What is digital image processing?

Image: a two-dimensional function *f(x,y),* where *x* and *y* are spatial coordinates and the amplitude *f* at any pair of coordinates *(x,y)* is called the intensity or gray level.

f can be a **vector** and represent a colour image (e.g. using the *RGB* or *Lab* model), or in general a multispectral image.

When *x*, *y,* and *f* are discrete quantities the image is **digital**.

A **video** signal is similarly expressed as a sequence of discrete-time **frames** *f(x,y,t).*

As far as we are concerned, the gray-level image will be represented by a **matrix** with 8-bit integer values, in the range [0=black, 255=white].

What is digital image processing?

Digital Image Processing (DIP) concerns the acquisition or transformation of an image to a digital format and its processing by a computer or by dedicated hardware

- both input and output are digital images

Image Coding is a branch of DIP devoted to efficient image representation for transmission and storage. It can benefit from:

Image Analysis and image understanding concern the description and recognition of the image contents.

- the input is a digital image, the output is a symbolic description

Computer Vision uses digital electronics to emulate human vision, including learning and making inferences. It may involve taking actions (e.g., moving the acquisition device to track an object)

History of digital images

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

"Halftone" pattern printing

History of digital images

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

Photographic process: light modulated by digital data acts on chemically-treated layers on paper support

History of digital images

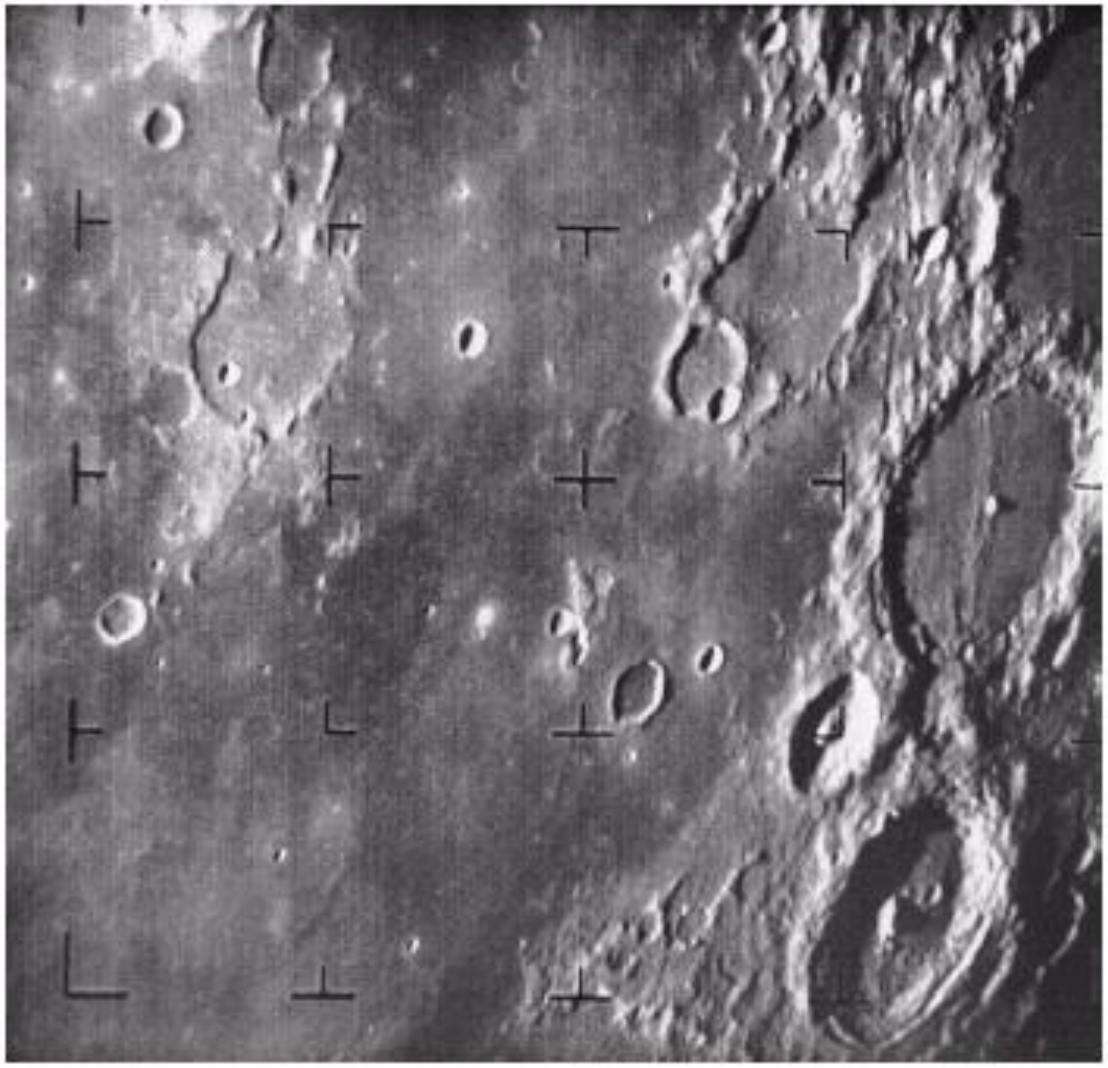


FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

Markers were used for geometric correction

History of digital images

Effects of a tsunami at Khao Lak, Thailand

Dec.29,2004

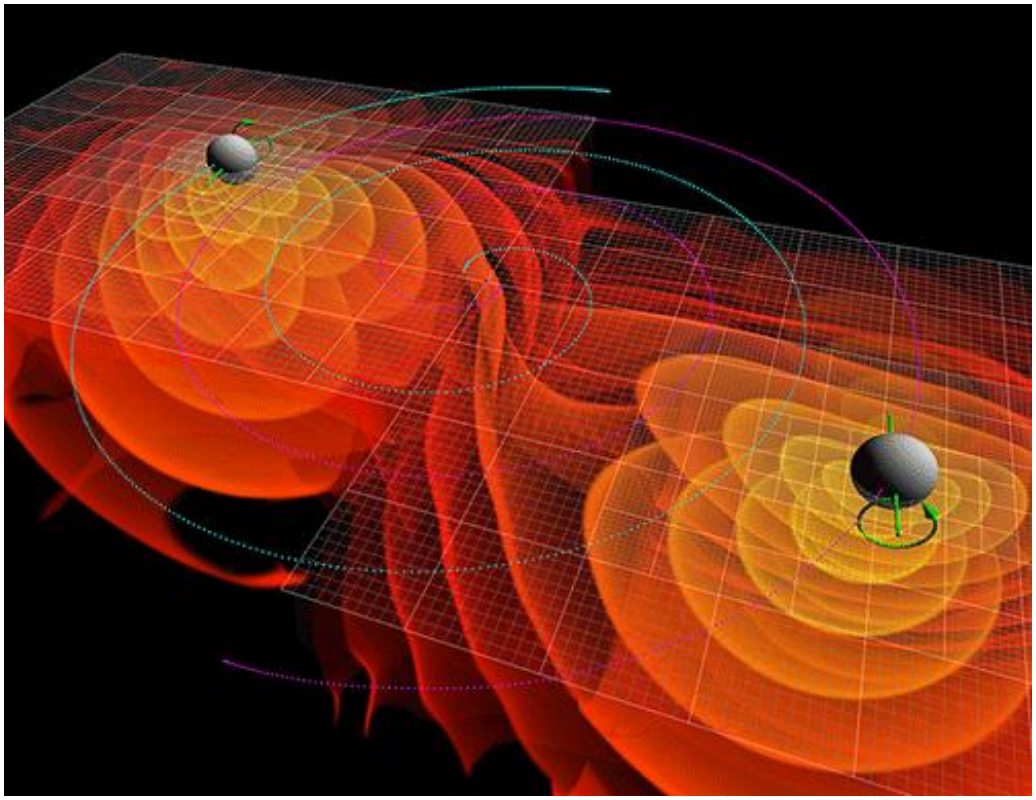
Jan.13,2003

Space Imaging/CRISP-Singapore

several IKONOS one-meter images fused together to create a larger-area, low-resolution image

