Introduction to Image Processing

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Course Description

- Intense introduction to image processing.
- Intended for advanced undergraduate and graduate students.
- Topics include:
  - Image enhancement
  - Digital filtering theory, Fourier transforms
  - Image reconstruction, resampling, antialiasing
  - Scanline algorithms, geometric transforms
  - Warping, morphing, and visual effects

Syllabus

Week	Topic
1	Introduction / overview
2-3	Point operations
4	Neighborhood operations
5-6	Fast Fourier transforms (FFT)
7-8	Sampling theory
9	Midterm, Image reconstruction
10	Fast filtering for resampling
11	Spatial transformations, texture mapping
12-14	Separable warping algorithms; visual effects

Required Text

Stan Birchfield, *Image Processing and Analysis*, Cengage Learning, Boston, MA, 2018.

Supplementary Texts

Rafael Gonzalez and Richard Woods, *Digital Image Processing, 4th* Edition, Prentice Hall, Wesley, 2018.

Milan Sonka, Vaclav Hlavac, and Roger Boyle, *Image Processing, Analysis, and Machine Vision,* Cengage Learning, 2015.

George Wolberg, *Digital Image Warping,* IEEE Computer Society Press, 1990.

Grading

- The final grade is computed as follows:
  - Midterm exam: 25%
  - Final exam: 25%
  - Homework programming assignments: 50%
- Substantial programming assignments are due every three weeks.
- Proficiency in C/C++ is expected.

CCNY Contact Information

- Prof. Wolberg
  - Office hours: After class and by appointment
  - Email: wolberg@ccny.cuny.edu
- Teaching Assistant (TA): Siavash Zokai
  - Email: ccny.cs470@gmail.com
- See class web page for all class info such as homework, sample source code, and link to our Piazza Q&A page:

www-cs.ccny.cuny.edu/~wolberg/cs470

Objectives

- These notes accompany the textbooks:
  - “Image Processing and Analysis” by Stan Birchfield
  - “Digital Image Processing” by Gonzalez and Woods
  - “Digital Image Warping” by George Wolberg
- They form the basis for approximately 14 weeks of lectures.
- Some figures and images come from the Birchfield text.
- Programs in C/C++ will be assigned to reinforce understanding.
  - Four homework assignments
  - Each due in 3 weeks and requiring ~4 programs

What is Image Processing?

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Objectives

- In this lecture we:
  - Explore what image processing is about
  - Compare it against related fields
  - Provide historical introduction
  - Survey some application areas

What is Digital Image Processing?

- Computer manipulation of pictures, or images, that have been converted into numeric form. Typical operations include:
  - Contrast enhancement
  - Remove blur from an image
  - Smooth out graininess, speckle, or noise
  - Magnify, minify, or rotate an image (image warping)
  - Geometric correction
  - Image compression for efficient storage/transmission

Image Processing Goals

- Image processing is a subclass of signal processing concerned specifically with pictures

- It aims to improve image quality for
  - human perception: subjective
  - computer interpretation: objective

- Compress images for efficient storage/transmission

Image Processing and Analysis

- **Image processing:** the field of study in which algorithms operate on input images to produce output images.

- **Image analysis:** the field of study in which algorithms operate on images to extract higher-level information.

Image Processing Problems (1)

- **Enhancement:** an image processing problem that involves transforming an input image into another image so as to improve its visual appearance.
- **Restoration:** an image processing problem that has as its purpose to restore an image that has been corrupted by some type of noise.
- **Compression:** an image processing problem that involves storing an image with fewer bits than are required by the original signal.

Image Processing Problems (2)

Enhancement Restoration Compression

Source: Movie *Hoop Dreams*, Stan Birchfield, Jessica Birchfield

Figure 1.1: Three example problems of image processing. Top: A dark image, an image corrupted by noise, and a clean image. Bottom: the results of contrast enhancement, image restoration, and compression. The latter shows intentionally poor quality to better illustrate the effects of the operation.

Image Analysis Problems (1)

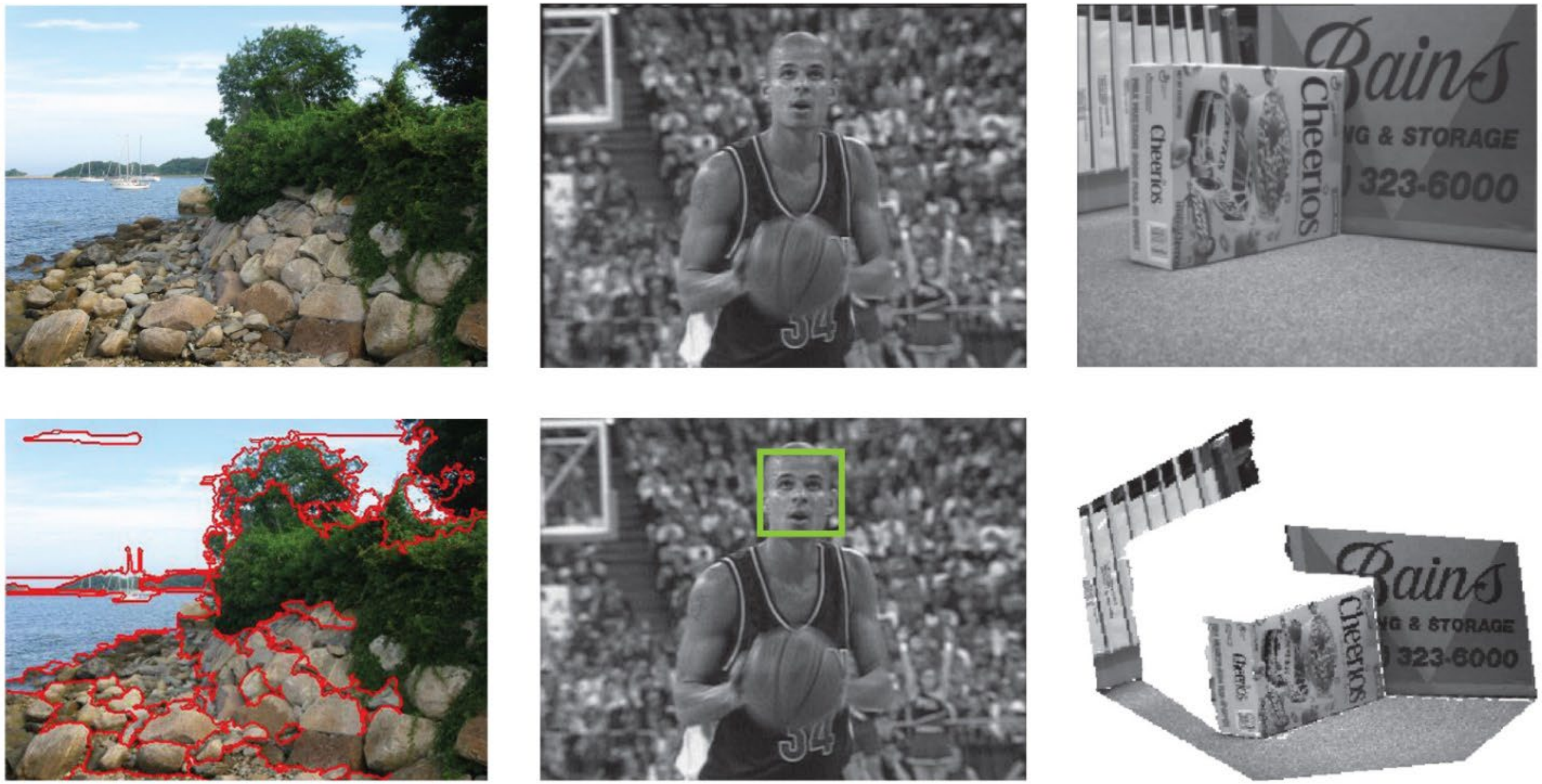
- **Segmentation:** an image analysis problem that involves the process of determining which pixels in an image belong together, that is, which pixels are projections of the same object in the scene. Bottom-up process in which pixels are grouped together based on low-level local pixel properties without any model of the particular object in the scene that produced the group of pixels.

- **Classification:** an image analysis problem that involves determining which pixels in an image belong to a model that has been created beforehand. Top-down process, relying upon supervised training to facilitate the creation of the model to which the pixels will be compared.

