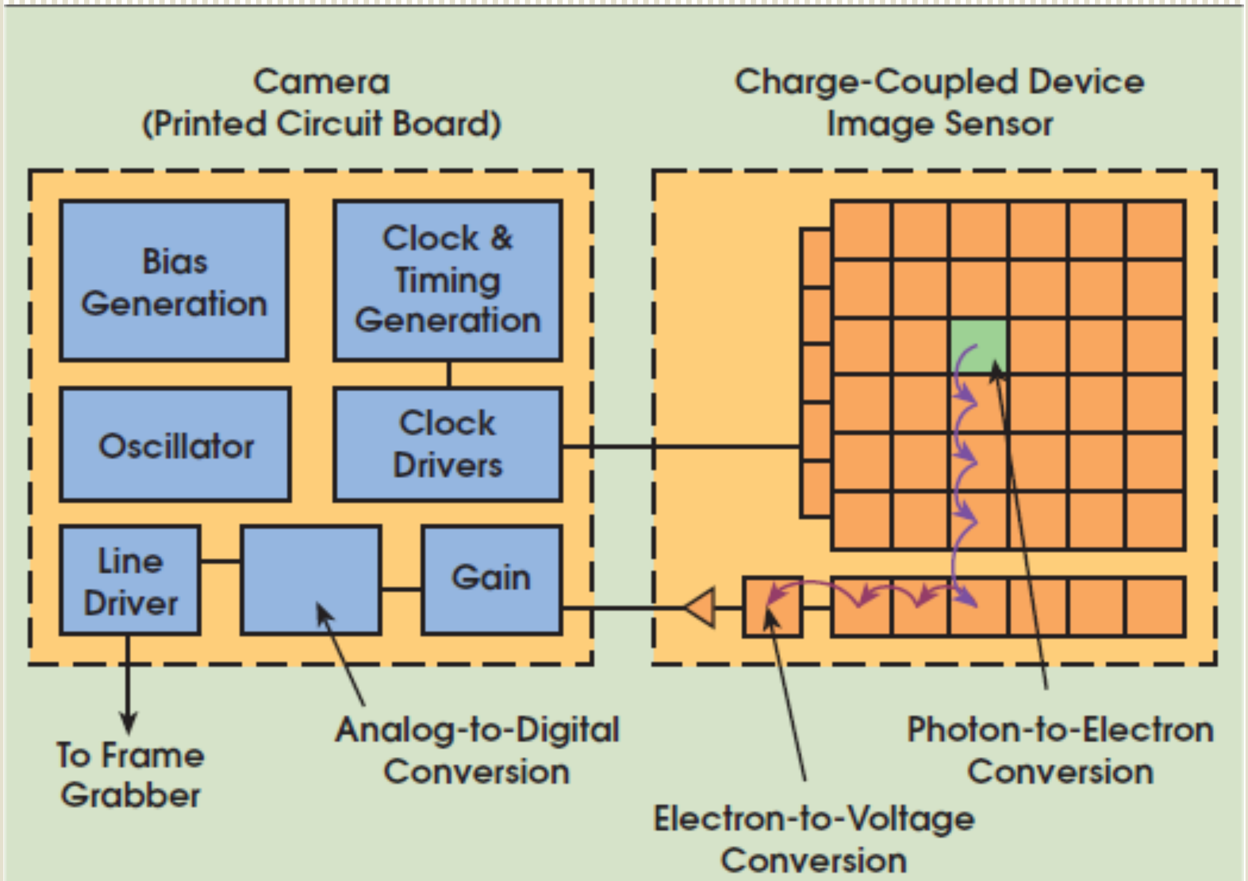


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Charge coupled device (CCD) image sensor



http://en.wikipedia.org/wiki/Charge-coupled_device

The Nobel Prize in Physics 2009

"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"

"for the invention of an imaging semiconductor circuit – the CCD sensor"


