Digital Image Processing

Medical
Image
Laboratory

1. Introduction

One picture is worth more than ten thousand words.

Anonymous

- **Two principal application areas:**
  - improvement of pictorial information for **human interpretation**
  - processing of image data for storage, transmission, and representation for **autonomous machine perception**.
- **In this chapter**
  - to define the scope of the field that we call image processing
  - to give a historical perspective of the origins of this field
  - to give an idea of the state of the art in image processing by examining some of the principal areas in which it is applied
  - to discuss briefly the principal approaches used in digital image processing
  - to give an overview of the components contained in a typical, general-purpose image processing system
  - to provide direction to the course and other literature where image processing work normally is reported.

- **What Is Digital Image Processing?**
  - **An image may be defined as a two-dimensional function, $f(x, y)$, where x and y are *spatial* (plane) coordinates**
  - **the amplitude of f at any pair of coordinates (x, y) is called the *intensity* or *gray level* of the image at that point.**
  - **When x, y, and the amplitude values of f are all finite, discrete quantities, we call the image a *digital image*.**

- A digital image is composed of a finite number of elements, each of which has a particular location and value.
- These elements are referred to as
  - *picture elements*
  - *image elements*
  - *Pels*
  - ***pixels***

- Three types of computerized processes from image processing
  - **Low-level** processes involve primitive operations
    - such as image preprocessing to reduce noise, contrast enhancement, and image sharpening. A low-level process is characterized by the fact that both its inputs and outputs are images.
  - **Mid-level** processing on images involves tasks
    - such as segmentation (partitioning an image into regions or objects) description of those objects to reduce them to a form suitable for computer processing, and classification (recognition) of individual objects. A mid-level process is characterized by the fact that its inputs generally are images, but its outputs are attributes extracted from those images (e.g., edges, contours, and the identity of individual objects).

- **Higher-level** processing involves
  - "making sense" of an ensemble of recognized objects, as in image analysis, and, at the far end of the continuum, performing the cognitive functions normally associated with vision.

- **The Origins of Digital Image Processing**
  - One of the first applications of digital images was in the newspaper industry.
    - Fig.1.1 (1921)
    - Fig.1.2 (1922)
    - Fig.1.3 (1929)
  - The first computers powerful enough to carry out meaningful image processing tasks appeared in the early 1960s.
    - Fig.1.4 (1964)
  - The invention in the early 1970s of computerized axial tomography (CAT), also called computerized tomography (CT) for short, is one of the most important events in the application of image processing in medical diagnosis.

FIGURE 1.1 A digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces. (McFarlane.)

FIGURE 1.2 A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice. Some errors are visible. (McFarlane.)

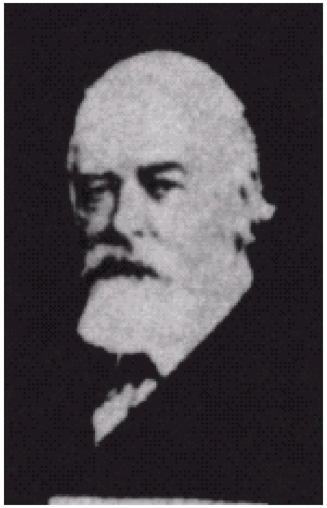


FIGURE 1.3 Unretouched cable picture of Generals Pershing and Foch, transmitted in 1929 from London to New York by 15-tone equipment. (McFarlane.)

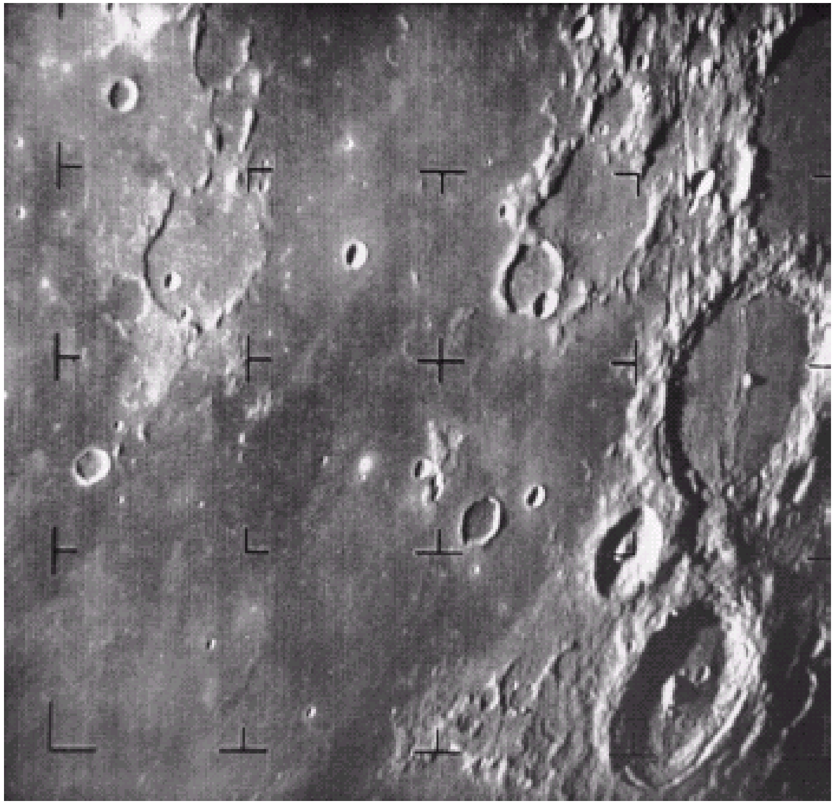


FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

- **Fields that Use Digital Image Processing**
  - **Electromagnetic waves can be conceptualized as propagating sinusoidal waves of varying wavelengths**
  - **Each traveling in a wavelike pattern and moving at the speed of light.**
  - **Each massless particle contains a certain amount (or bundle) of energy.**
  - **Each bundle of energy is called a *photon*.**
  - **If spectral bands are grouped according to energy per photon, we obtain the spectrum shown in Fig. 1.5, ranging from gamma rays (highest energy) at one end to radio waves (lowest energy) at the other.**

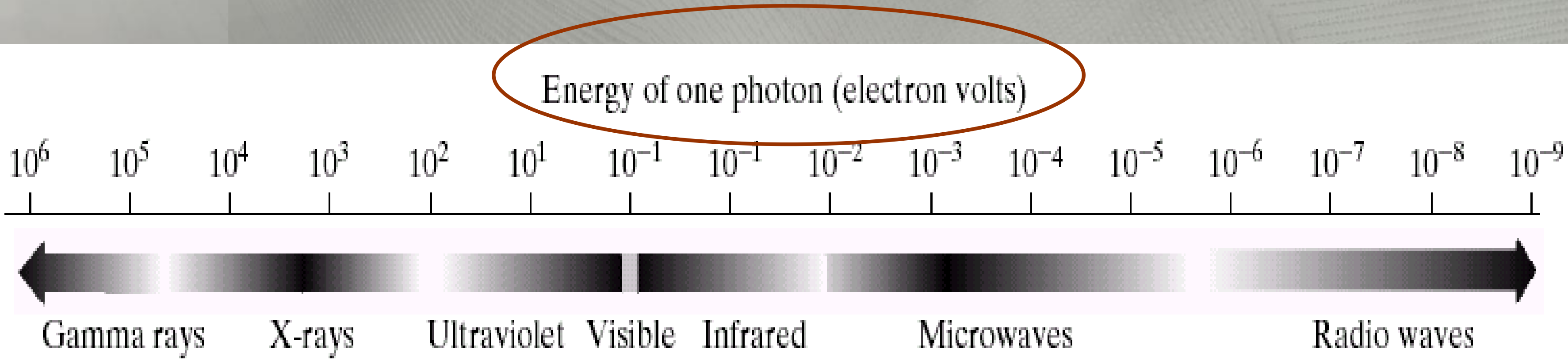
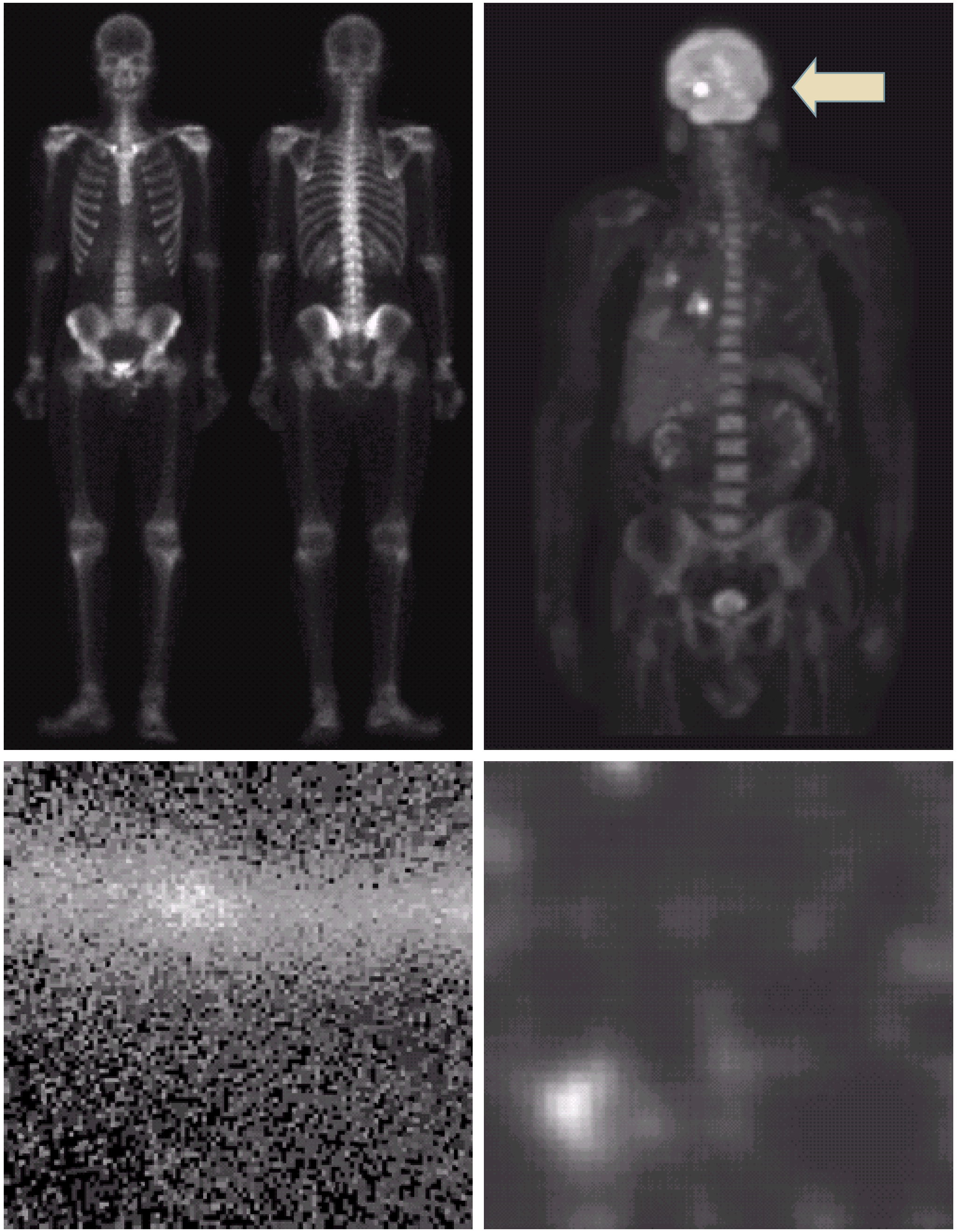


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

- **Gamma-Ray Imaging**
  - **Nuclear medicine**
  - **Astronomical observations.**
- **In figs.1.6**
  - **Major modality of nuclear imaging called positron emission tomography (PET)**
  - **A star in the constellation of Cygnus exploded about 15,000 years ago, generating a superheated stationary gas cloud (known as the Cygnus Loop) that glows in a spectacular array of colors.**

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.)