- **Shape from X:** an image analysis problem that aims to recover the three-dimensional (3D) structure of the scene using any of a variety of techniques (X), such as stereo, video, shading, or texture.

Image Analysis Problems (2)

Figure 1.2: Three example problems of image analysis. Top: input images. Bottom: From left to right, the results of color-based segmentation, human face detection (a type of classification), and 3D reconstruction.



Segmentation | Classification | Shape from X

Stan Birchfield, Source: Basketball game on TV, Stan Birchfield

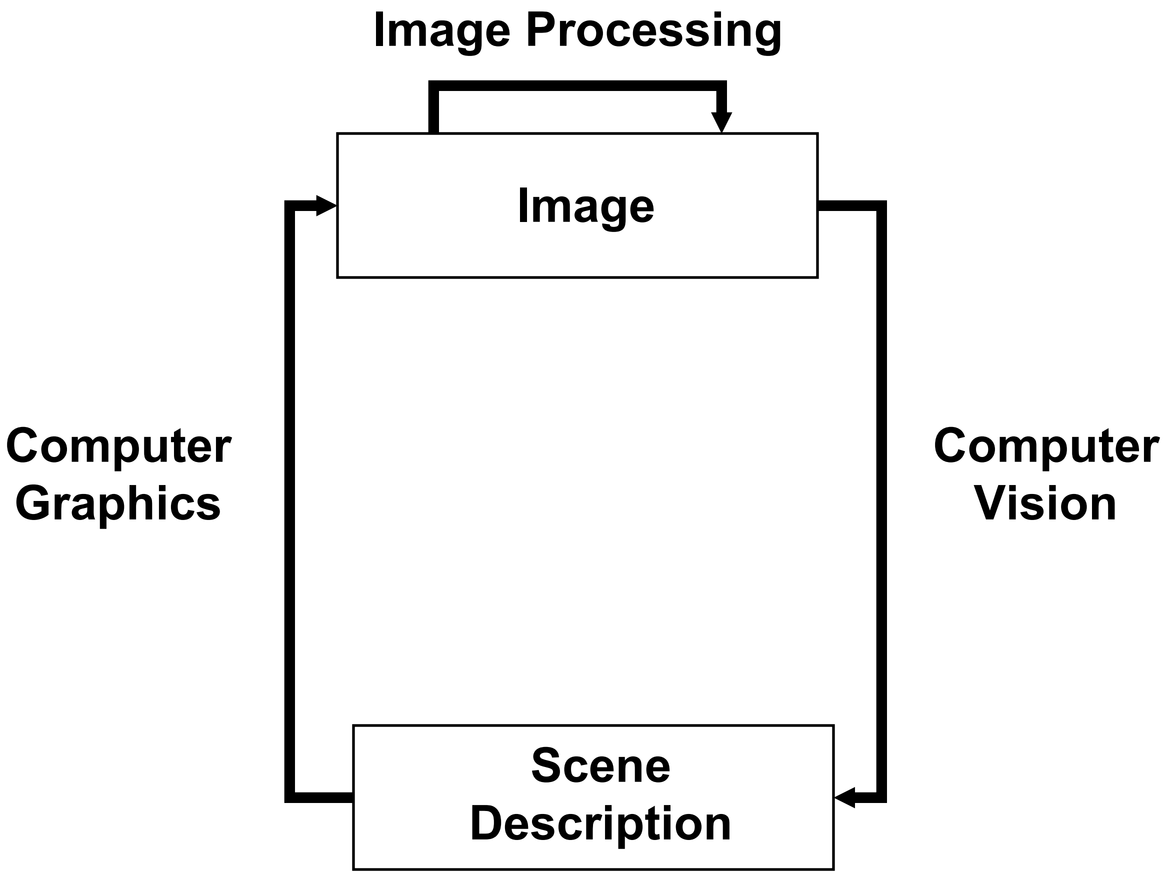
Machine and Computer Vision

- **Machine vision:** refers to systems in an industrial setting in which the placement of the camera and lighting conditions can be controlled.

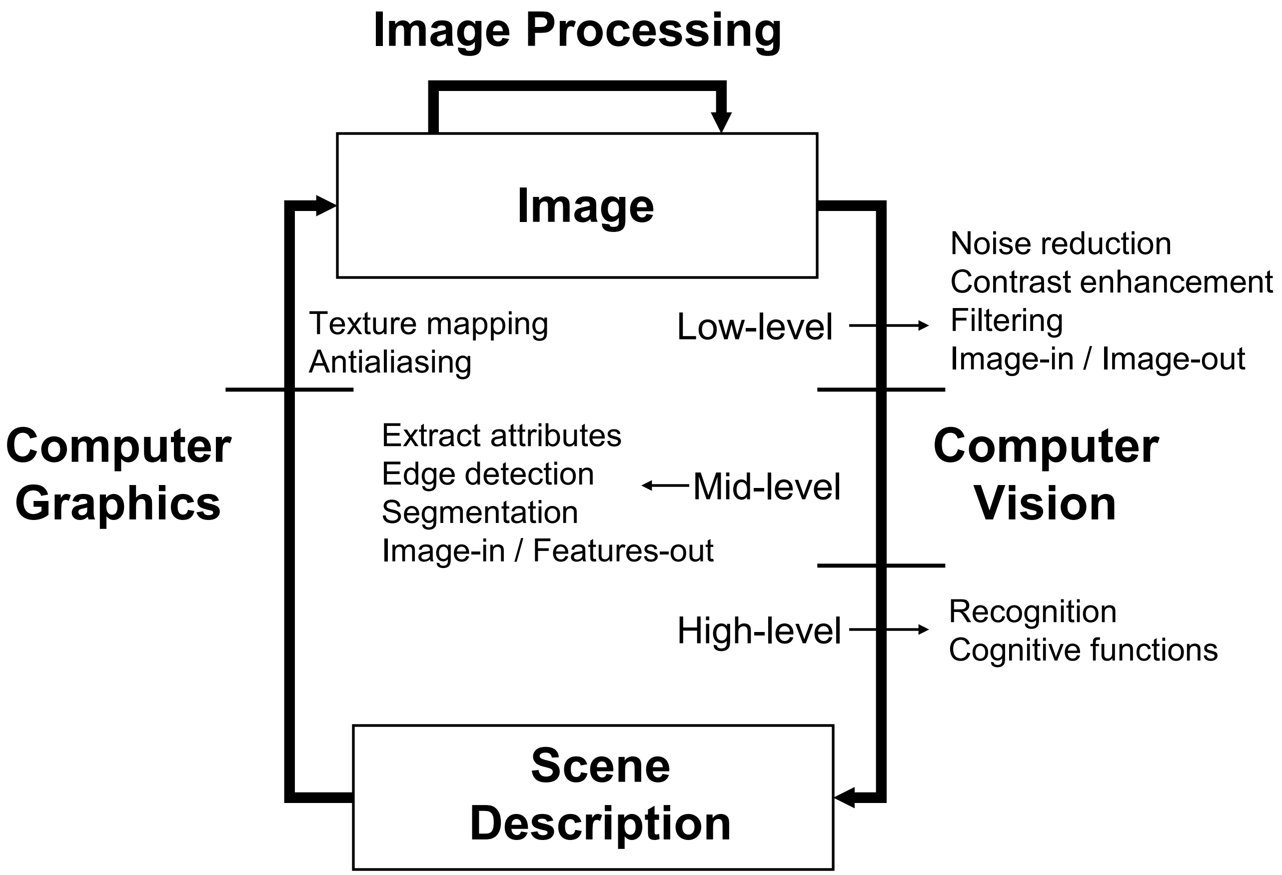
- **Computer vision:** refers to systems operating on images taken in unstructured settings, such as those taken by ordinary people in everyday life using their personal digital cameras.

These terms are often used interchangeably since their distinction is often too subtle.