Photo: U. Montan

Charles K. Kao

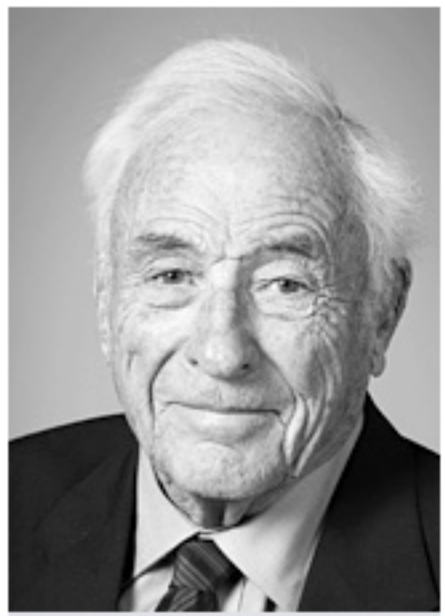


Photo: U. Montan

Willard S. Boyle


Photo: U. Montan

George E. Smith

Complementary Metal Oxide Semiconductor (CMOS) Image Sensor

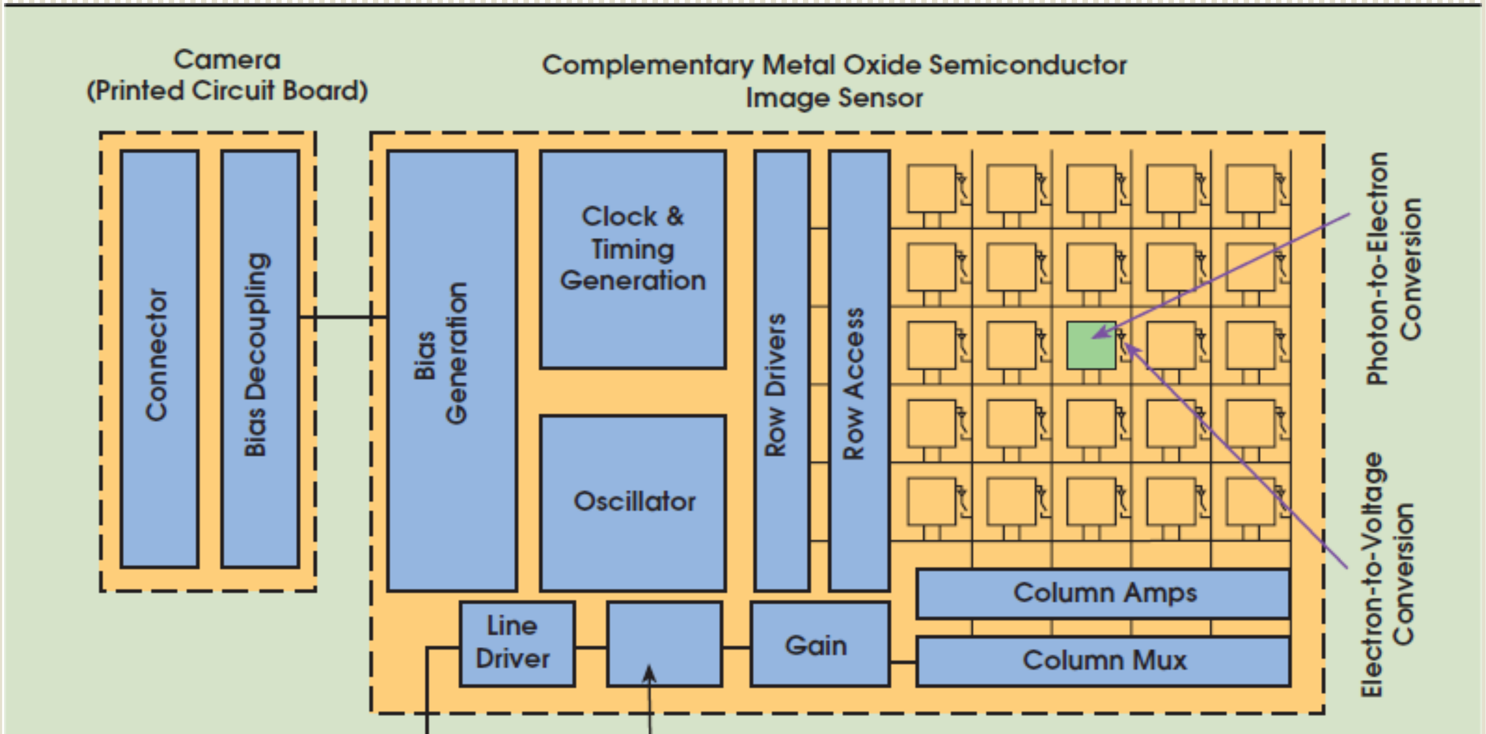


Figure 2. *A CMOS imager converts charge to voltage at the pixel, and most functions are integrated into the*

http://www.dalsa.com/corp/markets/CCD_vs_CMOS.aspx

Image Formation Model

$$f(x,y)=i(x,y)r(x,y)+n(x,y)$$

$0<f(x,y)<\infty$ Intensity – proportional to energy radiated by a physical source

$0<i(x,y)<\infty$ illumination

$0<r(x,y)<1$ reflectance ("intrinsic images")

$n(x,y)$ noise

Some Typical Ranges of Reflectance

- Reflectance
  - 0.01 for black velvet
  - 0.65 for stainless steel
  - 0.80 for flat-white wall paint
  - 0.90 for silver-plated metal
  - 0.93 for snow

