Introduction to Image Processing

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Topic 01
Introduction

What is Digital Image Processing?

1. Digital Signal Processing

• *Digital image processing* can be regarded as a subarea of *Digital Signal Processing.*

• Because of that, in the next slides some basic concepts about Digital Signal Processing will be presented.

• Then Digital Image Processing will be introduced.

1. Digital Signal Processing

- Some applications:
  - Image processing;
  - Video processing;
  - Audio processing;
  - Speech Analysis/Synthesis;
  - Biomedical Engineering;
  - Communications systems;
  - Space exploration; etc.

1. Digital Signal Processing

- What is a signal?

  ➢ A **signal** is a description of how one parameter is related to another parameter, typically describing physical phenomena.

    ✓ For example, a voltage that varies with time.

  ➢ If these parameters assume a continuous range of values, we will call this a **continuous signal.** Most signals observed in nature are continuous.

  ➢ **Analog signals** are those that have the "same aspect" of a continuous signal observed in nature.

  ➢ The **analog-to-digital** conversion allows for the signal to be processed by **digital computers**.

1. Digital Signal Processing

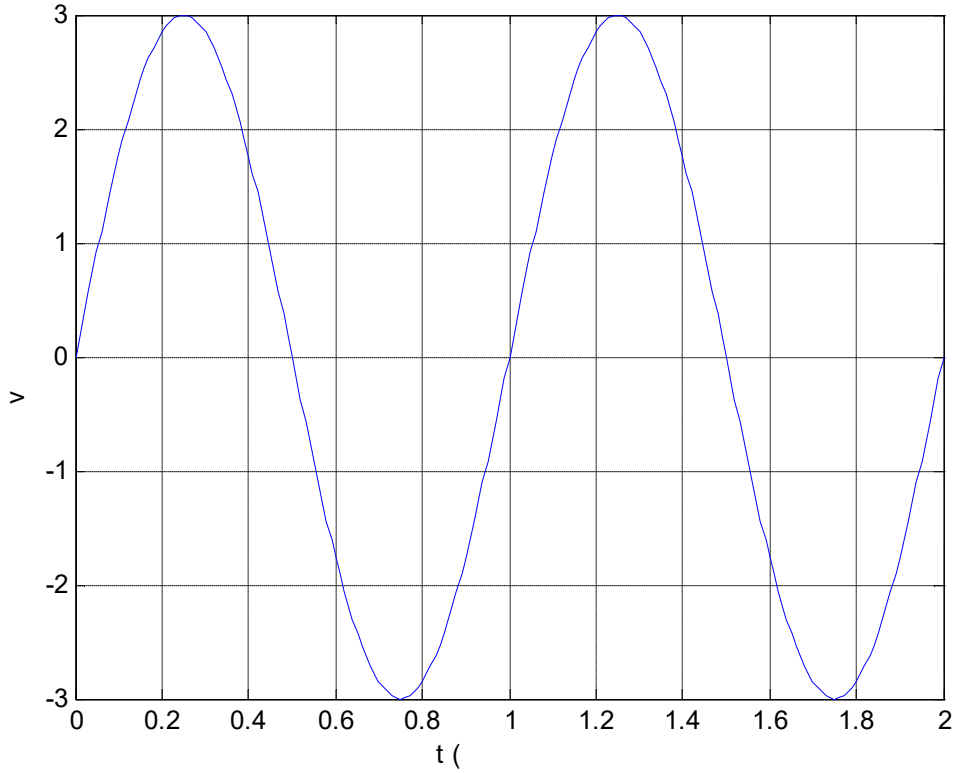
- What is a discrete-time signal?

  ➢ A discrete-time signal results from the **sampling** of the original analog signal:

    ✓ **Sampling** is the discretization of the *independent variable*.

1. Digital Signal Processing

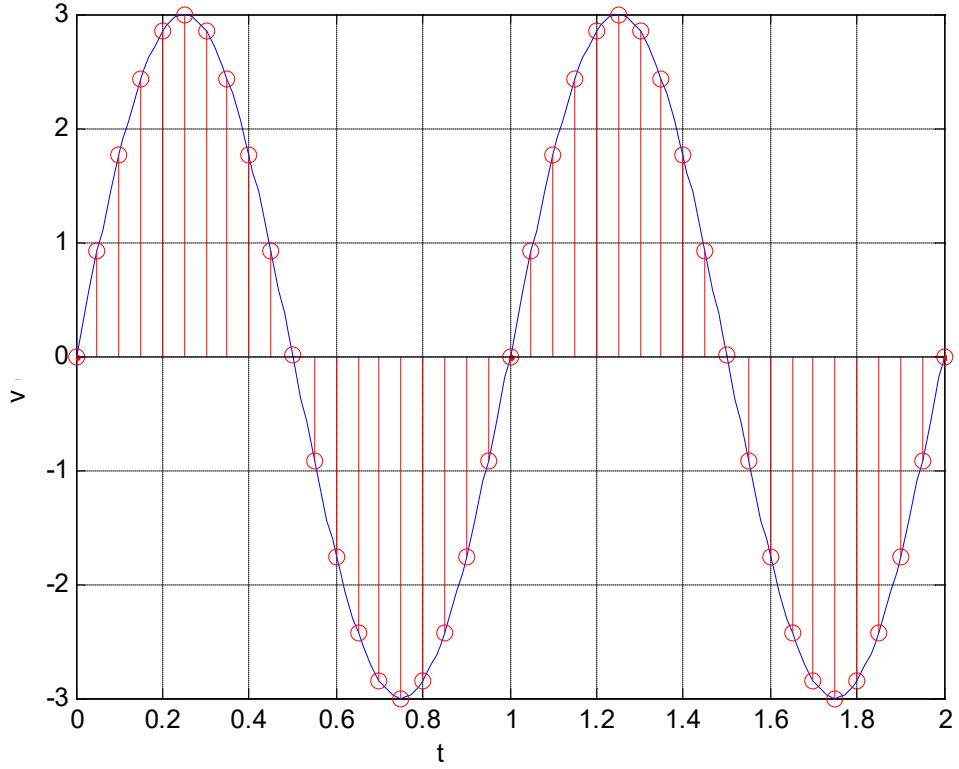
- What is a discrete-time signal?
  - Example: voltage (v) that varies with time (t).



1. Digital Signal Processing

- What is a discrete-time signal?

  - **Sampling:** discretization of the *independent variable t .*



Discrete-time signal

1. Digital Signal Processing

- What is a discrete-time signal?

  - Discrete-time signals:

    ✓ Are those that may be represented as a sequence of numbers:

$$\{x[n], n \in Z\}.$$

    ✓ **x[n]** is the amplitude of the signal at time ***nT,*** where ***T*** (**sampling period**) represents the time interval between two consecutive instants where the signal is defined.

    ✓ Thus, an alternative notation would be:

$$\{x[nT], n \in Z\}.$$

1. Digital Signal Processing

- What is a discrete-time signal?
  - $\{x[n], n \in Z\}$

    x[n] ➔ ..., x[0], x[1], x[2], x[3], x[4], ...

    n represent the nth position of a sample in the array.
  - $\{x[nT], n \in Z\}$

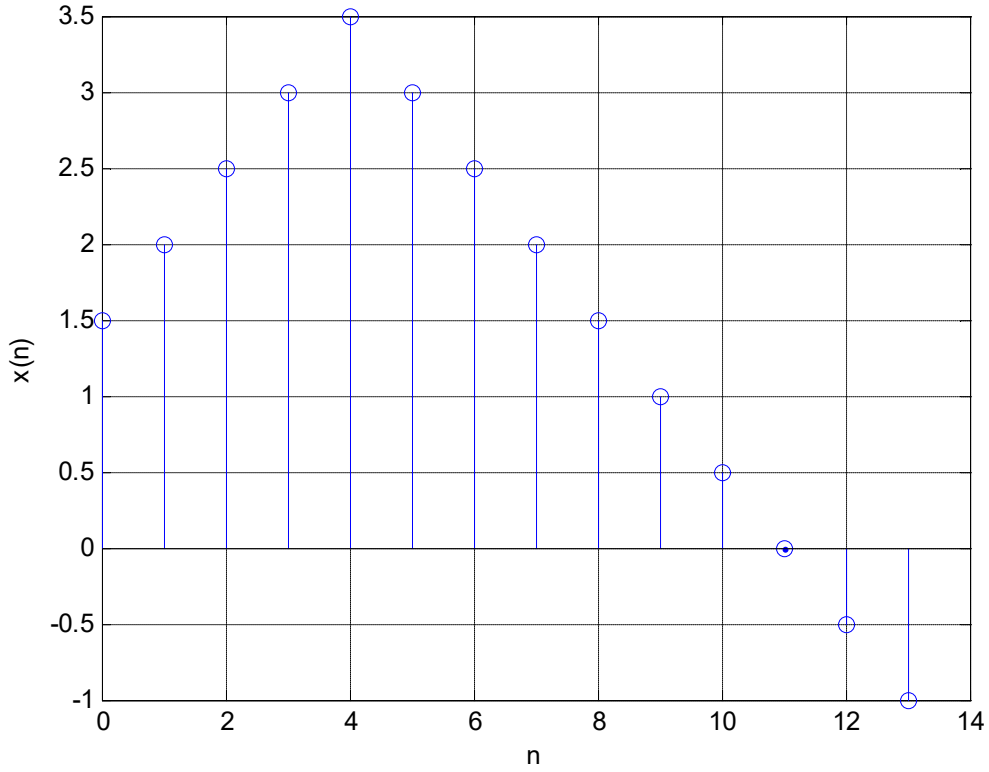
    x[*nT*] ➔ ..., x[0], x[0.03], x[0.06], x[0.09], x[0.12], ...

    nT represent the time at which the signal was sampled. In this example, the distance in time between two consecutive samples is 0.03 seconds.

1. Digital Signal Processing

- What is a discrete-time signal?

  - Example: x[n] = [1.5 2.0 2.5 3.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0 -0.5 -1.0]

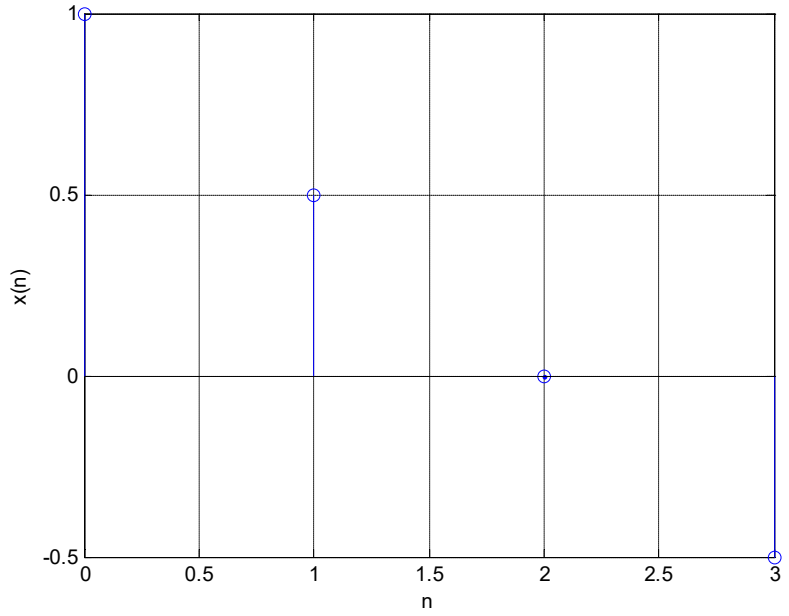


1. Digital Signal Processing

- What is a discrete-time signal?

  - Example: x[n] = [1.0 0.5 0 -0.5]

$x(0)\cdot\delta(n)$ $x(1)\cdot\delta(n-1)$ $x(2)\cdot\delta(n-2)$ $x(3)\cdot\delta(n-3)$



$$x[n]=\sum_{k=-\infty}^{+\infty} x[k]\cdot\delta[n-k]$$

1. Digital Signal Processing

- What is a discrete-time signal?

  - IMPORTANT:

    ✓ Although the term discrete-**time** signal is widely used to describe all kinds of discrete signals, time is not always the parameter to appear as the independent variable of acquired signals.

1. Digital Signal Processing

- What is a discrete-time signal?