Related Fields



Overlap with Related Fields



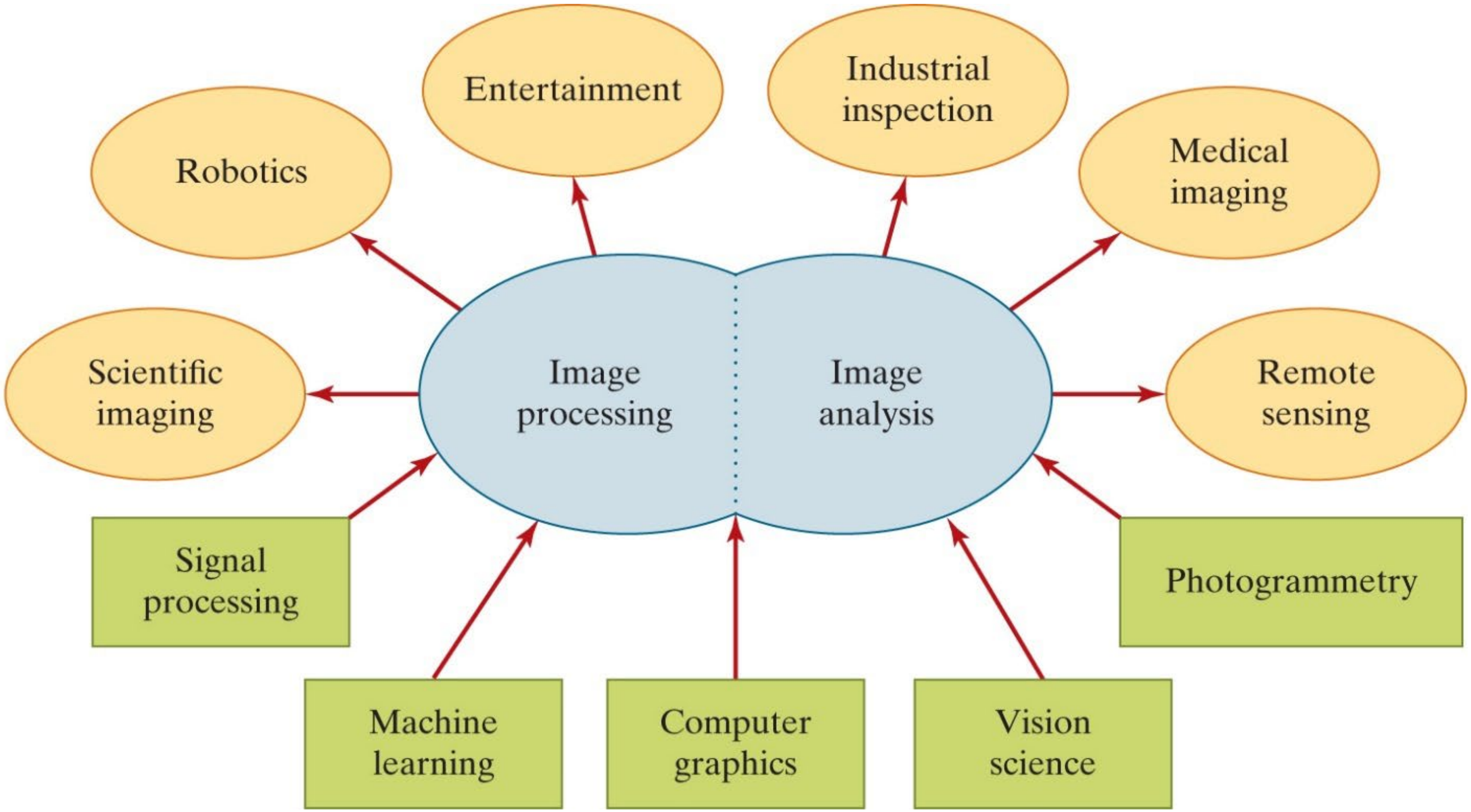
Distinctions

- No clear-cut boundaries between image processing on the one end and computer vision at the other
- Defining image processing as image-in/image-out does not account for
  - computation of average intensity: image-in / number-out
  - image compression: image-in / coefficients-out
- Nevertheless, image-in / image-out is true most of time

Input \ Output	**Image**	**Description**
Image	Image Processing	Computer Vision
Description	Computer Graphics	Artificial Intelligence

Industrial Landscape

Figure 1.3: Image processing and analysis, along with related fields (bottom rectangles) and sample applications (top ovals).



Sample Applications (1)

- Industrial inspection
  - Detect defects, missing components, misalignment, foreign objects in food
- Document image analysis
  - OCR for mail sorting, QR codes, vending machines, readers for the blind
- Transportation
  - Traffic volume, license plate readers, lane departure, automated parallel parking
- Security and surveillance
  - Fingerprint/iris readers, face identification, X-ray scanners at airports, crowd tracking
- Remote sensing
  - Collect aerial data in multiple spectral bands to measure land features, vegetation, ore deposits, changes in sea level

Sample Applications (2)

- Scientific imaging
  - Study and measure phenomena in biology, astronomy, chemistry, and other scientific fields
- Medical imaging
  - Detect tumors, diagnose diseases, detect broken bones, view neural activity, see artery blockage, guide surgery
- Robotics
  - Quality inspection, manufacturing assembly, arc welding, automatic wire bonding, environment navigation
- Entertainment
  - Computational photography to produce HDR images, all-focus images, mosaics, and panoramas; gesture recognition, first down markers in football, pitch speed in baseball, location of puck in hockey; combining CGI with live action footage by tracking features in the video to determine camera motion

Sample Application Examples

Figure 1.4: Sample applications. From left to right, top to bottom: industrial inspection, optical character recognition, tracking vehicles on a highway, detecting a drowning person at the bottom of a pool, photgrammetry, detecting tree roots in an underground image, medical imaging, robotic assembly, moviemaking.

Image Processing: 1960-1970

- Digital image processing was born in the mid-1960s due to the convergence of two phenomena:
  - the space program began to transmit a plethora of distorted moon images back to the earth
  - digital computers were becoming powerful enough to perform useful tasks such as removing that distortion