Sampling and Quantization: 1D Case

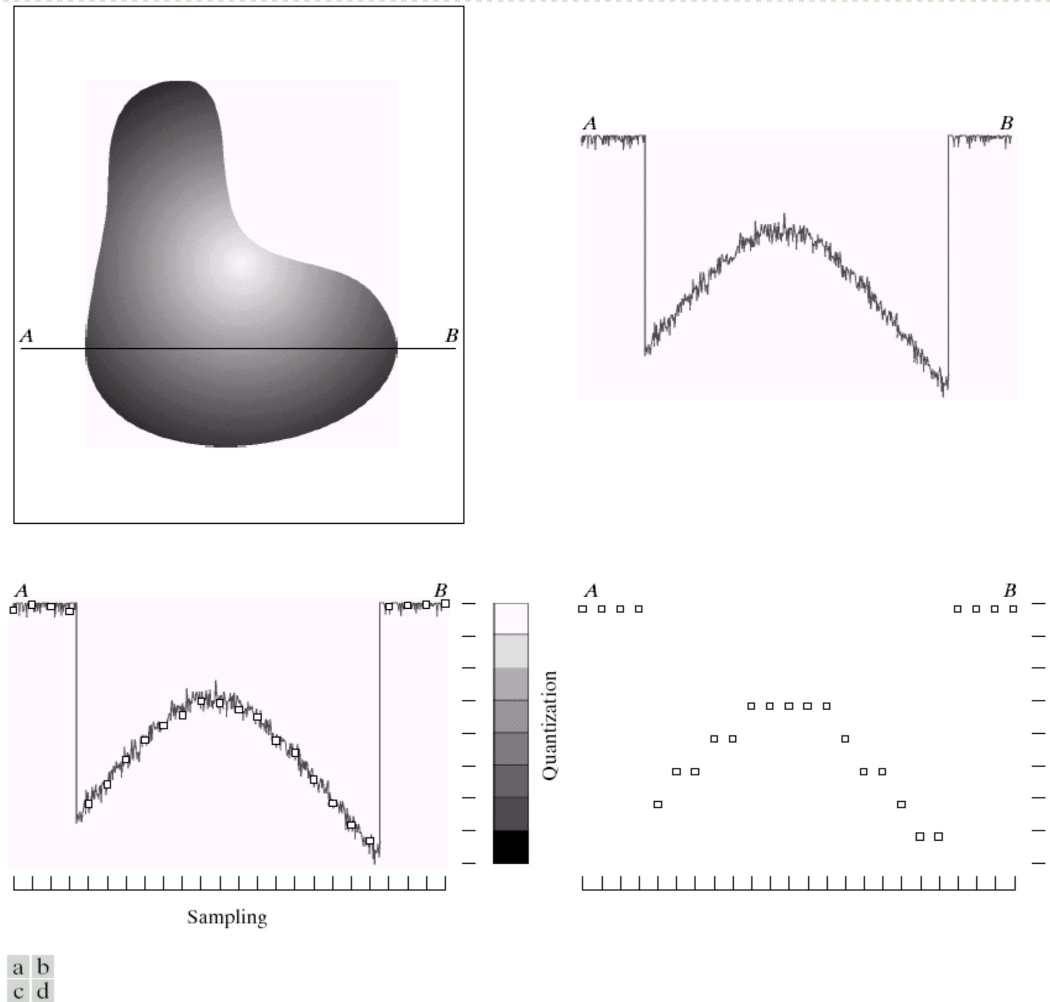


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

2D Sampling and Quantization

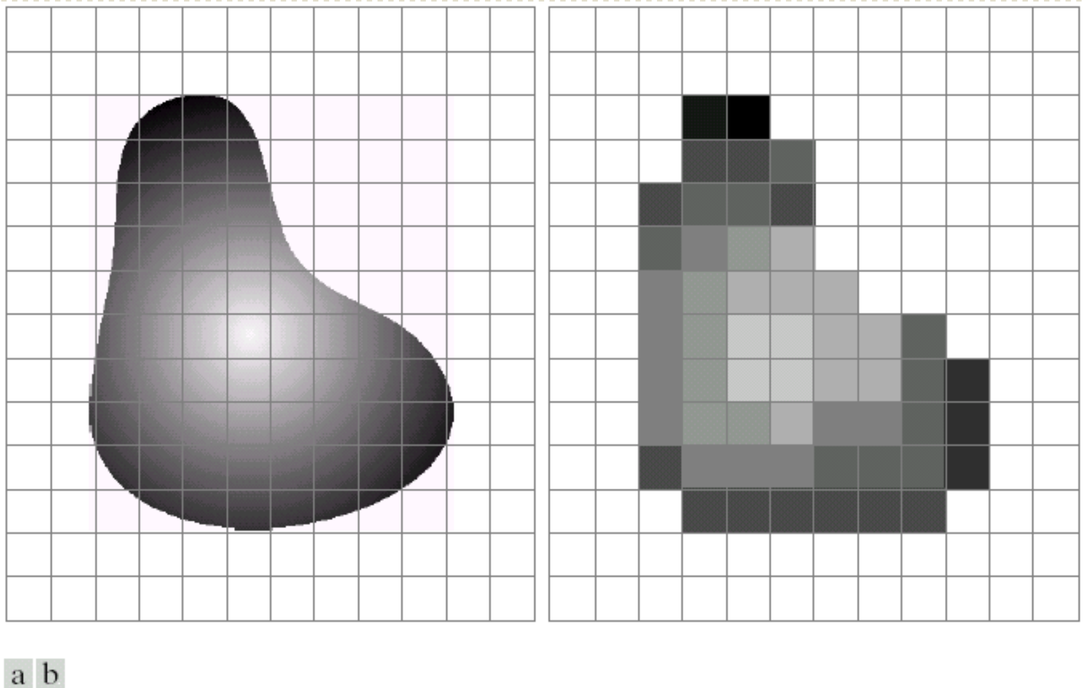
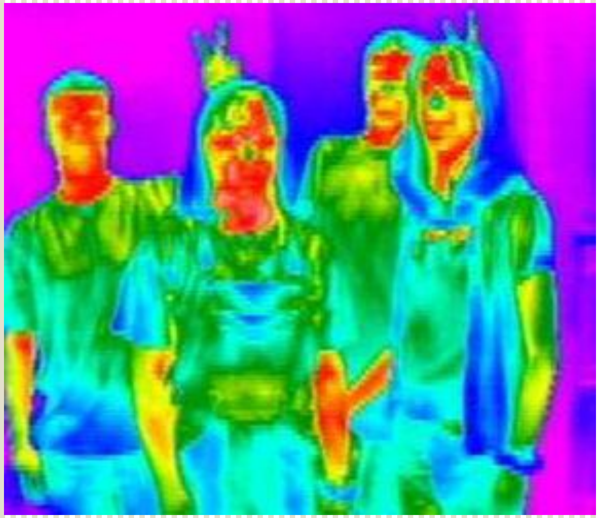


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

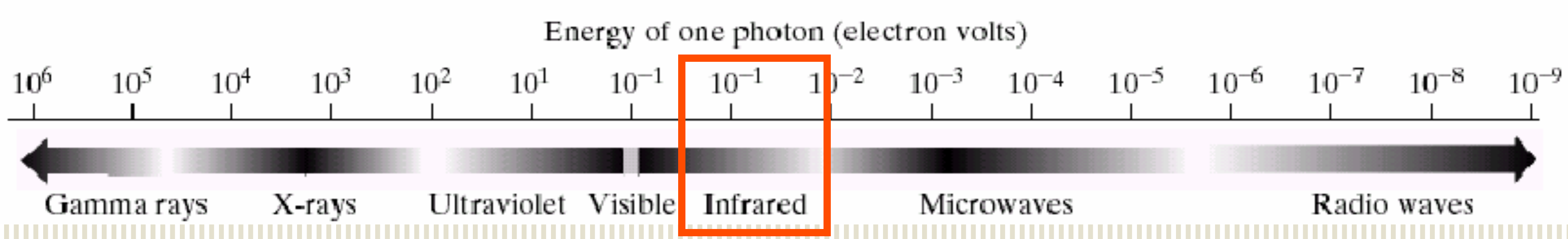
Thermal Imaging

Operate in infrared frequency

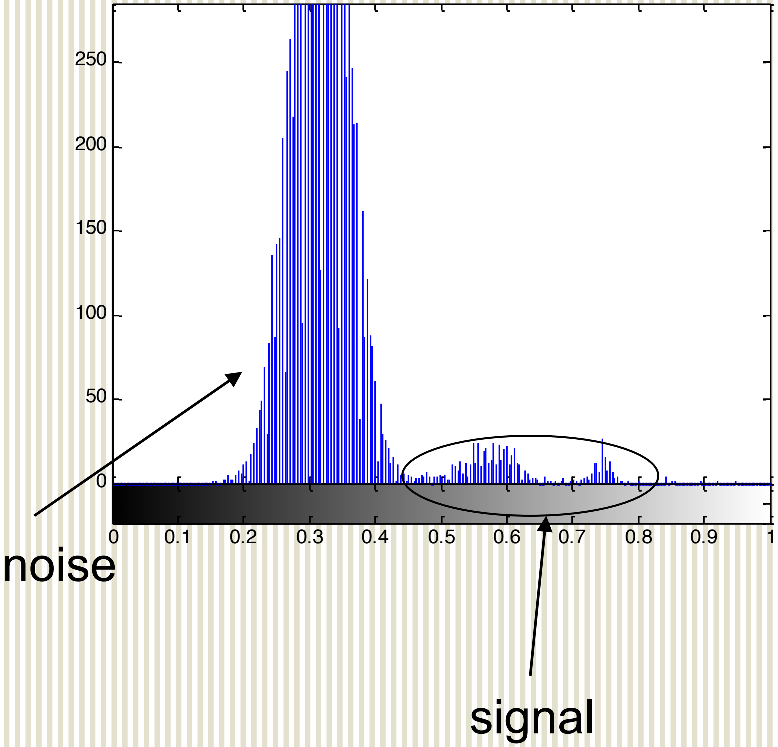
Grayscale representation (bright pixels correlate with high-temperature regions)



Pseudo-color representation (Human body dispersing heat denoted by red)