  - IMPORTANT:

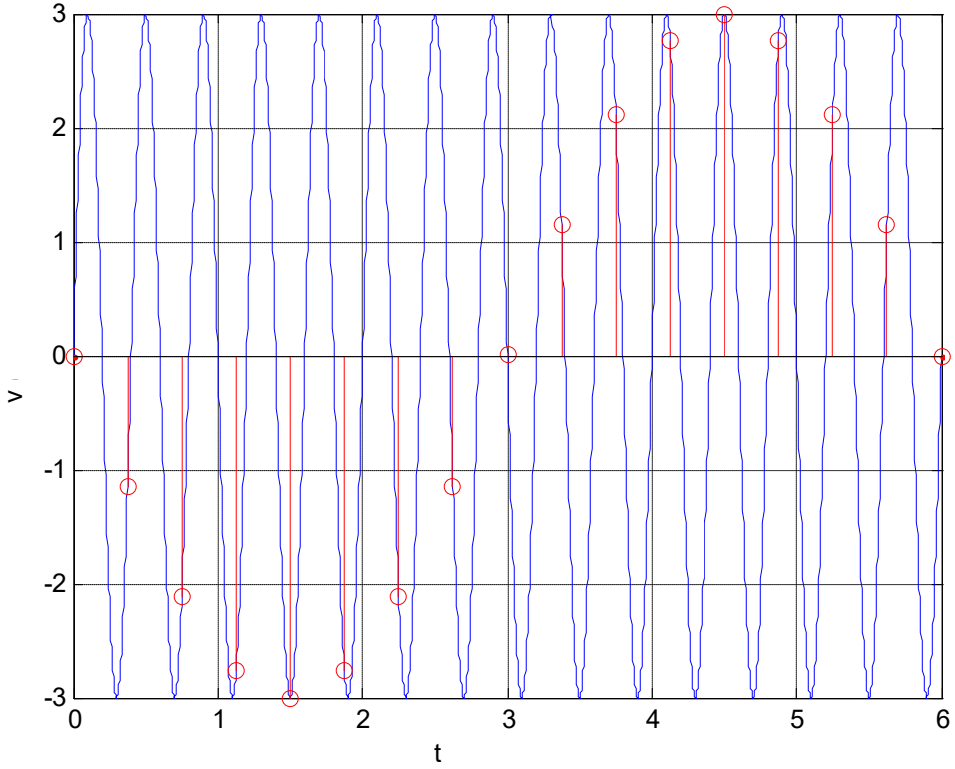
    ✓ Although the term discrete-**time** signal is widely used to describe all kinds of discrete signals, time is not always the parameter to appear as the independent variable of acquired signals.

    ✓ A geophysicist might acquire measurements of rock density at equally spaced distances along the surface of the earth. In this case, the independent variable is **distance**.

    ✓ To keep things general, it is better to simply label the independent variable as **sample number.**

1. Digital Signal Processing

- What is a discrete-time signal?
  - ➢ Problem: sampling frequency.



1. Digital Signal Processing

- Nyquist–Shannon sampling theorem:

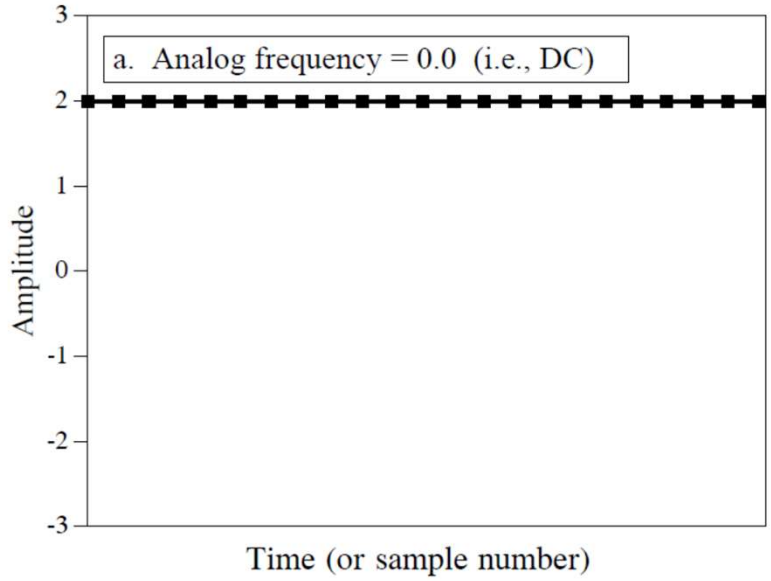
  ➢ Suppose you sample a continuous signal in some manner. If you can exactly reconstruct the analog signal from the samples, you must have done the sampling *properly*.

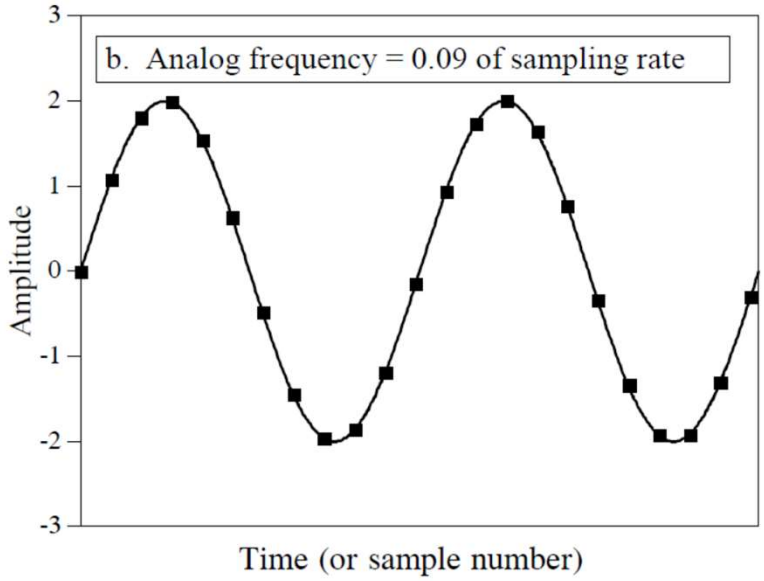
  ➢ The sampling theorem indicates that a continuous signal can be properly sampled, *only if it does not contain frequency components above one-half of the sampling rate*.

  ✓ Consider an analog signal composed of frequencies between DC and 3 kHz. To properly digitize this signal it must be sampled at 6,000 samples/sec (6 kHz) or higher.

1. Digital Signal Processing

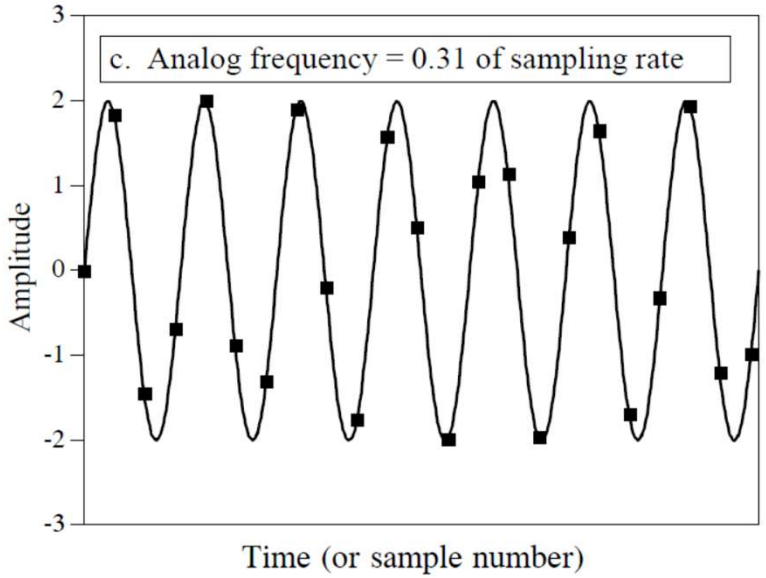
- Nyquist–Shannon sampling theorem: examples.

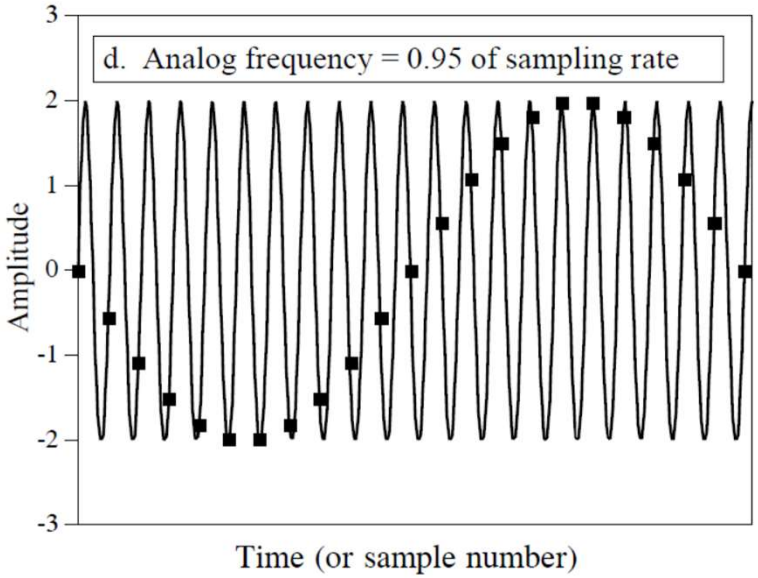




1. Digital Signal Processing

- Nyquist–Shannon sampling theorem: examples.





1. Digital Signal Processing

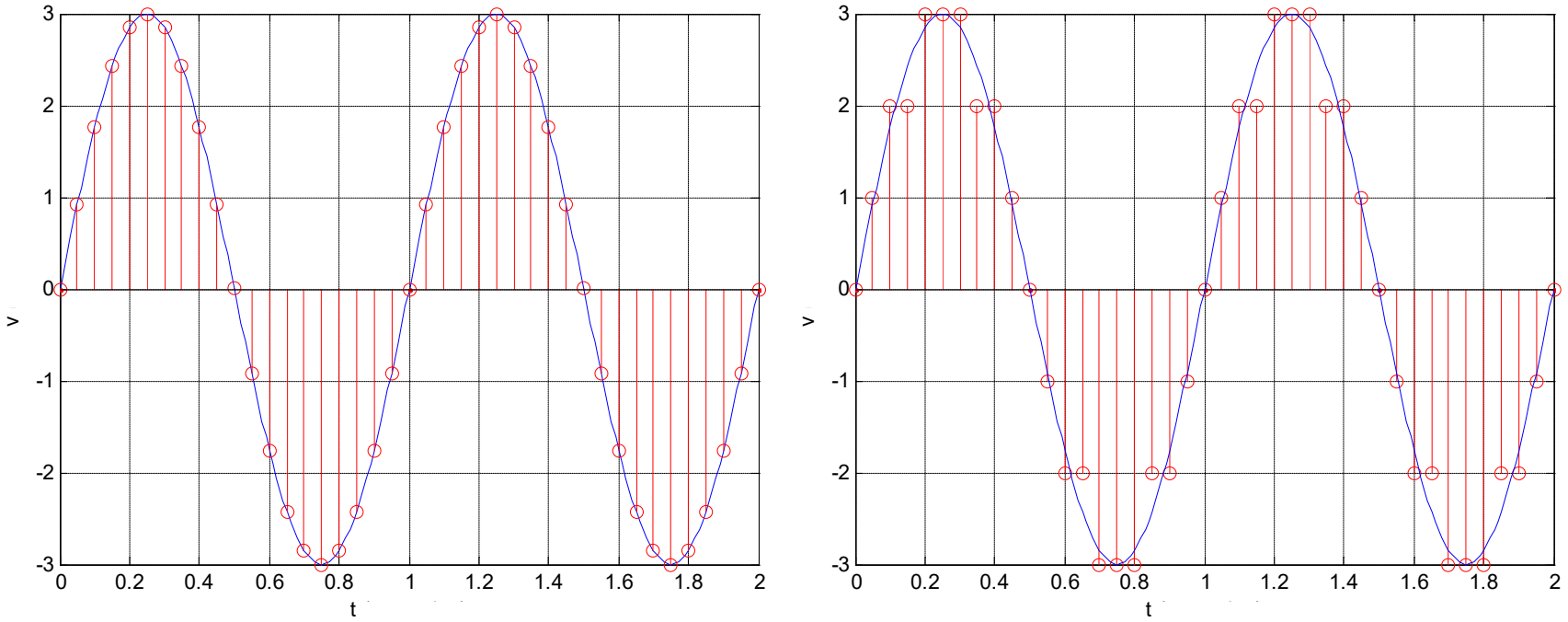
- What is a digital signal?

  ➢ A **digital signal** results from the **quantization** of a discrete-time signal:

    ✓ **Quantization** is the discretization of the *dependent variable*.

1. Digital Signal Processing

- What is a digital signal?

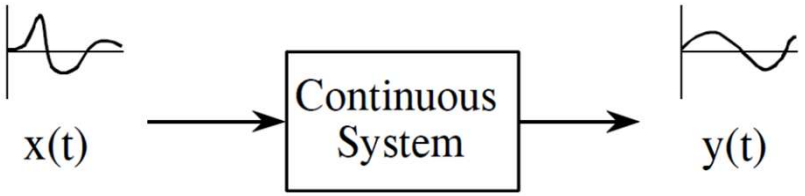


1. Digital Signal Processing

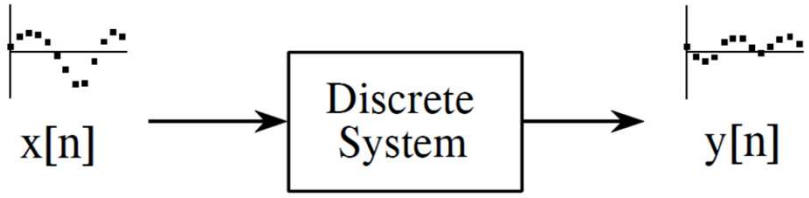
- What is a discrete system?

  ➢ A **system** is any process that produces an output signal in response to an input signal

  ➢ In **continuous systems** input and output signals are continuous.



  ➢ In **discrete systems** input and output signals are discrete.