Image Processing: 1960-1970

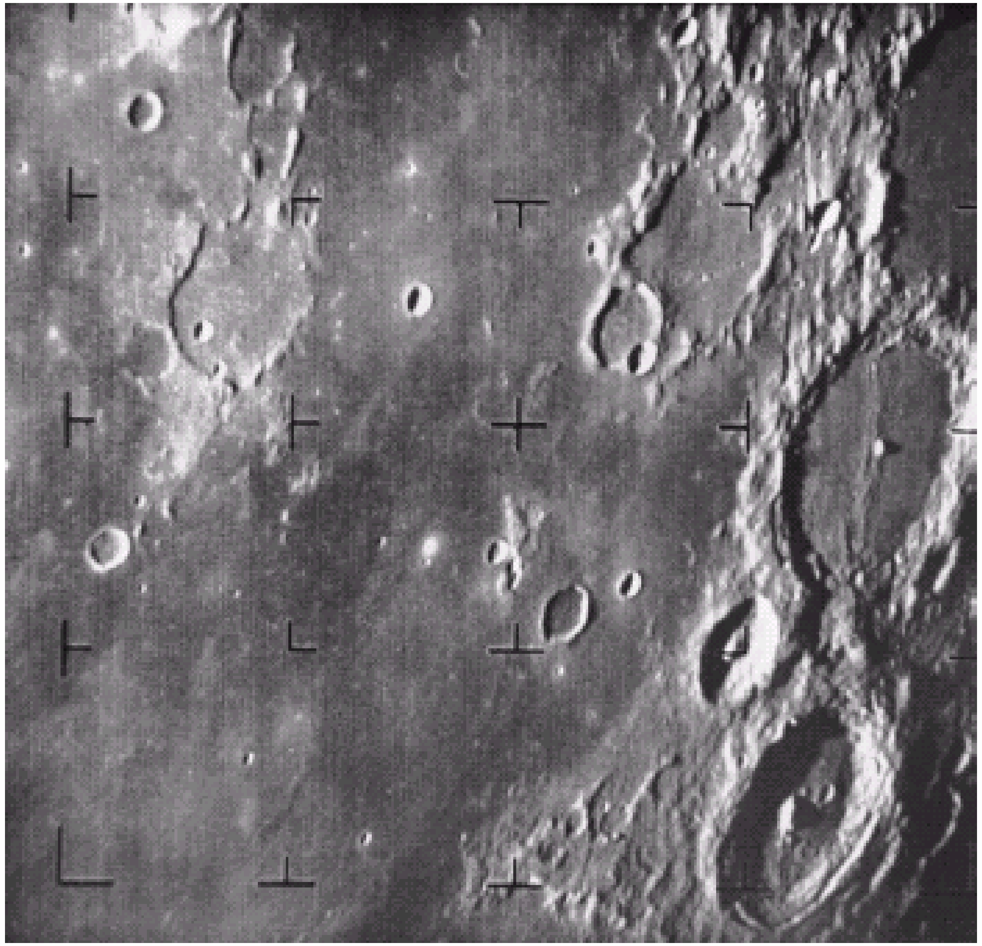


FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

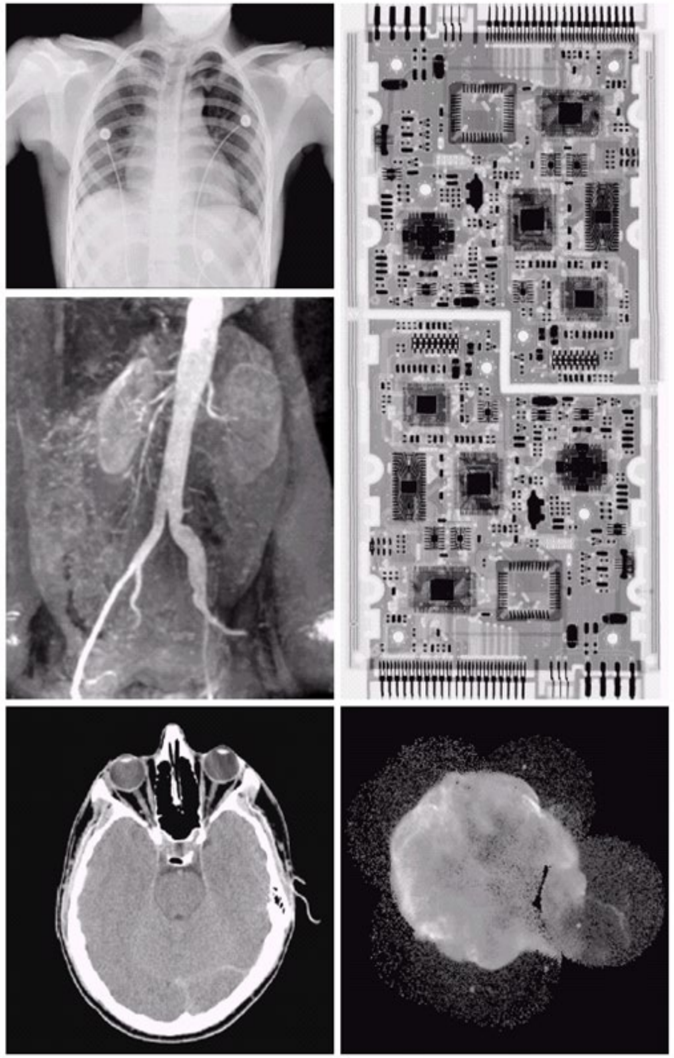
Image Processing: 1970-1980

Medical imaging: invention of computerized axial tomography (CAT) and magnetic resonance imaging (MRI, formerly NMR). CAT scans use X-ray imaging; MRI uses strong magnetic fields.

Remote sensing: LANDSAT earth observation

Document image analysis: optical character recognition (OCR)

Inspection of manufactured parts: X-ray imaging



a b c d e **FIGURE 1.7** Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, (d) Mr. Joseph E. Pascente, Lixi, Inc., and (e) NASA.)

Image Processing: 1980-1990

- Satellite infrared imaging: LANDSAT, NOAA
- Fast resampling and texture mapping in computer graphics

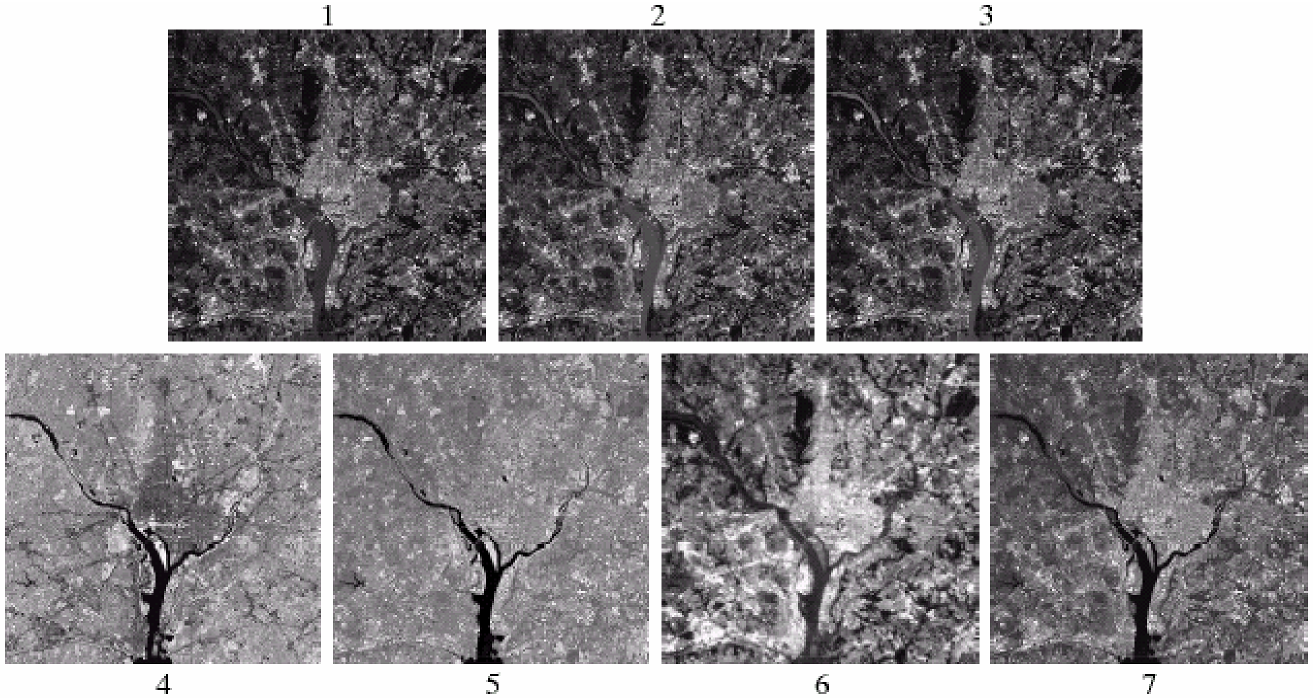


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Image Processing: 1990-2000

- Morphing / visual effects algorithms
- JPEG/MPEG compression, wavelet transforms
- Adobe PhotoShop

Image Processing: 2000-2010

- Widespread proliferation of fast graphics processing units (GPU) from nVidia and ATI to perform real-time image processing
- Ubiquitous digital cameras, camcorders, and cell phone cameras rely heavily on image processing and compression

Image Processing: 2010-2020

- Virtual Reality
- Augmented Reality
- Machine Learning / Deep Learning
  - Face recognition (Windows Hello, surveillance)
  - Self-driving cars

Image Processing: 2020-

- Virtual/Augmented Reality
  - Meta Quest
  - Apple Vision Pro
- AI Image Processing
  - Dall-E2: text-to-image AI generator
  - Lensa: AI art image generator / AI photo editing
  - Neural network image enhancer

Sources of Images

- The principal energy source for images is the electromagnetic (EM) energy spectrum.
- Light is an EM stream of massless proton particles traveling in a wavelike pattern at the speed of light. Spectral bands are grouped by energy/photon
  - Gamma rays, X-rays, UV, Visible, Infrared, Microwaves, radio waves
- Other sources: acoustic, ultrasonic, electronic

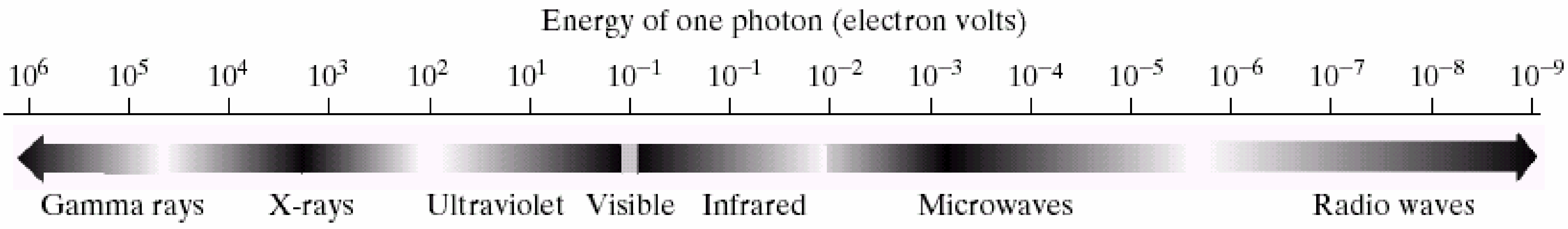


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

Light Wavelength and Frequency

- **Wavelength λ (measured in meters):** the distance between successive peaks in the sinusoid of a wave.
- **Frequency *v* (measured in hertz):** inversely related to the wavelength.
  - λ times ***v*** is the speed of light in the medium.