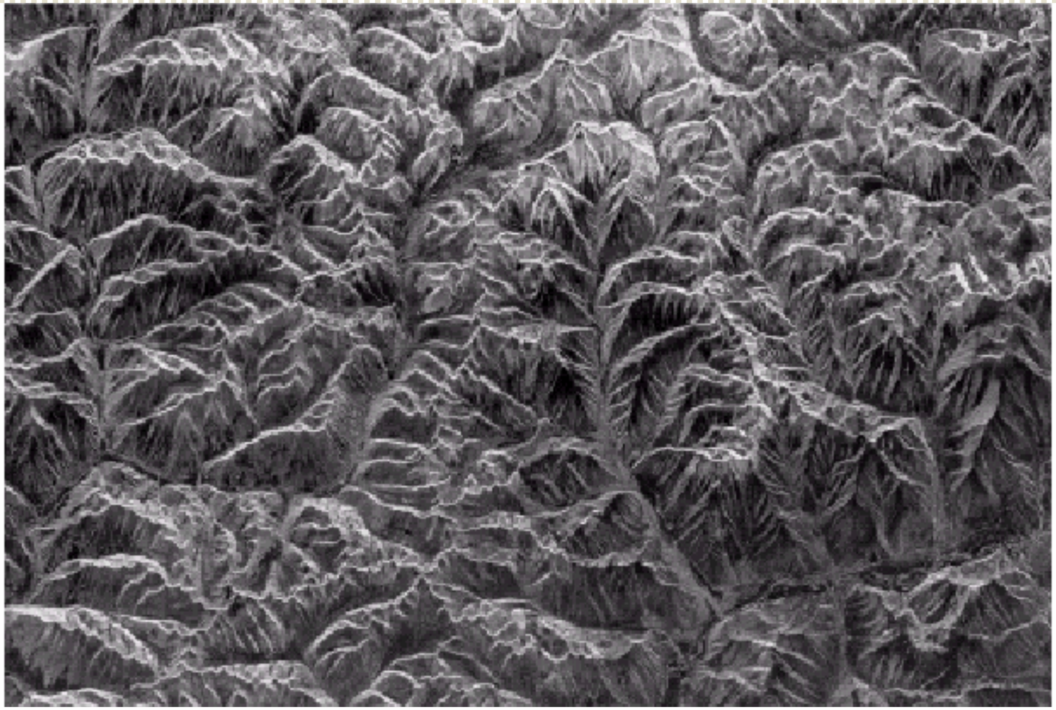


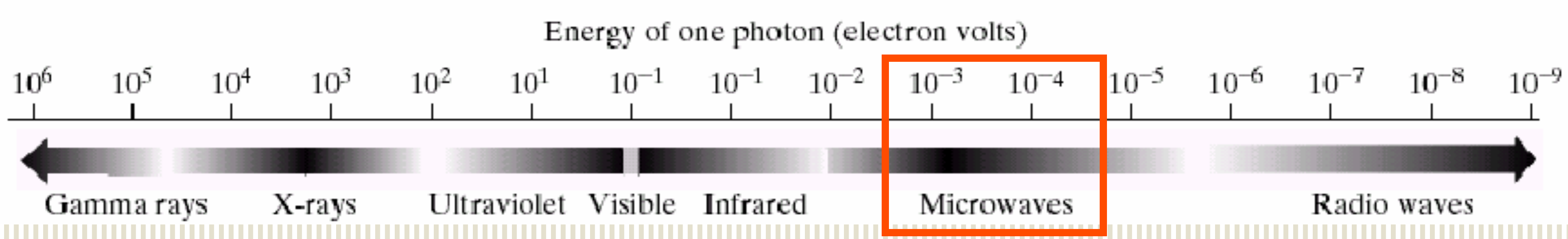
Low Signal-to-Noise (SNR) Behavior



Radar Imaging

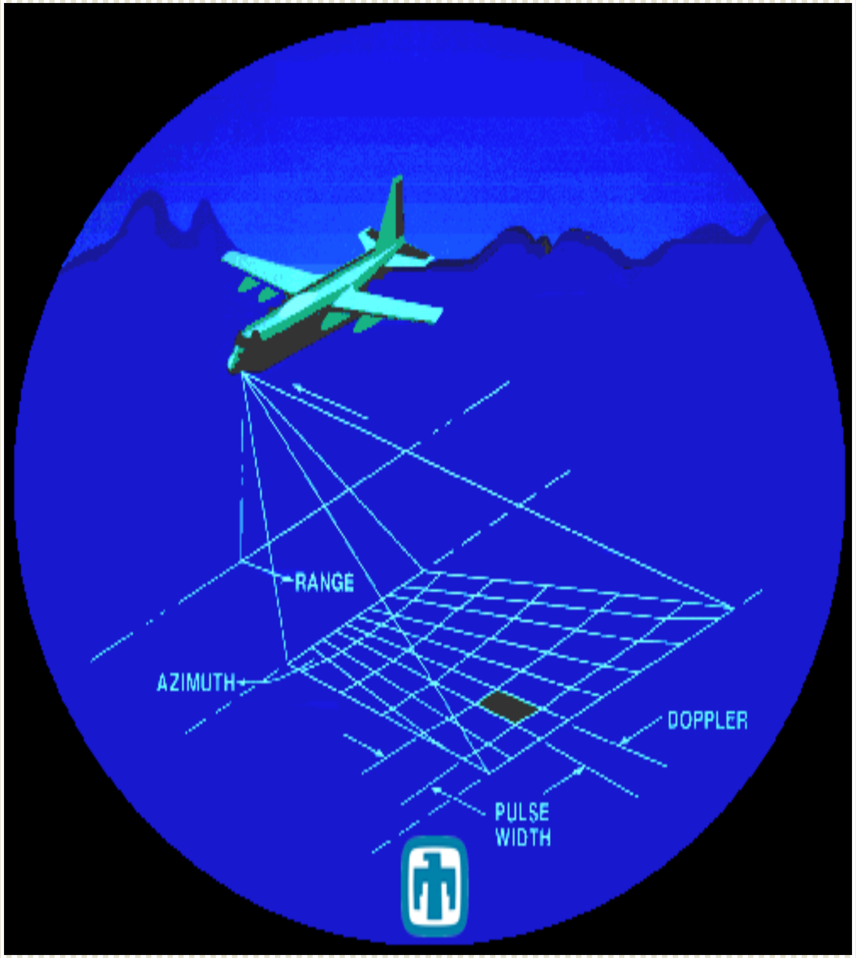
Operate in microwave frequency





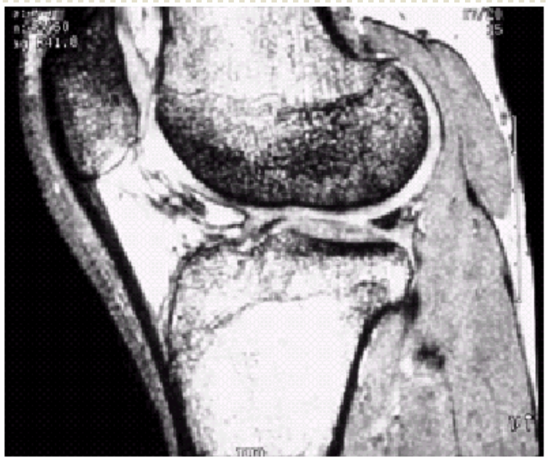
Synthetic Aperture Radar (SAR)

- Environmental monitoring, earth-resource mapping, and military systems
- SAR imagery must be acquired in inclement weather and all-day-all-night.
- SAR produces relatively fine azimuth resolution that differentiates it from other radars.