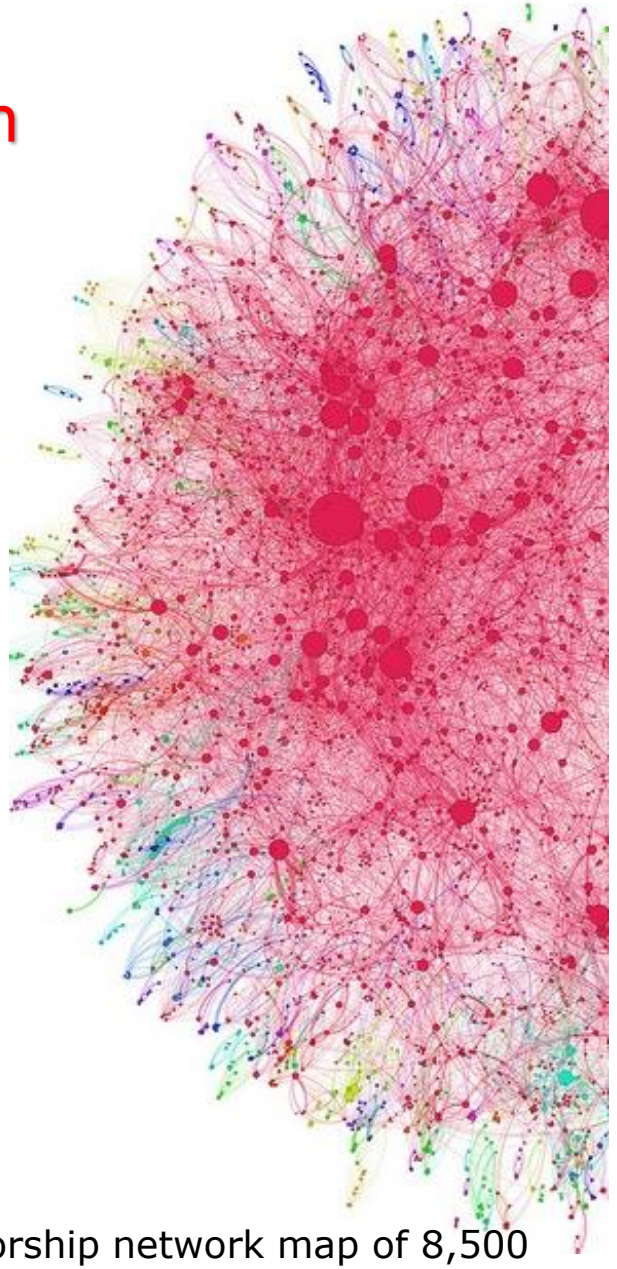
Digital images for data representation

Big data representation, rendering, …



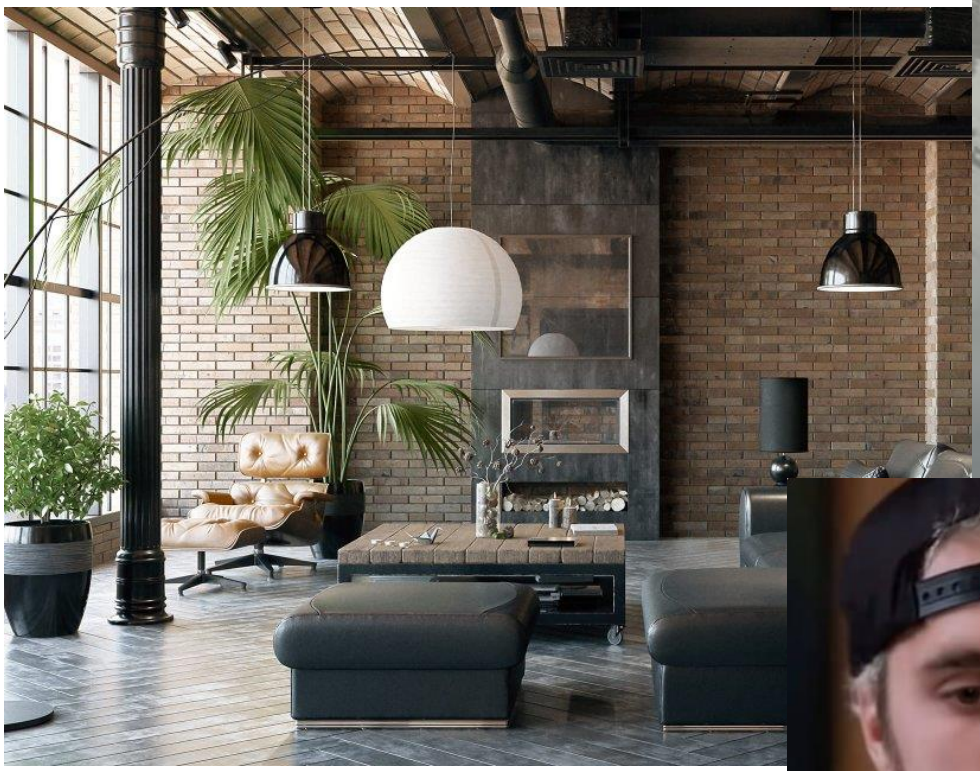
Gravitational waves emitted by the merger of two black holes

C. Henze/NASA Ames Research Center



Co-authorship network map of 8,500 doctors and scientists publishing on hepatitis C between 2008 and 2012

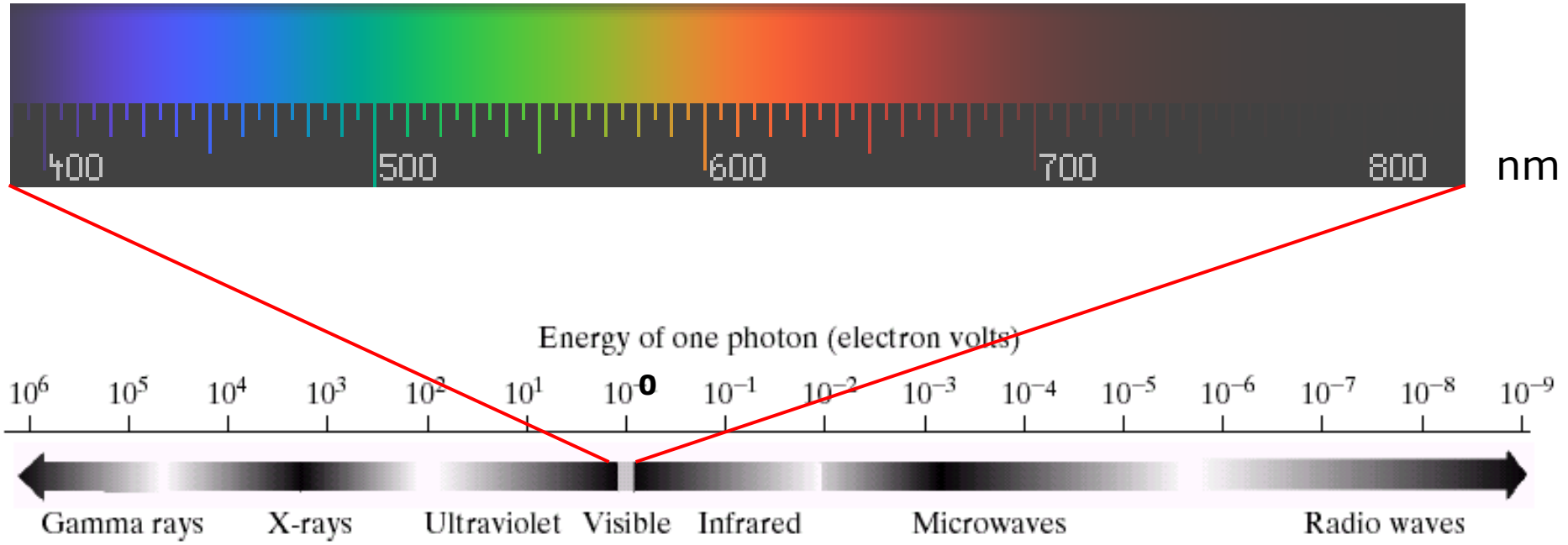
Digital images of non-existing objects



3-D architectural design

Deep fake: Justin Bieber → Arnold Schwarzenegger

The whole EM spectrum sources images



$$E = h\nu = hc/\lambda$$

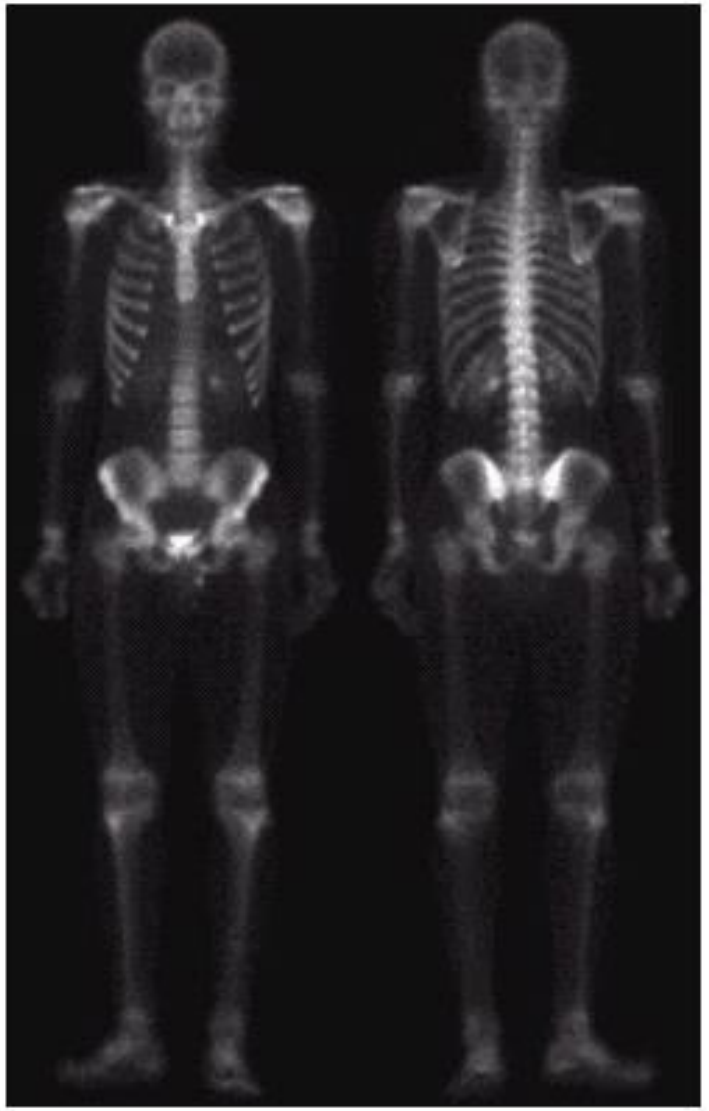
$$h = 4.135\times10\text{\^{}}{-15}\ \text{eV}\cdot\text{s} = 6.626\times10\text{\^{}}\text{-}34\ \text{J}\cdot\text{s}\ \ (\textit{Planck})$$

$$c = 3\cdot10^8\ \text{m/sec}$$

The whole EM spectrum sources images

Gamma-ray imaging

A radioactive isotope is injected, which emits positrons as it decays; when a positron meets an electron, they annihilate and two gamma rays are generated.