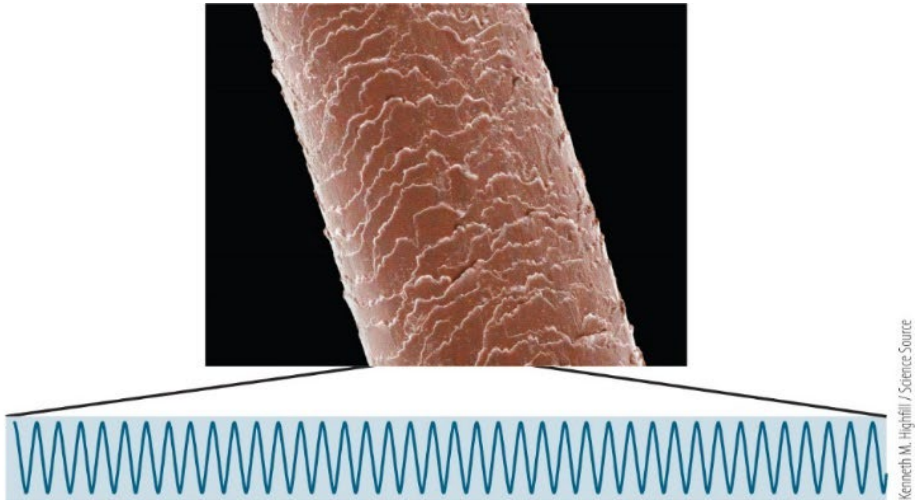


Figure 2.19 The wavelength of visible light is about 1/100th the diameter of a human hair.

Visible Spectrum

- Thin slice of the full electromagnetic spectrum

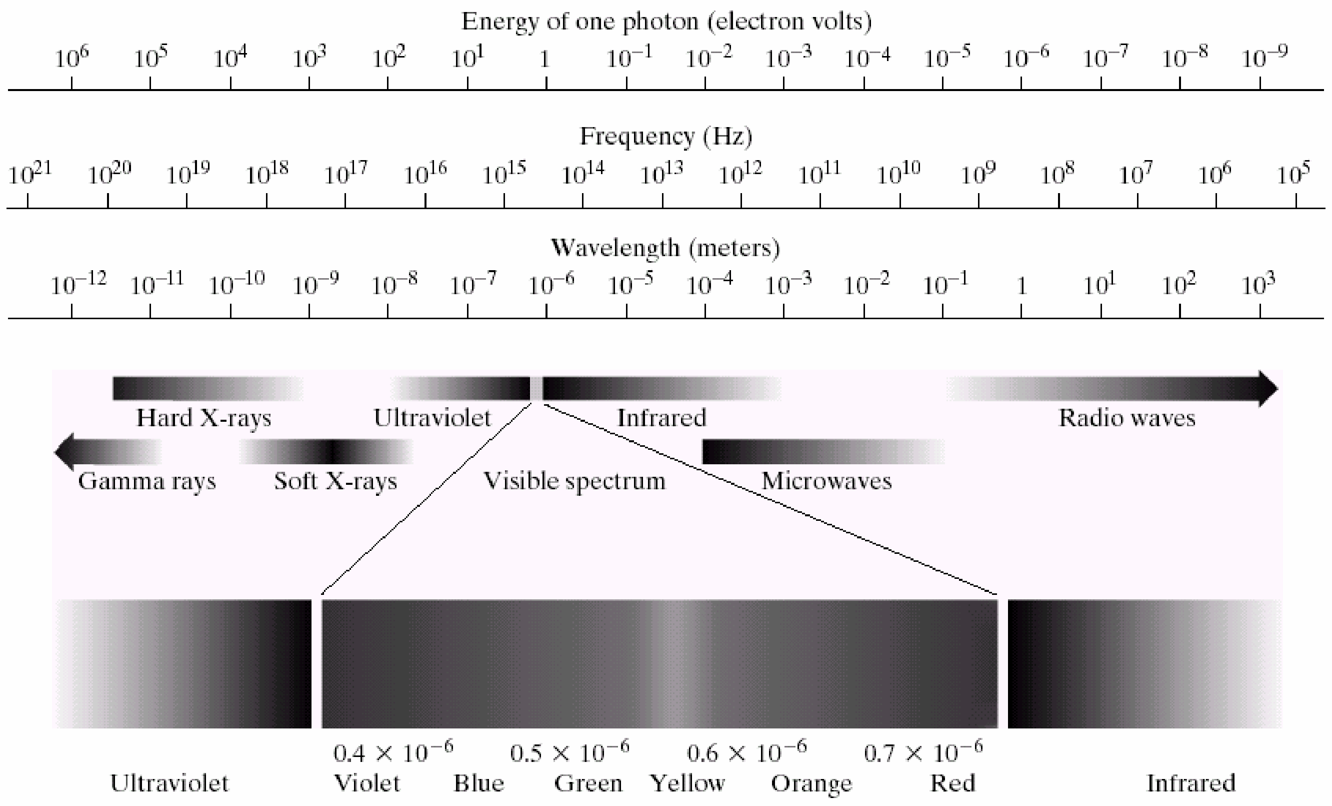
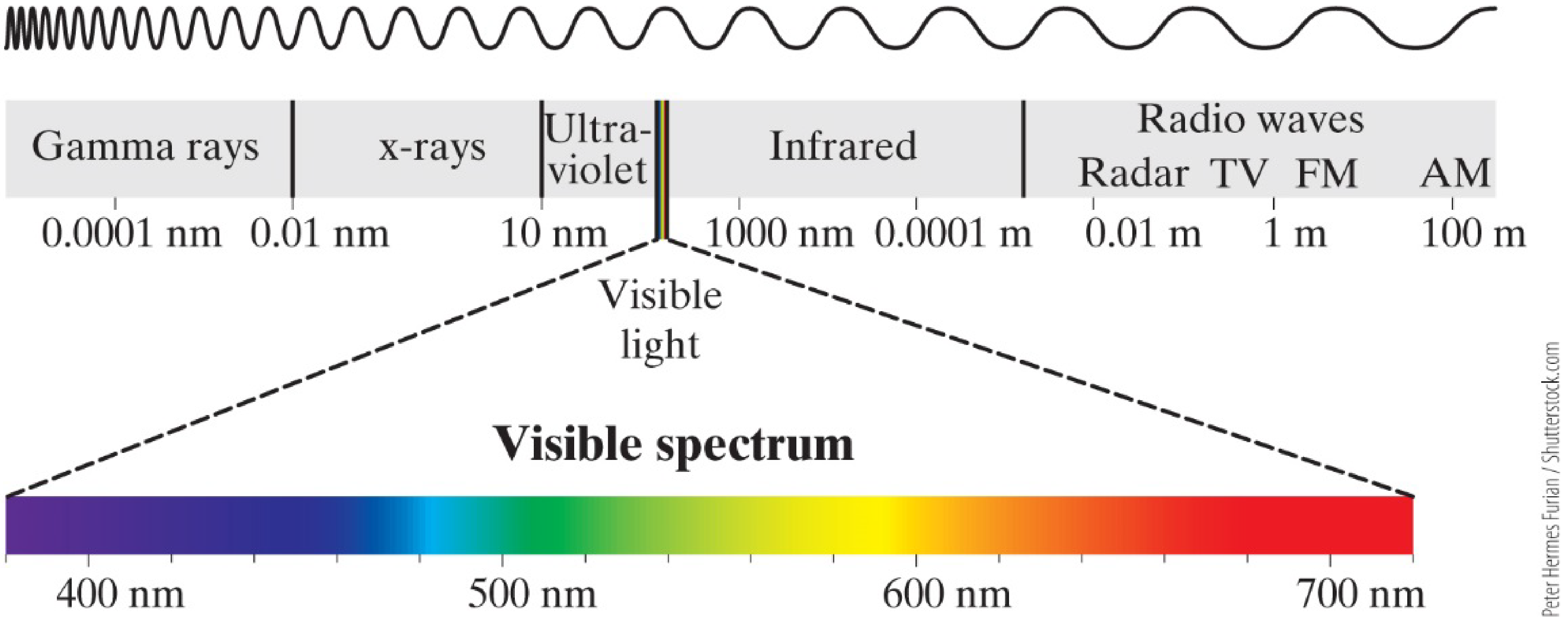


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Electromagnetic Spectrum

Figure 2.20 The electromagnetic spectrum consists of gamma rays and X-rays at one end, and radio waves and microwaves at the other end. The visible spectrum is between about 380 and 720 nm.