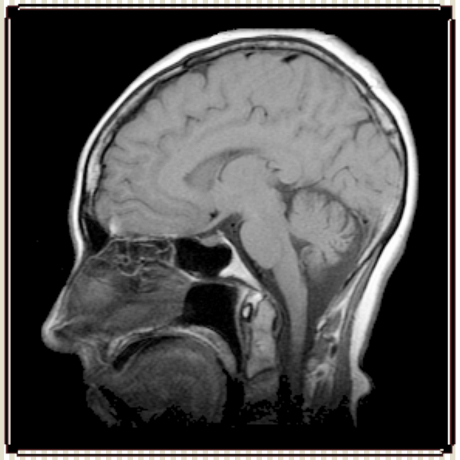
Magnetic Resonance Imaging (MRI)

Operate in radio frequency

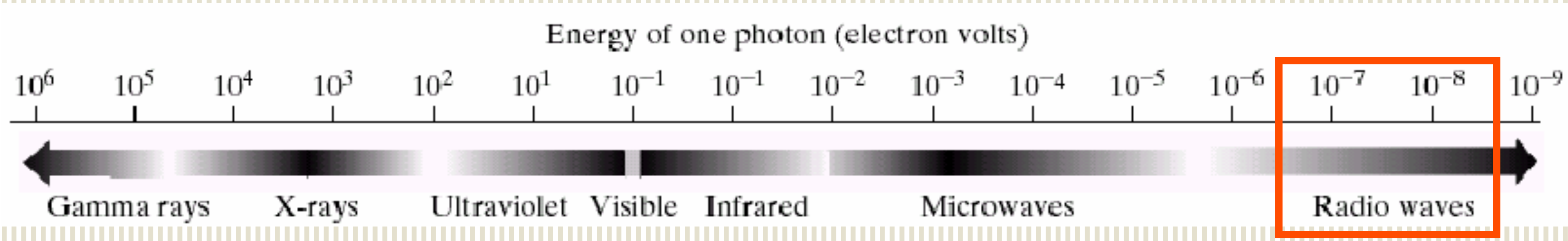


knee

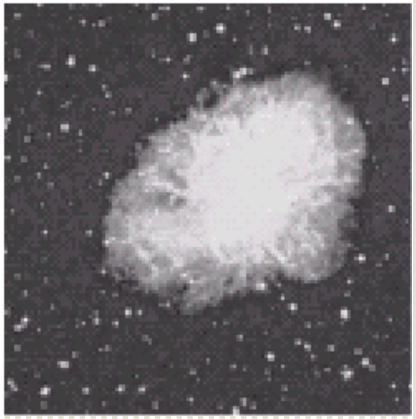
spine



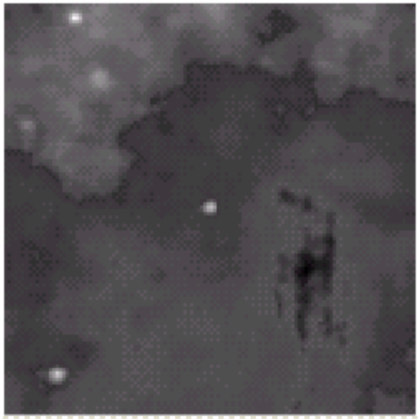
head



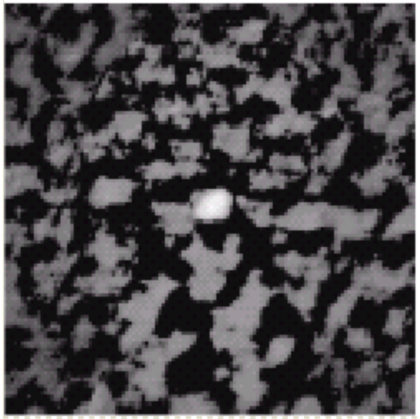
Comparison of Different Imaging Modalities