The whole EM spectrum sources images

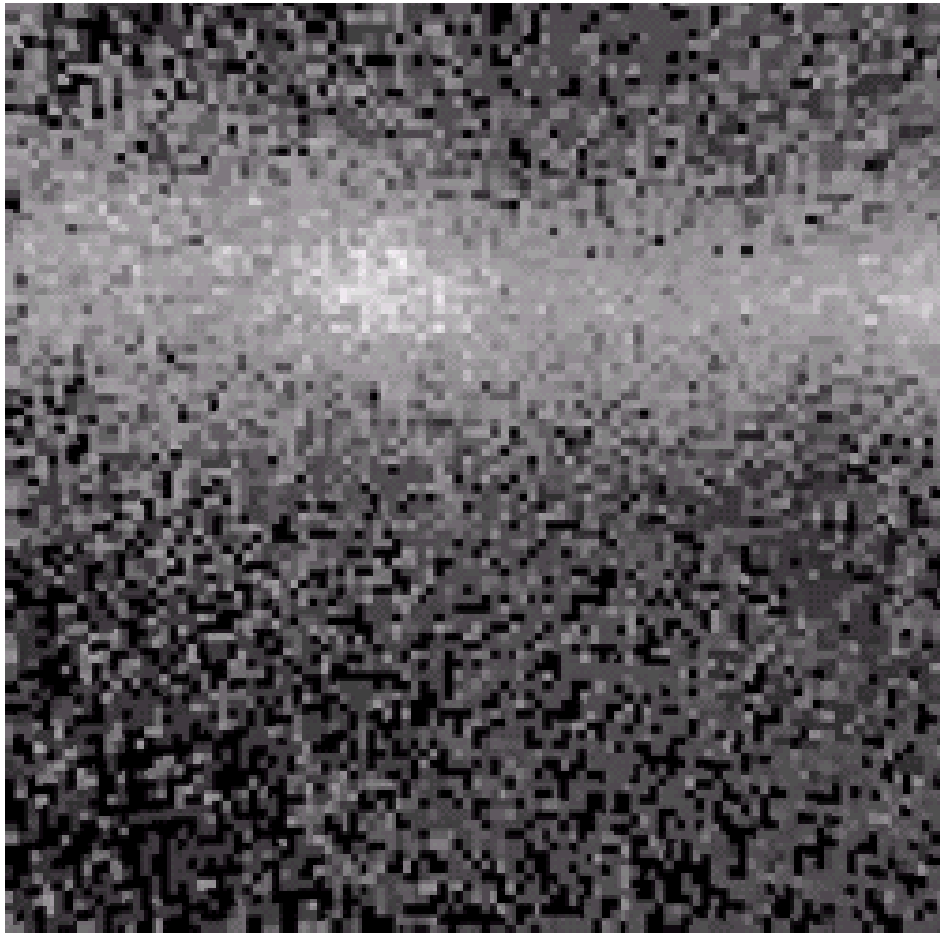
Positron-Emission Tomography

The collected gamma rays are used to construct a CT

The whole EM spectrum sources images

Natural gamma ray source

Superheated stationary gas cloud in the constellation of Cygnus ("Cygnus Loop", 15,000 light-years from earth)



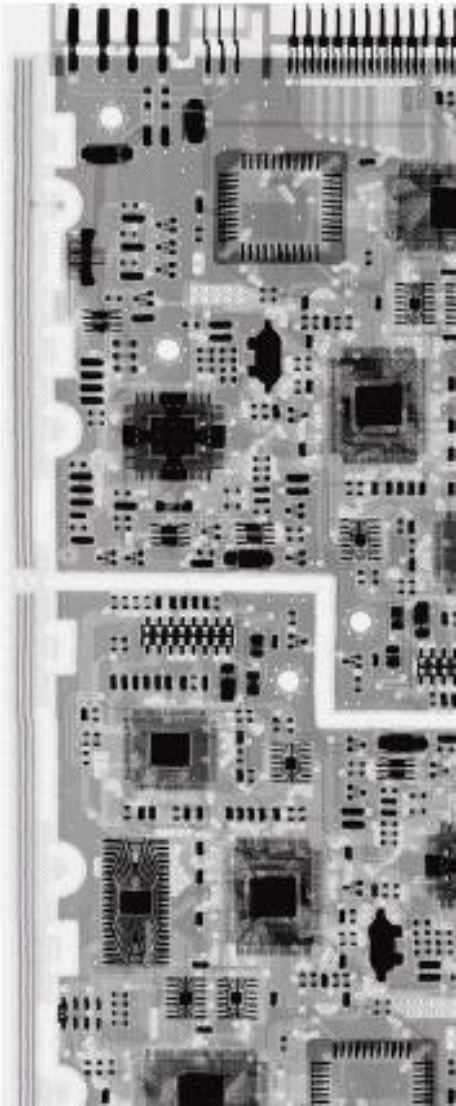
The whole EM spectrum sources images

X-ray imaging

Chest; aortic angiogram; circuit boards.

Electrons are emitted from a heated cathode with an energy such that their impact on a nucleus generates X-rays. A film or a digital sensor collects the transmitted rays.

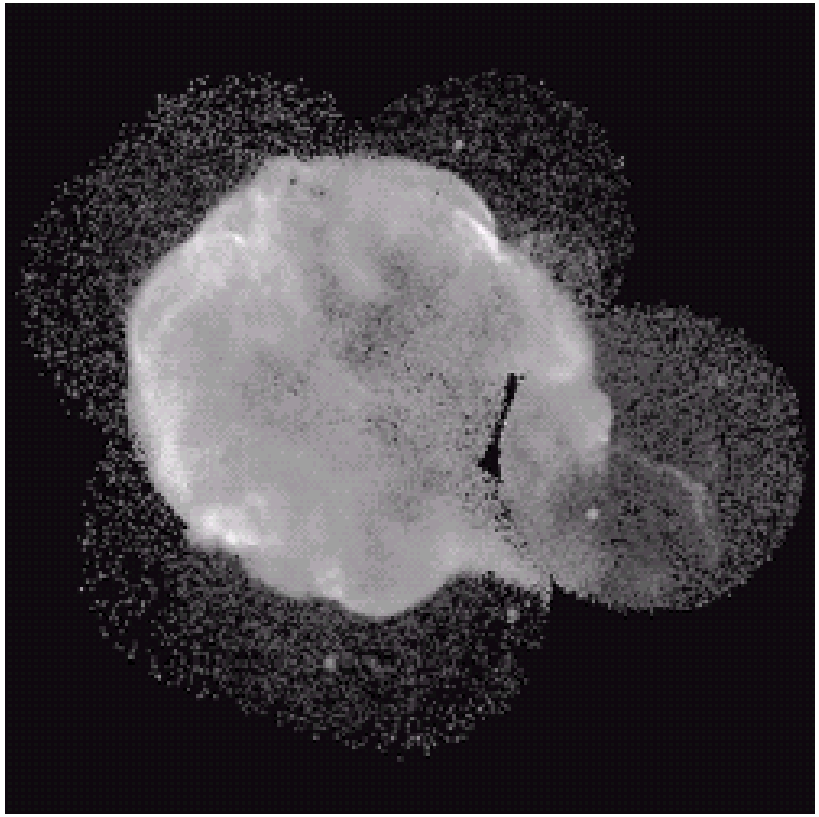
In angiography, a contrast medium is injected.



The whole EM spectrum sources images

X-ray imaging

Head CT; Cygnus Loop.