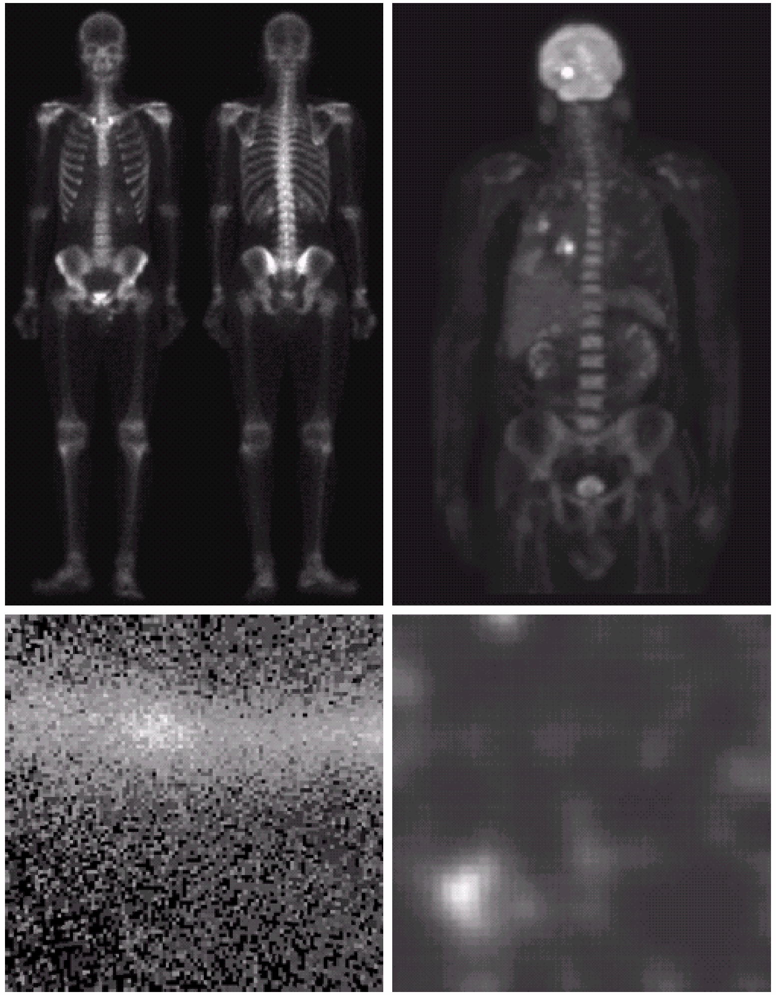
The EM spectrum arranged according to wavelength

Gamma-Ray Imaging

- Used in nuclear medicine, astronomy
- Nuclear medicine: patient is injected with radioactive isotope that emits gamma rays as it decays. Images are produced from emissions collected by detectors.

a b
c d

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of Michigan.)



X-Ray Imaging

- Oldest source of EM radiation for imaging
- Used for CAT scans
- Used for angiograms where X-ray contrast medium is injected through catheter to enhance contrast at site to be studied.
- Industrial inspection

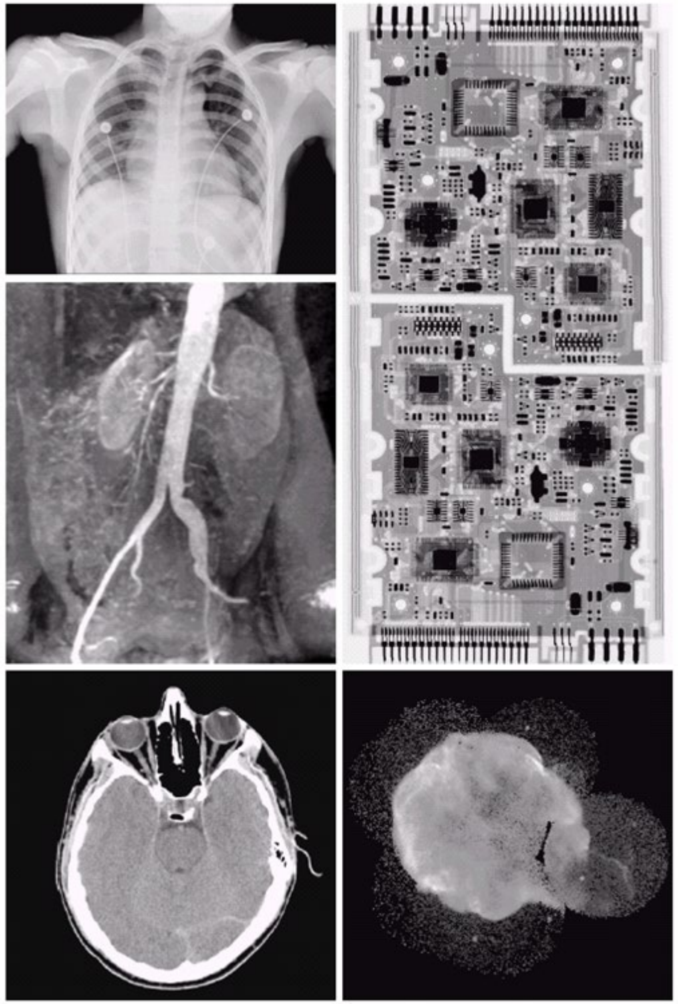


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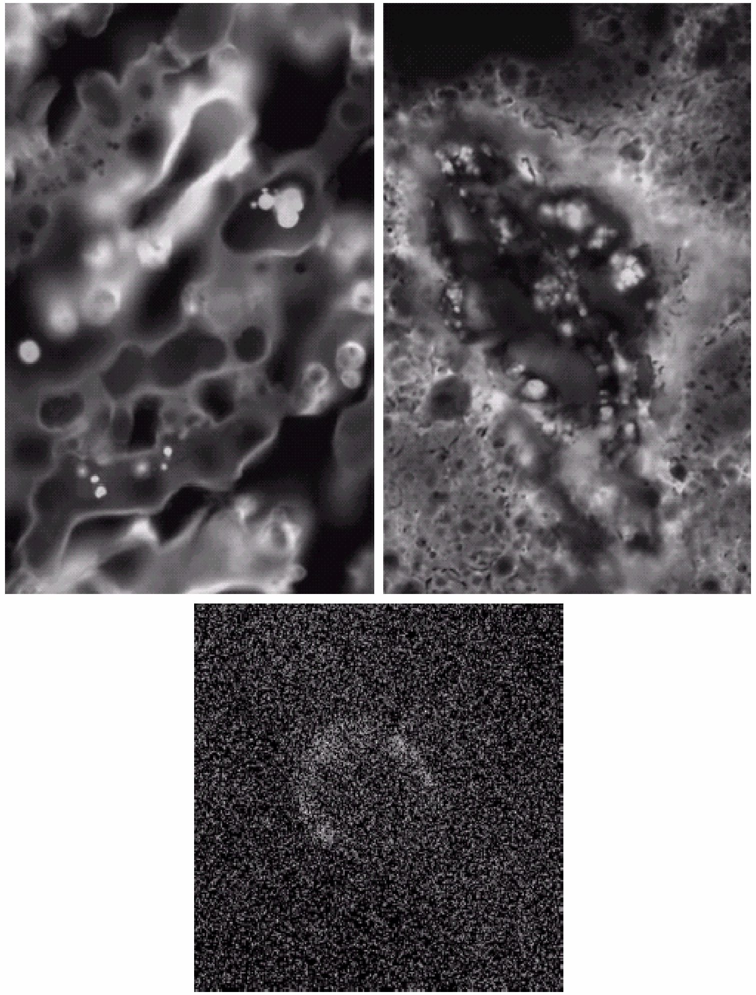
FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, (d) Mr. Joseph E. Pascente, Lixi, Inc., and (e) NASA.)