1. Digital Signal Processing

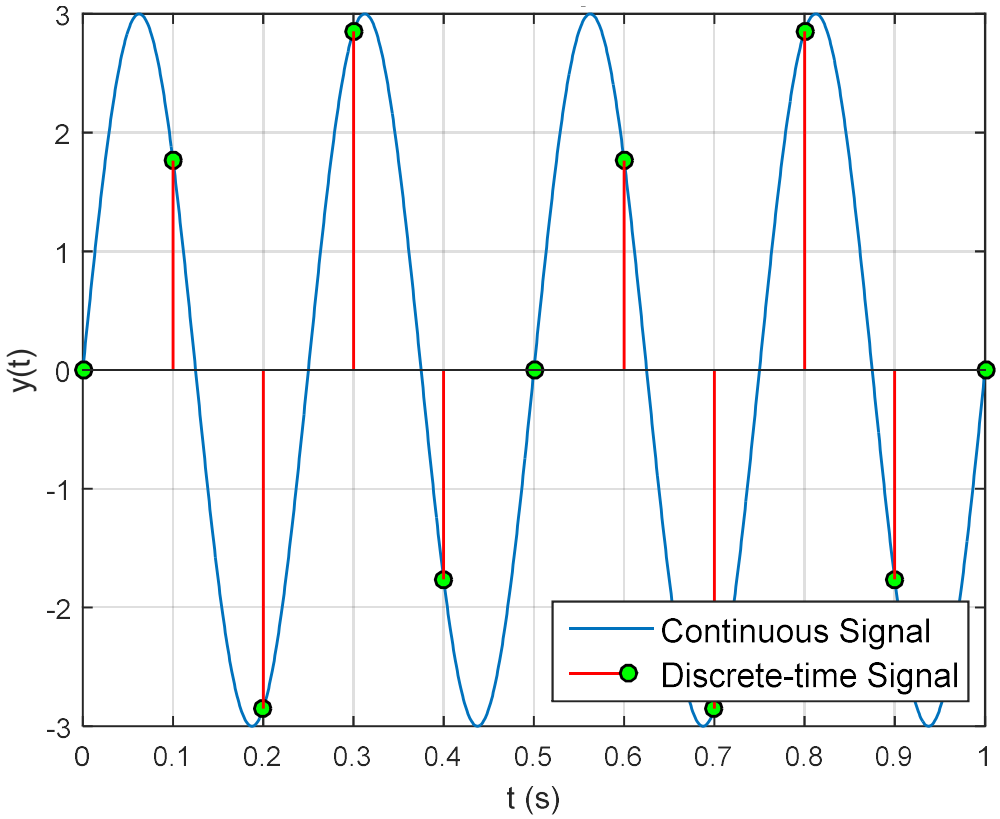
- What is Digital Signal Processing?

  ➢ It is the area in Electrical and Computer Engineering/ Computer Science that deals with de **systems** that manipulate **digital signals**.

  ➢ Thus, the development of Digital Signal Processing is intimately tied to the development of the digital computer.

1. Digital Signal Processing

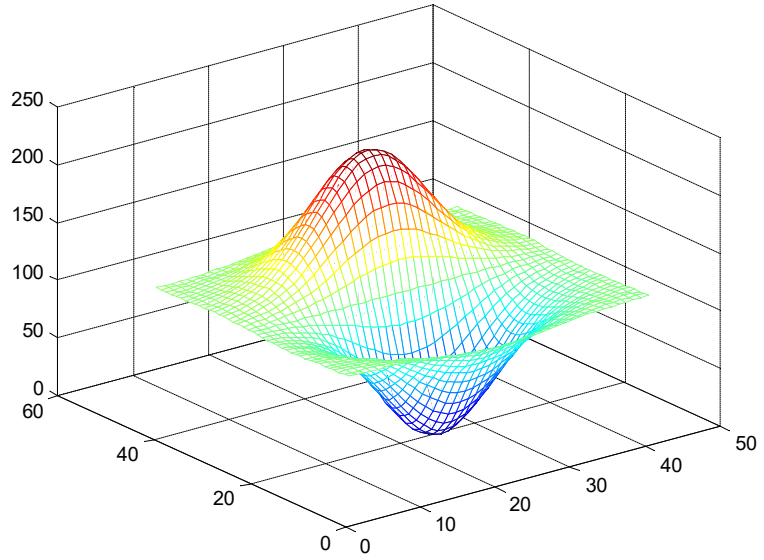
- MATLAB: s24Sampling.m

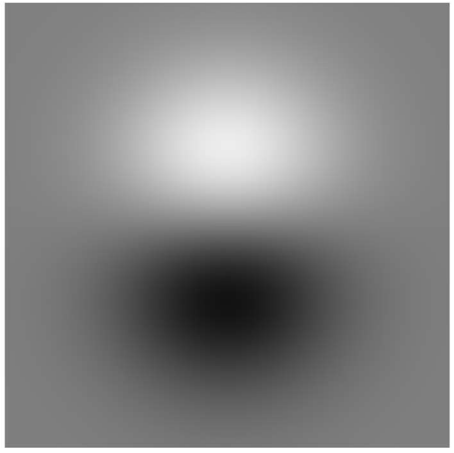


2. Digital Image Processing

• 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.





2. Digital Image Processing

- MATLAB: s26ImageFunc.m

```
clear all
close all

x = -2:0.1:2;
y = -2:0.1:2;

for i = 1:length(x)
    for j = 1:length(y)
        z(i,j) =  round(255*(0.5+ x(i).*exp(-x(i)^2 - y(j)^2)));
    end
End

imshow(uint8(z));
figure
mesh(z);
```

MATLAB Primer
https://www.mathworks.com/help/pdf_doc/matlab/getstart.pdf

2. Digital Image Processing

• When x, y, and the amplitude values of f are all finite, discrete quantities, we call the image a **digital image**.

• **Digital image processing** refers to processing digital images by means of a digital computer.

• Note that 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 or **pixels**.

• The human visual system is limited to the visual band of the electromagnetic (EM) spectrum.

2. Digital Image Processing

• Imaging machines cover almost the entire EM spectrum, ranging from gamma to radio waves.

- They can operate on images generated by sources that humans are not accustomed to associating with images. These include:
  - Ultrasound;
  - electron microscopy; and
  - computer-generated images.

• Thus, digital image processing encompasses a wide and varied field of applications.

2. Digital Image Processing

• **Low-level processes:** involve primitive operations such as denoising, contrast enhancement and image sharpening. Inputs and outputs are images.

• **Mid-level:** involves tasks such as segmentation, description of objects and classification of individual objects. Inputs are images, but outputs are attributes extracted from those images.

• **High-level:** involves "making sense" of an ensemble of recognized objects, as in image analysis, and performing the cognitive functions normally associated with vision.

• There are no clear-cut boundaries in the continuum from low-level processes at one end to high-level processes at the other.

3. The Origins

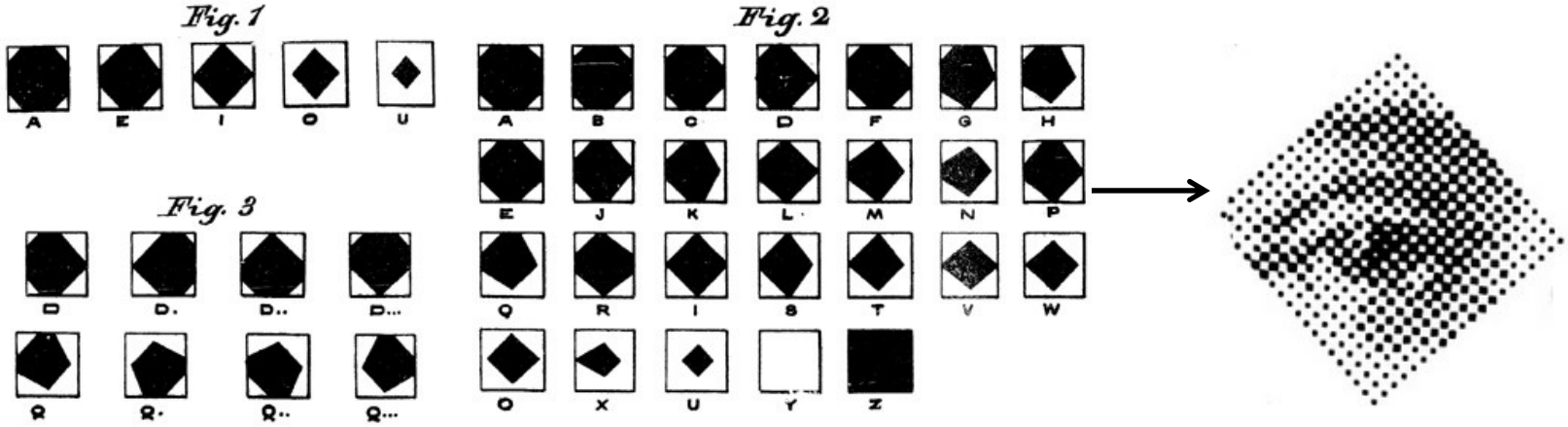
• One of the first applications of digital images was in the newspaper industry, when pictures were first sent by submarine cable between London and New York (Bartlane cable picture transmission system).

- Digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces simulating a halftone pattern.

3. The Origins

• One of the first applications of digital images was in the newspaper industry, when pictures were first sent by submarine cable between London and New York (Bartlane cable picture transmission system).

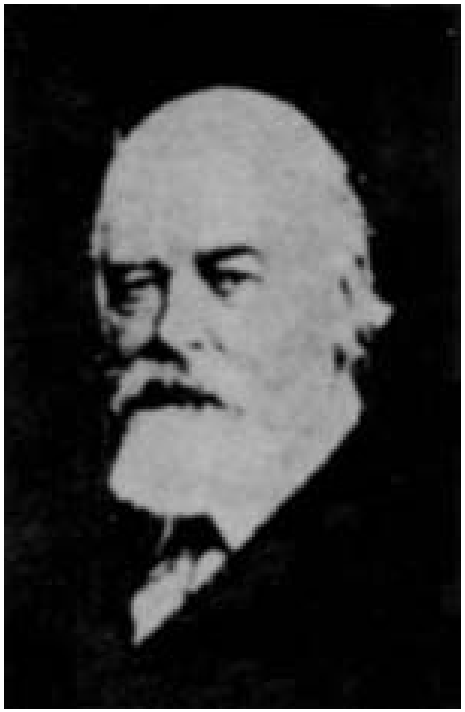
- Digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces simulating a halftone pattern.



http://www.jmcvey.net/cable/elements/index.htm

3. The Origins

- Photographic reproduction made in 1922 from a tape punched after the signals had crossed the Atlantic twice. The system was capable of coding images in five distinct levels of gray.



3. The Origins

✓ This capability was increased to 15 levels in 1929.

3. The Origins

• The examples just cited are not considered digital image processing results because computers were not involved in their creation.

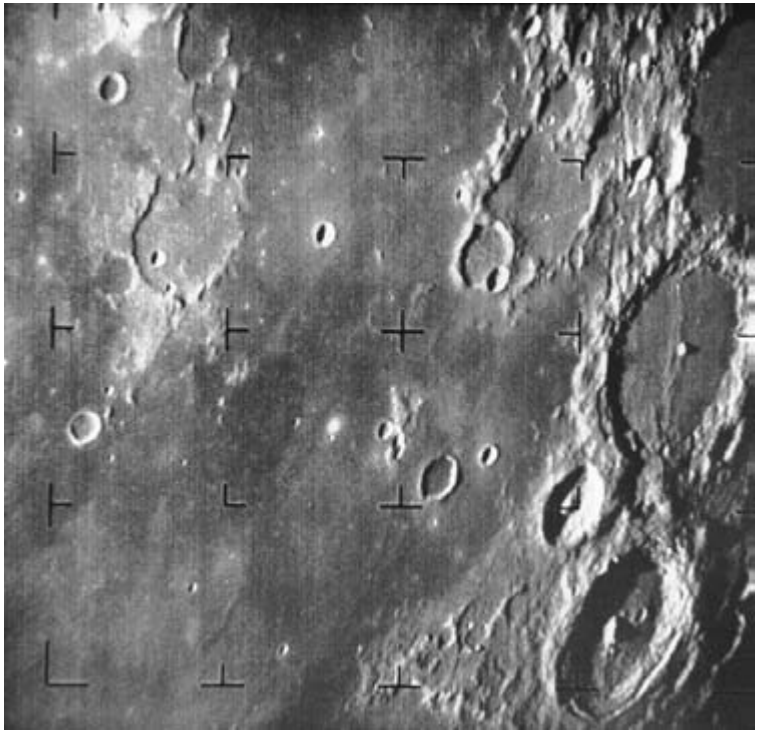
• Thus, the history of digital image processing is intimately tied to the development of the digital computer.

• The idea of a computer goes back to the invention of the abacus in Asia Minor, more than 5000 years ago.

• But the first computers powerful enough to carry out meaningful image processing tasks appeared only in the early 1960s.

3. The Origins

• In 1964, pictures of the moon were transmitted by Ranger 7 and processed by a computer to correct various types of image distortion inherent in the on-board television camera.



3. The Origins

• In the late 1960s and early 1970s image processing techniques began to be used in medical imaging, remote Earth resources observations, and astronomy.

• The invention in the early 1970s of computerized axial tomography (CAT) is one of the most important events in the application of image processing in medical diagnosis.

• Tomography was invented independently by Sir Godfrey N. Hounsfield and Professor Allan M. Cormack, who shared the 1979 Nobel Prize in Medicine for their invention.

4. Examples of Fields that Use Digital Image Processing

• From the 1960s until the present, the field of image processing has grown vigorously.

• The principal energy source for images in use today is the electromagnetic energy spectrum.

• Other important sources of energy include acoustic, ultrasonic, and electronic (in the form of electron beams used in electron microscopy).

• Synthetic images, used for modeling and visualization, are generated by computer.