Positron Emission Tomography - GE

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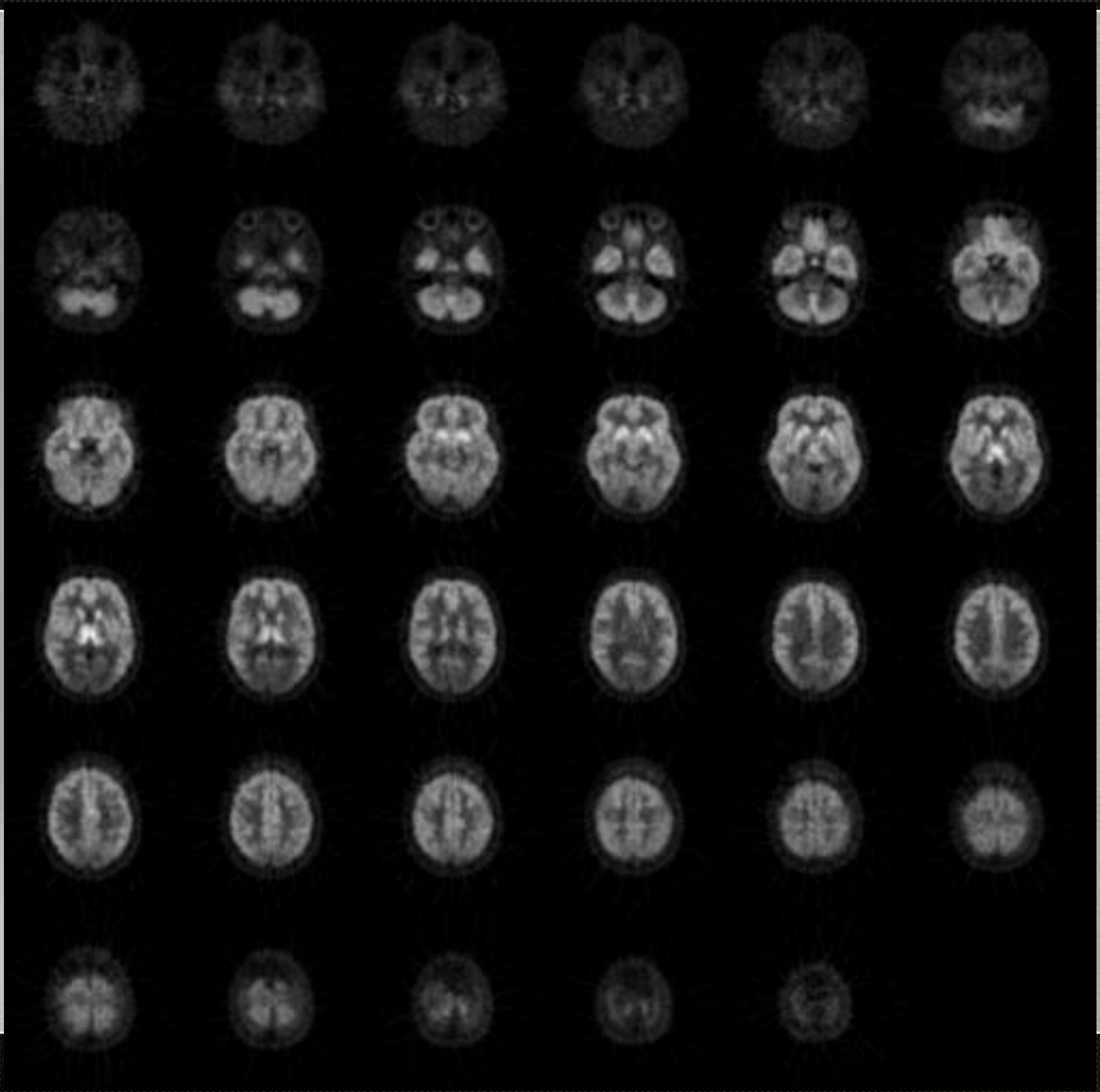

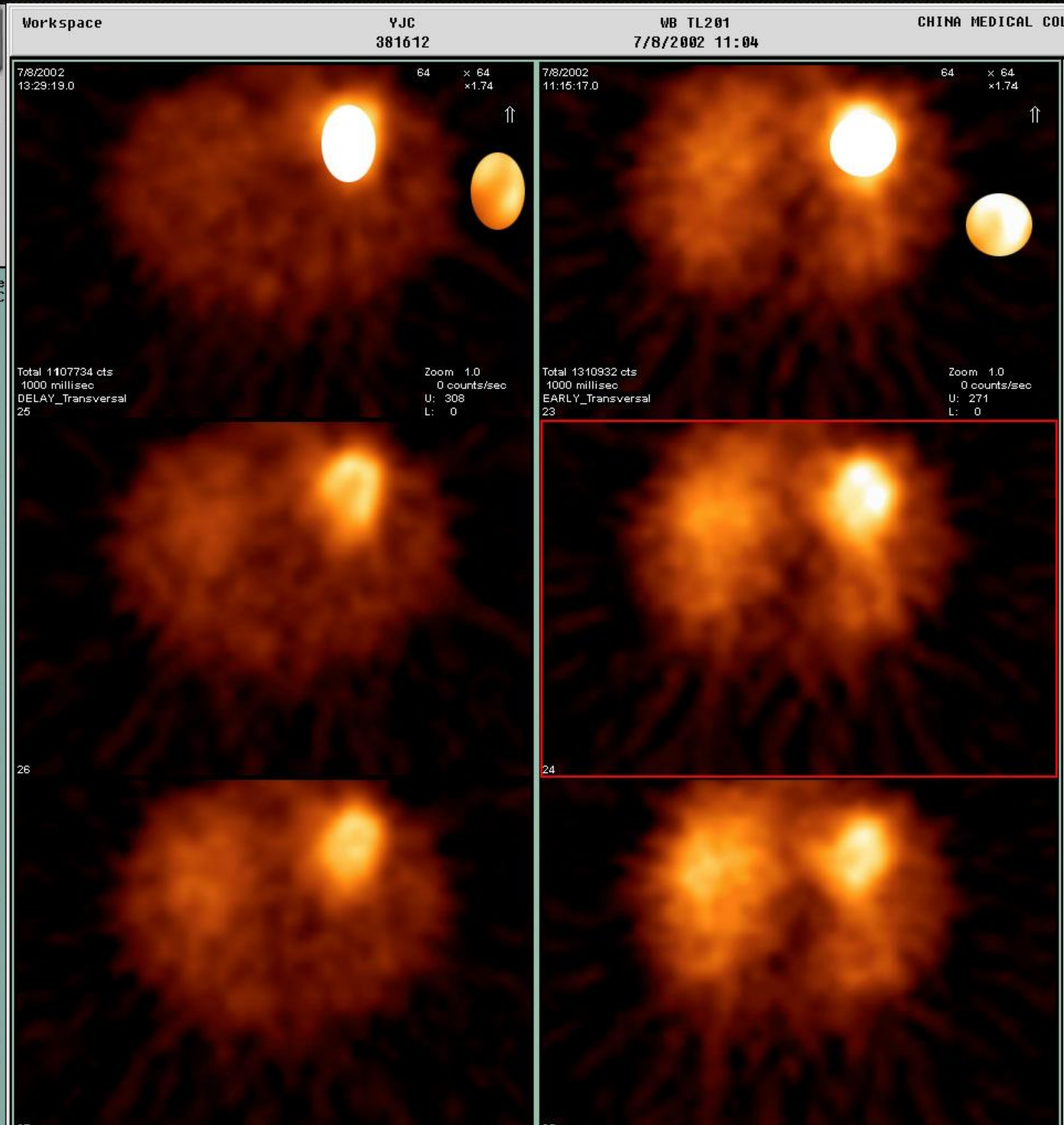
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- **X-ray Imaging**
  - X-rays are among the oldest sources of EM radiation used for imaging.
    - Medical diagnostics
    - Industry
    - Astronomy
  - In digital radiography, digital images are obtained by one of two methods:
    - By digitizing X-ray films
    - By having the X-rays that pass through the patient fall directly onto devices (such as a phosphor screen) that convert X-rays to light.The light signal in turn is captured by a light-sensitive digitizing system.

- In Figs. 1.7
- Angiography(血管造影法)
  - is another major application in an area called contrast enhancement radiography. This procedure is used to obtain images (called *angiograms*) of blood vessels.
  - A catheter (a small, flexible, hollow tube) is inserted, for example, into an artery or vein in the groin.
  - The catheter is threaded into the blood vessel and guided to the area to be studied.
  - Figure 1.7(b) shows an example of an aortic angiogram.

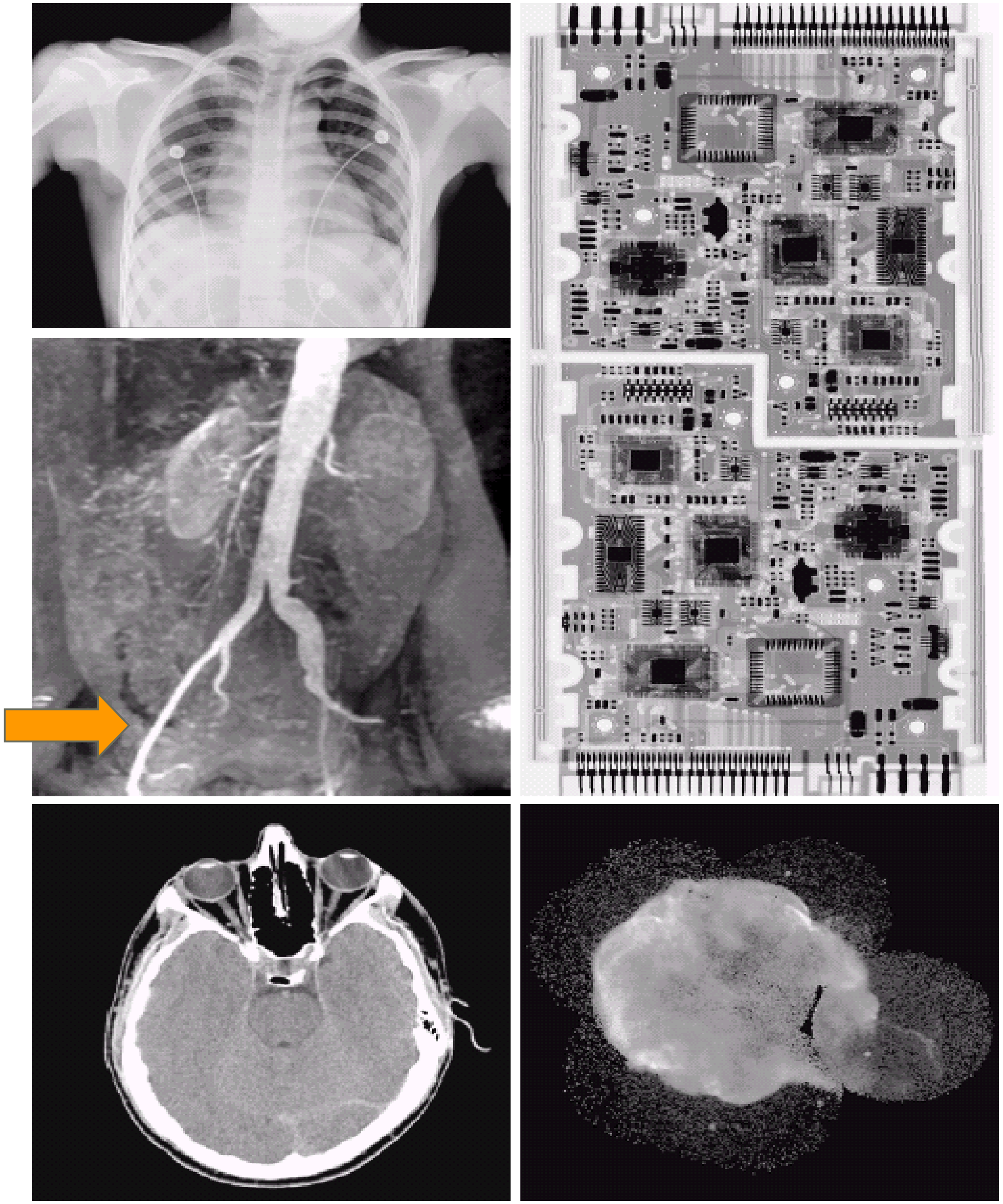
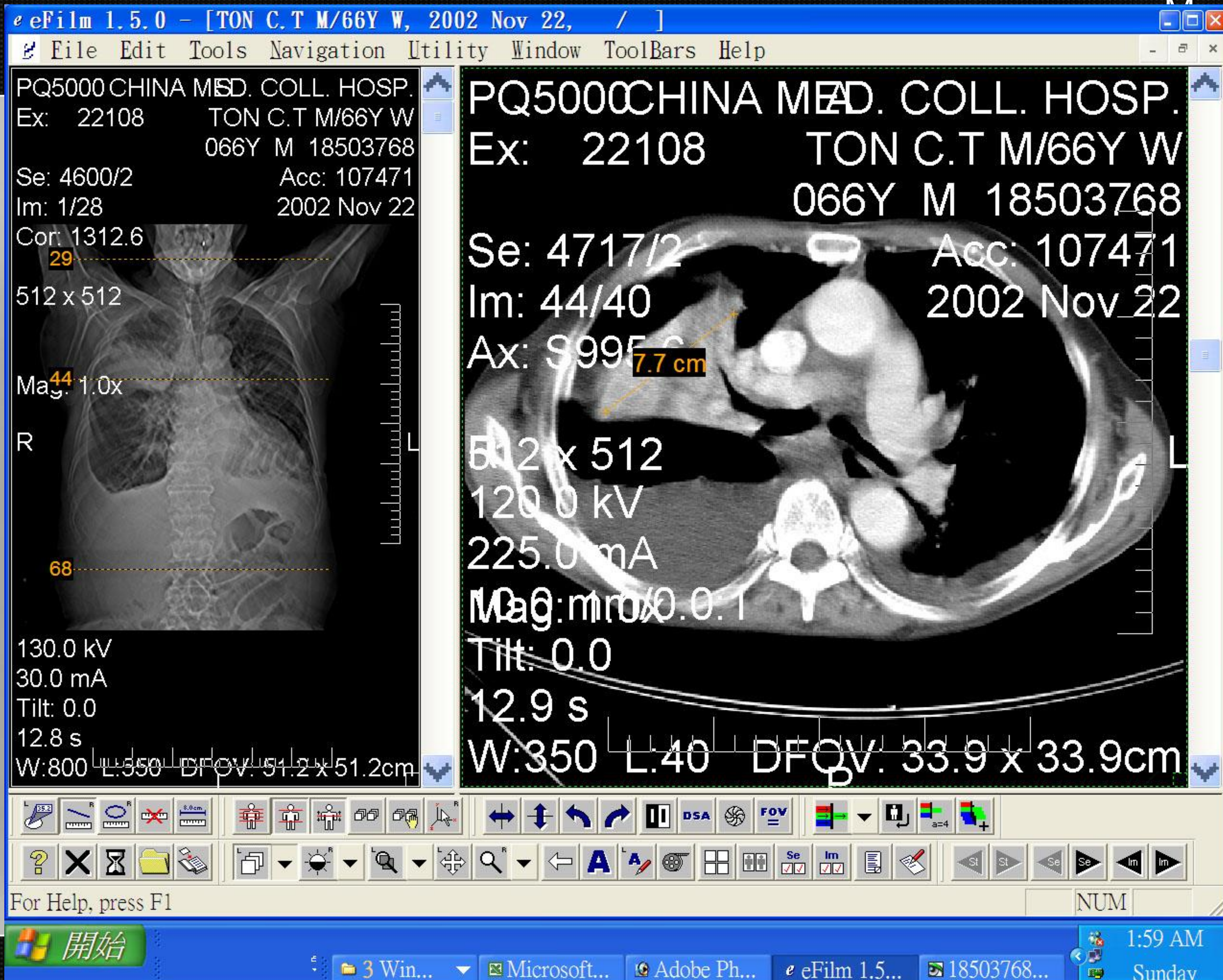


FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical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

1.內外側斜位像(Mediolateral oblique **view**; **MLO view**)：以壓迫裝置自內上方向外下方壓迫乳房並固定之(約45度)，予以照相。
2.顱尾側正位像(Cranio-caudal **view**; CC **view**)：以壓迫裝置自上往下壓迫乳房並固定之(90度)，予以照相。

- Imaging in the Ultraviolet Band
  - Applications of ultraviolet “light” are varied
    - Lithography (平版印刷術)
    - Industrial inspection
    - Microscopy(顯微鏡學)-Fluorescence microscopy
    - Lasers
    - Biological imaging
    - Astronomical observations.
  - Figures 1.8 illustrates imaging in this band with examples from microscopy and astronomy.