Ultraviolet Imaging

- Used for lithography, industrial inspection, flourescence microscopy, lasers, biological imaging, and astronomy
- Photon of UV light collides with electron of fluorescent material to elevate its energy. Then, its energy falls and it emits red light.

a b
c

FIGURE 1.8 Examples of ultraviolet imaging. (a) Normal corn. (b) Smut corn. (c) Cygnus Loop. (Images courtesy of (a) and (b) Dr. Michael W. Davidson, Florida State University, (c) NASA.)



Visible and Infrared Imaging (1)

- Used for astronomy, light microscopy, remote sensing

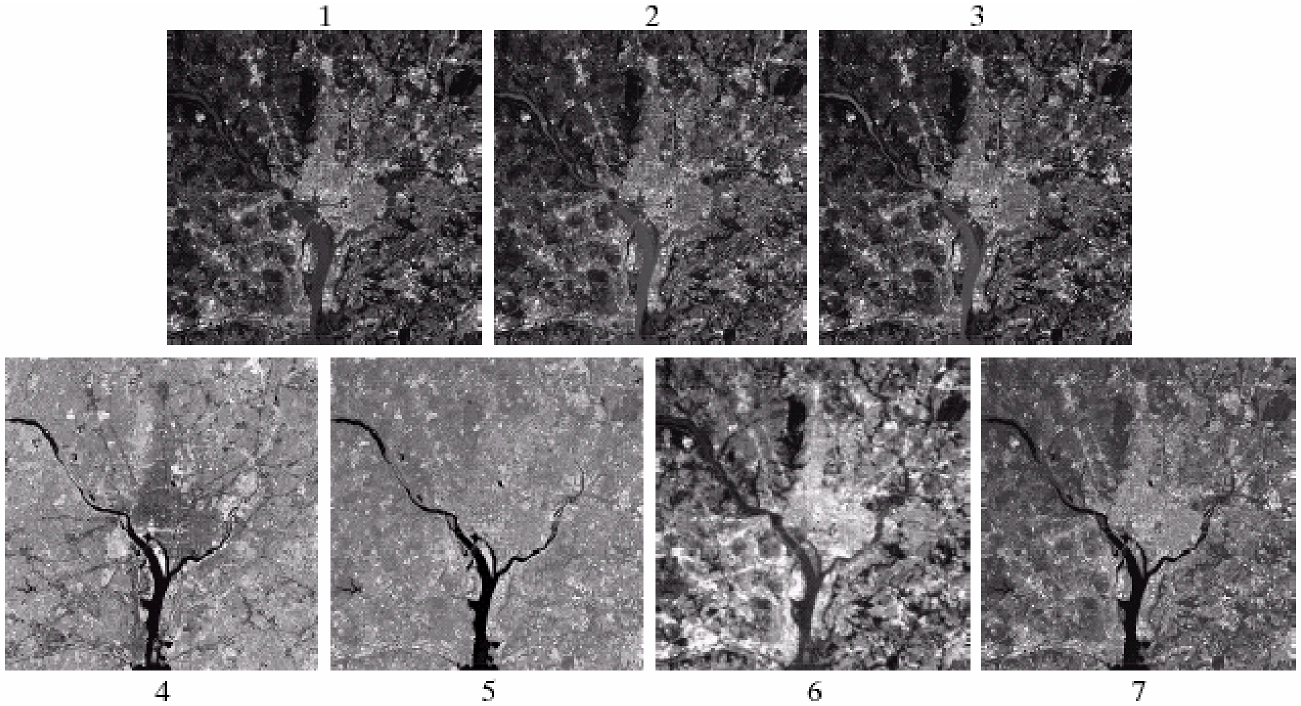


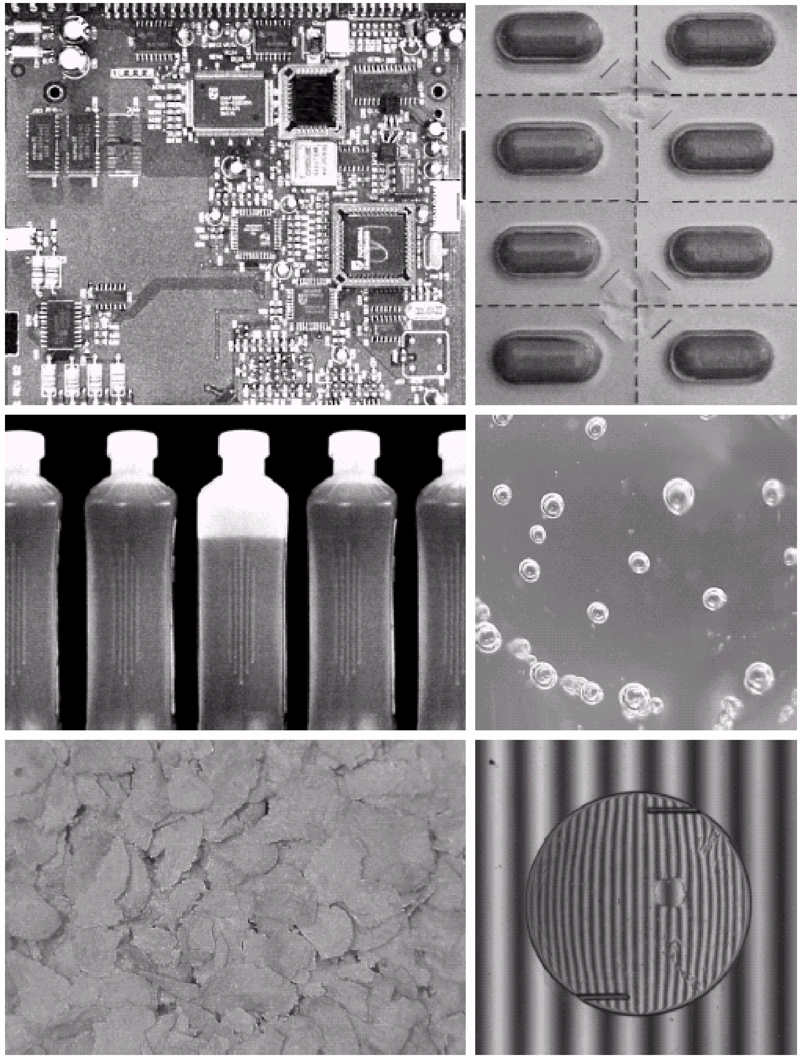
FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

Visible and Infrared Imaging (2)

- Industrial inspection
  - inspect for missing parts
  - missing pills
  - unacceptable bottle fill
  - unacceptable air pockets
  - anomalies in cereal color
  - incorrectly manufactured replacement lens for eyes



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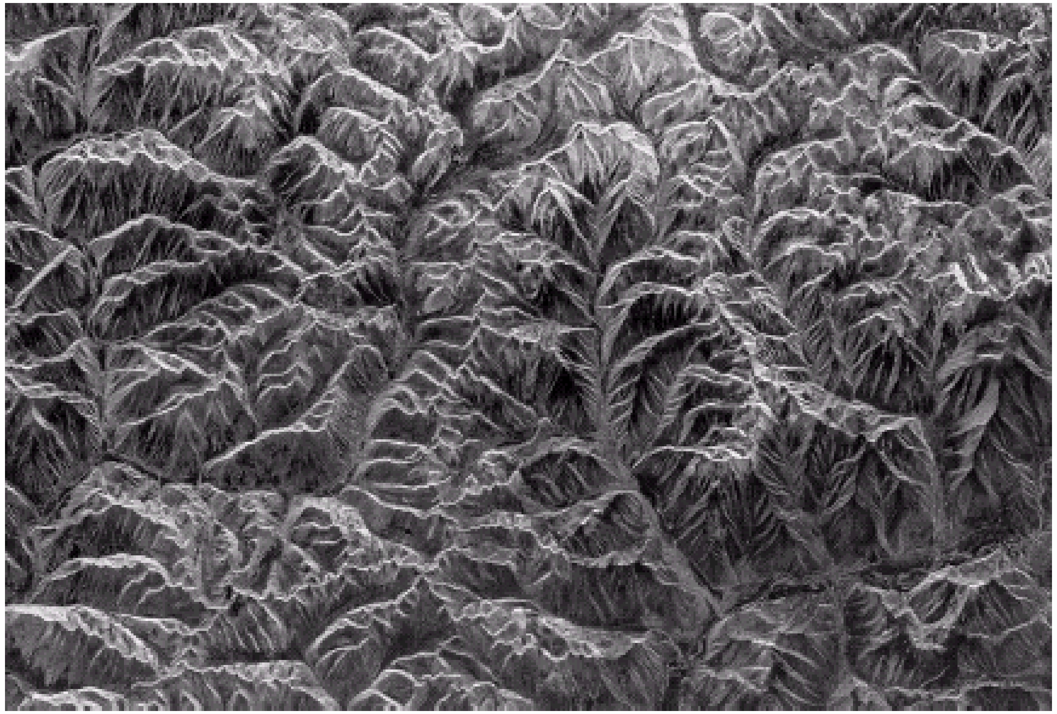
c d
e f