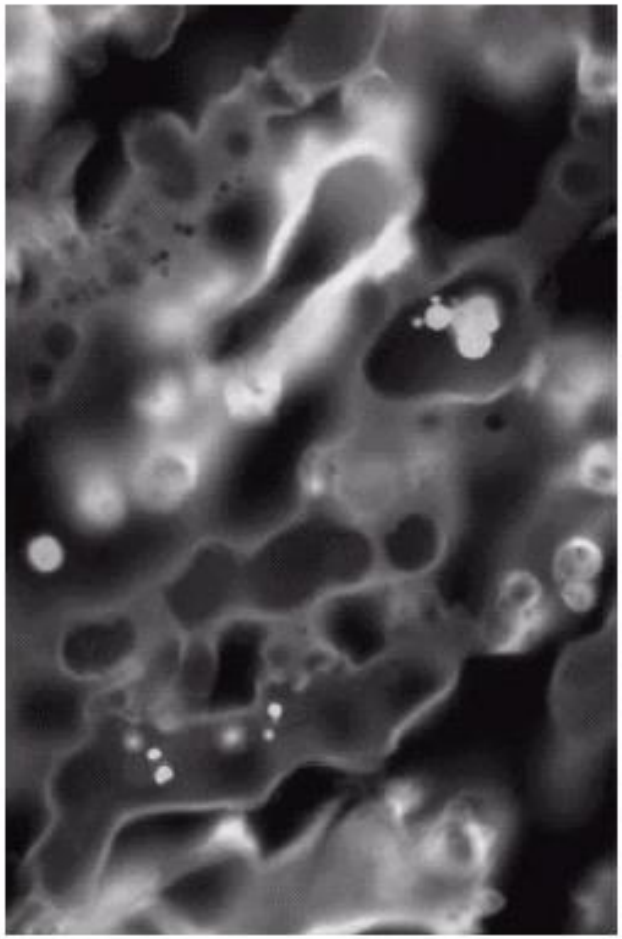


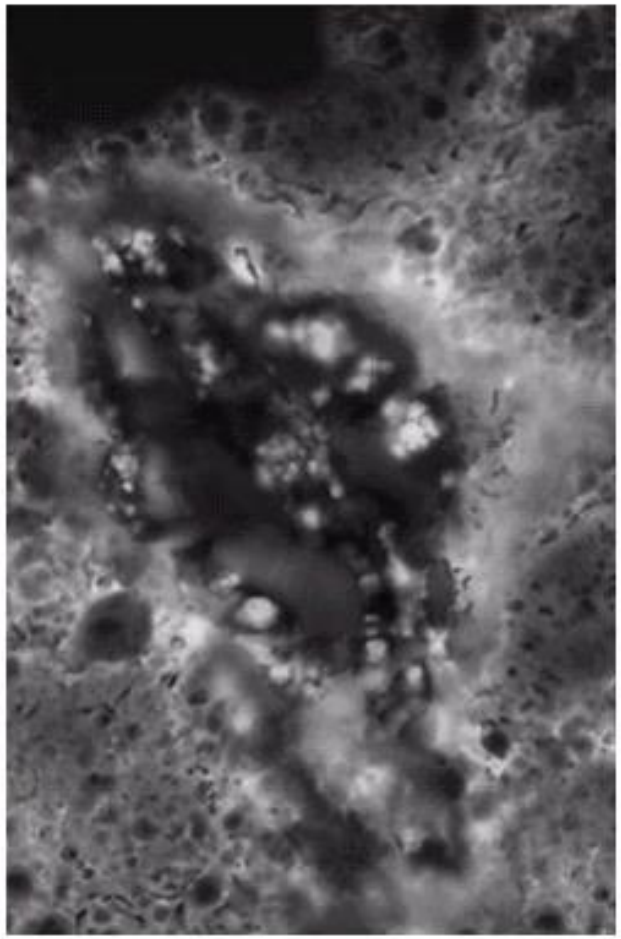
The whole EM spectrum sources images

Ultraviolet imaging

Microphotography; normal corn and corn infected by parasites

Visible radiation is excited by UV light (fluorescence)





The whole EM spectrum sources images

Visible-light imaging

a b
c d
e f

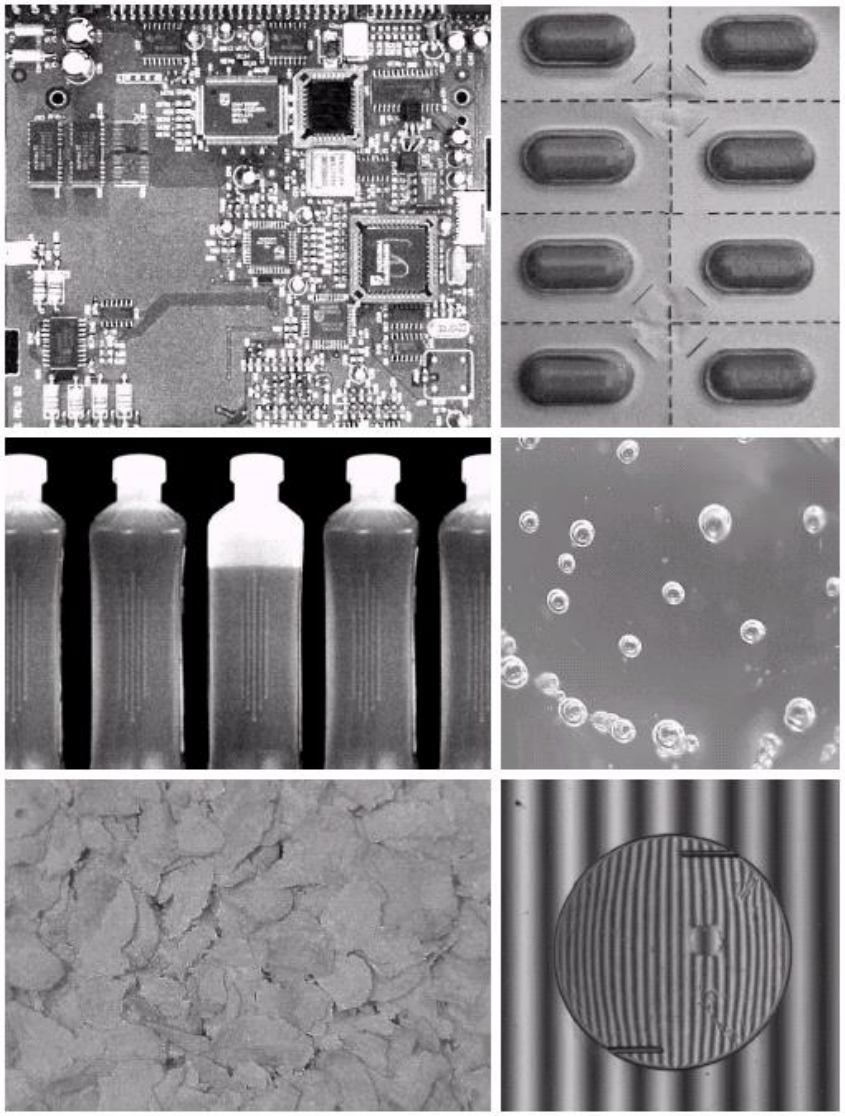


FIGURE 1.14
Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant.

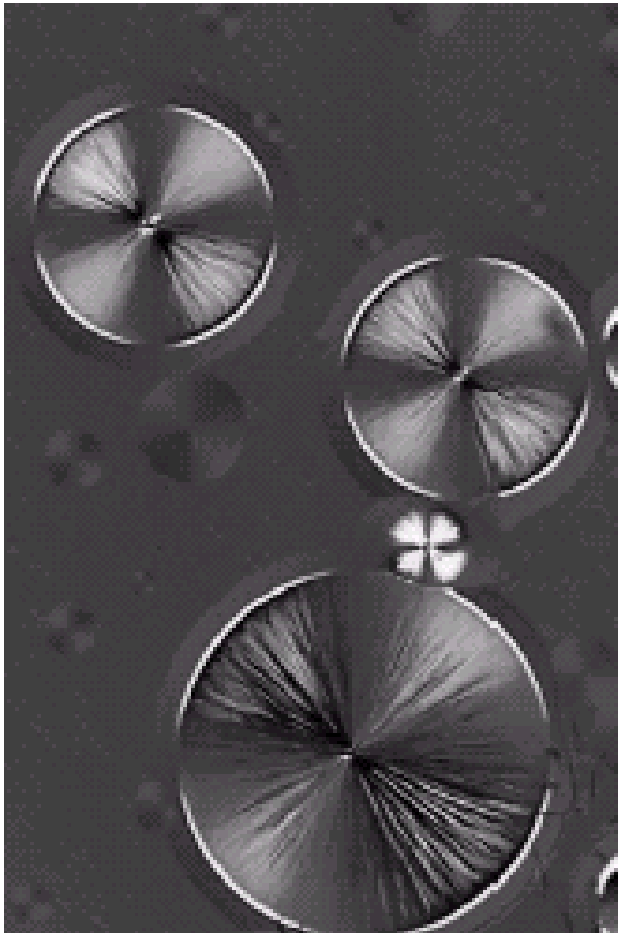
Structured light is used to gather 3-D info

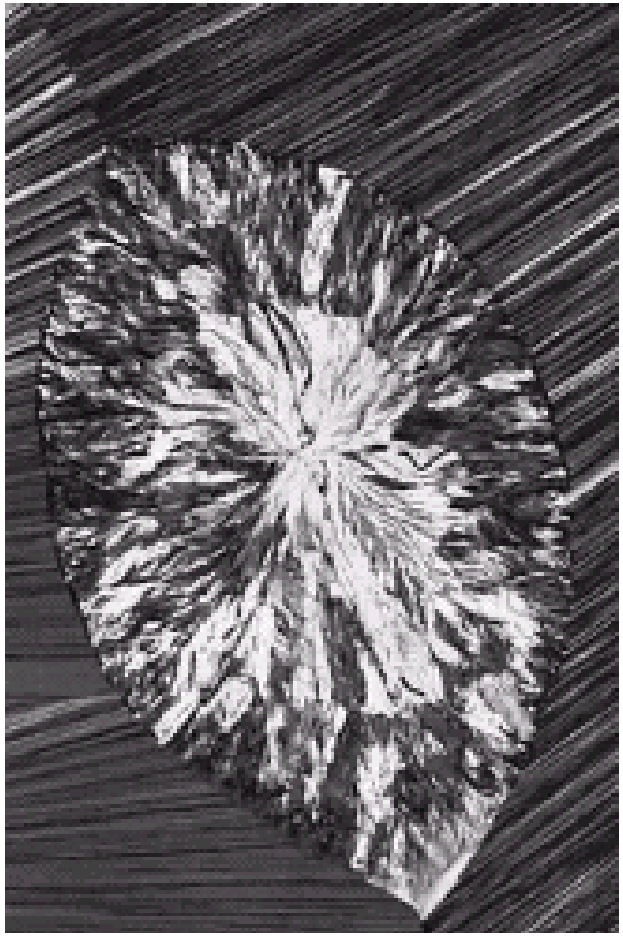
The whole EM spectrum sources images

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

https://www.leonardo.com/it/
https://www.leonardocompany-us.com/lpr
https://ampedsoftware.com/