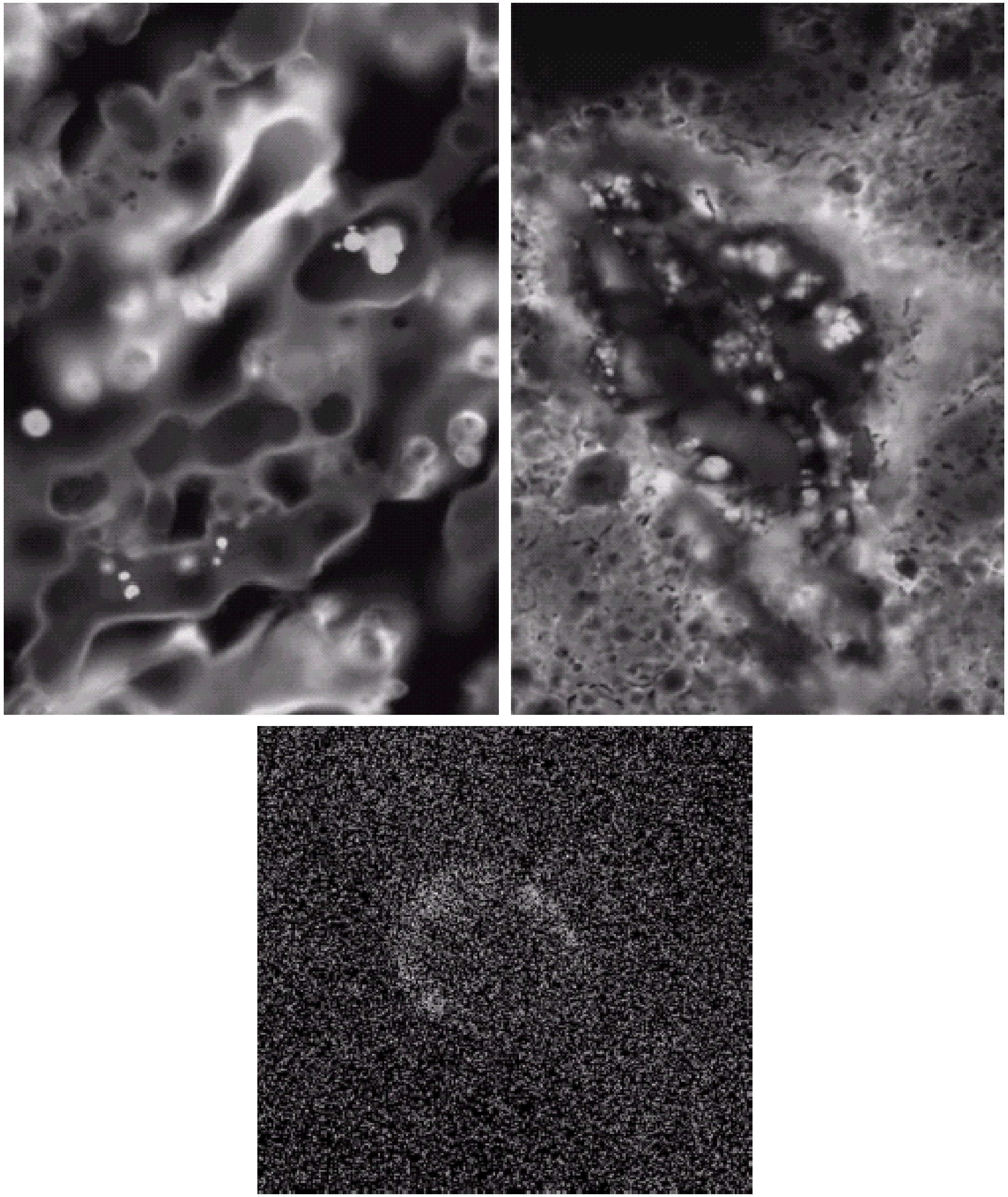
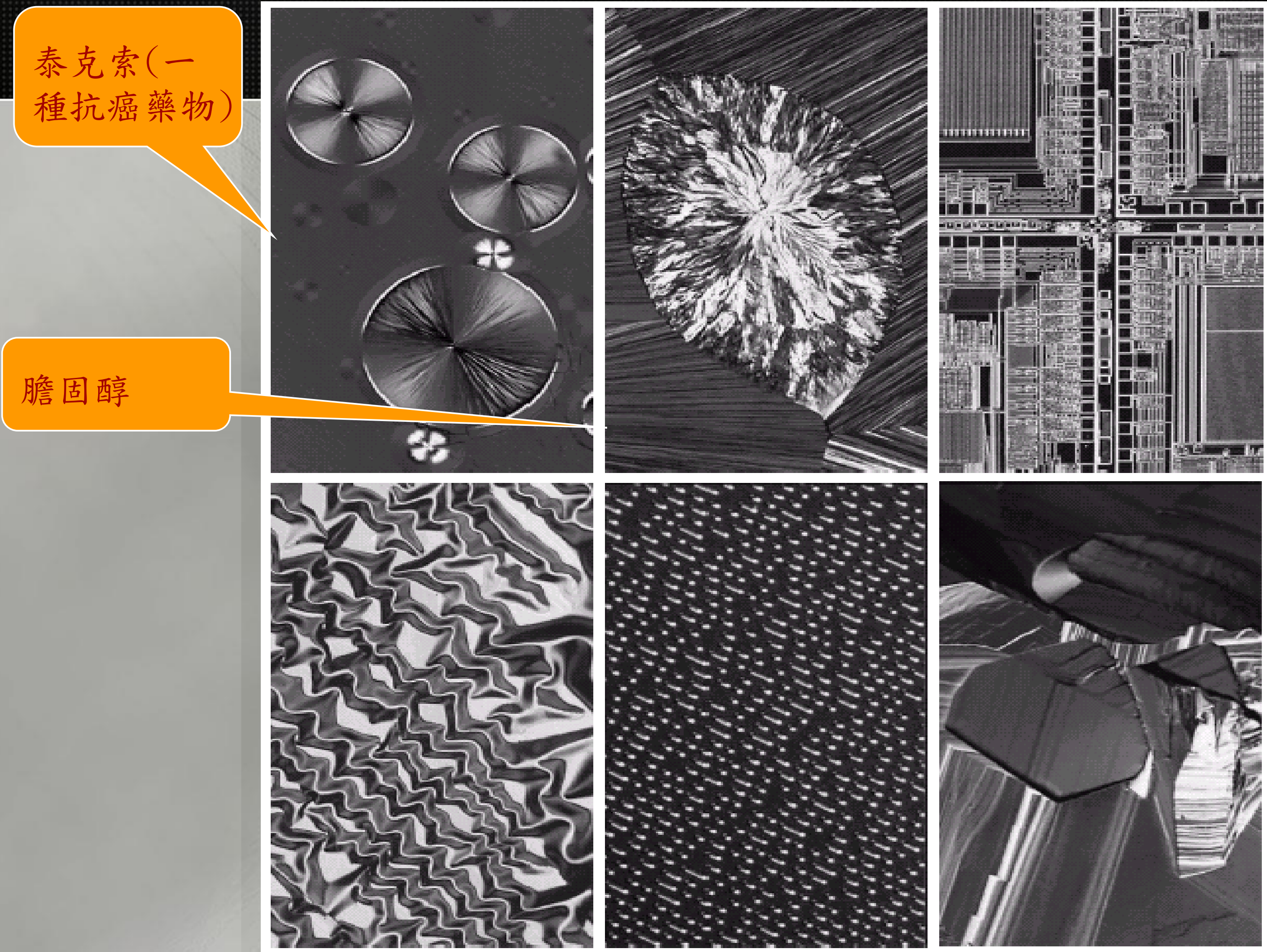


FIGURE 1.8 Examples of ultraviolet imaging. (a) Normal corn. (b) Smut corn. (c) Cygnus Loop. (Images courtesy of (a) and (b) Dr. Michael W. Davidson, Florida State University, (c) NASA.)

- **Imaging in the Visible and Infrared Bands**
  - **The infrared band often is used in conjunction with visual imaging.**
  - **Figure 1.9 shows several examples of images obtained with a light microscope.**



a b c
d e f

FIGURE 1.9 Examples of light microscopy images. (a) Taxol (anticancer agent), magnified 250×. (b) Cholesterol—40×. (c) Microprocessor—60×. (d) Nickel oxide thin film—600×. (e) Surface of audio CD—1750×. (f) Organic superconductor—450×. (Images courtesy of Dr. Michael W. Davidson, Florida State University.)

- Another major area of visual processing is remote sensing
  - Usually includes several bands in the visual and infrared regions of the spectrum.
- Table 1.1 shows the so-called *thematic bands* in NASA's LANDSAT satellite.
  - The primary function of LANDSAT is to obtain and transmit images of the Earth from space, for purposes of monitoring environmental conditions on the planet.
- *Multispectral* imaging
  - consider Fig. 1.10

TABLE 1.1 Thematic bands of 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	0.53–0.61	Measures plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.78–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content: soil/vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Short-wave infrared	2.09–2.35	Mineral mapping

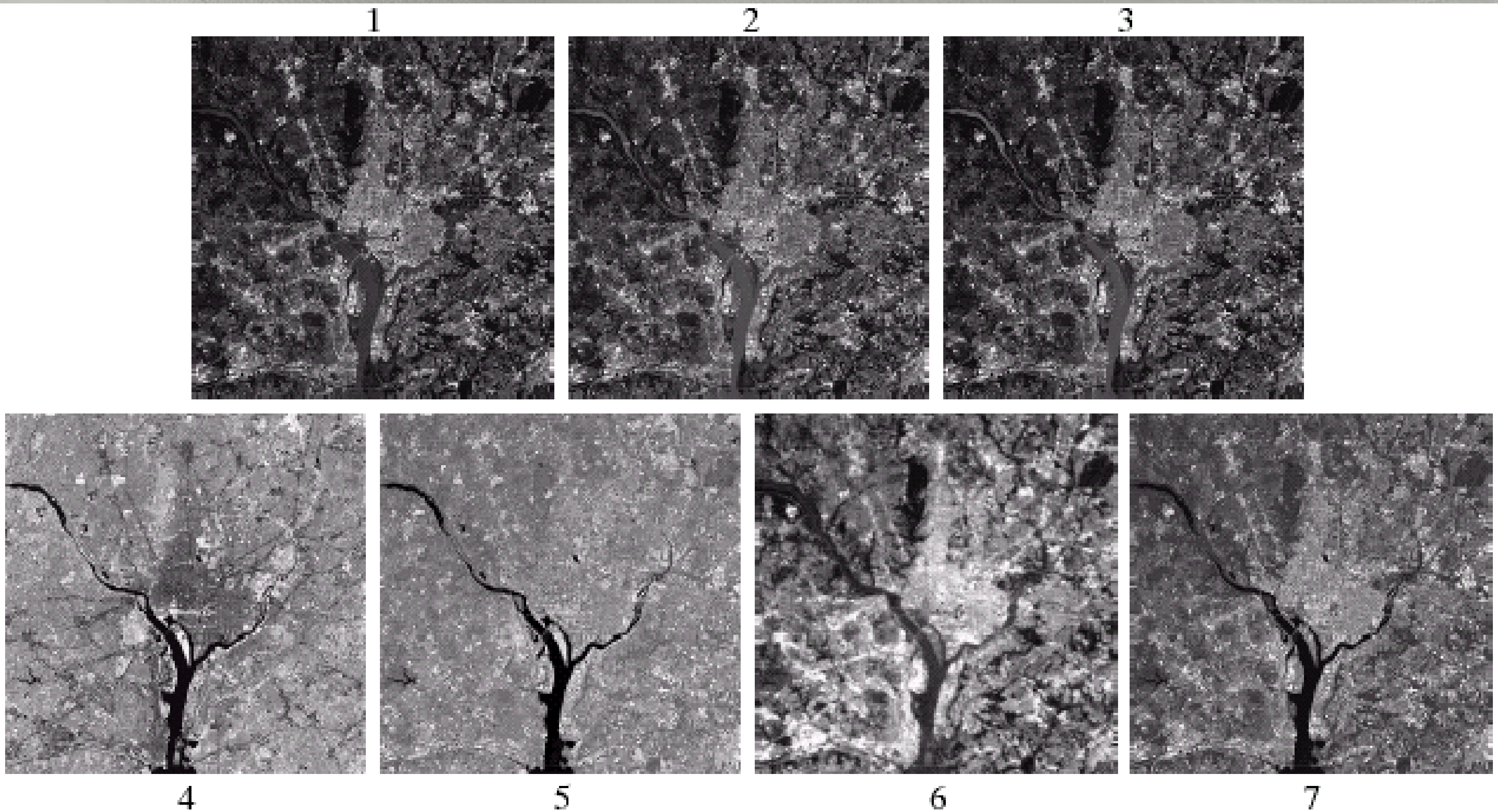


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

- Weather observation and prediction also are major applications of multispectral imaging from satellites.
  - Fig. 1.11 is an image of a hurricane taken by a National Oceanographic and Atmospheric Administration (NOAA) satellite using sensors in the visible and infrared bands.
  - The eye of the hurricane is clearly visible in this image.
- Infrared imaging
  - Figures 1.12 and 1.13 are part of the *Nighttime Lights of the World* data set
  - The images were generated by the infrared imaging system mounted on a NOAA DMSP (Defense Meteorological Satellite Program) satellite.