FIGURE 1.14 Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)

Microwave Imaging

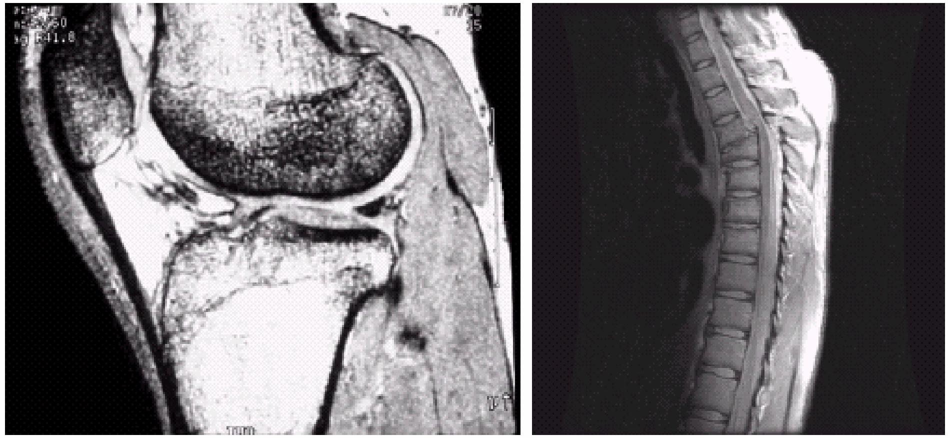
- Radar is dominant application
- Microwave pulses are sent out to illuminate scene
- Antenna receives reflected microwave energy

FIGURE 1.16 Spaceborne radar image of mountains in southeast Tibet. (Courtesy of NASA.)



Radio-Band Imaging

- Magnetic resonance imaging (MRI):
  - places patient in powerful magnet
  - passes radio waves through body in short pulses
  - each pulse causes a responding pulse of radio waves to be emitted by patient’s tissues
  - Location and strength of signal is recorded to form image



a b

FIGURE 1.17 MRI images of a human (a) knee, and (b) spine. (Image (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Images Covering EM Spectrum

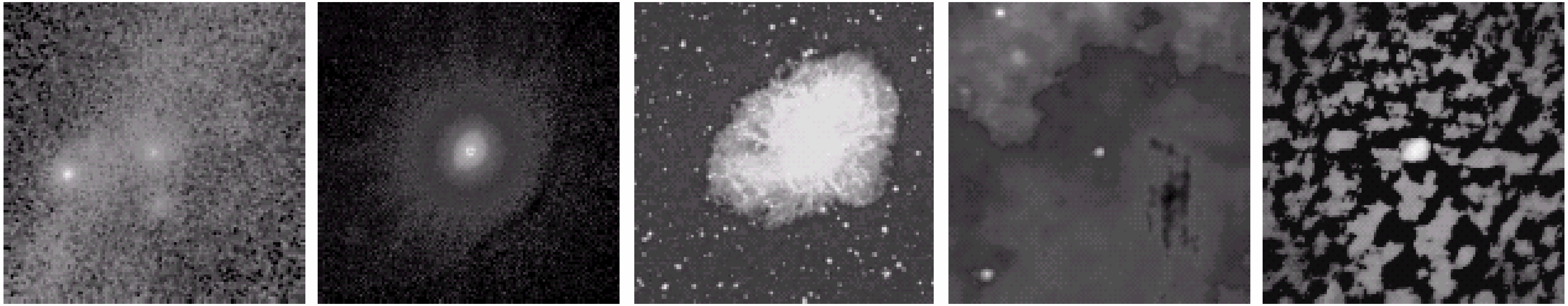
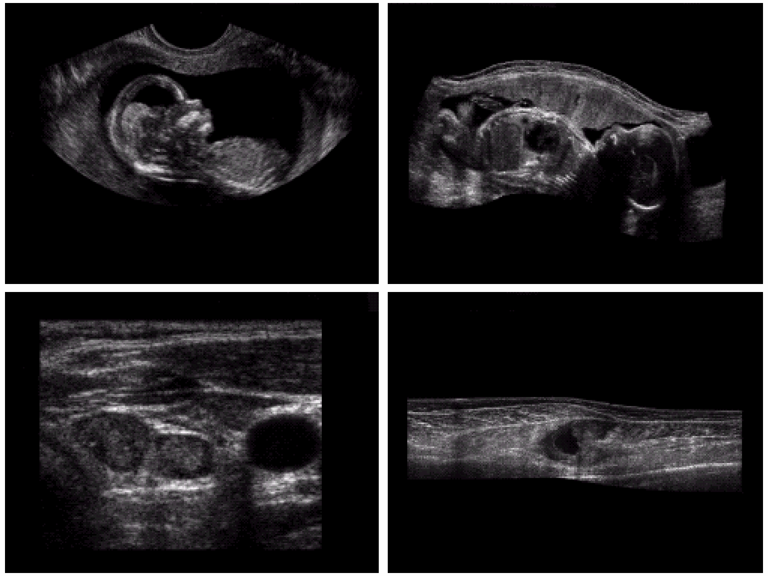


FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

Non-EM modality: Ultrasound

- Used in geological exploration, industry, medicine:
  - transmit high-freq (1-5 MHz) sound pulses into body
  - record reflected waves
  - calculate distance from probe to tissue/organ using the speed of sound (1540 m/s) and time of echo's return
  - display distance and intensities of echoes as a 2D image



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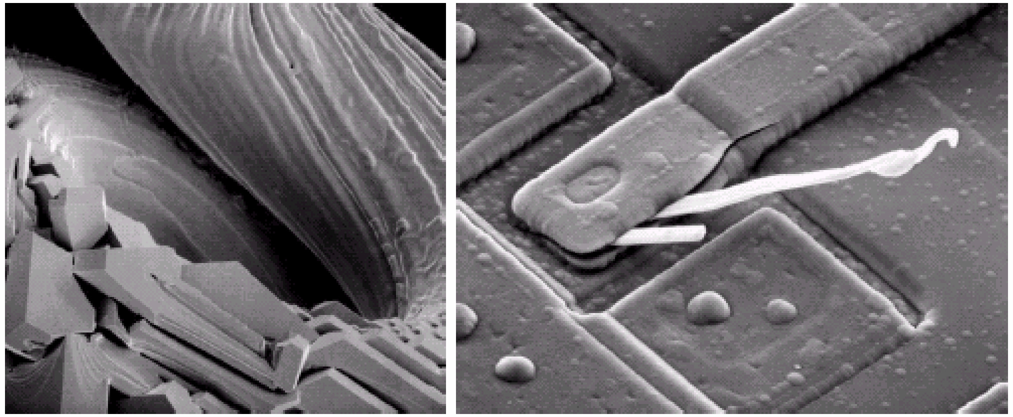
c d

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.)

Non-EM modality:
Scanning Electron Microscope

- Stream of electrons is accelerated toward specimen using a positive electrical potential
- Stream is focused using metal apertures and magnetic lenses into a thin beam
- Scan beam; record interaction of beam and sample at each location (dot on phosphor screen)



a b

FIGURE 1.21 (a) 250× SEM image of a tungsten filament following thermal failure. (b) 2500× SEM image of damaged integrated circuit. The white fibers are oxides resulting from thermal destruction. (Figure (a) courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene; (b) courtesy of Dr. J. M. Hudak, McMaster University, Hamilton, Ontario, Canada.)