The whole EM spectrum sources images





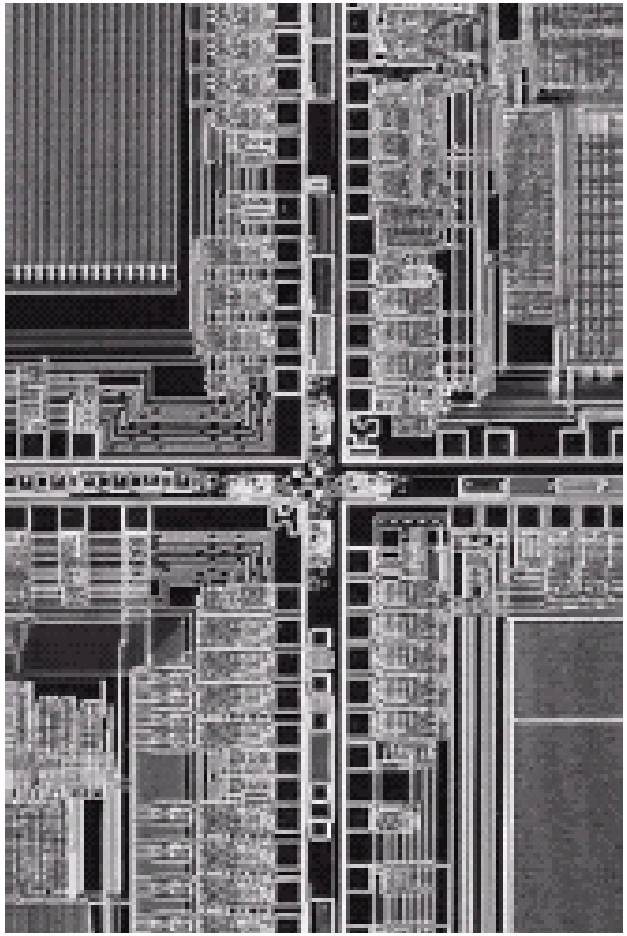
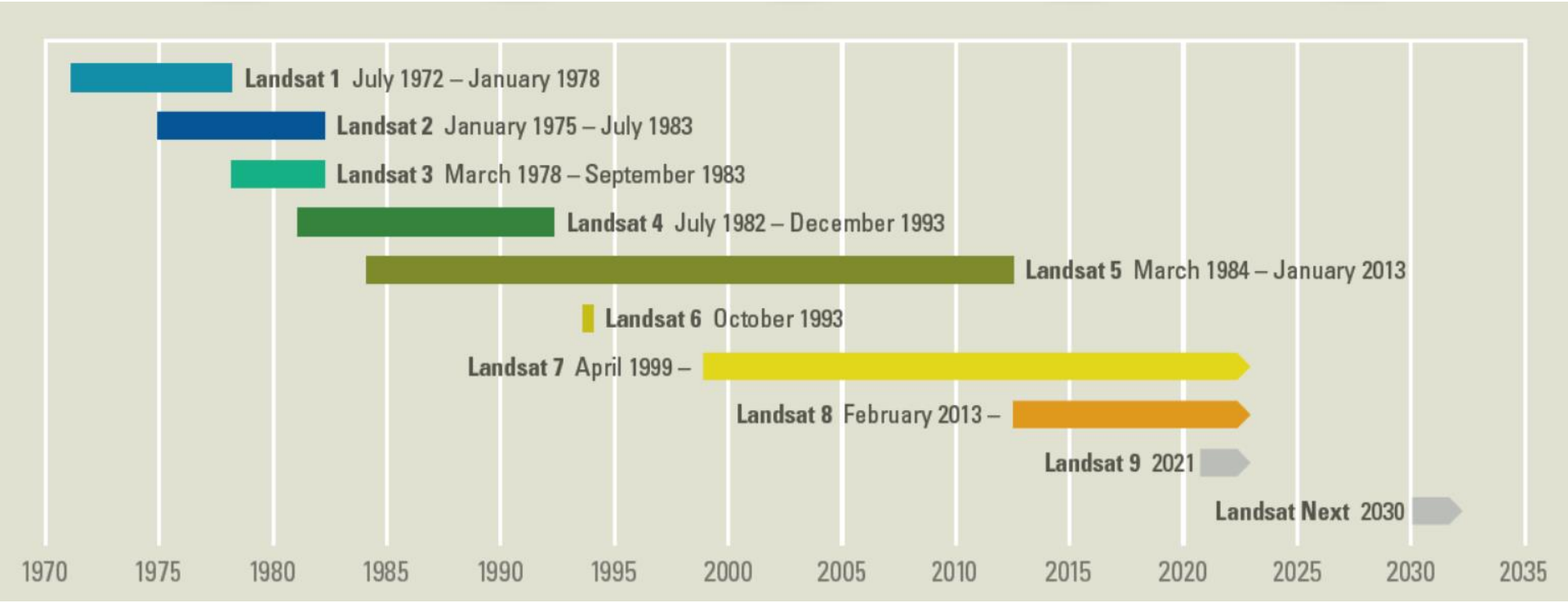


FIGURE 1.9 Examples of light microscopy images. (a) Taxol (anticancer agent), magnified 250×. (b) Cholesterol—40×. (c) Microprocessor—60×. (d) Nickel oxide thin film—600

The whole EM spectrum sources images

Remote Sensing via Multispectral imaging



Since the July 23, 1972 launch of the Earth Resources Technology Satellite (ERTS-1, later renamed Landsat 1), the joint U.S. Geological Survey / NASA Landsat series of satellites have continuously acquired images of the Earth's land surface, providing uninterrupted data to help land managers and policymakers make informed decisions about natural resources and the environment.

https://www.usgs.gov/landsat-missions (later about ESA and Sentinel missions)

The whole EM spectrum sources images

Remote Sensing via Multispectral imaging

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

Bands in LANDSAT-7 [launched 1999, still active] imagery. Resolution 30m. One more band exists, with 10m res., 0.50-0.90 μm ("panchromatic")