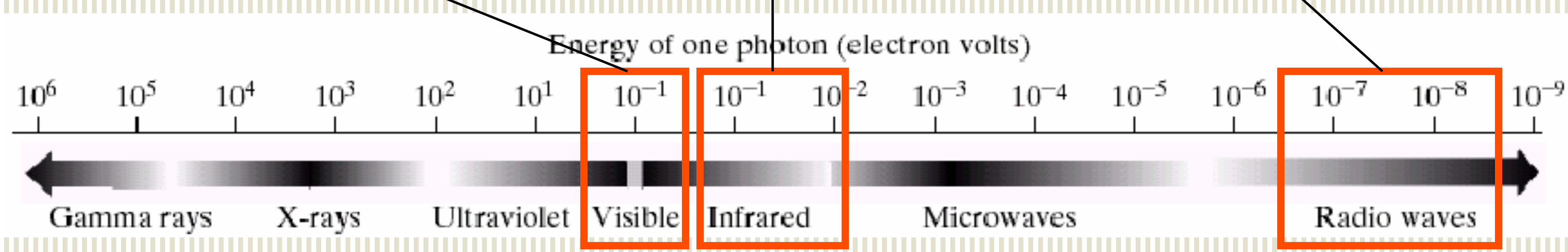
visible



infrared

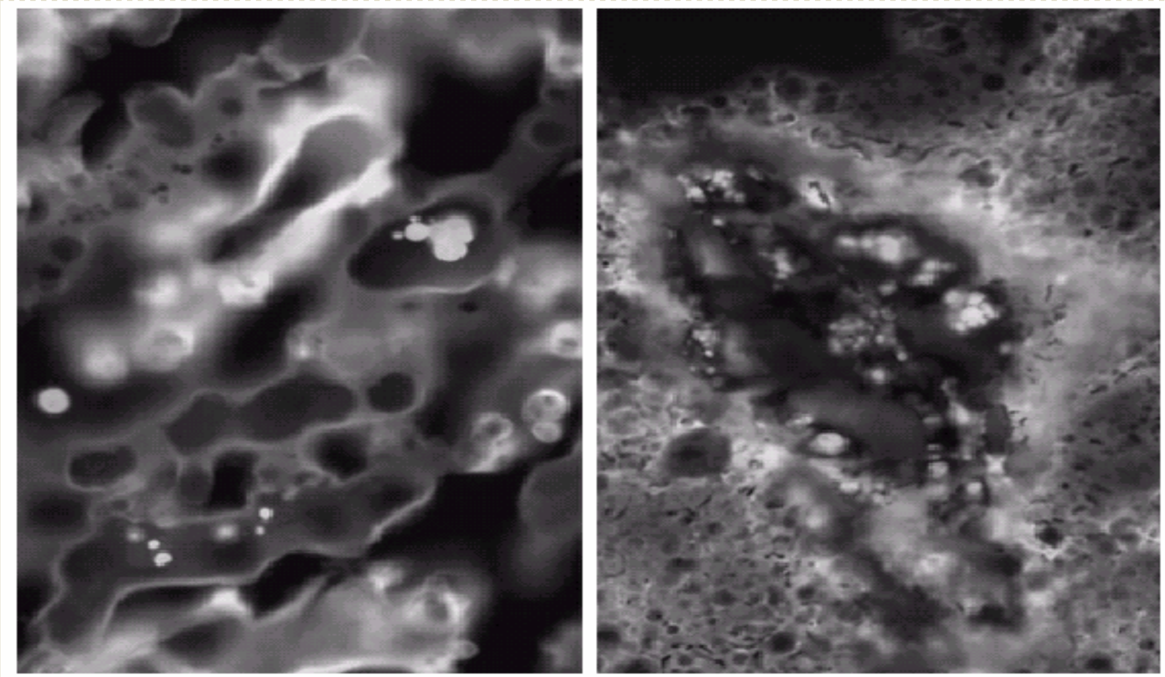


radio

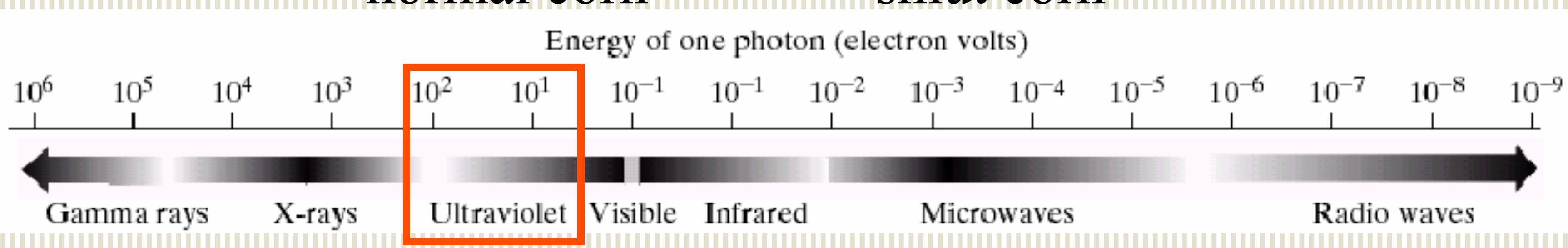


Fluorescence Microscopy Imaging

Operate in ultraviolet frequency

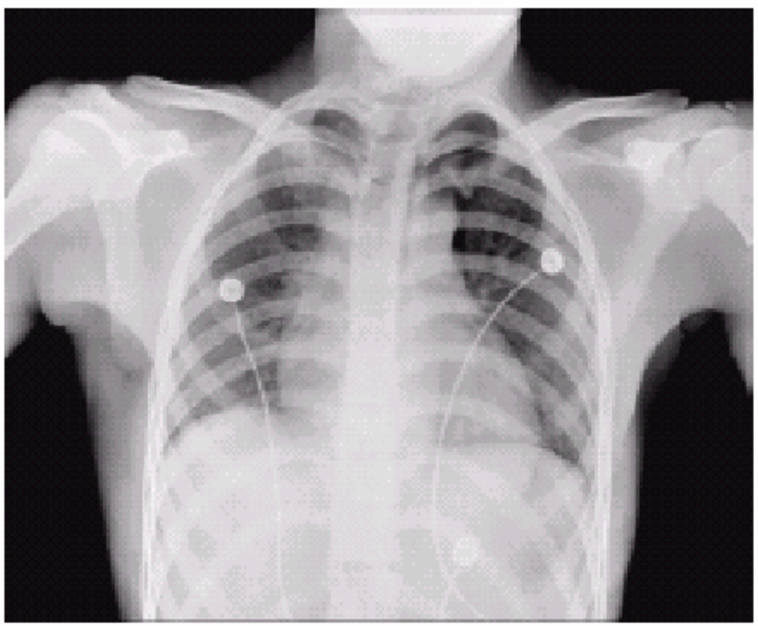


normal corn smut corn



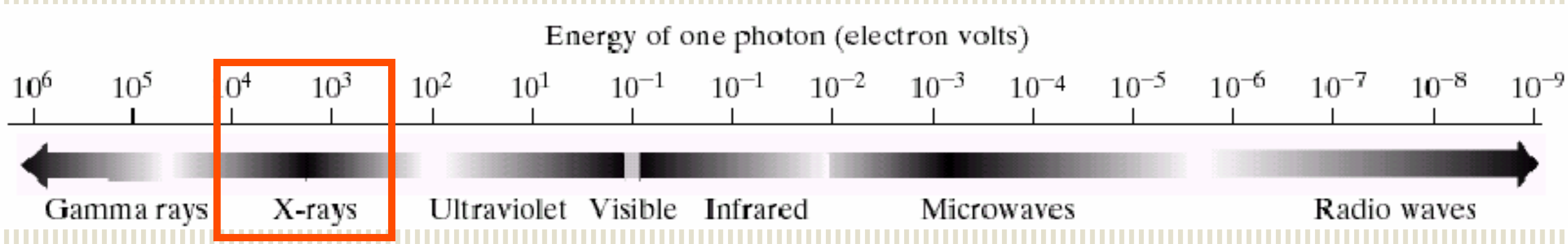
X-ray Imaging

Operate in X-ray frequency



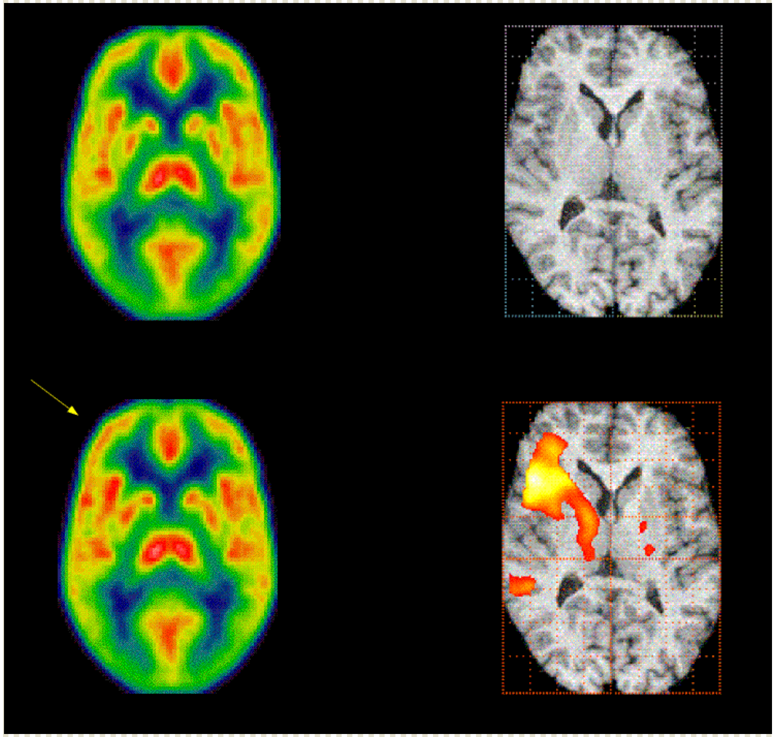
chest

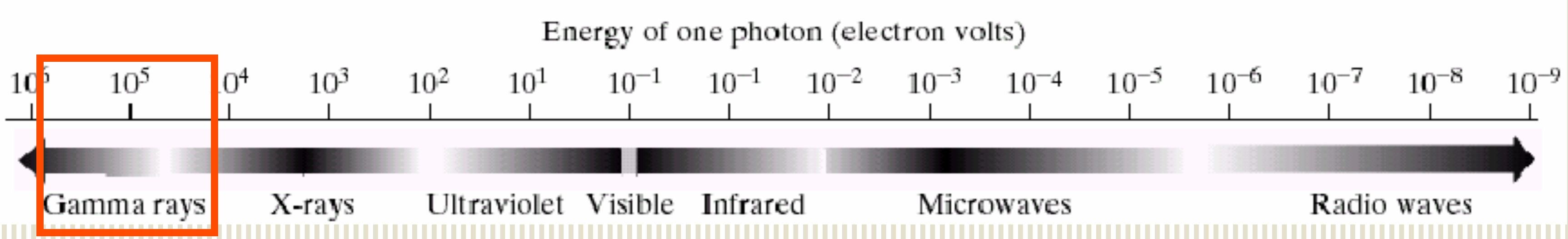
head



Positron Emission Tomography

Operate in gamma-ray frequency

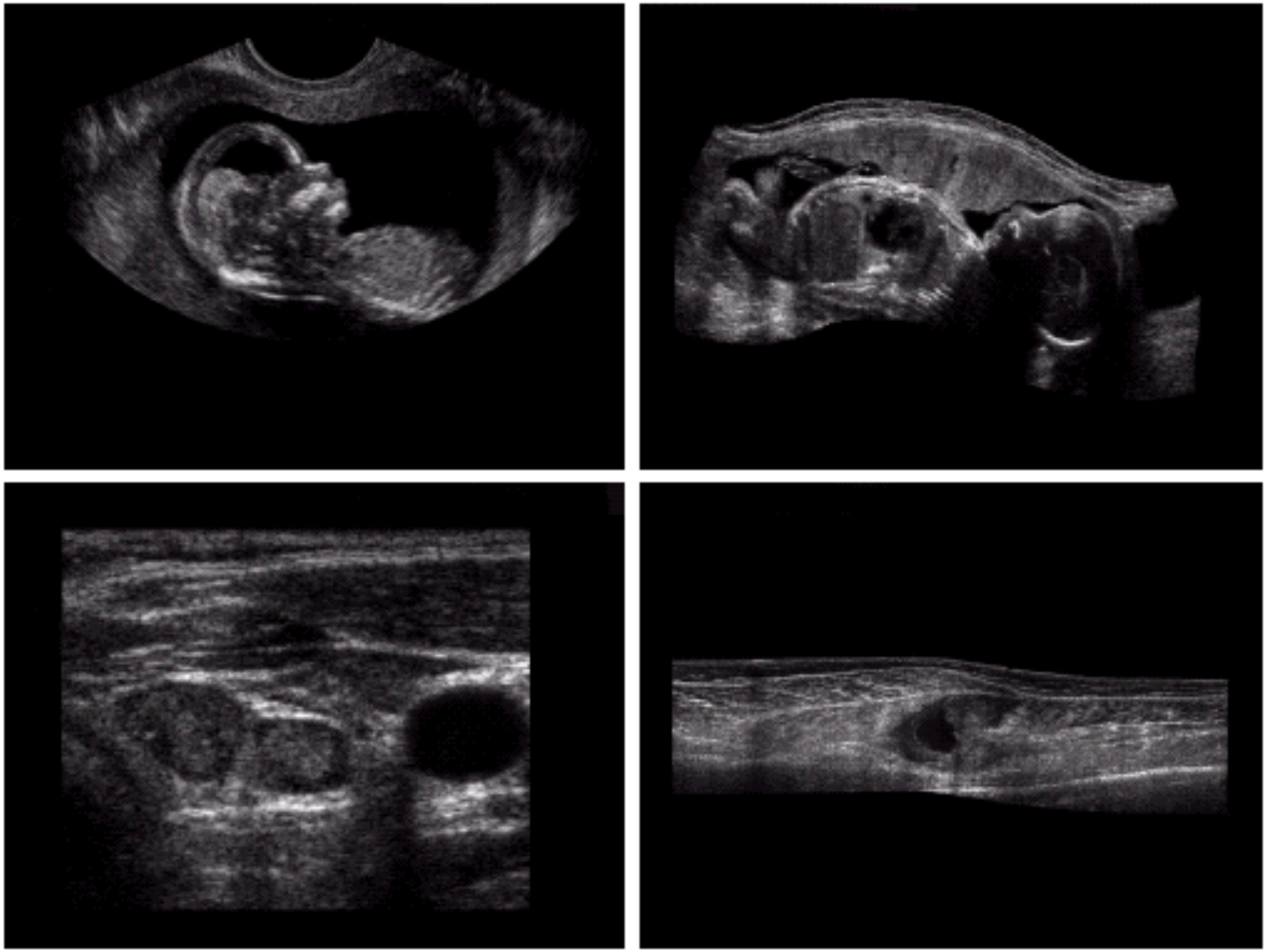