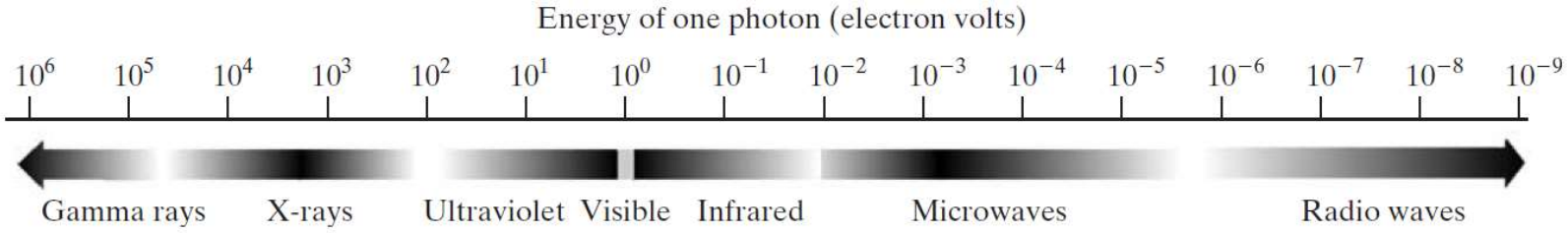
4. Examples of Fields that Use Digital Image Processing

• Electromagnetic waves can be conceptualized as propagating sinusoidal waves of varying wavelengths.

• They can be thought of as a stream of massless particles, each traveling in a wavelike pattern and moving at the speed of light.

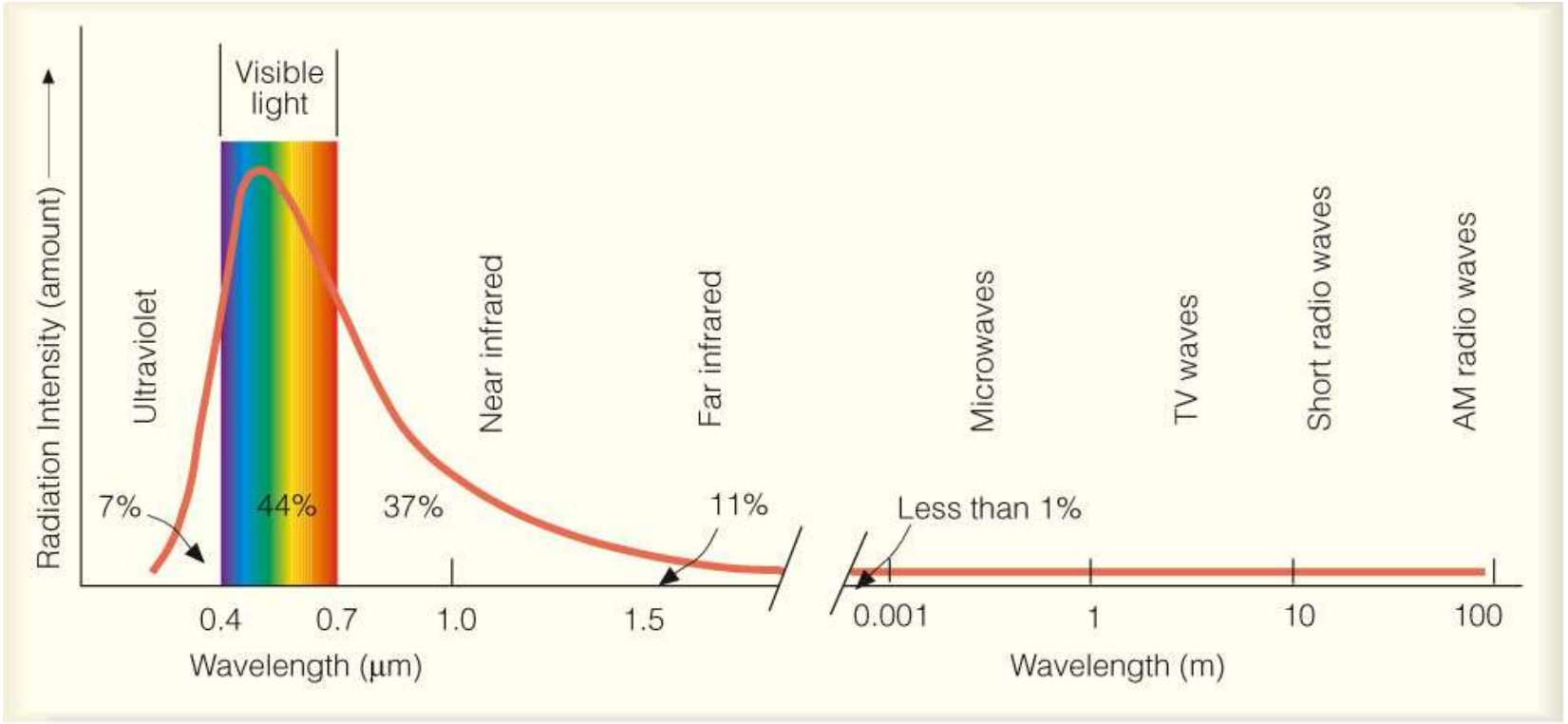
• Each massless particle contains a certain amount (or bundle) of energy. Each bundle of energy is called a photon.

• If spectral bands are grouped according to energy per photon, we obtain:



4. Examples of Fields that Use Digital Image Processing

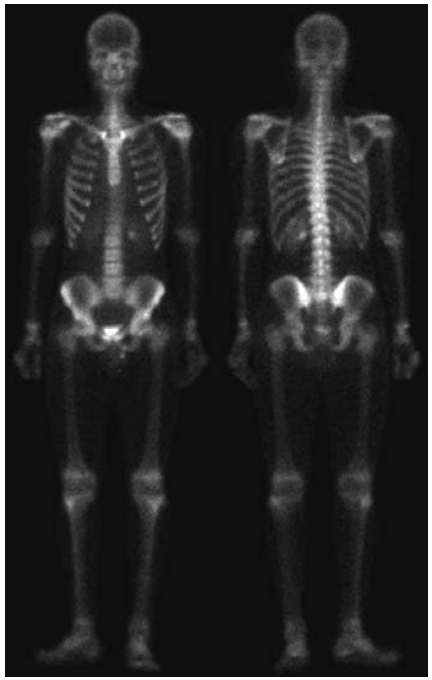
- Curiosity (solar radiation):



4. Examples of Fields that Use Digital Image Processing

- Gamma-Ray Imaging

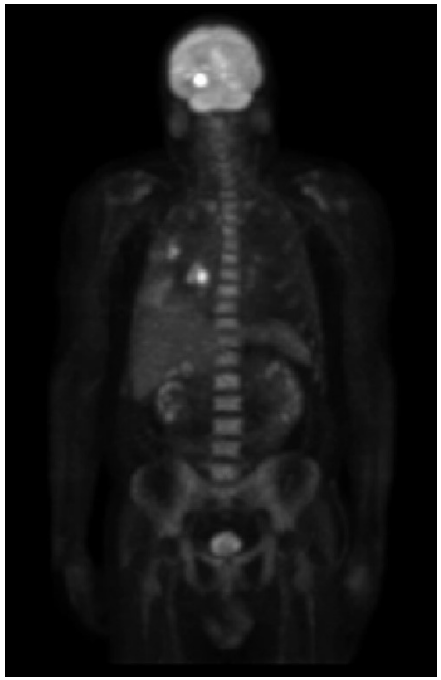
  - Nuclear medicine: one approach is to inject a patient with a radioactive isotope that emits gamma rays as it decays. Complete bone scan.



4. Examples of Fields that Use Digital Image Processing

- Gamma-Ray Imaging

  - Nuclear medicine: another major modality of nuclear imaging called positron emission tomography (PET).



4. Examples of Fields that Use Digital Image Processing

- X-ray Imaging

  - Chest X-ray generated simply by placing the patient between an X-ray source and a film sensitive to X-ray energy.

4. Examples of Fields that Use Digital Image Processing

- X-ray Imaging

  - Angiography is another major application in an area called *contrast enhancement radiography*. This procedure is used to obtain images of blood vessels.

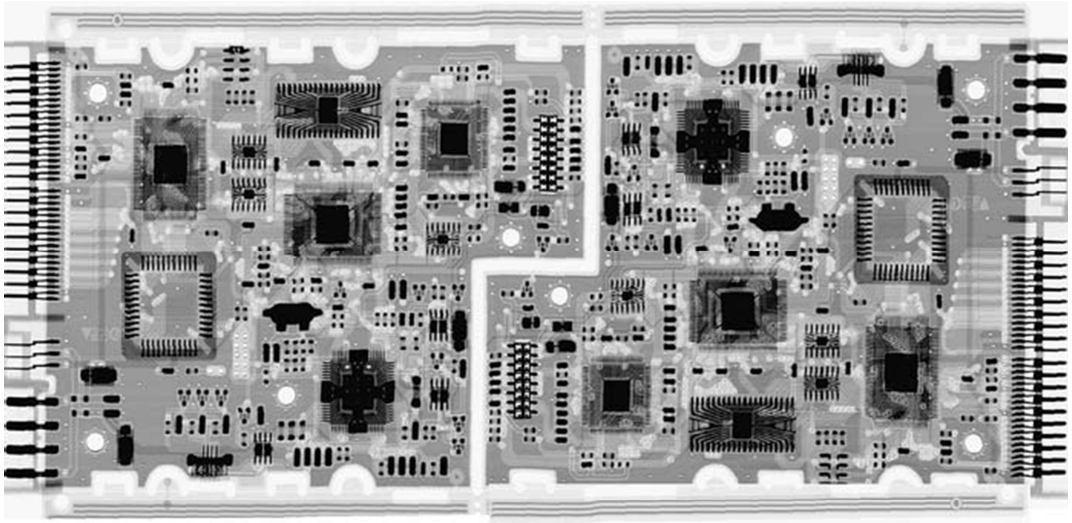
4. Examples of Fields that Use Digital Image Processing

- X-ray Imaging
  - Computerized axial tomography (CAT).

4. Examples of Fields that Use Digital Image Processing

- X-ray Imaging

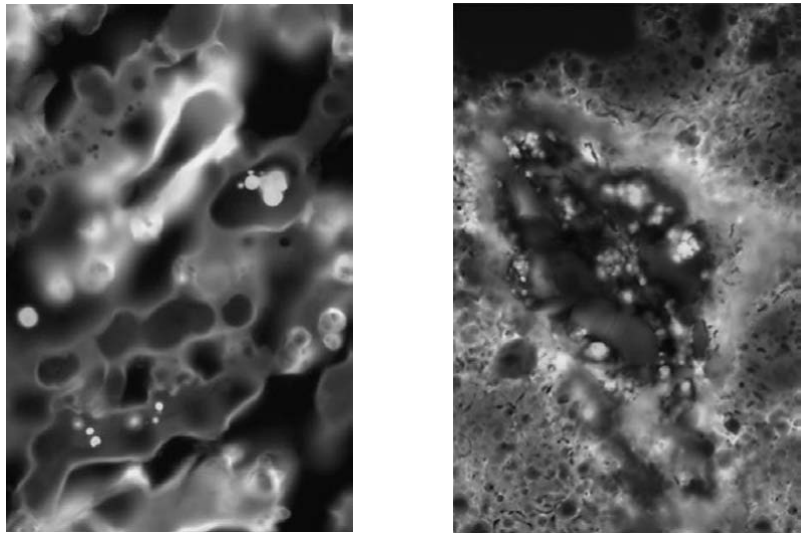
  - X-ray image of an electronic circuit board used to examine circuit boards for flaws in manufacturing, such as missing components or broken traces.



4. Examples of Fields that Use Digital Image Processing

- Imaging in the Ultraviolet Band

  - Fluorescence microscopy: is an excellent method for studying materials that can be made to fluoresce, either in their natural form or when treated with chemicals capable of fluorescing.



Normal corn Smut corn

4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

  - The visual band of the electromagnetic spectrum is the most familiar in all our activities,

    - ✓ It is not surprising that imaging in this band outweighs by far all the others in terms of scope of application.

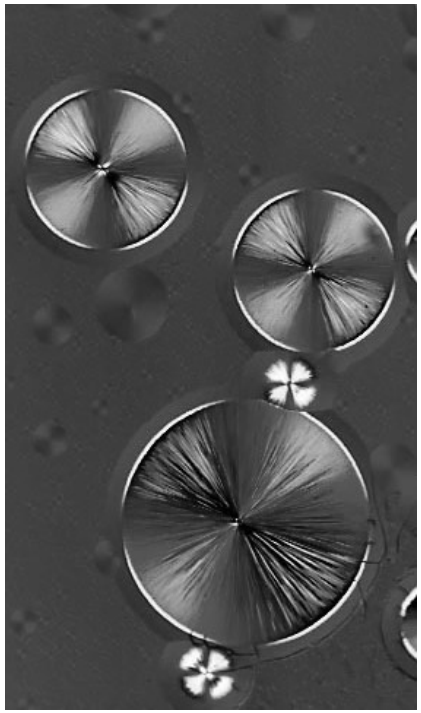
  - The infrared band often is used in conjunction with visual imaging, so they have been grouped for the purpose of illustration.