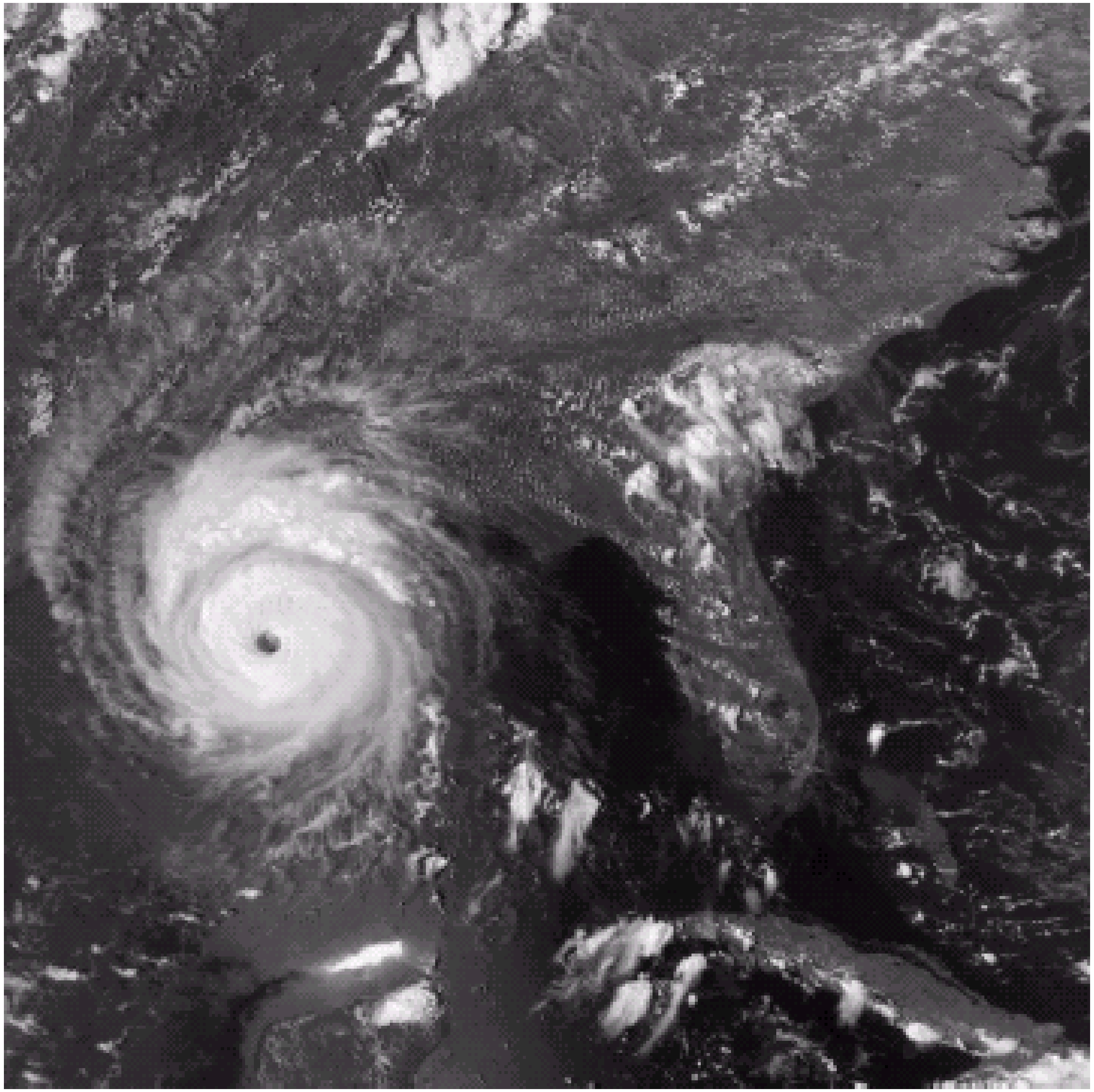
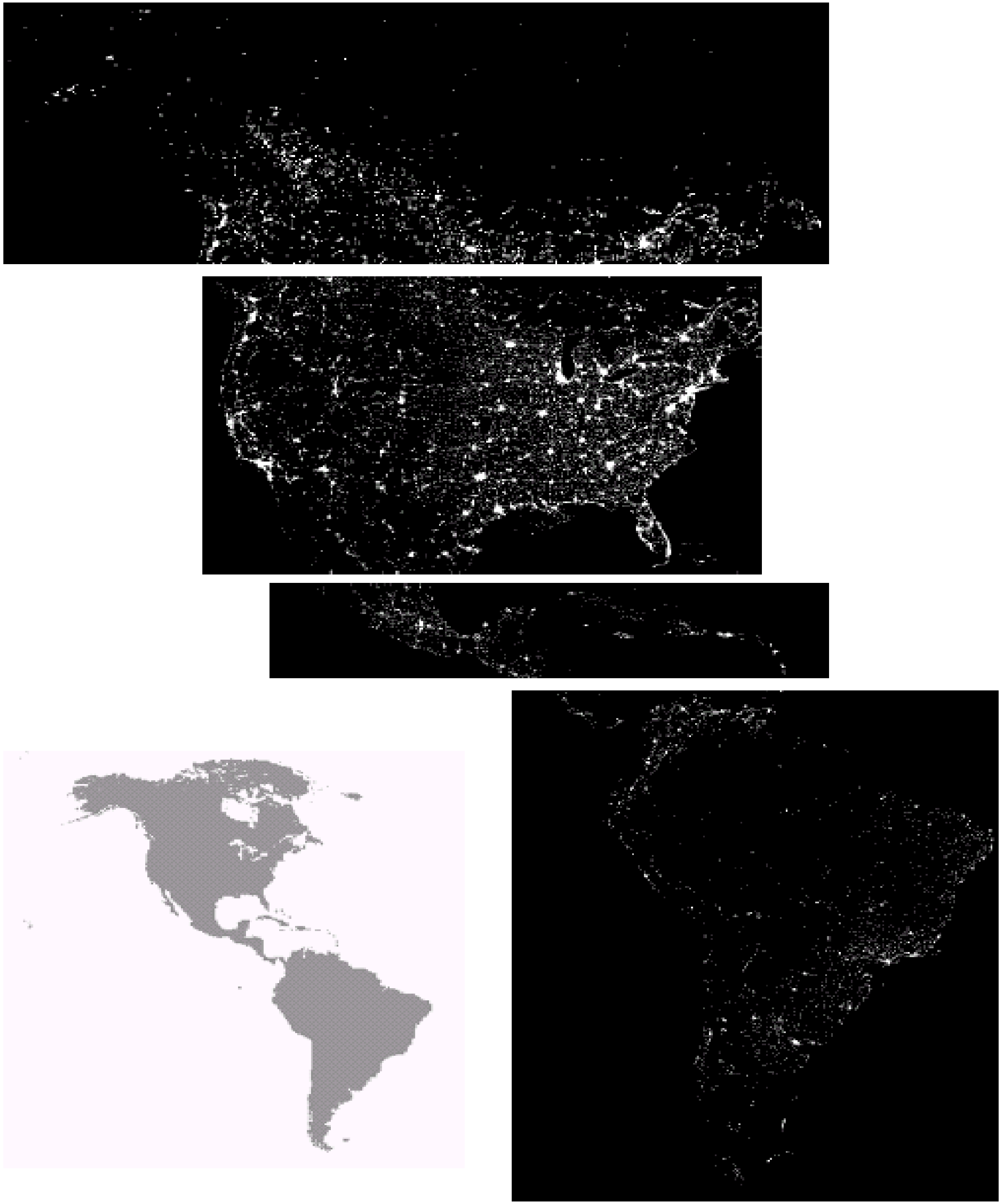


FIGURE 1.11 Multispectral image of Hurricane Andrew taken by NOAA GEOS (Geostationary Environmental Operational Satellite) sensors. (Courtesy of NOAA.)

FIGURE 1.12 Infrared satellite images of the Americas. The small gray map is provided for reference. (Courtesy of NOAA.)



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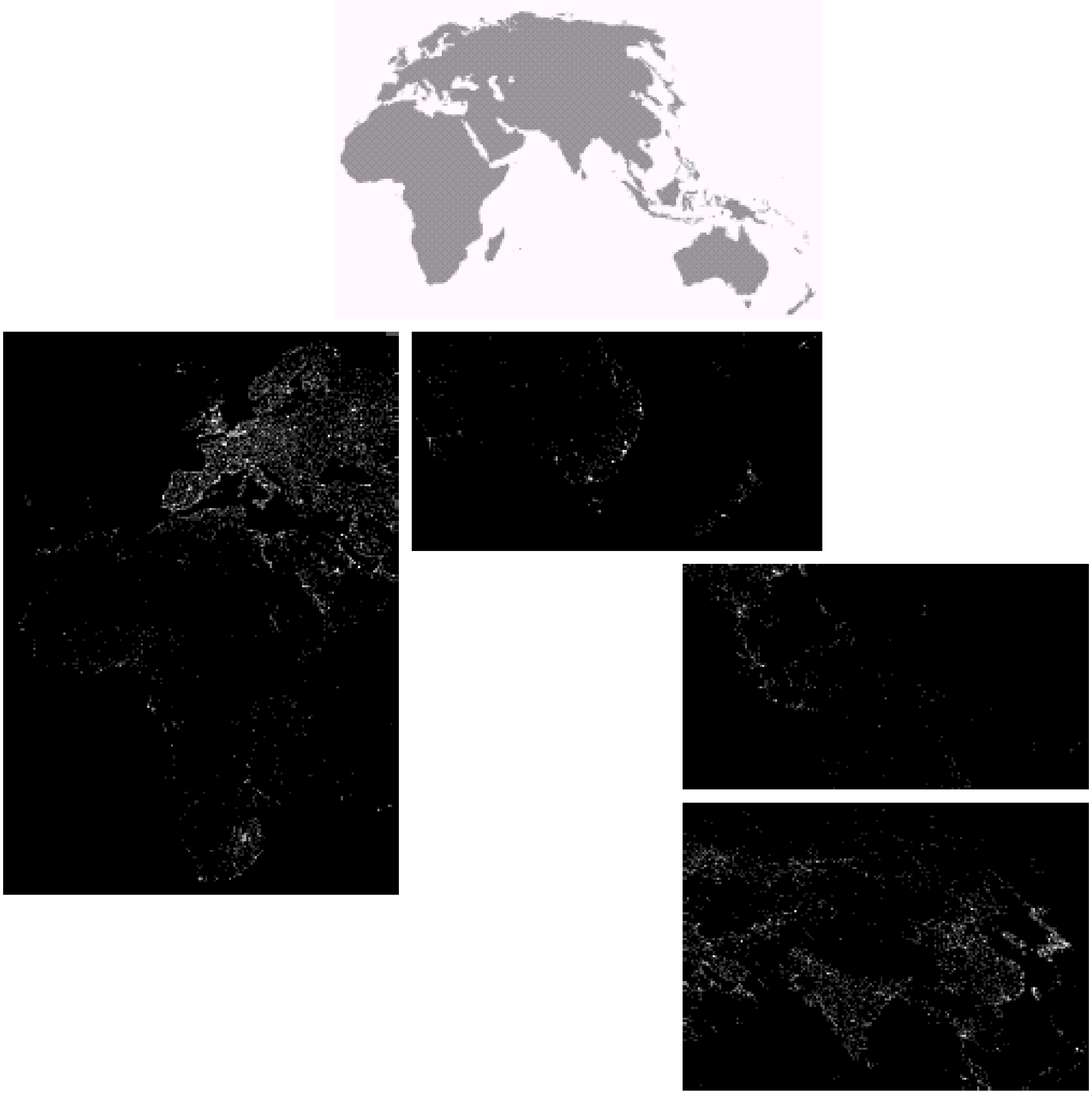


FIGURE 1.13 Infrared satellite images of the remaining populated part of the world. The small gray map is provided for reference. (Courtesy of NOAA.)