The whole EM spectrum sources images

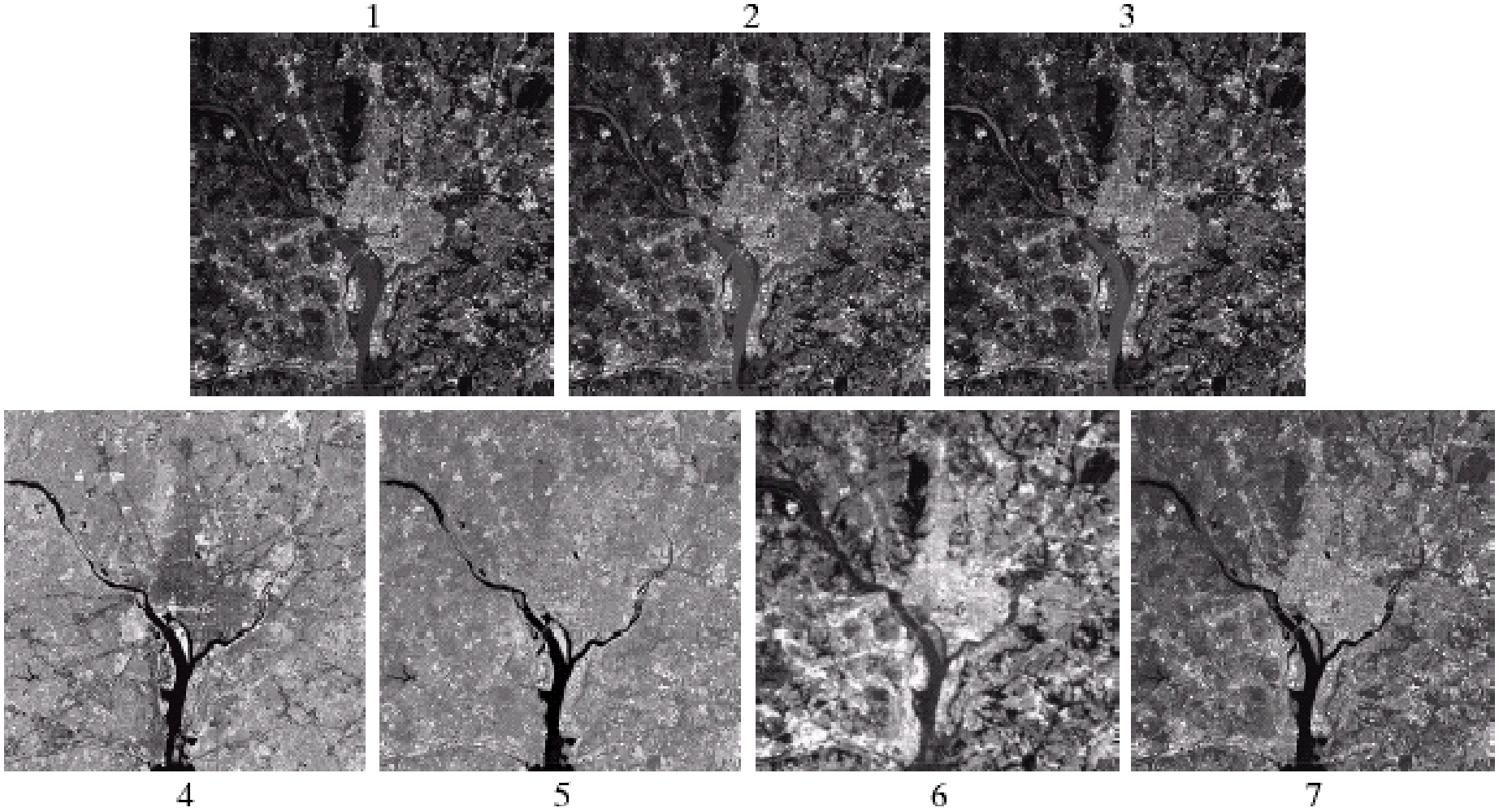


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

→ z01_Landsat_8_9.pdf
→ z01_satellites_Spectrum22.pdf

The whole EM spectrum sources images

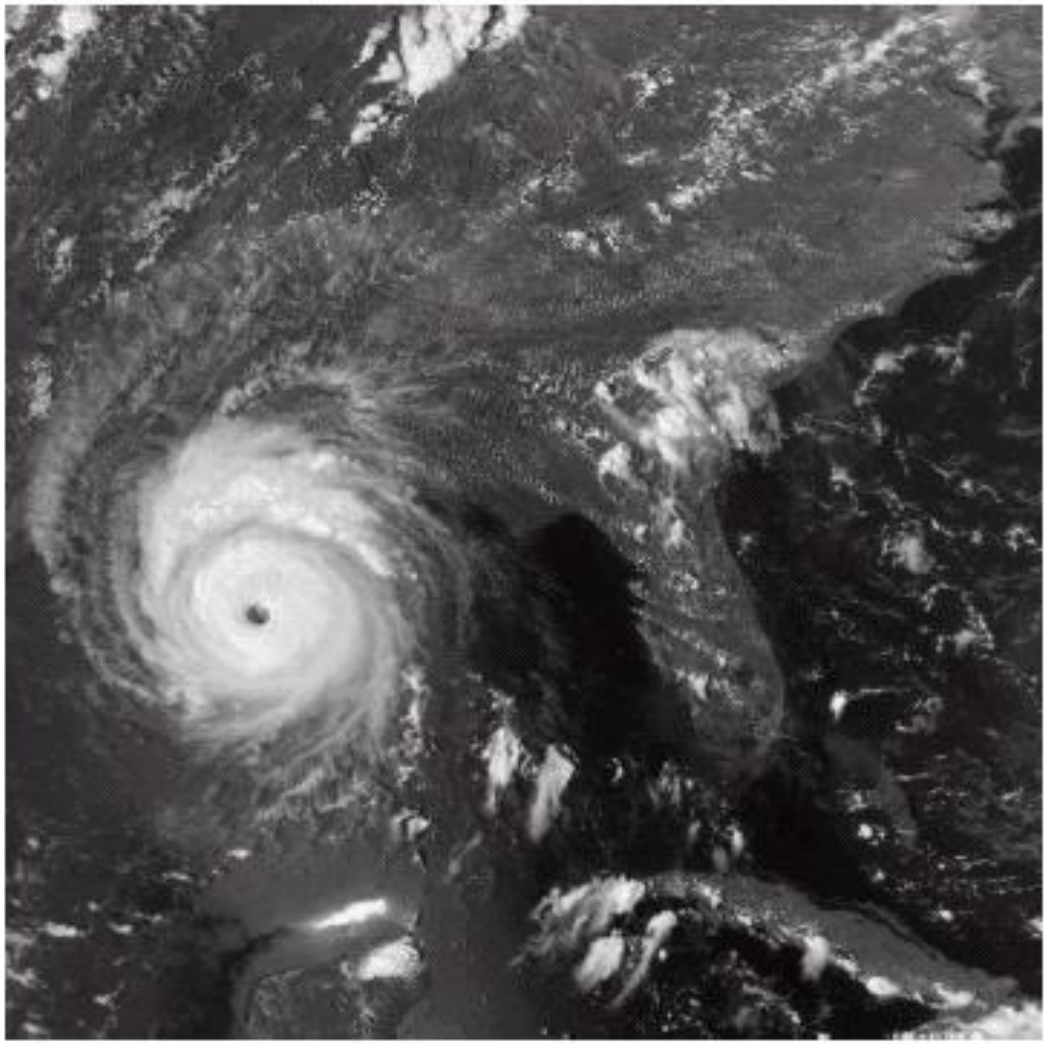


FIGURE 1.11 Multispectral image of Hurricane Andrew taken by NOAA GEOS (Geostationary Environmental Operational Satellite) sensors. (Courtesy of NOAA.)

(National Oceanographics and Atmospheric Admin.)

The whole EM spectrum sources images

Infrared imaging: map of the US

The whole EM spectrum sources images

Microwave band imaging:

Mt. Vesuvius

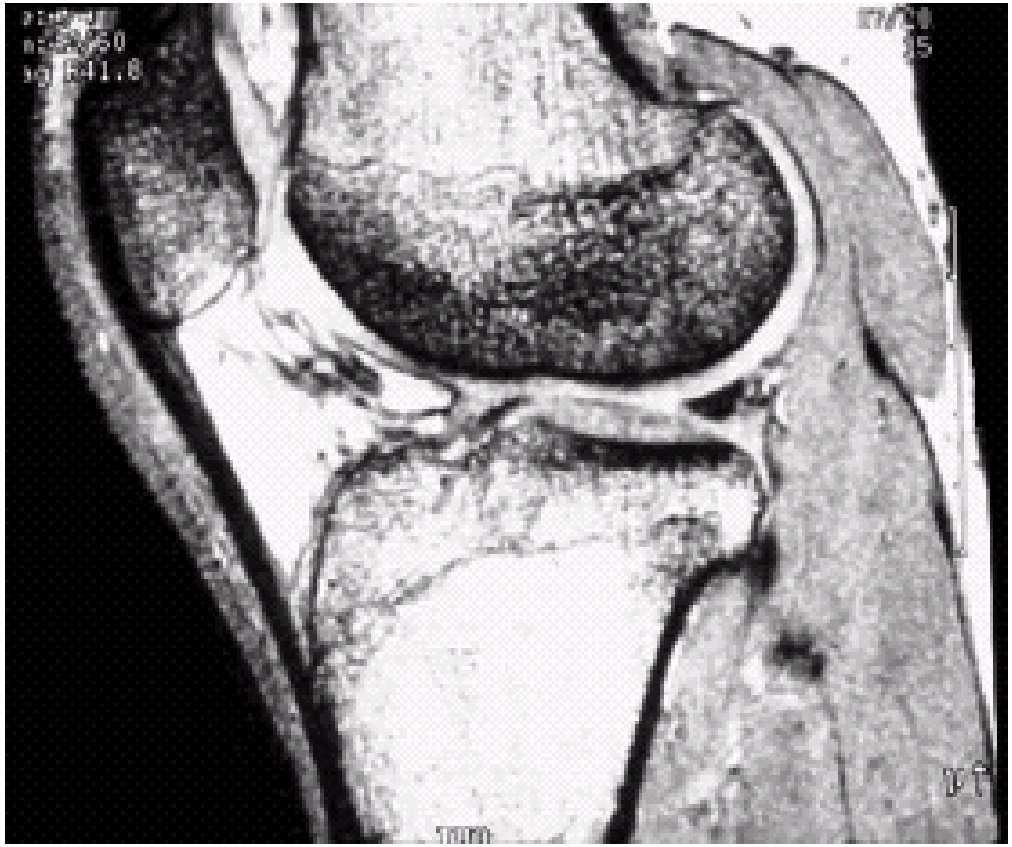
Image acquired on April 15, 1994 by the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture **Radar** (SIR-C/X-SAR) aboard the Space Shuttle Endeavour.

Wrt to Landsat etc.:

- Lower resolution
- Insensitive to cloud cover

The whole EM spectrum sources images

Human knee



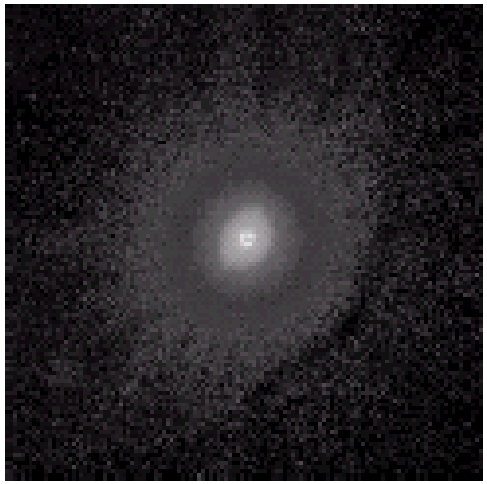
Radio frequency imaging:

Magnetic Resonance Imaging (MRI or NMR): nuclei with nonzero magnetic moment will align with a strong magnetic field, and resonate with a time-varying component of the field. After the time-varying component is removed, the exponential decay time of the re-alignment is measured and used to develop image contrast between different tissues.