USA 2003

Examples: Infrared Satellite Imaging

Examples: Ultrasound Imaging



a b
c d

FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

Image Represented by a Matrix

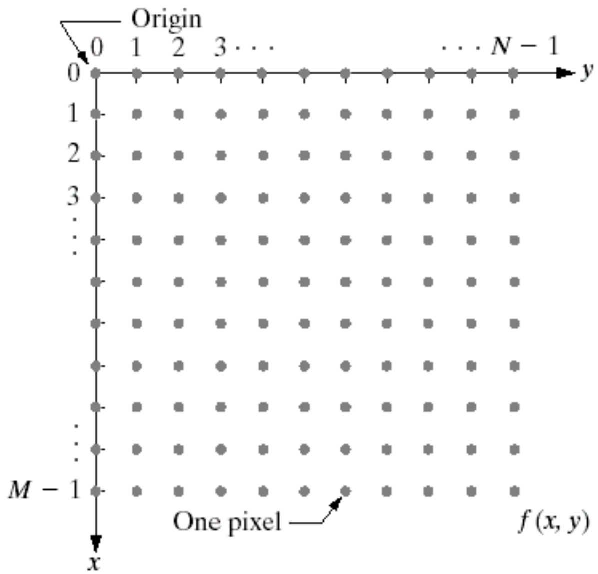


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Spatial resolution

Bit-depth resolution

Representing Digital Images

- The representation of an M×N numerical array in MATLAB

$$f(x,y) = \begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \dots & \dots & \dots & \dots \\ f(M,1) & f(M,2) & \dots & f(M,N) \end{bmatrix}$$