- A major area of imaging in the visual spectrum is in automated visual inspection of manufactured goods
  - Figures 1.14 and 1.15 show some examples

a	b
c	d
e	f

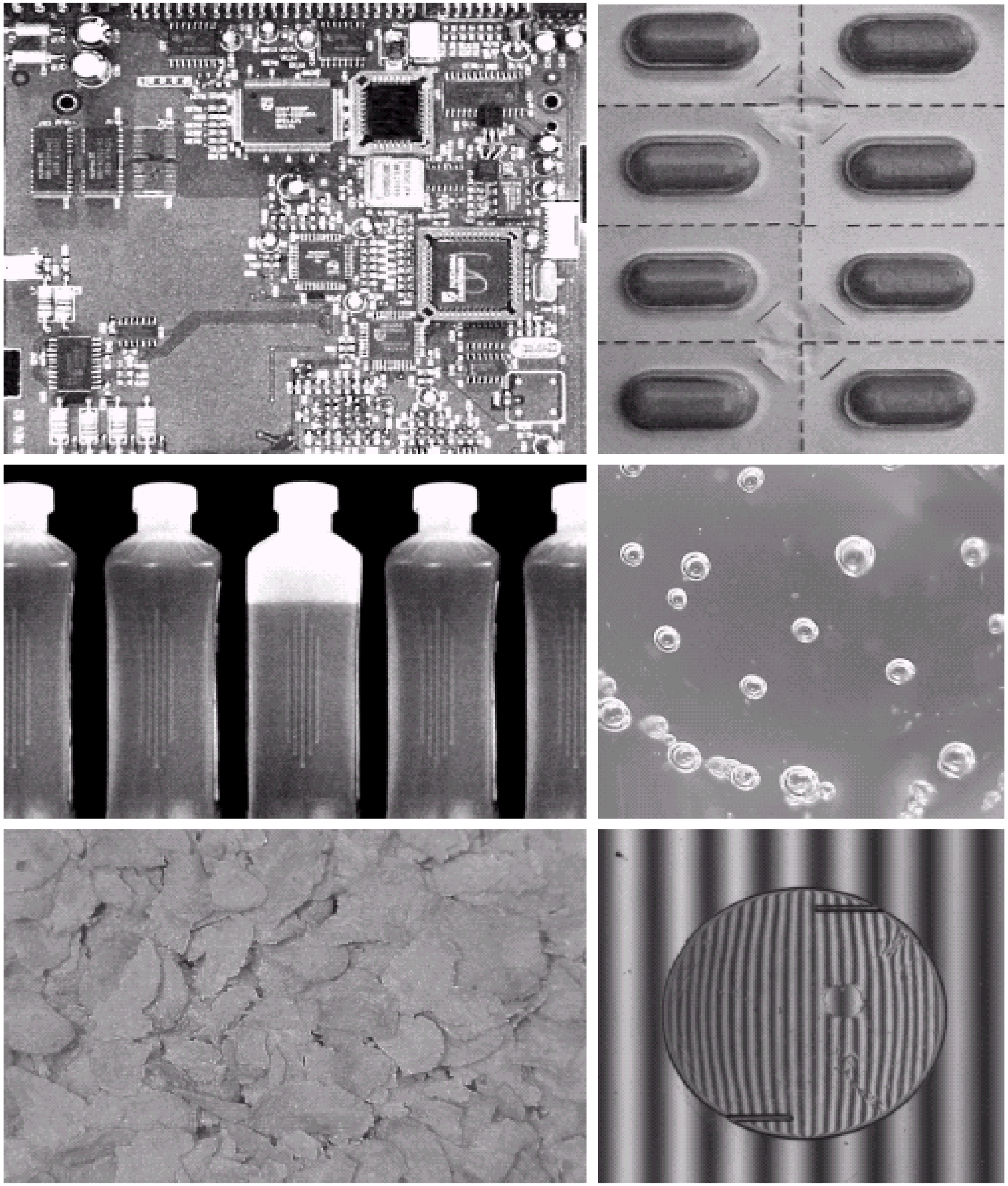
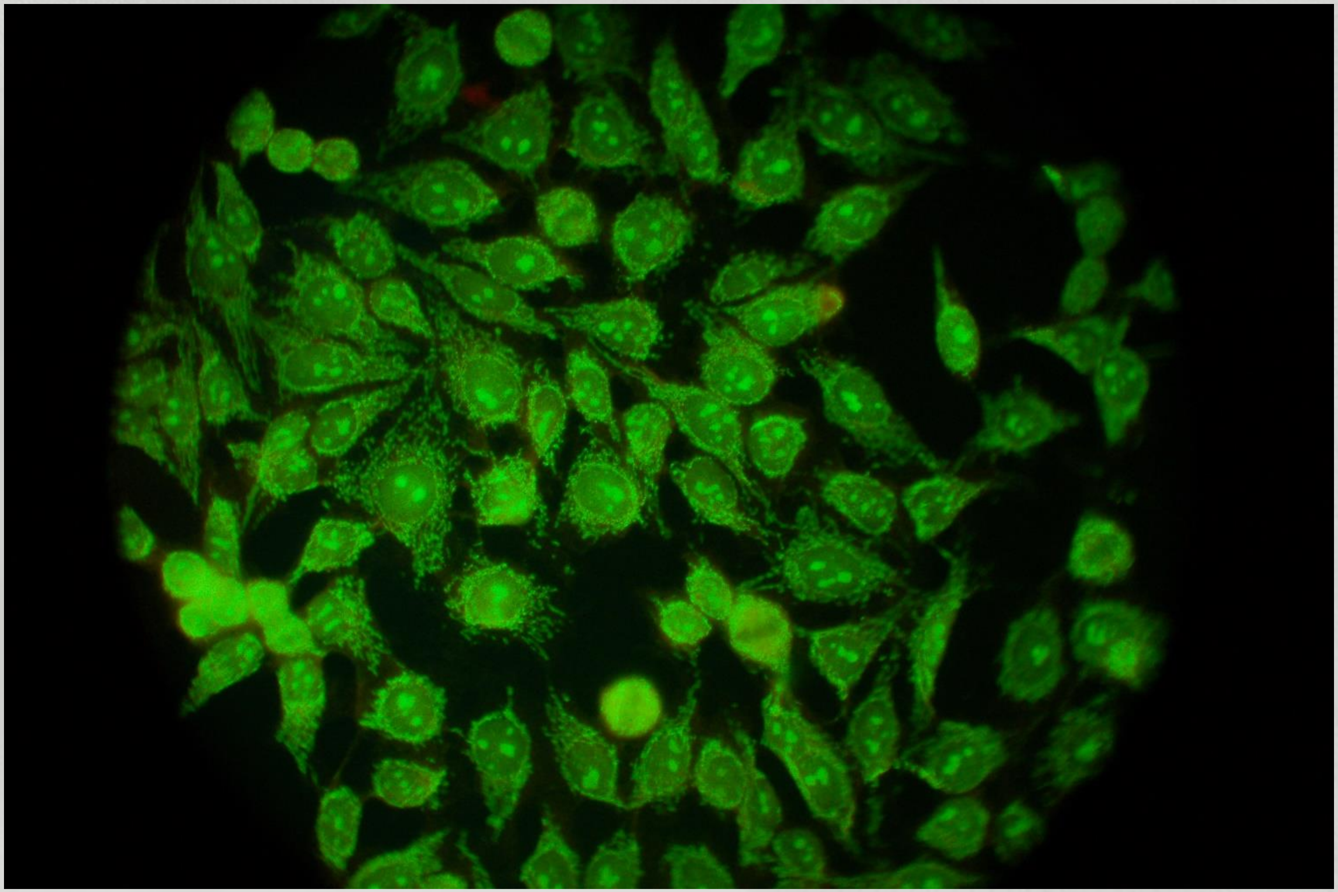
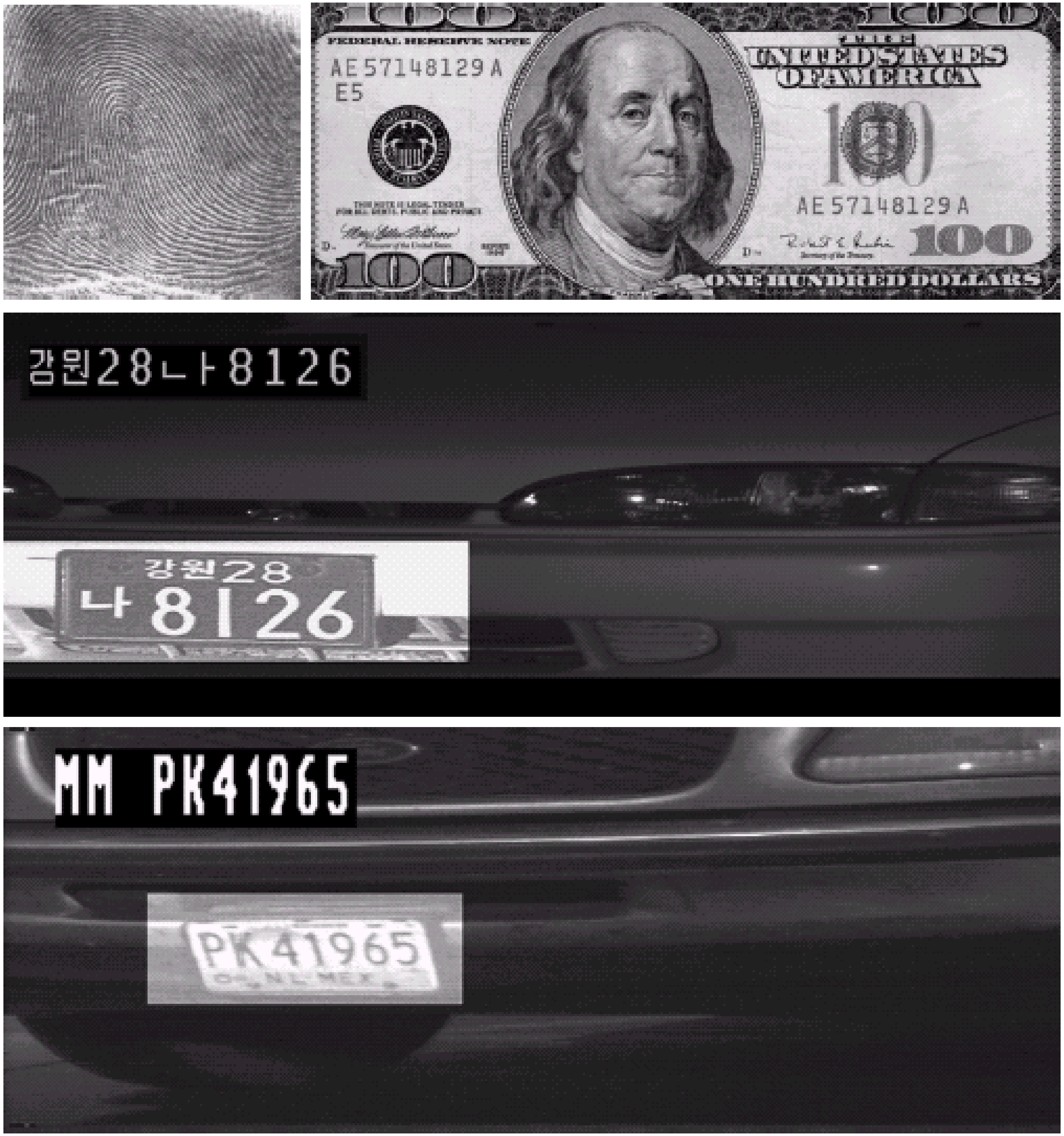


FIGURE 1.14 Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)





a b
c
d

FIGURE 1.15 Some additional examples of imaging in the visual spectrum. (a) Thumb print. (b) Paper currency. (c) and (d). Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)

- Imaging in the Microwave Band
  - The dominant application of imaging in the microwave band is Radar.
    - The unique feature of imaging radar is its ability to collect data over virtually any region at any time, regardless of weather or ambient lighting conditions.
  - Figure 1.16 shows a spaceborne radar image covering a rugged mountainous area of southeast Tibet (西藏)
    - About 90 km east of the city of Lhasa.
    - In the lower right corner is a wide valley of the Lhasa River