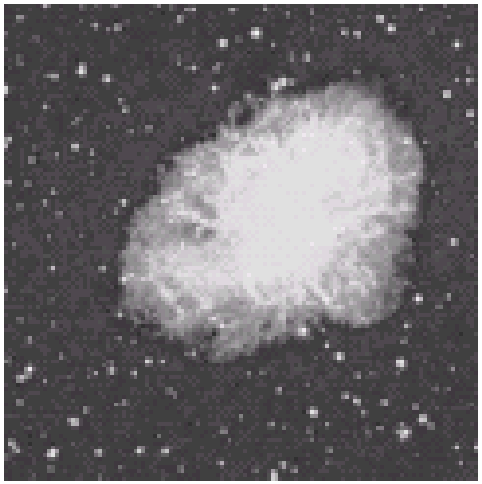
E.g.: Hydrogen nuclei in a 1.5 Tesla magnetic field resonate at 64 MHz

The whole EM spectrum sources images

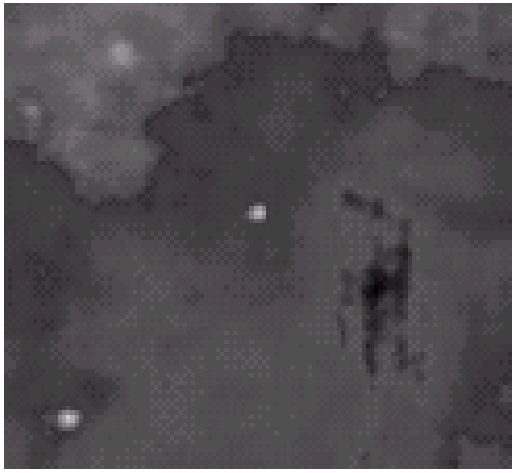
Gamma



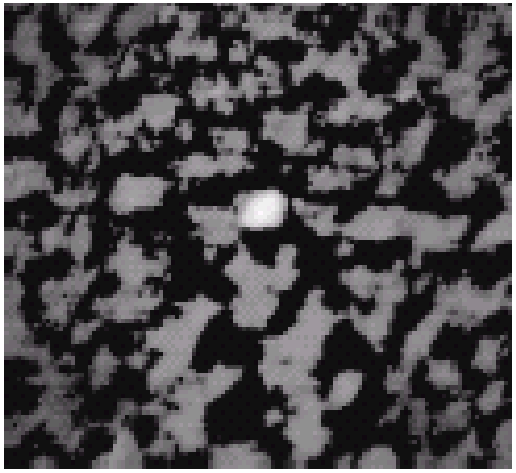
X-ray



Optical



Infrared



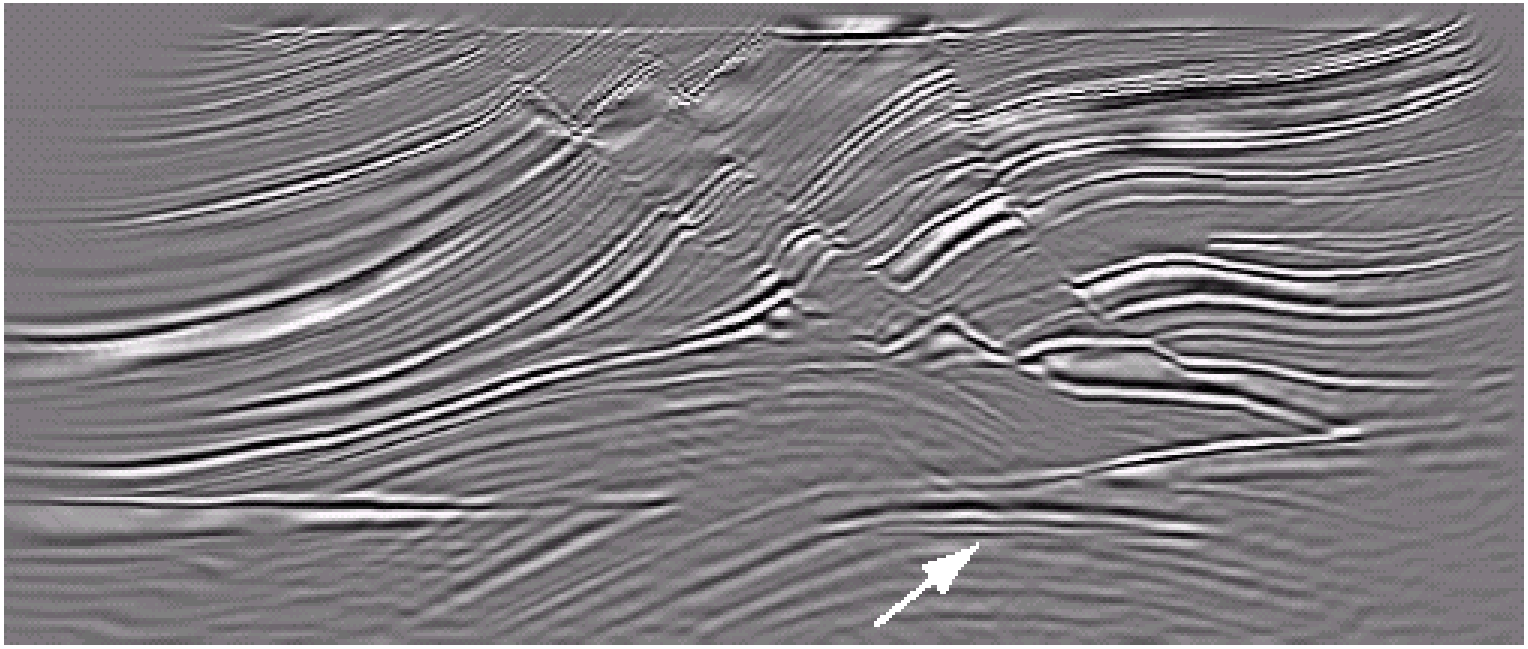
Radio

Crab Pulsar (in the center of images)

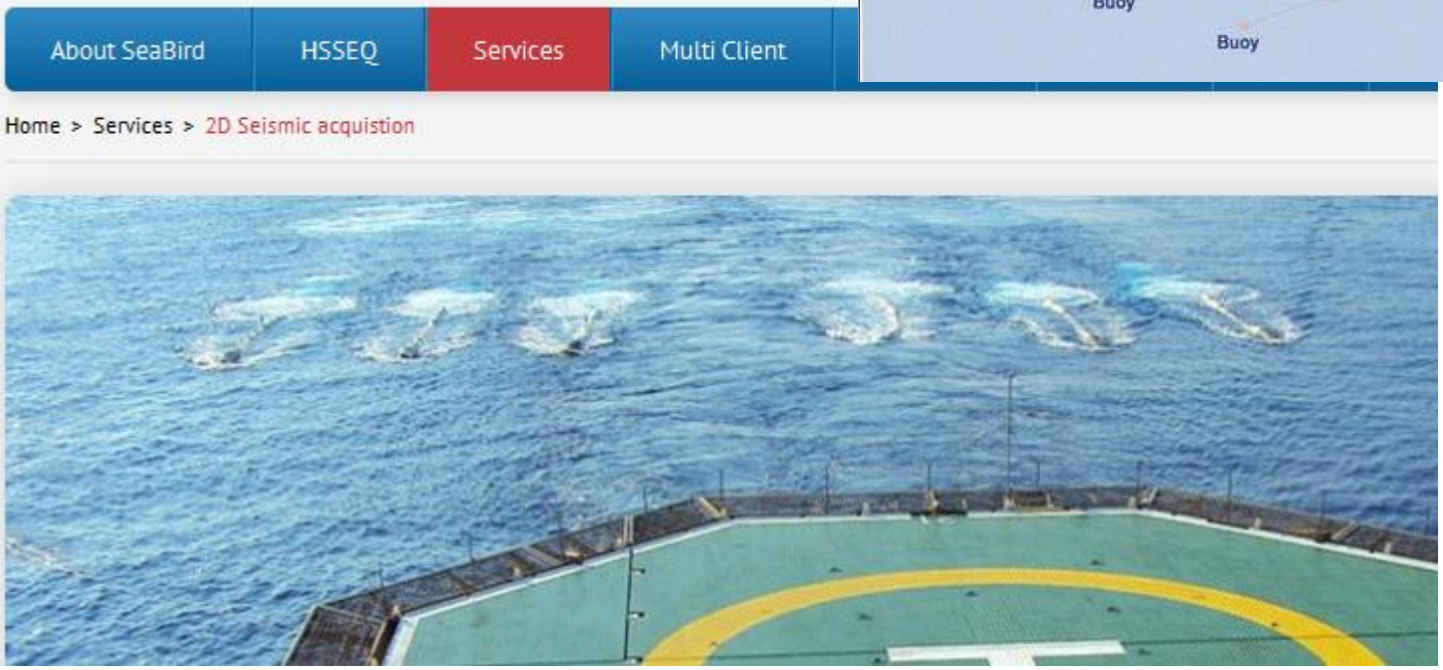
Non-EM image sources

Acoustic echo imaging:
at low frequencies (<100 Hz)