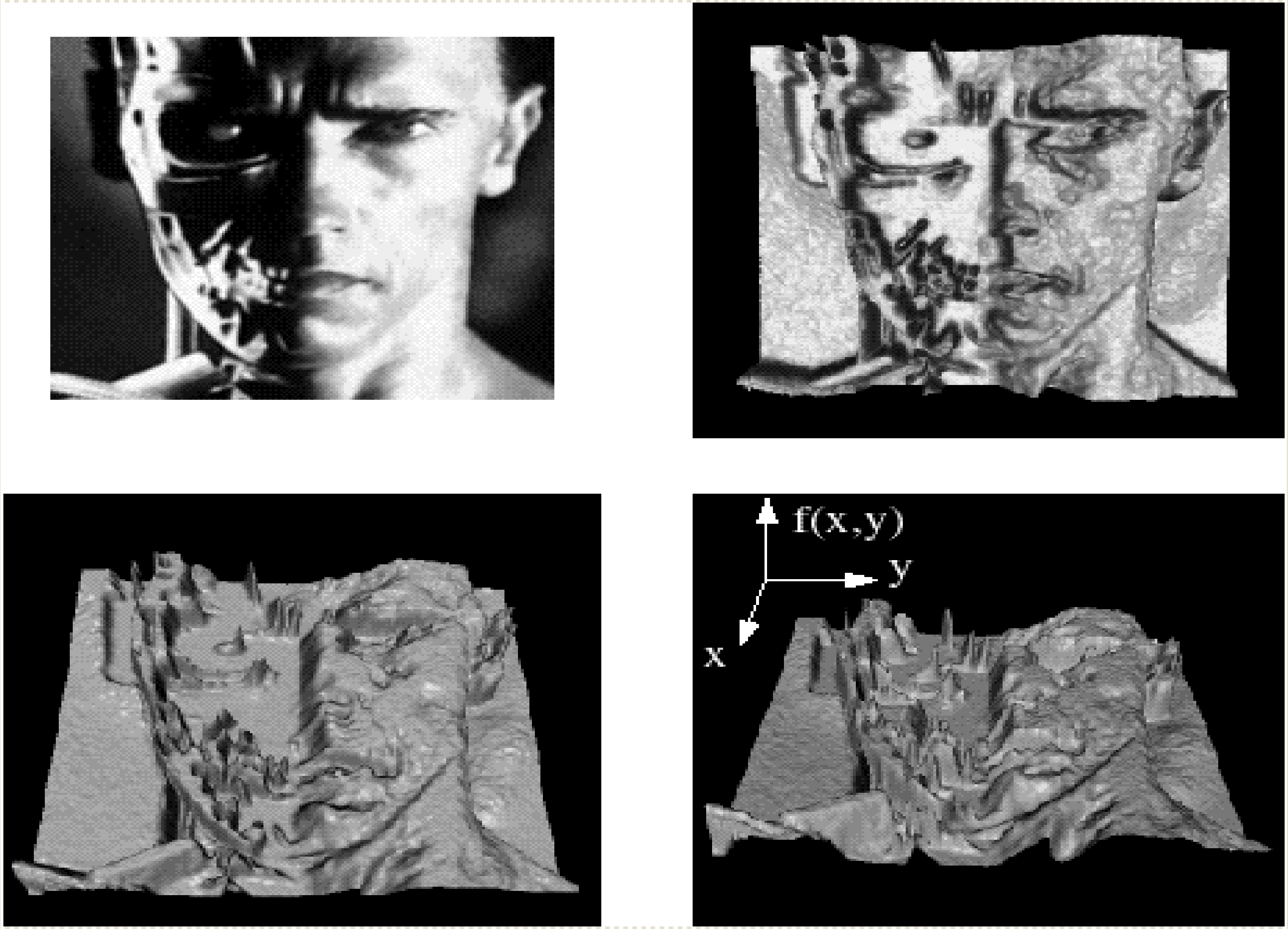
What is an image?

- We can think of an **image** as a function, f, from R^2 to R:
  - $f(x, y)$ gives the **intensity** at position (x, y)
  - Realistically, we expect the image only to be defined over a rectangle, with a finite range:
    - f: $[a,b]\times[c,d] \rightarrow [0,1]$

- A color image is just three functions pasted together. We can write this as a "vector-valued" function:

$$f(x,y) = \begin{bmatrix} r(x,y) \\ g(x,y) \\ b(x,y) \end{bmatrix}$$

Images as functions



What is a digital image?

- We usually operate on **digital** (**discrete**) images:
  - **Sample** the 2D space on a regular grid
  - **Quantize** each sample (round to nearest integer)
- If our samples are Δ apart, we can write this as:

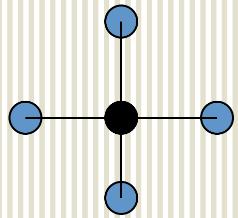
  $f[i, j] = \text{Quantize}\{ f(i\,\Delta, j\,\Delta) \}$
- The image can now be represented as a matrix of integer values

j

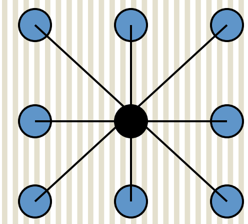
62	79	23	119	120	105	4	0
10	10	9	62	12	78	34	0
10	58	197	46	46	0	0	48
176	135	5	188	191	68	0	49
2	1	1	29	26	37	0	77
0	89	144	147	187	102	62	208
255	252	0	166	123	62	0	31
166	63	127	17	1	0	99	30

Commonly-used Terminology

Neighbors of a pixel $p=(i,j)$



$N_4(p)=\{(i-1,j),(i+1,j),(i,j-1),(i,j+1)\}$



$N_8(p)=\{(i-1,j),(i+1,j),(i,j-1),(i,j+1),$
$(i-1,j-1),(i-1,j+1),(i+1,j-1),(i+1,j+1)\}$

Adjacency

4-adjacency: p,q are 4-adjacent if p is in the set $N_4(q)$

8-adjacency: p,q are 8-adjacent if p is in the set $N_8(q)$

Note that if p is in $N_{4/8}(q)$, then q must be also in $N_{4/8}(p)$

Common Distance Definitions

Euclidean distance
(2-norm)

$2\sqrt{2}$	$\sqrt{5}$	2	$\sqrt{5}$	$2\sqrt{2}$
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
2	1	0	1	2
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
$2\sqrt{2}$	$\sqrt{5}$	2	$\sqrt{5}$	$2\sqrt{2}$

D_4 distance
(city-block distance)

4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

D_8 distance
(checkboard distance)

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

Block-based Processing