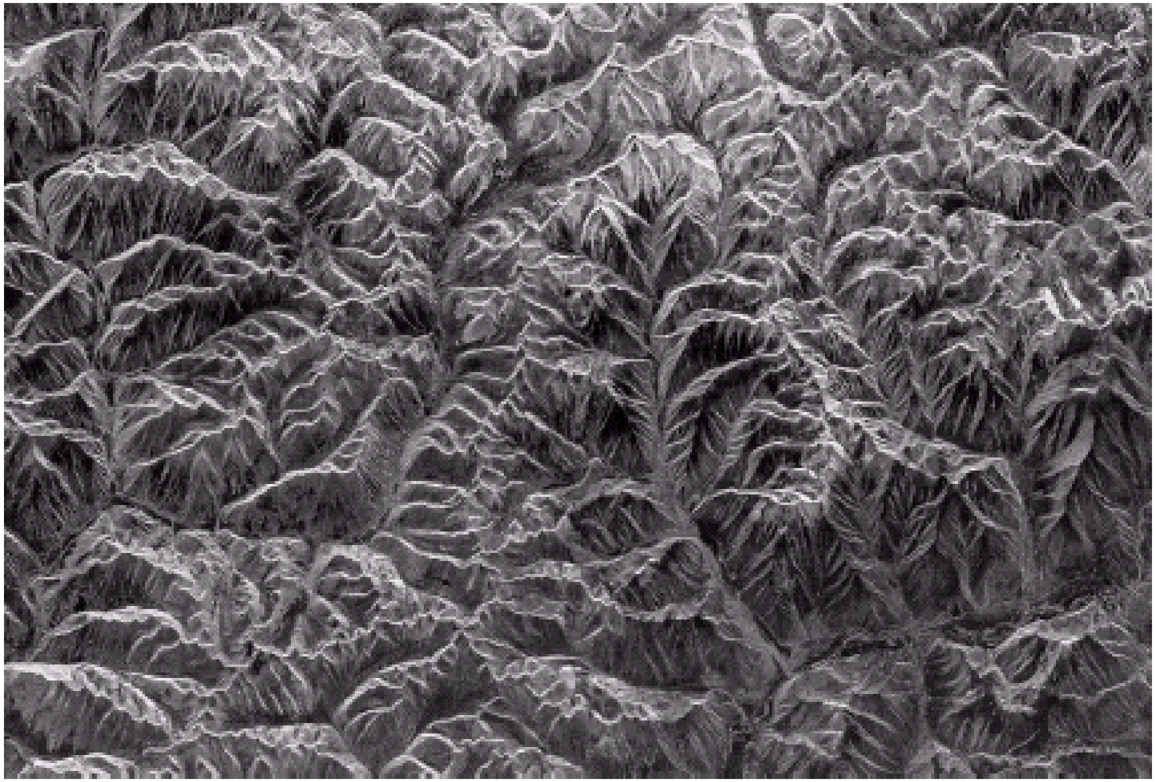
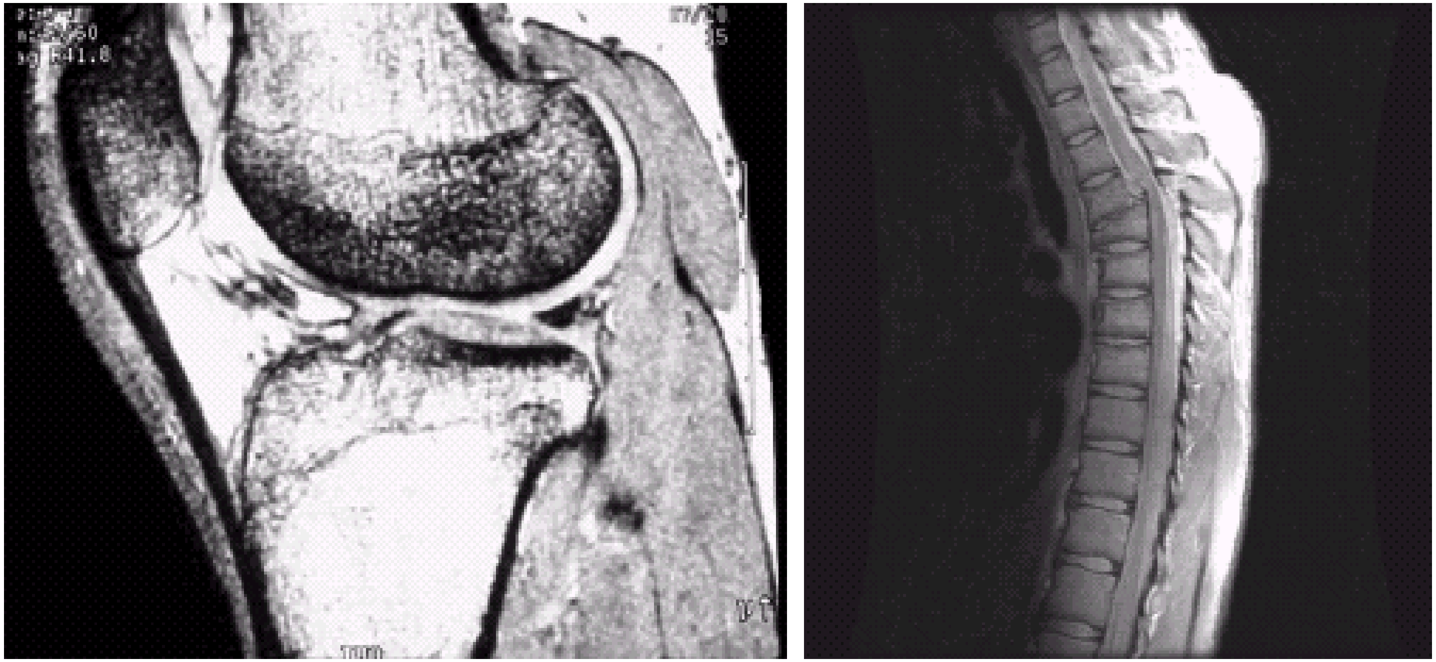


FIGURE 1.16 Spaceborne radar image of mountains in southeast Tibet. (Courtesy of NASA.)

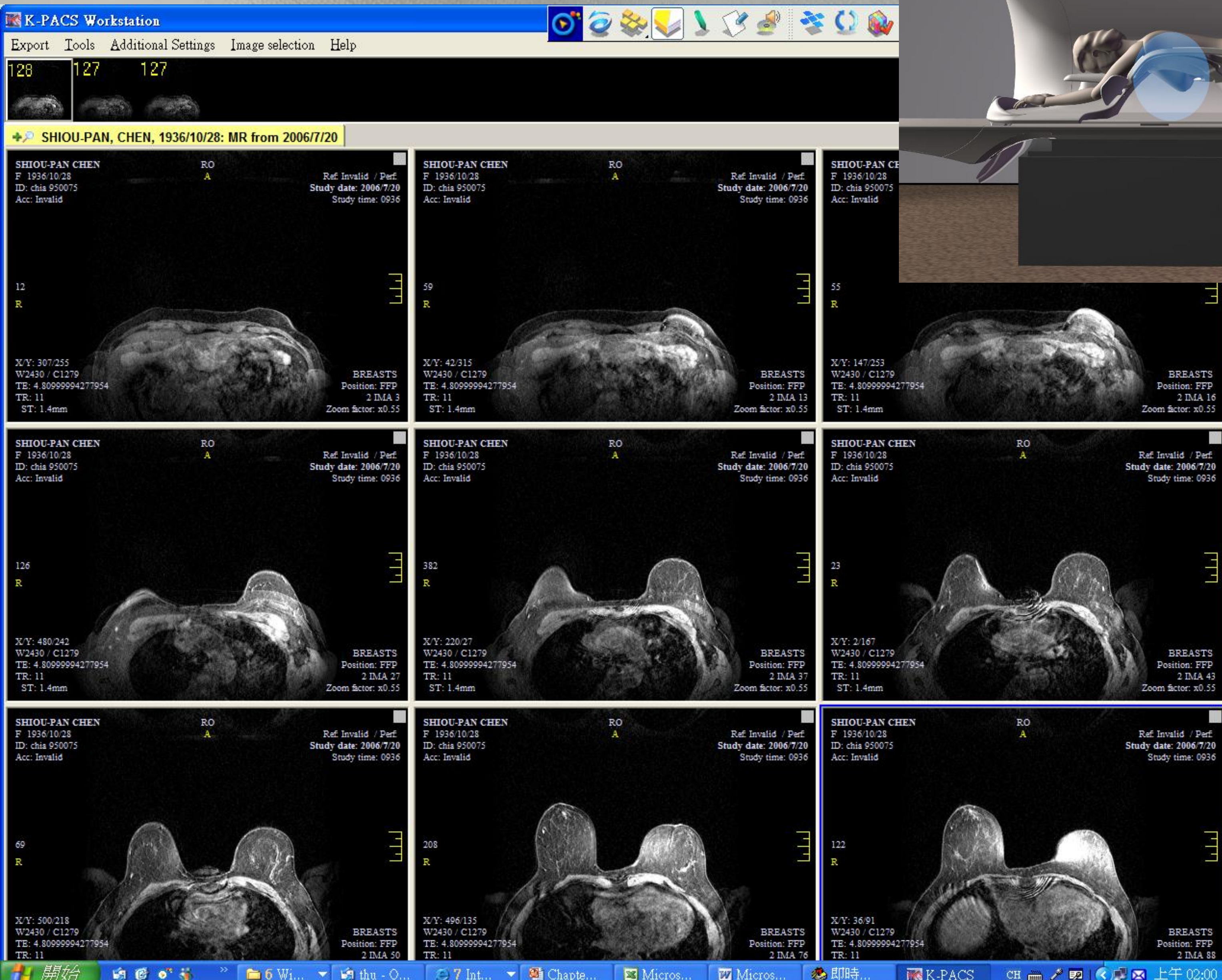
- Imaging in the Radio Band
  - In medicine radio waves are used in **magnetic resonance imaging** (MRI).
    - This technique places a patient in a powerful magnet and passes radio waves through his or her body in short pulses.
    - Each pulse causes a responding pulse of radio waves to be emitted by the patient's tissues.
    - The location from which these signals originate and their strength are determined by a computer, which produces a two-dimensional picture of a section of the patient.
  - MRI can produce pictures in any plane.
  - Figure 1.17 shows MRI images of a human knee and spine.
  - Figure 1.18 shows an image of the Crab Pulsar in the radio band.



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.)

Breast MRI



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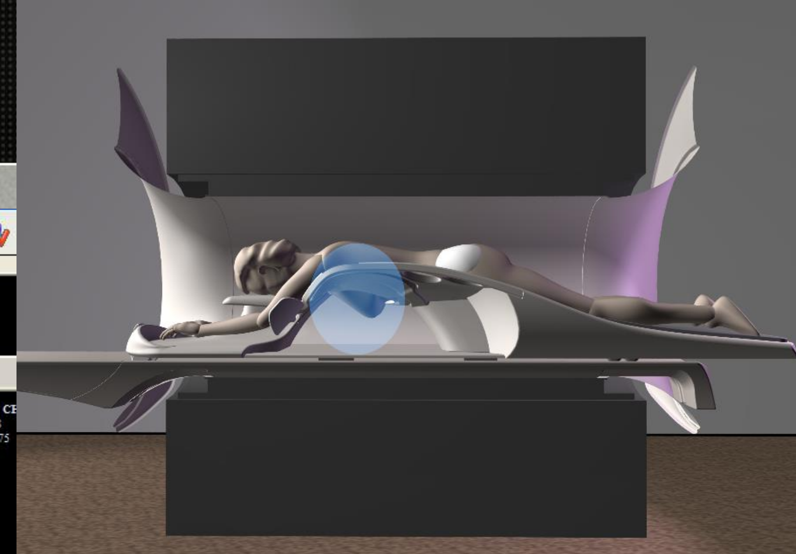
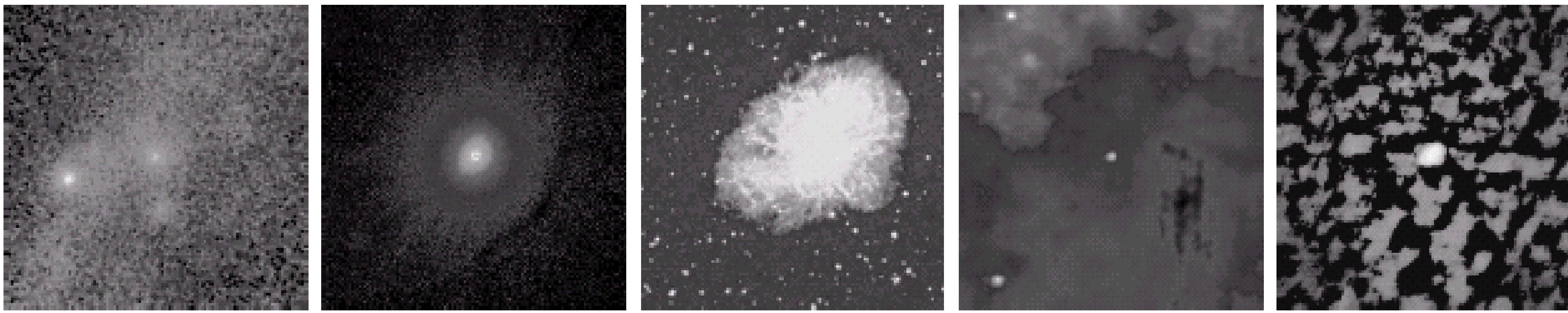