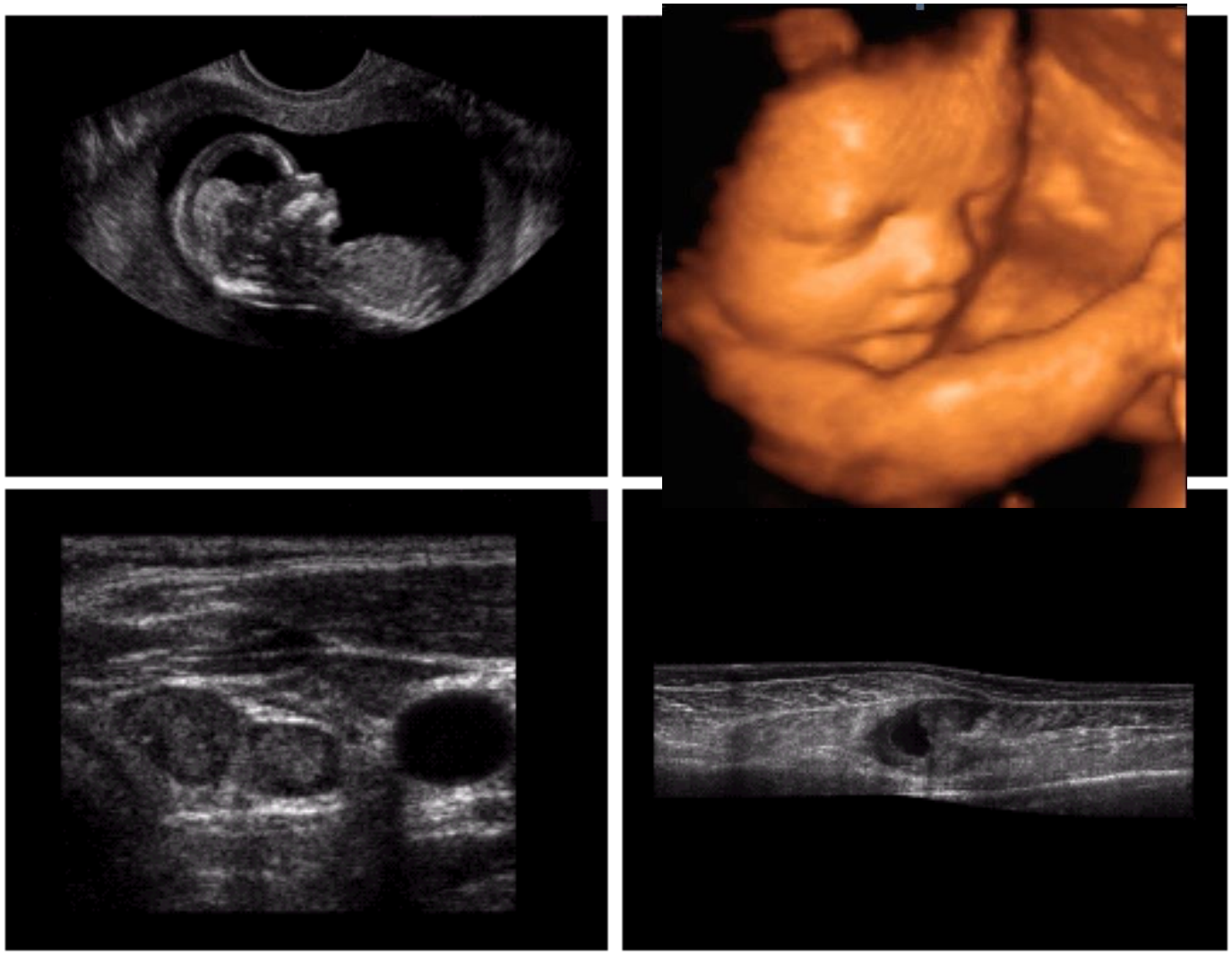
FIGURE 1.19
Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)



Non-EM image sources



Non-EM image sources



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.)

High frequency «acoustic» imaging

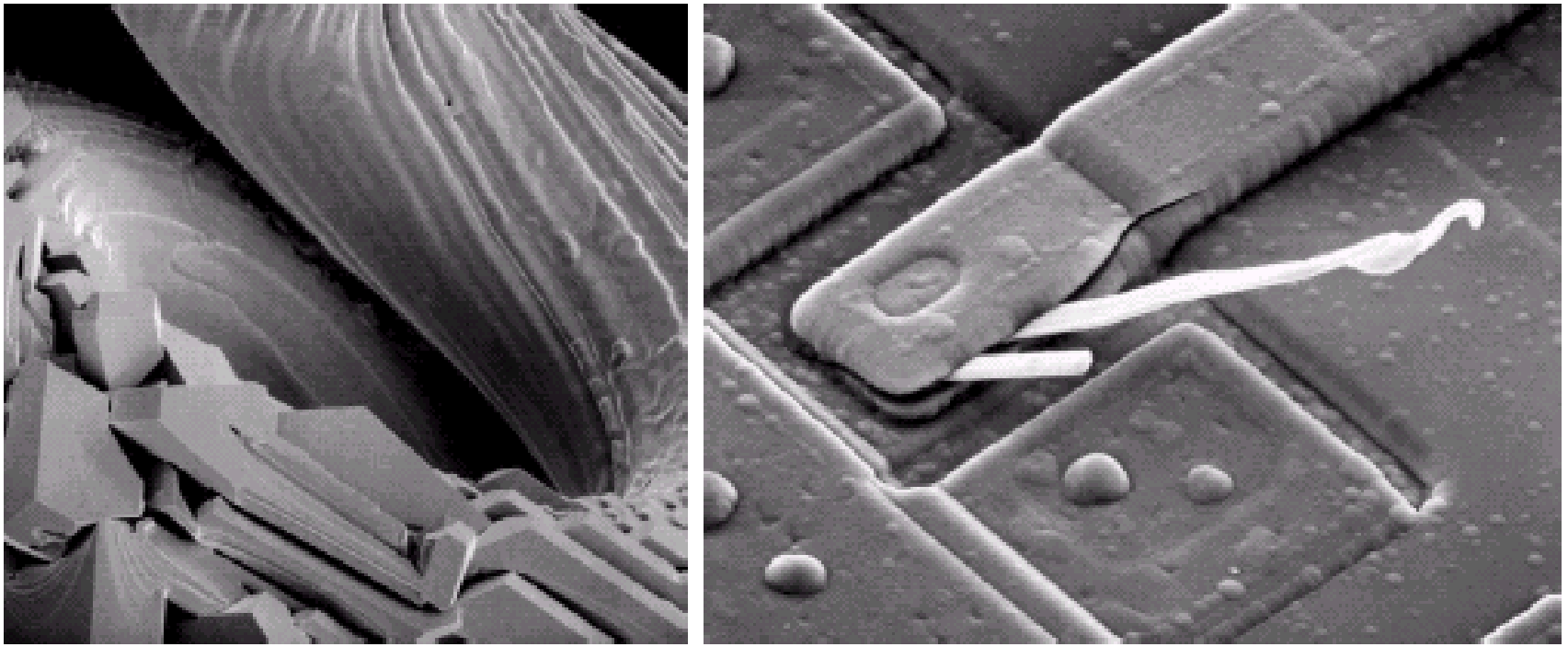
2-3 MHz: Abdomen

7-10 MHz: Breast

15 MHz: superficial structures

Non-EM image sources

Scanning Electron Microscopy: direct excitation of phosphors by an electronic beam (e^- backscattering and/or secondary emission)



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, Depart-

Image enhancement & restoration

Make an image «better looking» or easier to interpret by a human user

- *Enhancement*: local or global, linear or nonlinear operators
- *Restoration*: exploits specific knowledge about image acquisition and previous manipulations

«Photoshopped» image

Image analysis

Image analysis: techniques for extracting ***information*** from an image

Conventional steps:

- *segmentation:* subdivides an image into its constituent regions or objects

- *representation* in terms of external (boundary) and internal (texture) characteristics

- *description*, e.g. length of the boundary; mean and st.dev. of the gray levels

- *object/pattern recognition*: feature extraction and classification

...possibly using deep learning methods

Computer vision

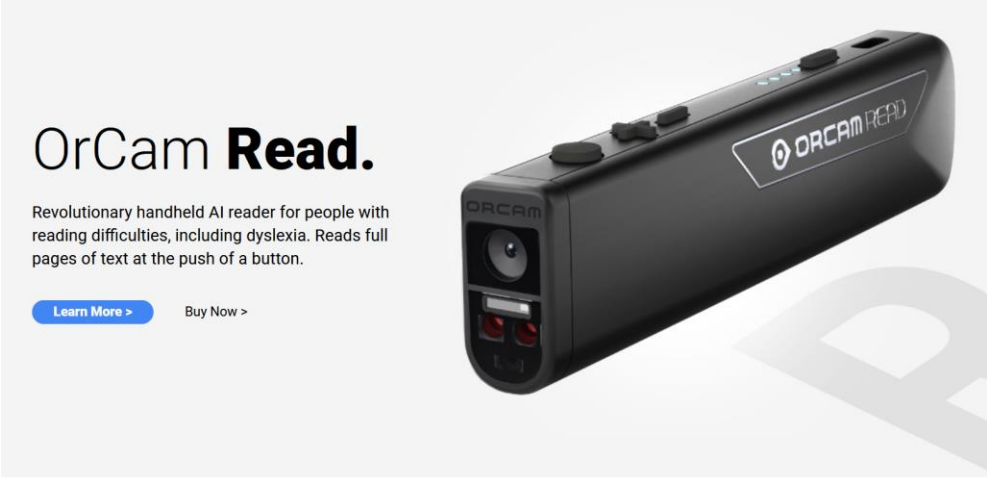
Example:

A robotic sentry for Korea's demilitarized zone (continuously surveilled, 250 km, one guard-post every 50 m, two guards per post)

- Under development by Samsung Techwin (2007) → [model SGR-A1] → Hanwha Techwin (2015) → Hanwha Defense → ...
- 2 high-sensitivity color cameras for stereo vision and tracking, 1 for zooming-in
- Distinguishes humans from animals and objects
- May fire its machine gun
- Does *not* distinguish friend from foe

Computer vision

Example: aids for persons with disabilities



OrCam MyEye
https://www.orcam.com/en/myeye/