4. Examples of Fields that Use Digital Image Processing

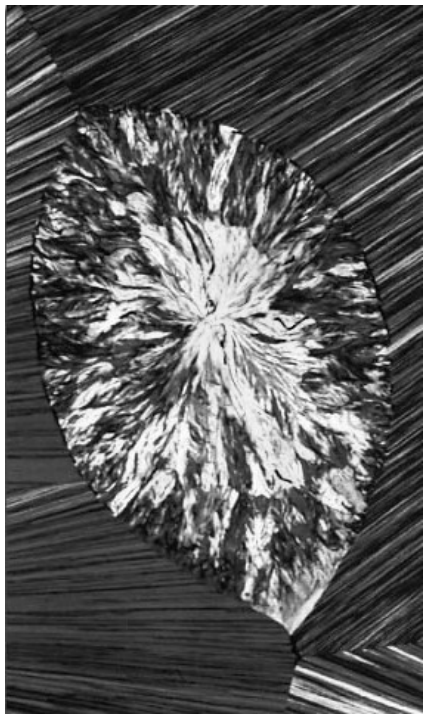
- Imaging in the Visible and Infrared Bands

  - Light microscopy:

Taxol (anticancer agent)



Cholesterol

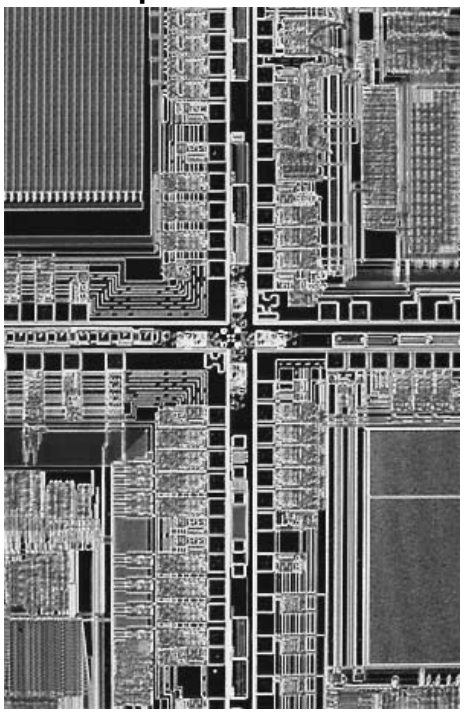


4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

  - Light microscopy:

Microprocessor



Nickel oxide thin film

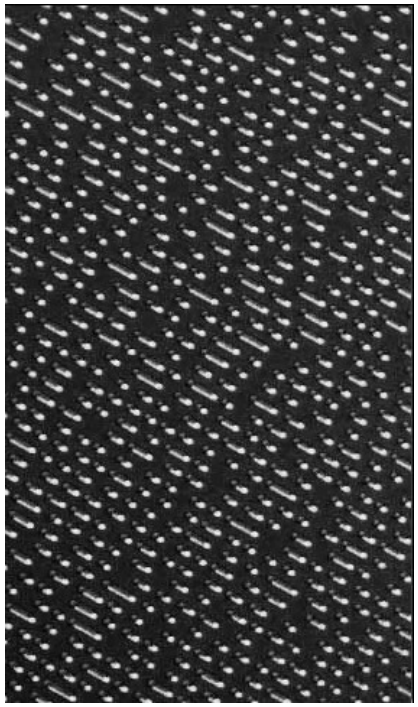
4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

  - Light microscopy:

Organic superconductor

Surface of audio CD



4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

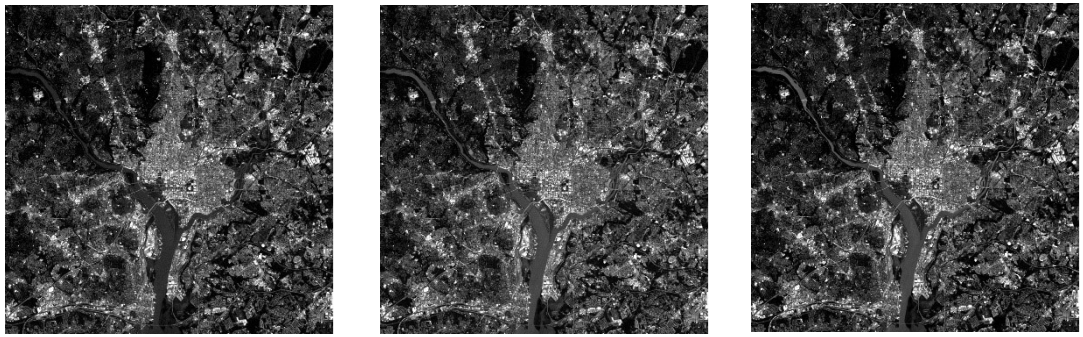
  - Another major area of visual processing is **remote sensing** (monitoring environmental conditions)

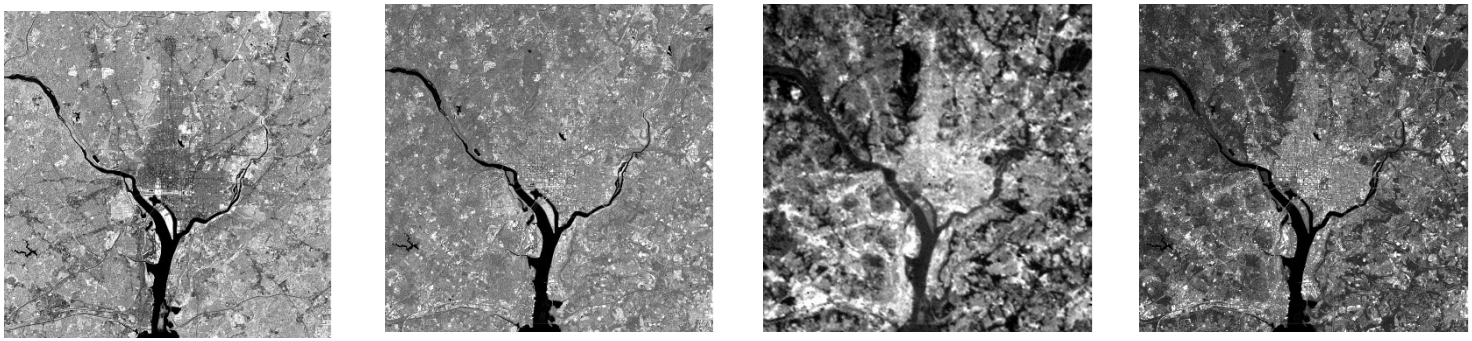
Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture 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

4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

  - LANDSAT satellite images of the Washington, D.C. area (thematic bands from 1 to 7):





4. Examples of Fields that Use Digital Image Processing

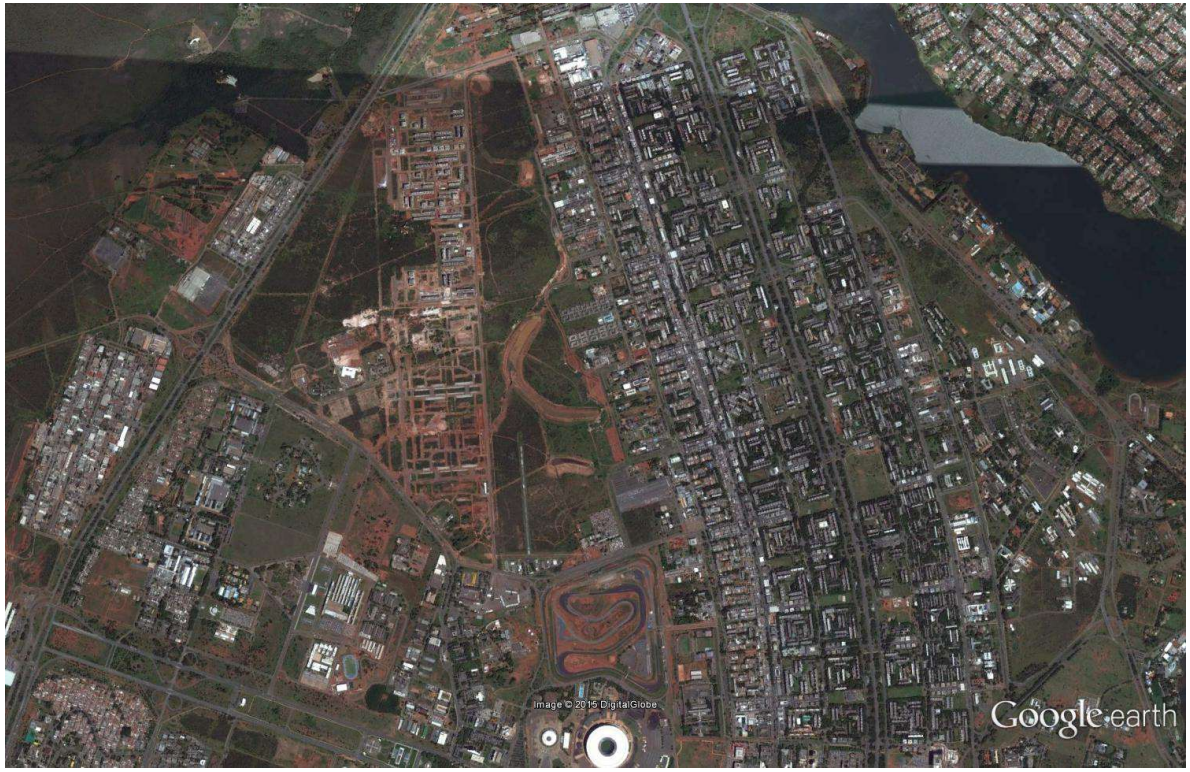
- Imaging in the Visible and Infrared Bands

  - Setor Noroeste, Brasília, Brazil, 2002:

4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

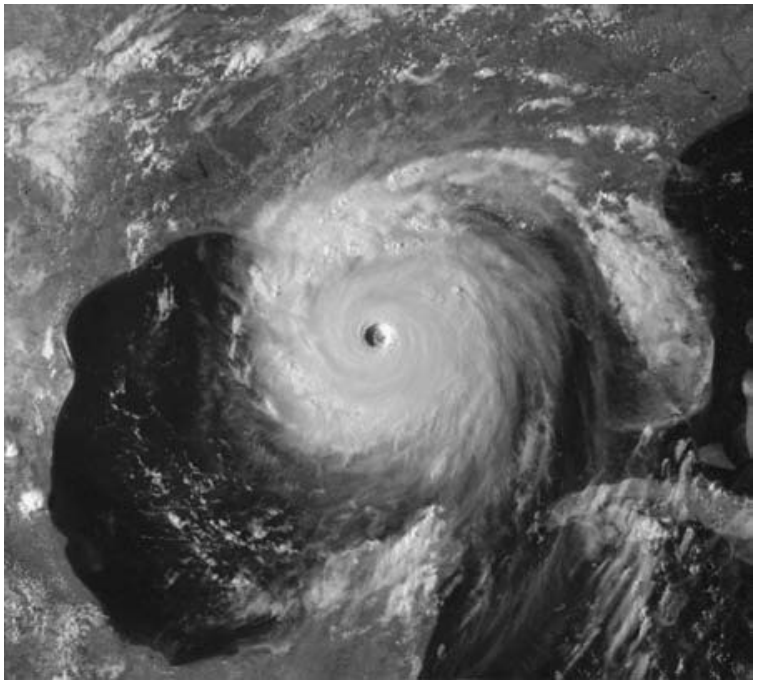
  - Setor Noroeste, Brasília, Brazil, 2015:



4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

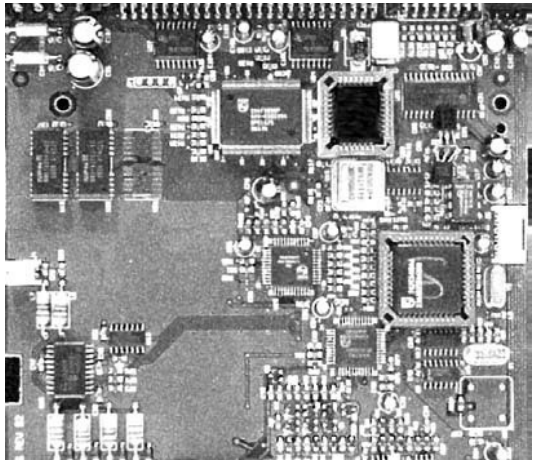
  - Weather observation and prediction (Multispectral image of Hurricane – visible and infrared bands):

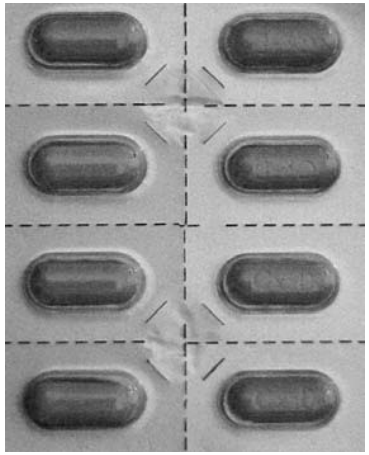


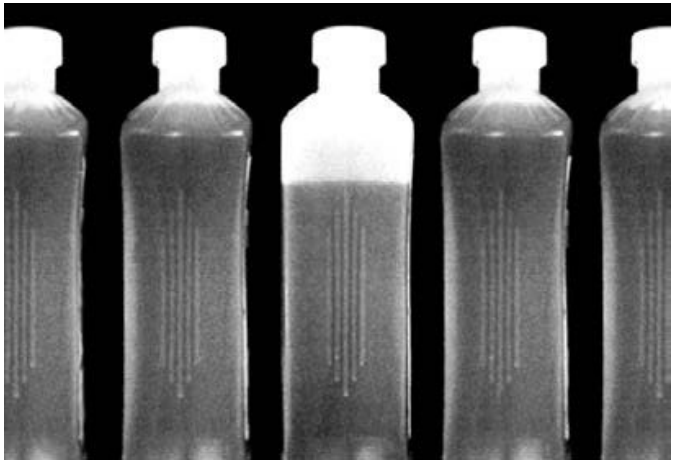
4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

  - A major area of imaging in the visual spectrum is in automated visual inspection of manufactured goods.