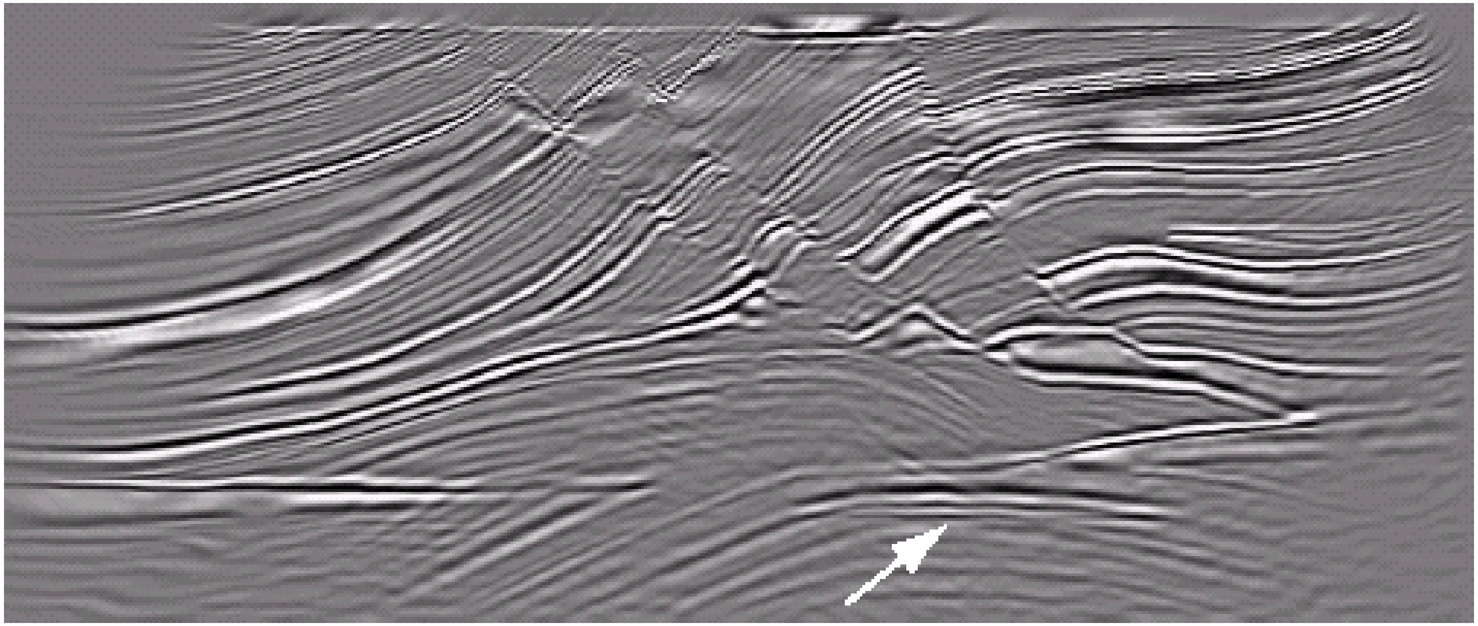


Gamma X-ray Optical Infrared Radio

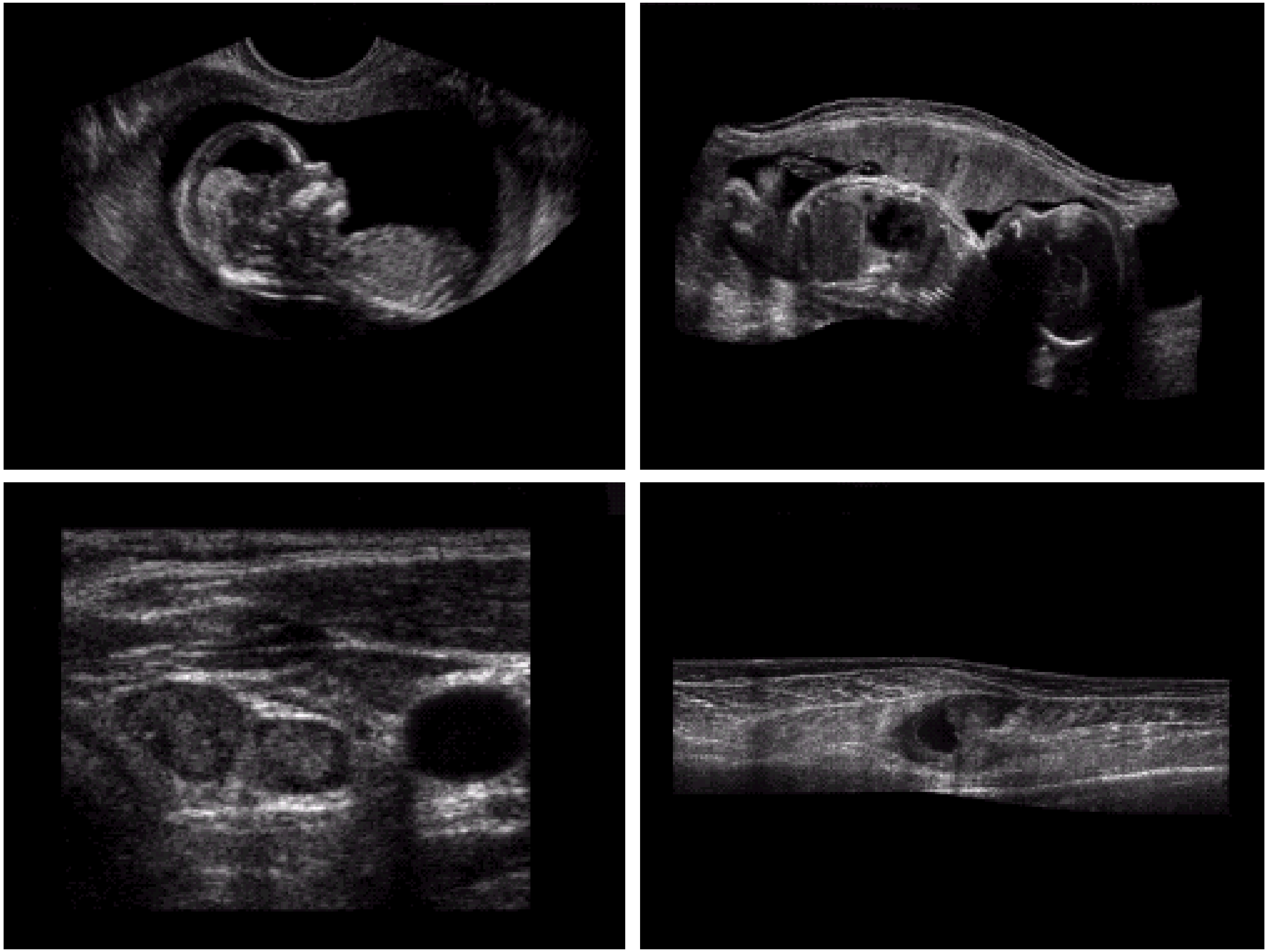
FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

- Ultrasound
  - Geological exploration
    - use sound in the low end of the sound spectrum (hundreds of Hertz) - mineral and

FIGURE 1.19 Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)



- Medicine
  - In a typical ultrasound image, millions of pulses and echoes are sent and received each second.
  - The probe can be moved along the surface of the body and angled to obtain various views.
  - Figure 1.20 shows several examples.



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.)

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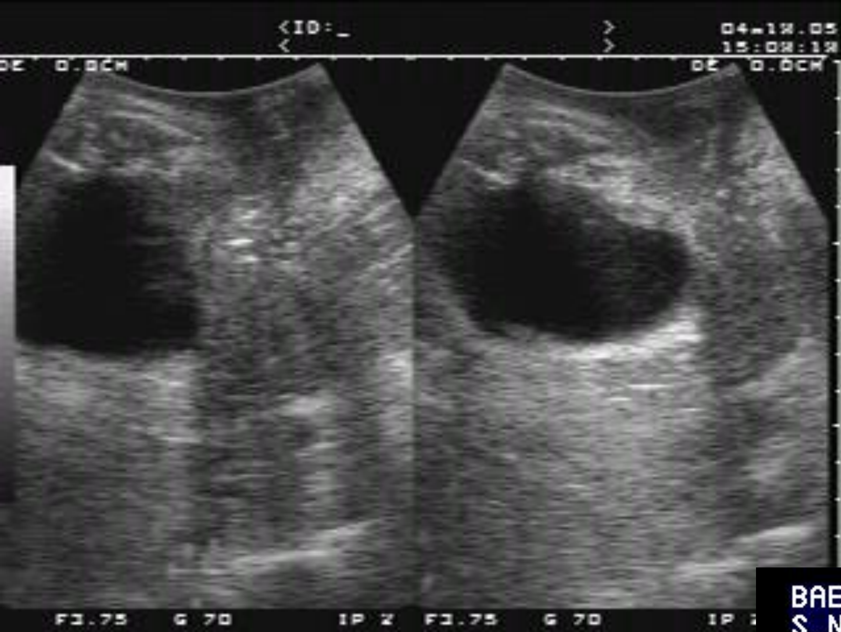

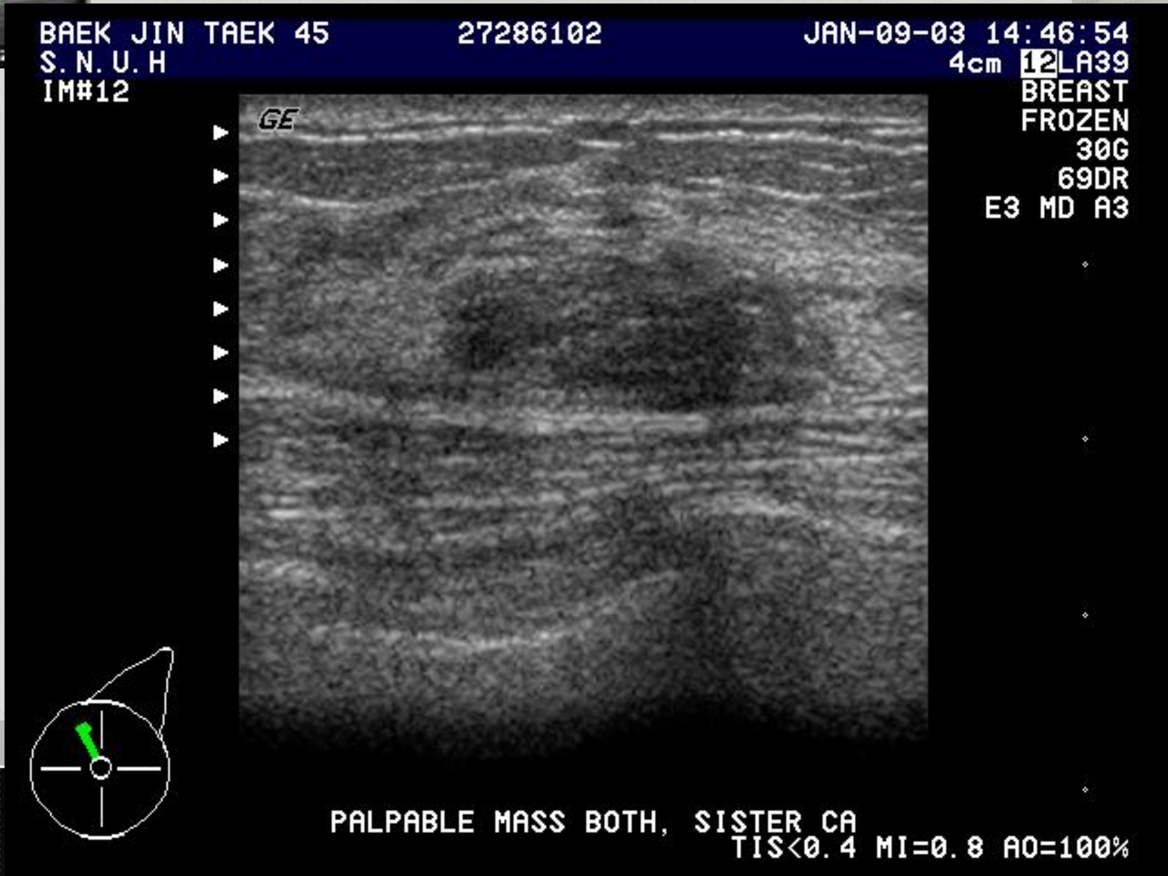

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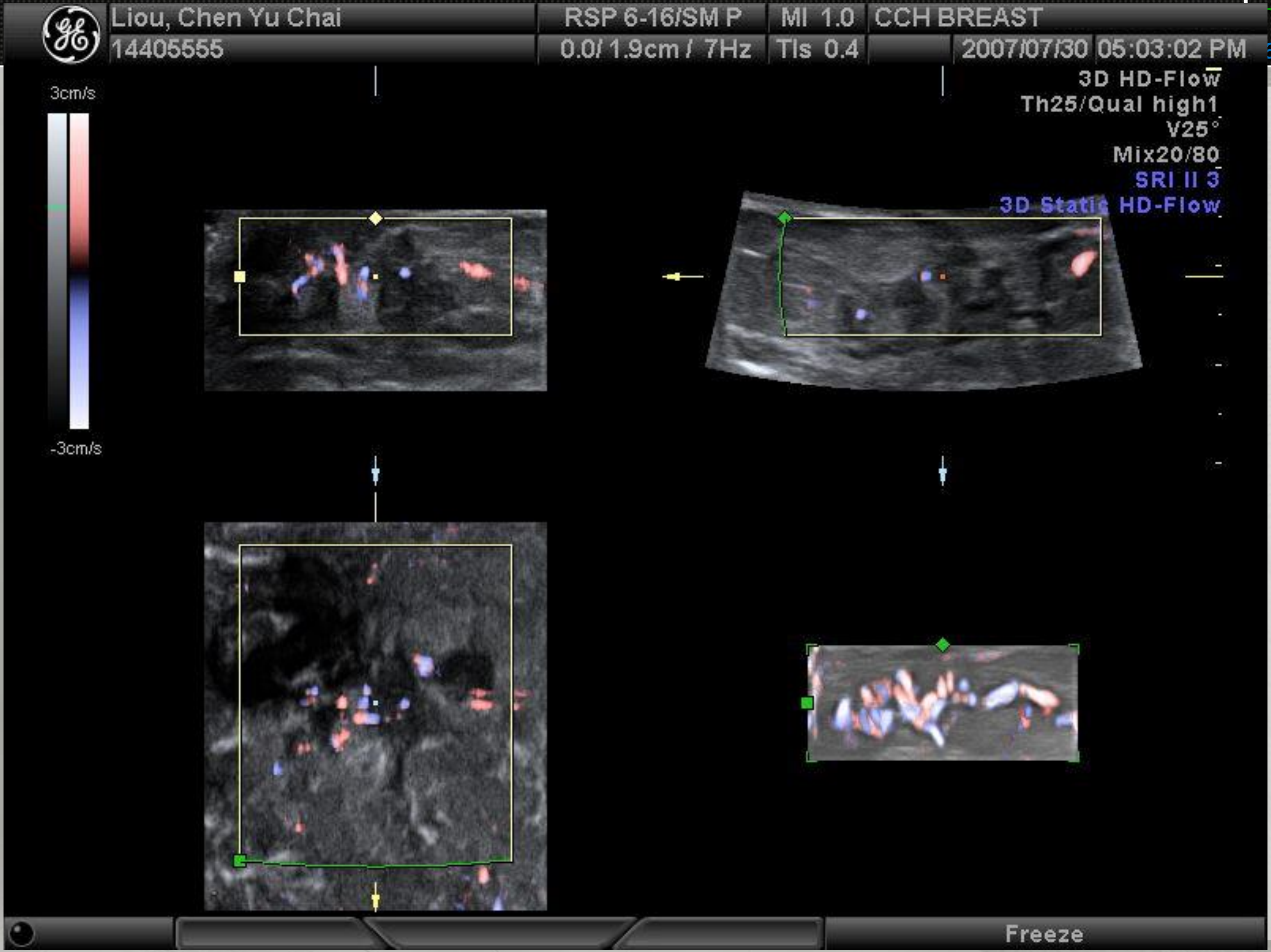
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- Electron microscopes
  - *transmission* (透射式) *electron microscope* (TEM)
    - works much like a slide projector
  - *Scanning electron microscope* (SEM)
    - Actually scans the electron beam and records the interaction of beam and sample at each location.
    - This produces one dot on a phosphor screen.
    - A complete image is formed by a raster scan of the bean through the sample, much like a TV camera.
  - Figure 1.21 shows two SEM images of specimen failures due to thermal overload.

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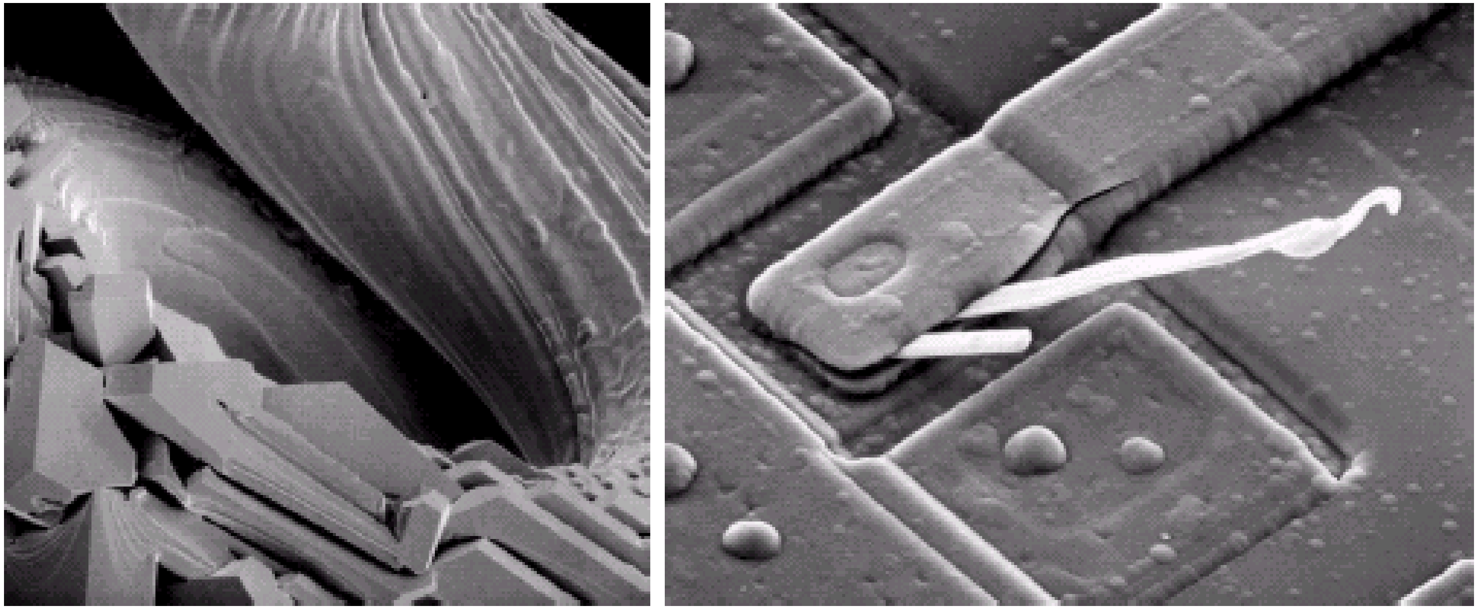


a b

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.)

- **Computer-generated images**
  - ***Fractals***
    - **Basically, a fractal is nothing more than an iterative reproduction of a basic pattern according to some mathematical rules.**
    - **For instance, *tiling* is one of the simplest ways to generate a fractal image.**
    - **They are useful sometimes as random textures.**
  - **3-D modeling**
  - **Figure 1.22**

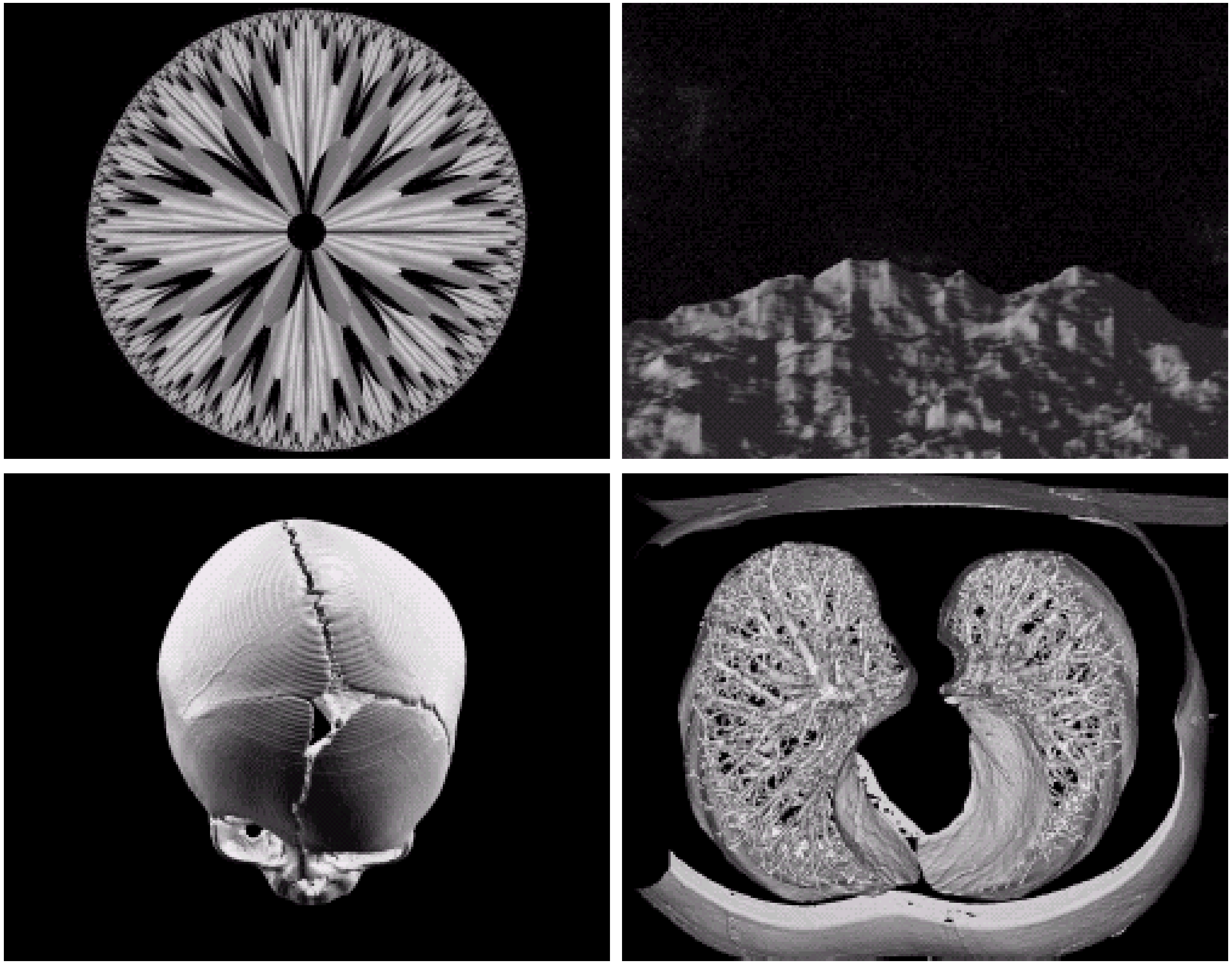
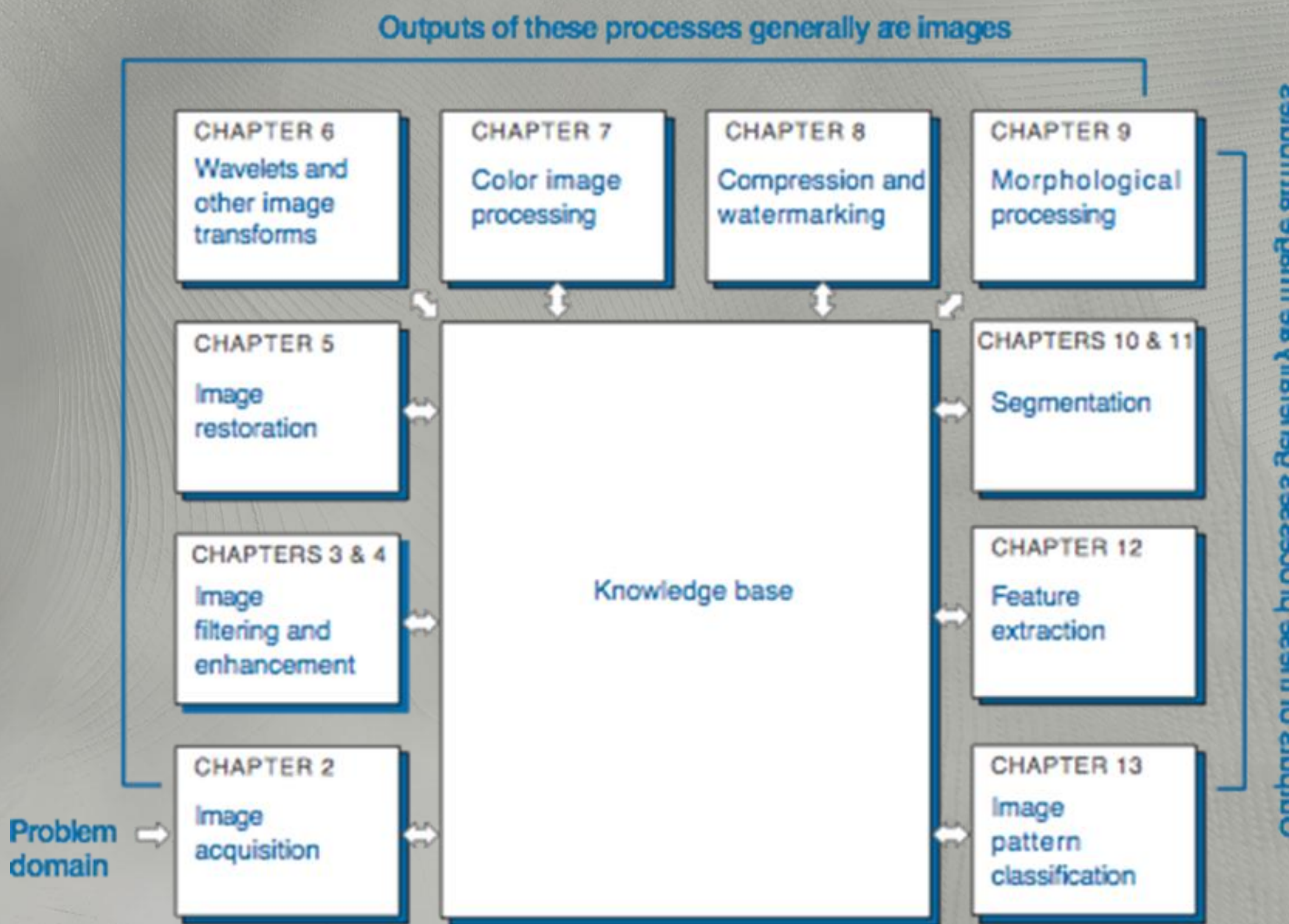


FIGURE 1.22 (a) and (b) Fractal images. (c) and (d) Images generated from 3-D computer models of the objects shown. (Figures (a) and (b) courtesy of Ms. Melissa D. Binde, Swarthmore College, (c) and (d) courtesy of NASA.)

- **Fundamental Steps in Digital Image Processing (Fig. 1.23)**
  - ***Image acquisition***
  - ***Image enhancement***
  - ***Image restoration***
  - ***Color image processing***
  - ***Wavelets and multiresolution processing***
  - ***Compression***
  - ***Morphological processing***
  - ***Segmentation***
  - ***Representation and description***
  - ***Recognition***

FIGURE 1.23 Fundamental steps in digital image processing. The chapter(s) indicated in the boxes is where the material described in the box is discussed.



- **Components of an Image Processing System**
  - **Figure 1.24 shows the basic components comprising a typical *general-purpose* system used for digital image processing**

FIGURE 1.24
Components of a general-purpose image processing system.