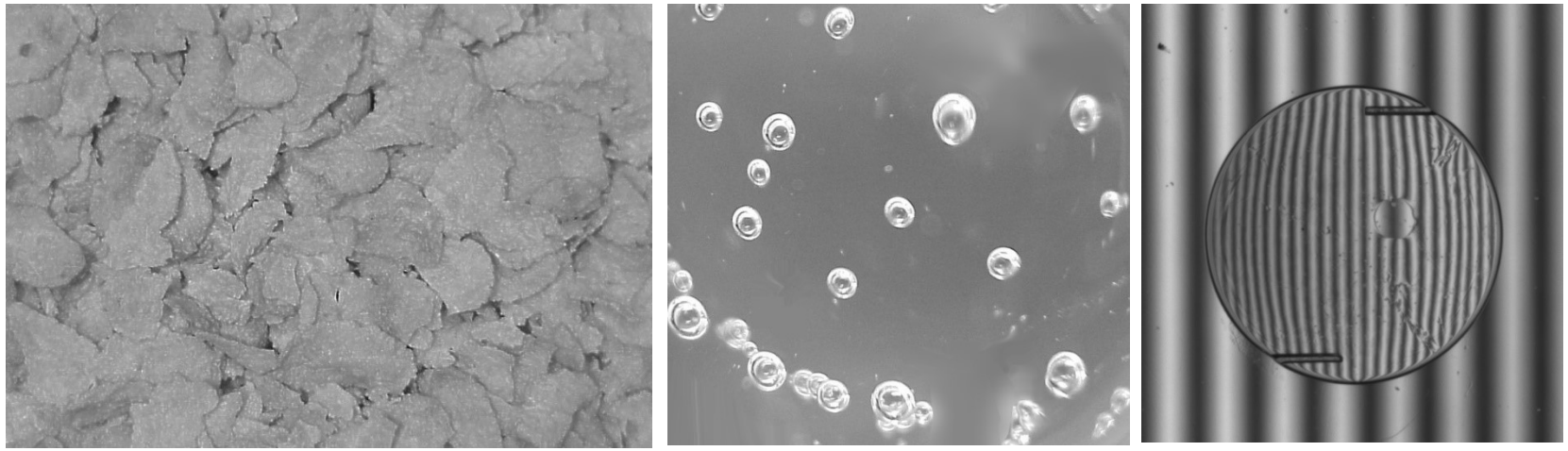




4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

  - A major area of imaging in the visual spectrum is in automated visual inspection of manufactured goods.



4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

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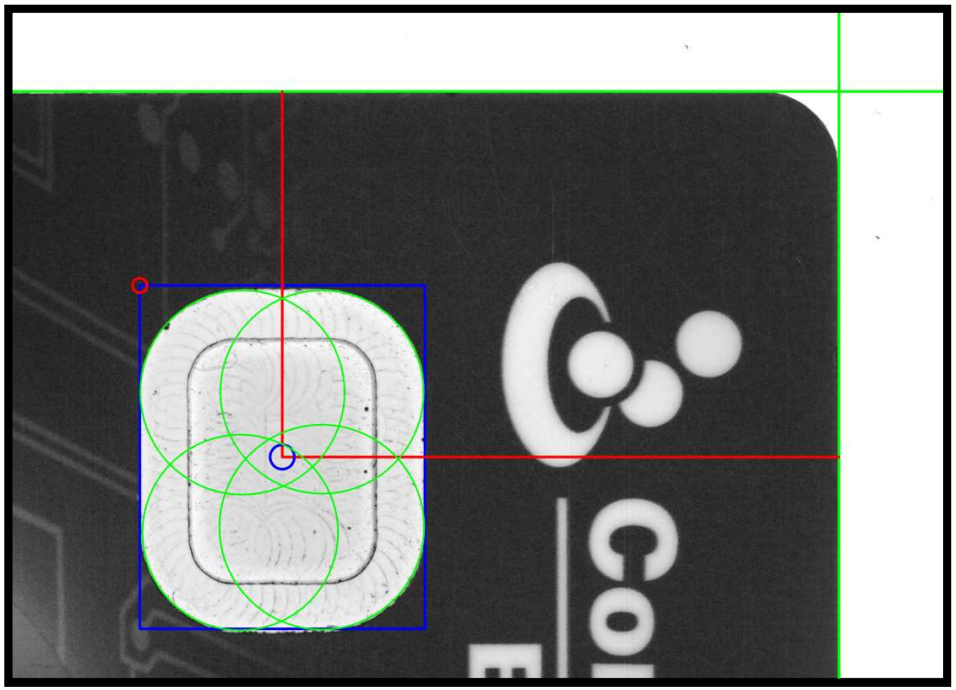
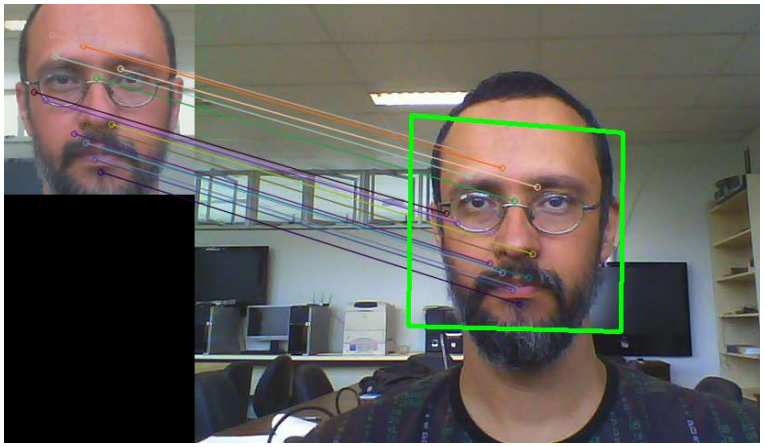
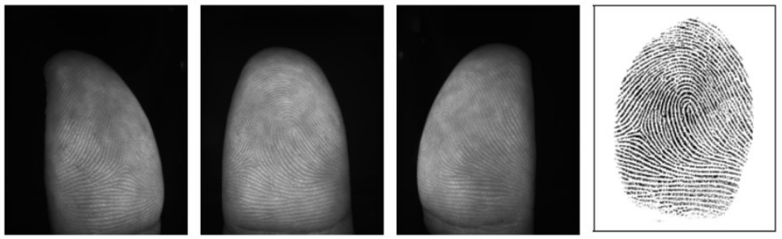


4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands
  - ➢ Other applications:

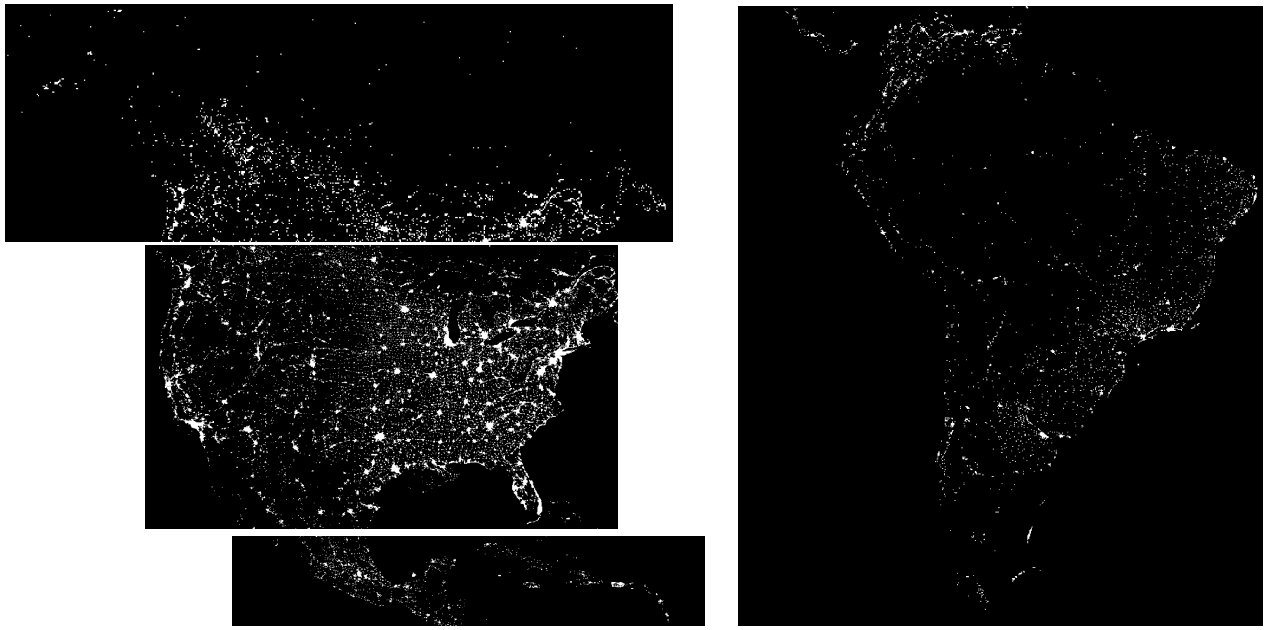




4. Examples of Fields that Use Digital Image Processing

- Imaging in the Visible and Infrared Bands

  ✓ Global inventory of human settlements (infrared):



Nighttime Lights of the World data set

4. Examples of Fields that Use Digital Image Processing

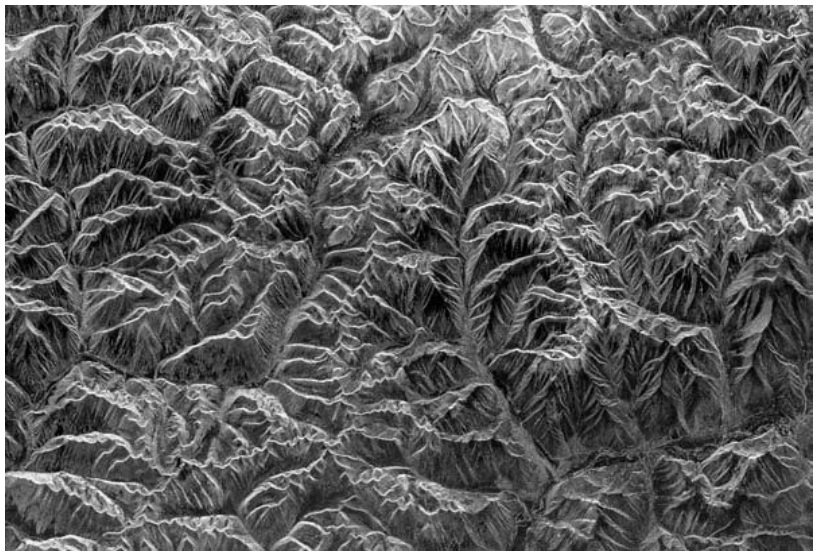
- Imaging in the Visible and Infrared Band:

  ✓ 3D video depth map:

4. Examples of Fields that Use Digital Image Processing

- Imaging in the Microwave Band

  ✓ The dominant application of imaging in the microwave band is **radar.**



Mountainous area of southeast Tibet

4. Examples of Fields that Use Digital Image Processing

- Imaging in the Radio Band:

  ✓ In medicine radio waves are used in magnetic resonance imaging (MRI).

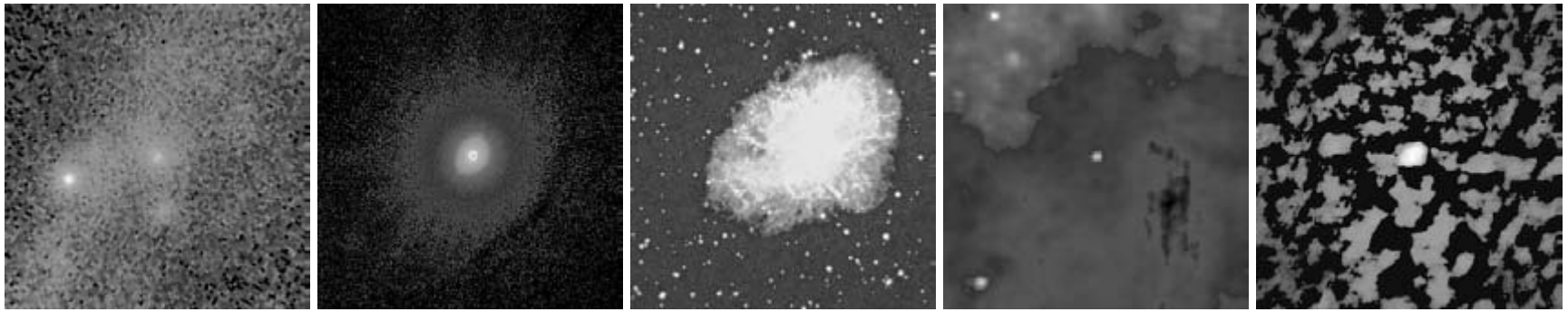
Knee

Spine

4. Examples of Fields that Use Digital Image Processing

- Multispectral imaging

  ✓ Astronomy (images of the Crab Pulsar covering the electromagnetic spectrum):



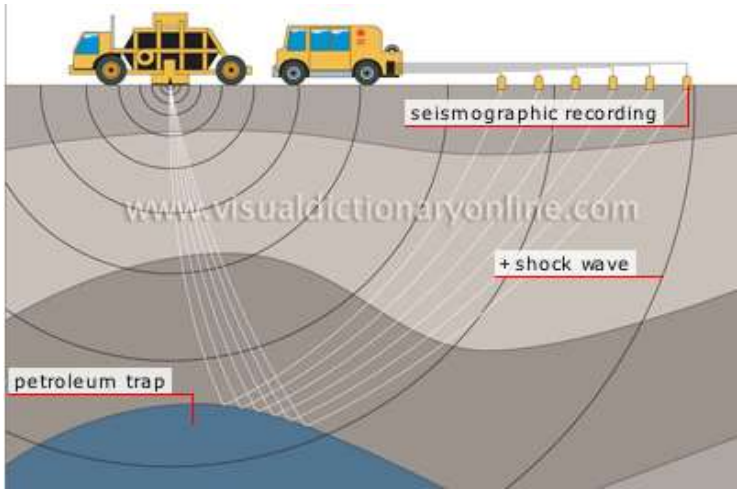
Gamma X-ray Optical Infrared Radio

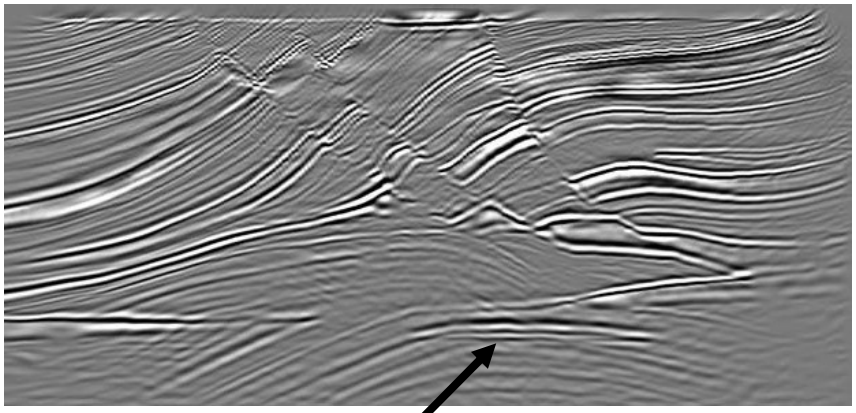
4. Examples of Fields that Use Digital Image Processing

- Examples in which Other Imaging Modalities Are Used

  ✓ Acoustic imaging:

  ➢ Geology (mineral and oil exploration):

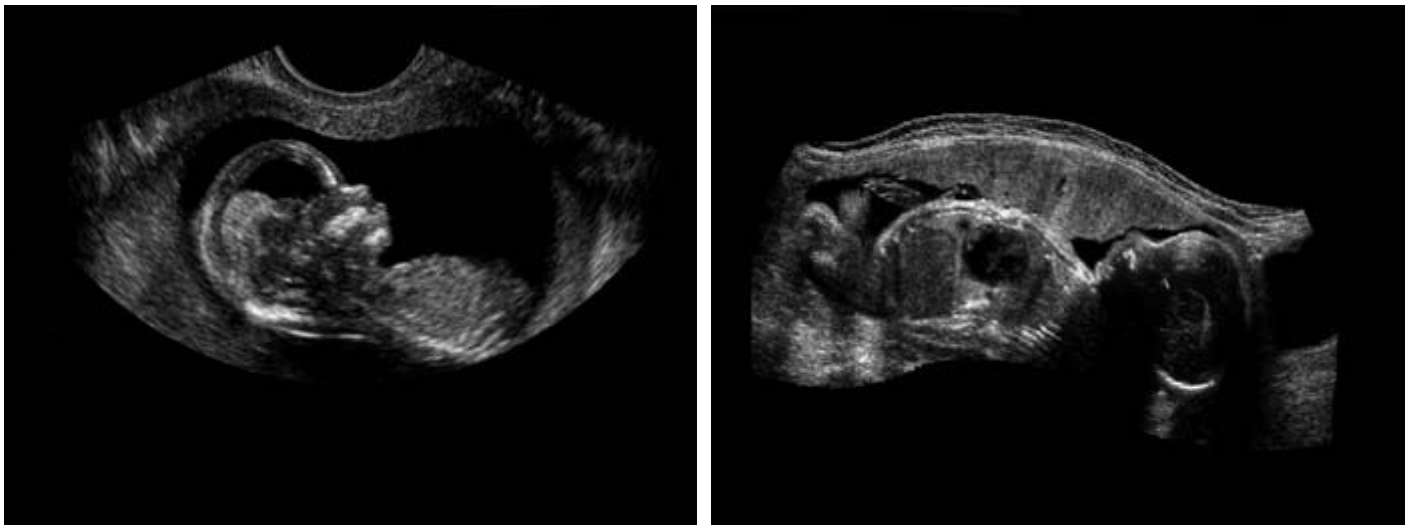




Hydrocarbon trap.

4. Examples of Fields that Use Digital Image Processing

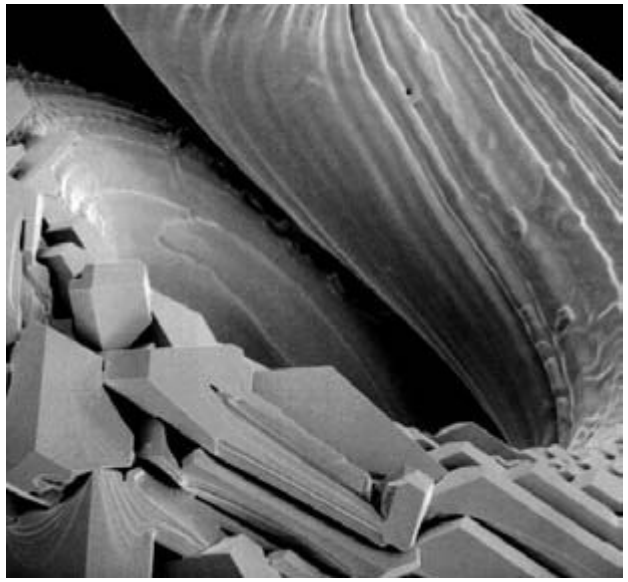
- Examples in which Other Imaging Modalities Are Used
  - ✓ Acoustic imaging:
    - ➢ Obstetrics (ultrasonography):



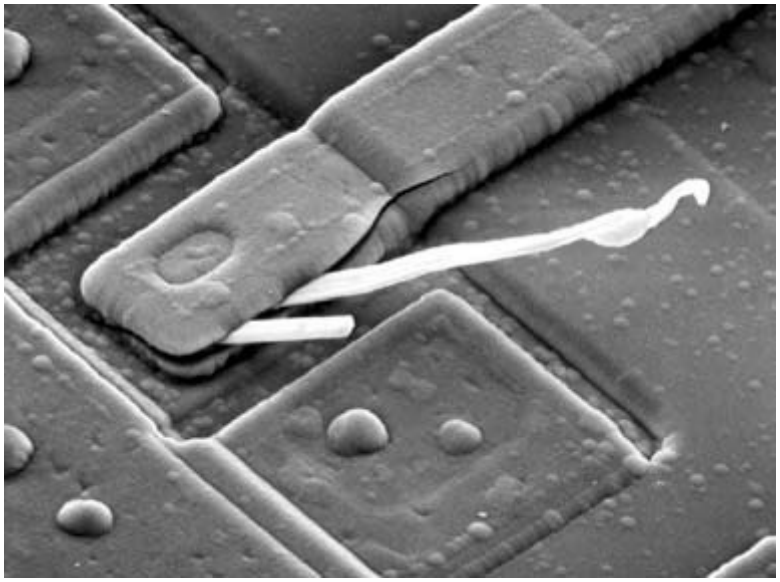
4. Examples of Fields that Use Digital Image Processing

- Examples in which Other Imaging Modalities Are Used

  ✓ Electron microscopy (up to x10.000 magnification):



Tungsten filament (x250)

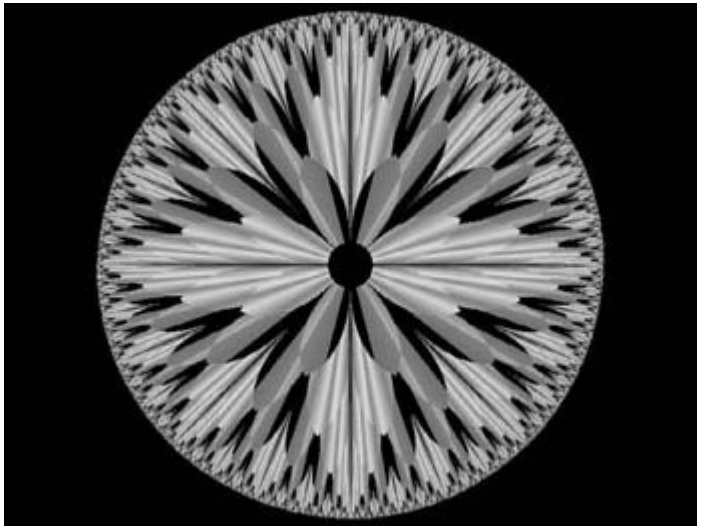


Integrated circuit (x2500)

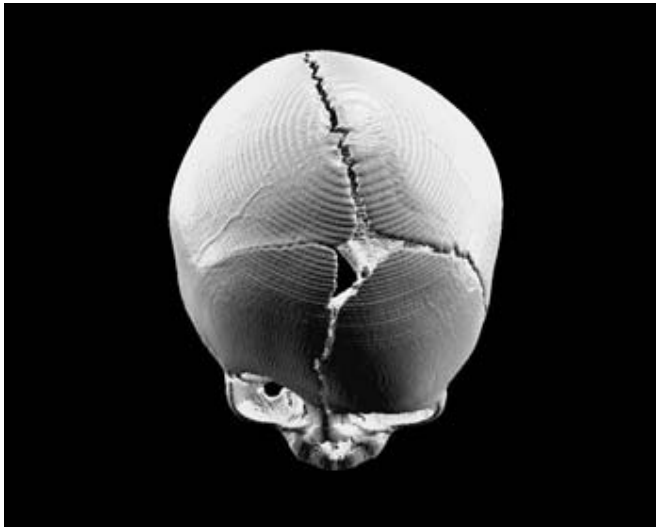
4. Examples of Fields that Use Digital Image Processing

- Examples in which Other Imaging Modalities Are Used

  ✓ Computer-generated images:

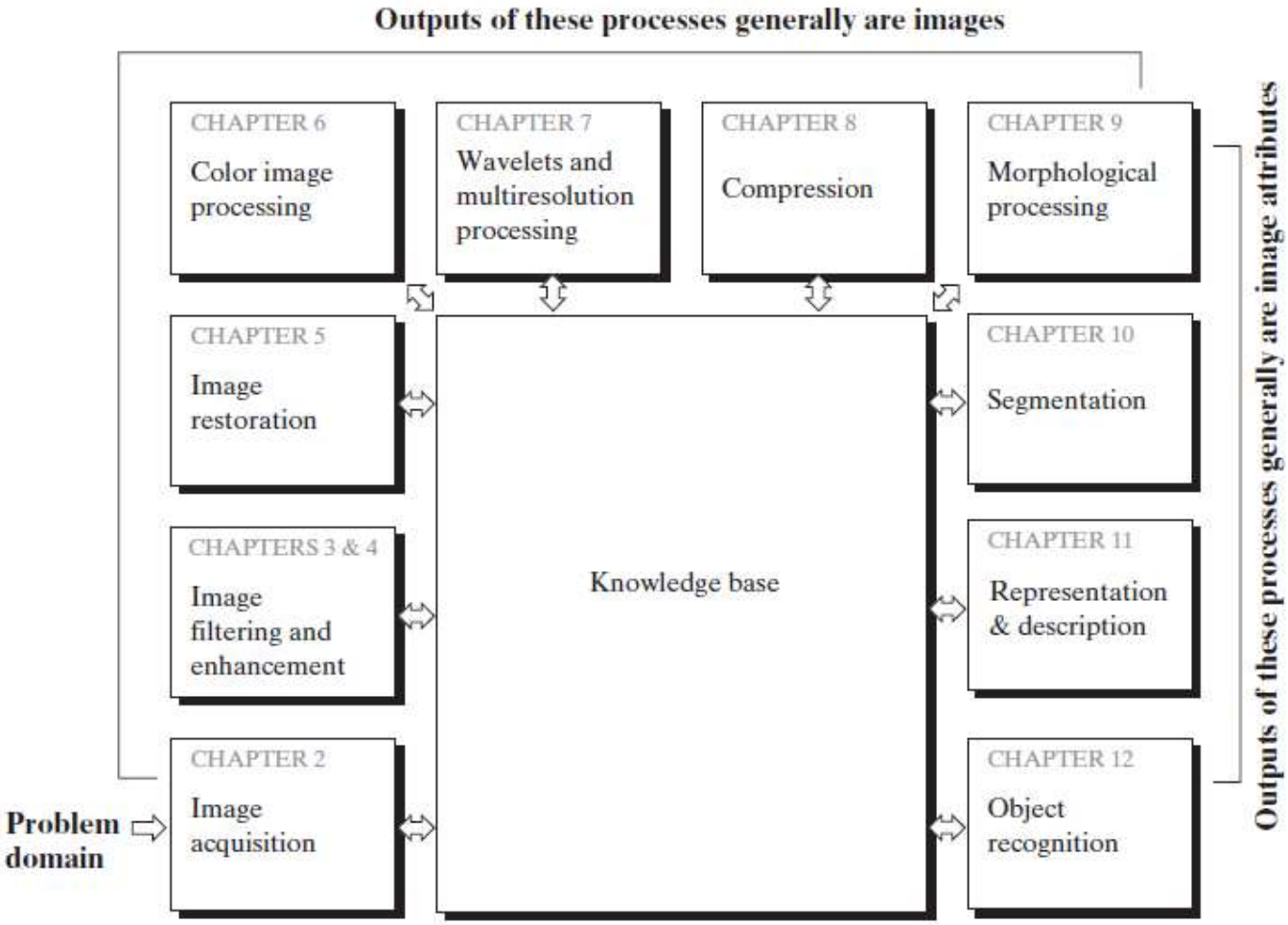


Fractals

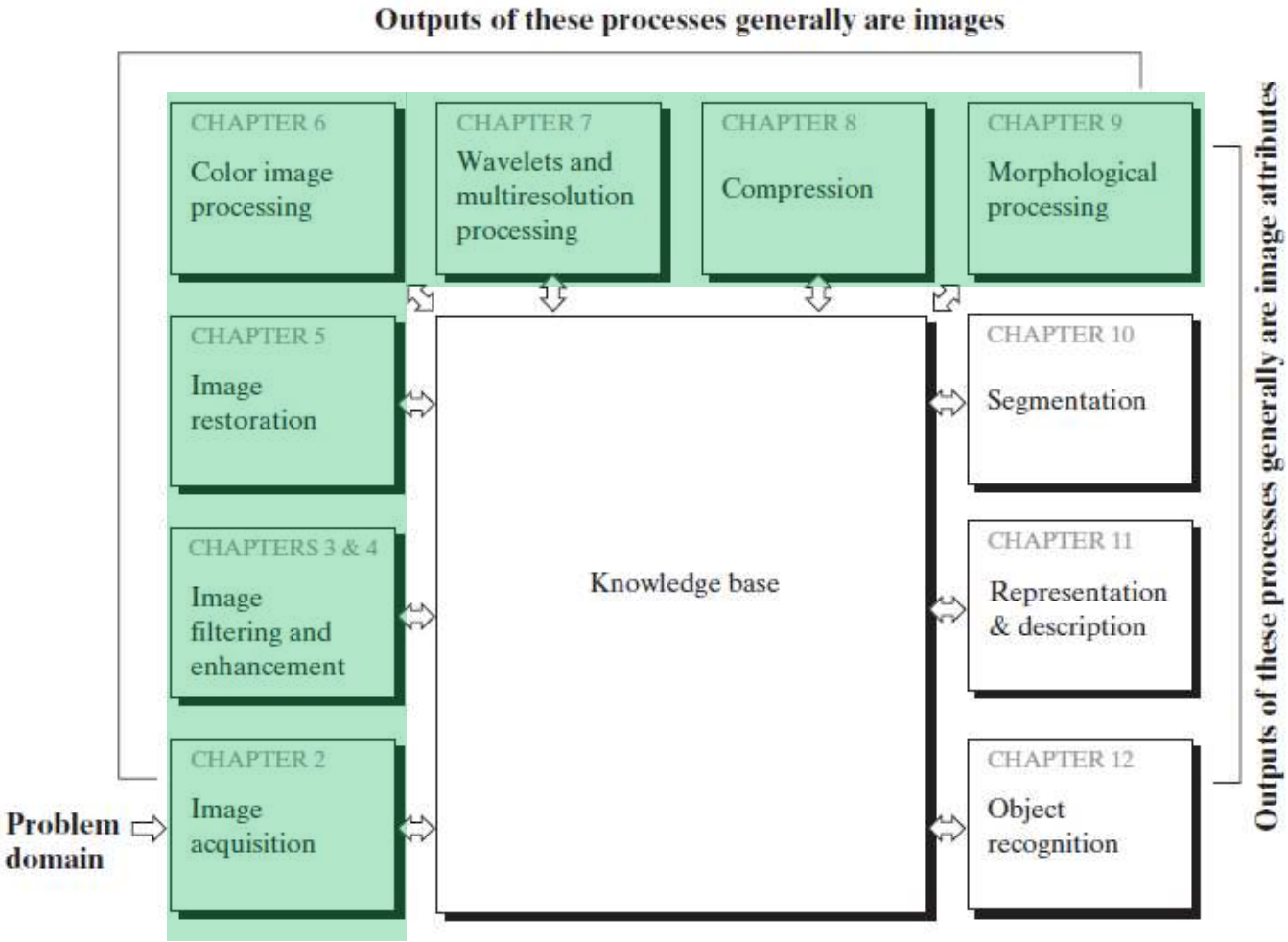


3-D modeling

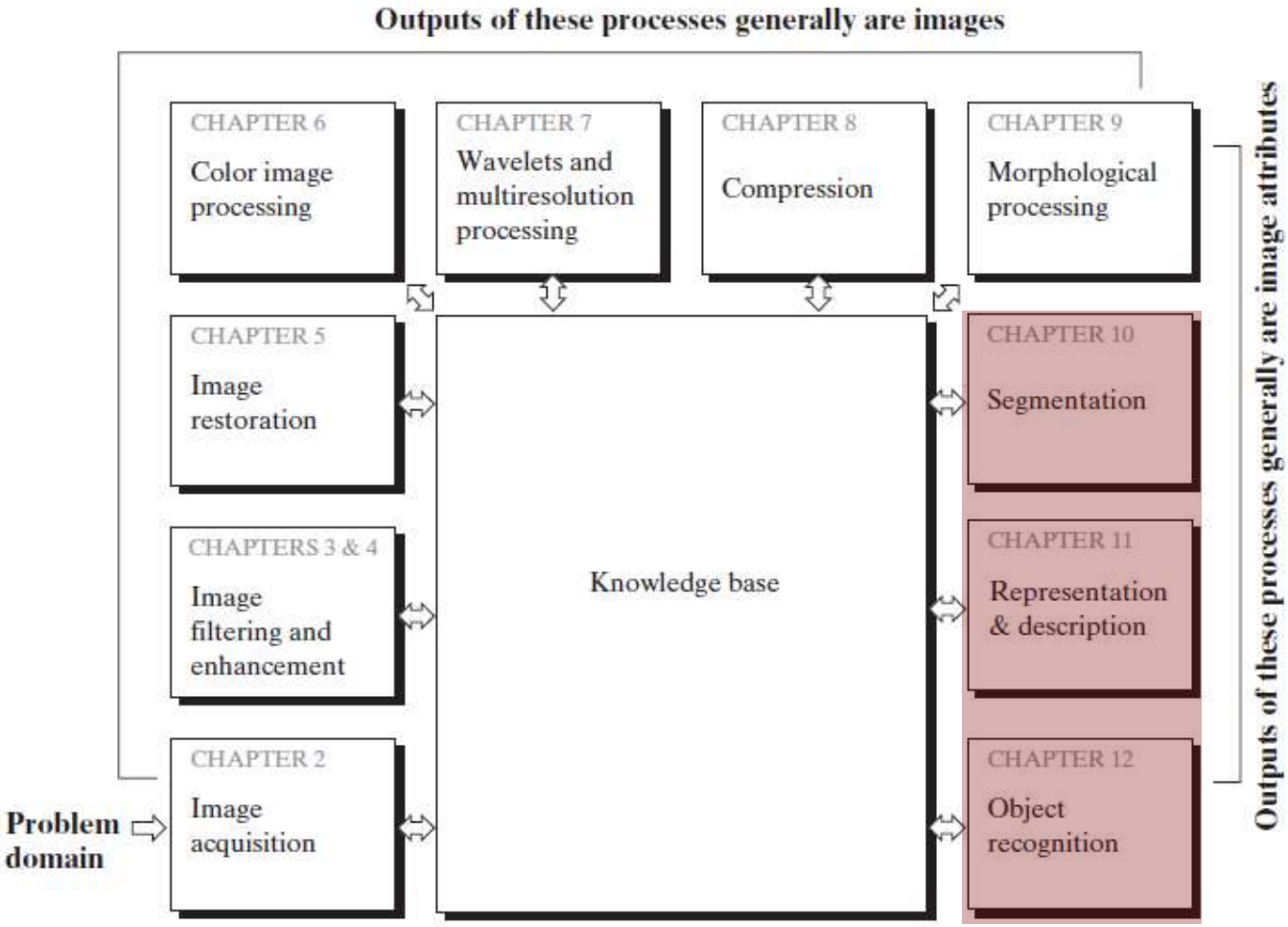
5. Fundamental Steps in Digital Image Processing



5. Fundamental Steps in Digital Image Processing



5. Fundamental Steps in Digital Image Processing



5. Fundamental Steps in Digital Image Processing

• ***Image acquisition***: could be as simple as being given an image that is already in digital form. Generally, the image acquisition stage involves preprocessing.

• ***Image enhancement***: brings out detail that is obscured, or simply to highlight certain features of interest (subjective improvement) in an image.

• ***Image restoration***: deals with objectively improving the appearance of an image.

• ***Color image processing***: covers basic color processing in a digital domain.

• ***Wavelets***: are the foundation for representing images in various degrees of resolution. Used for image data compression and pyramidal representation.

5. Fundamental Steps in Digital Image Processing

• ***Compression***: deals with techniques for reducing the storage required to save an image, or the bandwidth required to transmit it.

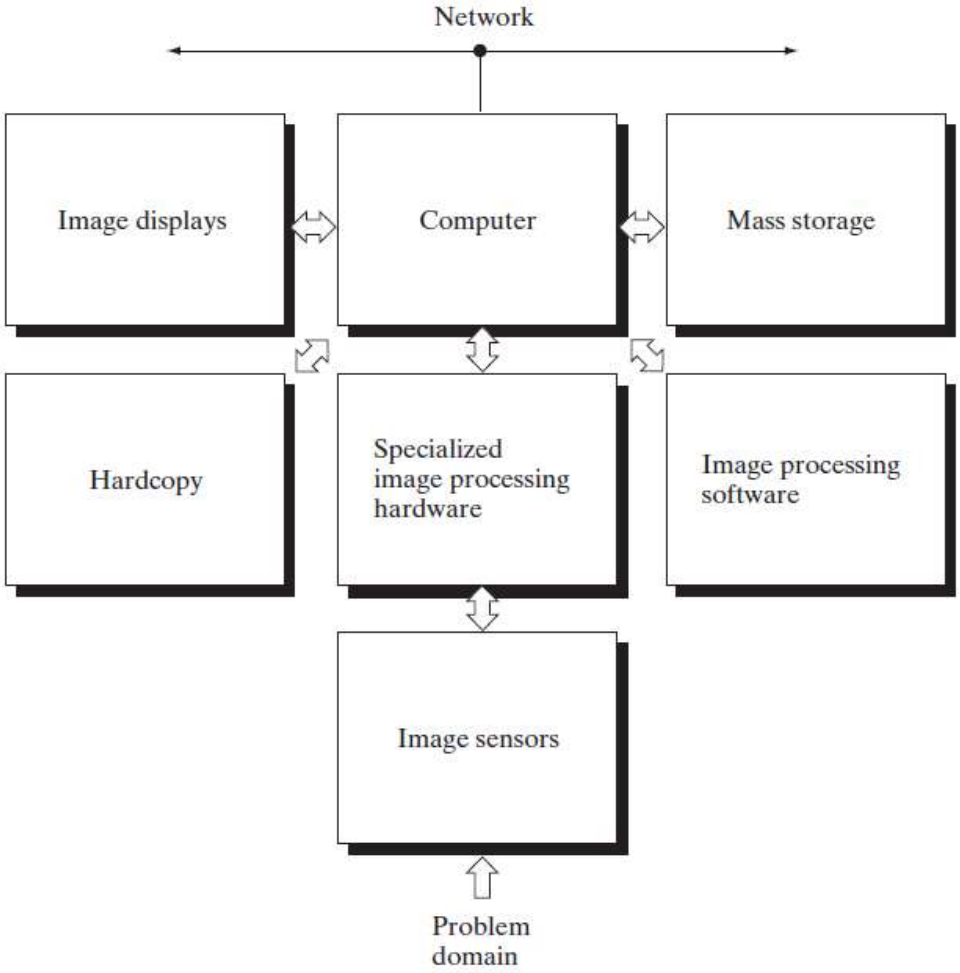
• ***Morphological processing***: deals with tools for extracting image components that are useful in the representation and description of shape.

• ***Segmentation***: partitions an image into its constituent parts or objects.

• ***Representation and description***: transforms raw data into a form suitable for subsequent processing.

• ***Recognition***: is the process that assigns a label (e.g., "vehicle") to an object based on its descriptors.

6. Components of an Image Processing System



6. Components of an Image Processing System

• ***Image sensors***: physical device that is sensitive to the energy radiated by the object we wish to image.

• ***Specialized hardware****:* digitizer plus hardware that performs other primitive operations.

• ***Computer****:* general-purpose computer.

• ***Software***: consists of specialized modules that perform specific tasks.

• ***Mass storage capability***: when dealing with thousands, or even millions, of images, providing adequate storage in an image processing system can be a challenge.

• ***Image displays***: are mainly color monitors.

6. Components of an Image Processing System

- ***Hardcopy***: devices for recording images (include laser printers, film cameras, heat-sensitive devices, inkjet units, and digital units, such as CD-ROM disks).

- ***Networking***: image transmission.

Suggested reading: Gonzales & Woods DIP - Chapter 1

Sample Book Material
http://www.imageprocessingplace.com/DIP-3E/dip3e_sample_book_material.htm