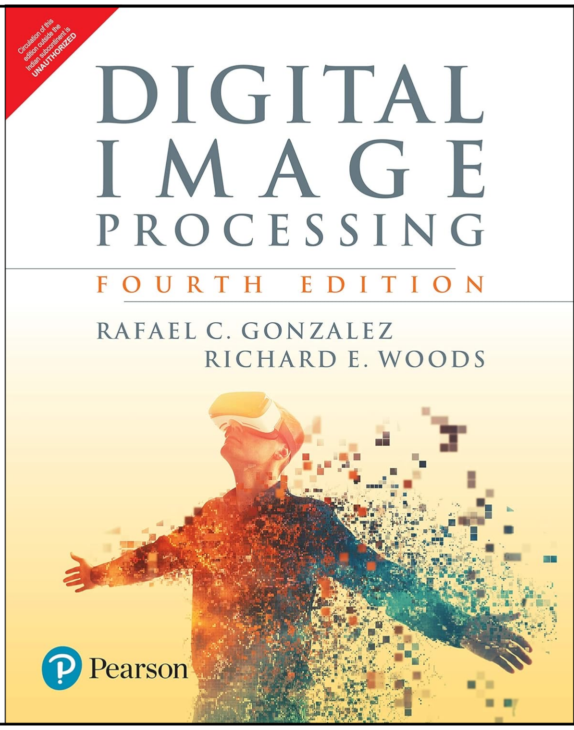
Image Processing and Pattern Recognition

1



2

Lecture – 01

Harimohan Khatri

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In this lecture…

i. Digital Image
ii. Digital Image Processing
iii. Fundamental Steps in Digital Image Processing
iv. Components of an Image Processing System
v. Examples of Fields that Use Digital Image Processing

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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, and 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 intensity values of f are all finite, discrete quantities, we call the image a digital image.
- The field of 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 called picture elements, image elements, pels, and pixels.
- Pixel is the term used to denote the elements of a digital image.

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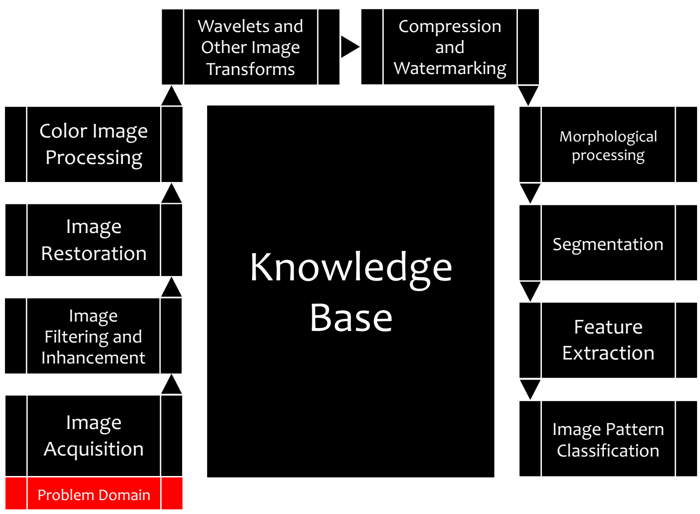
Fundamental steps in Digital Image Processing



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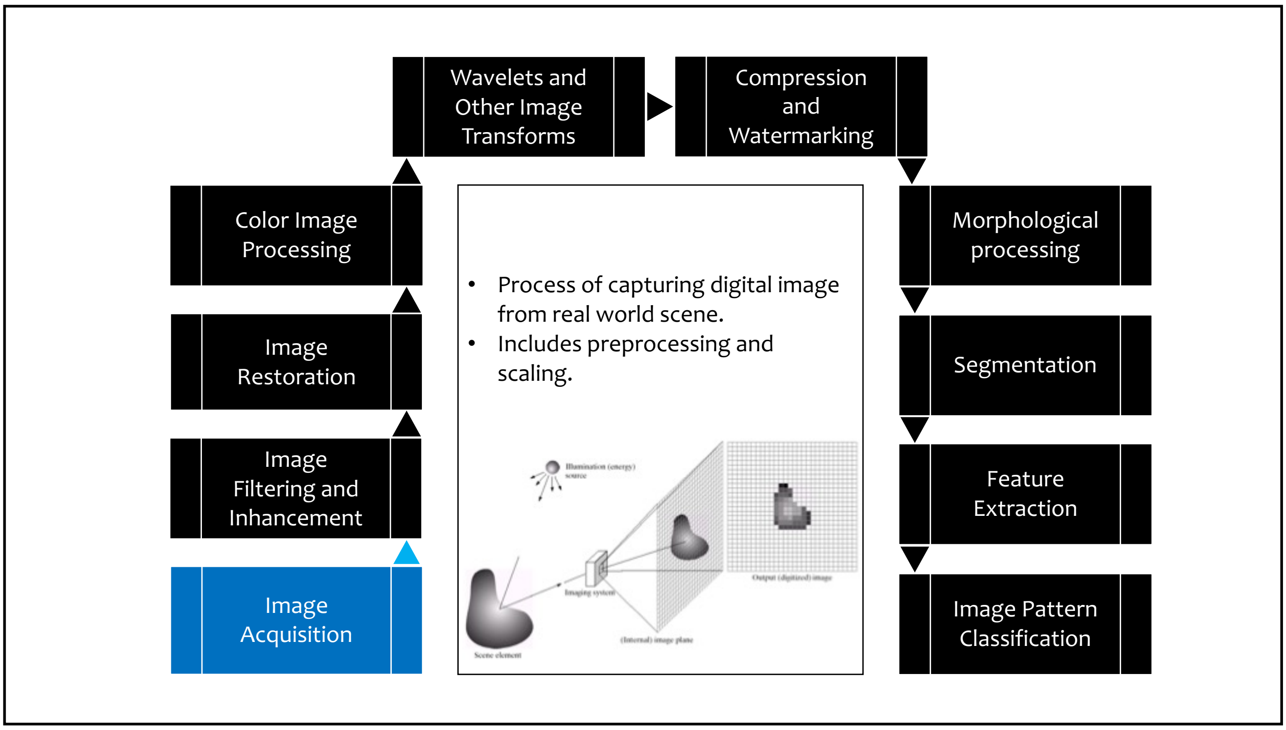
Wavelets and Other Image Transforms
Compression and Watermarking
Color Image Processing
Morphological processing
Image Restoration
Segmentation
Image Filtering and Inhancement
Feature Extraction
Image Acquisition
Image Pattern Classification
• Process of capturing digital image from real world scene.
• Includes preprocessing and scaling.

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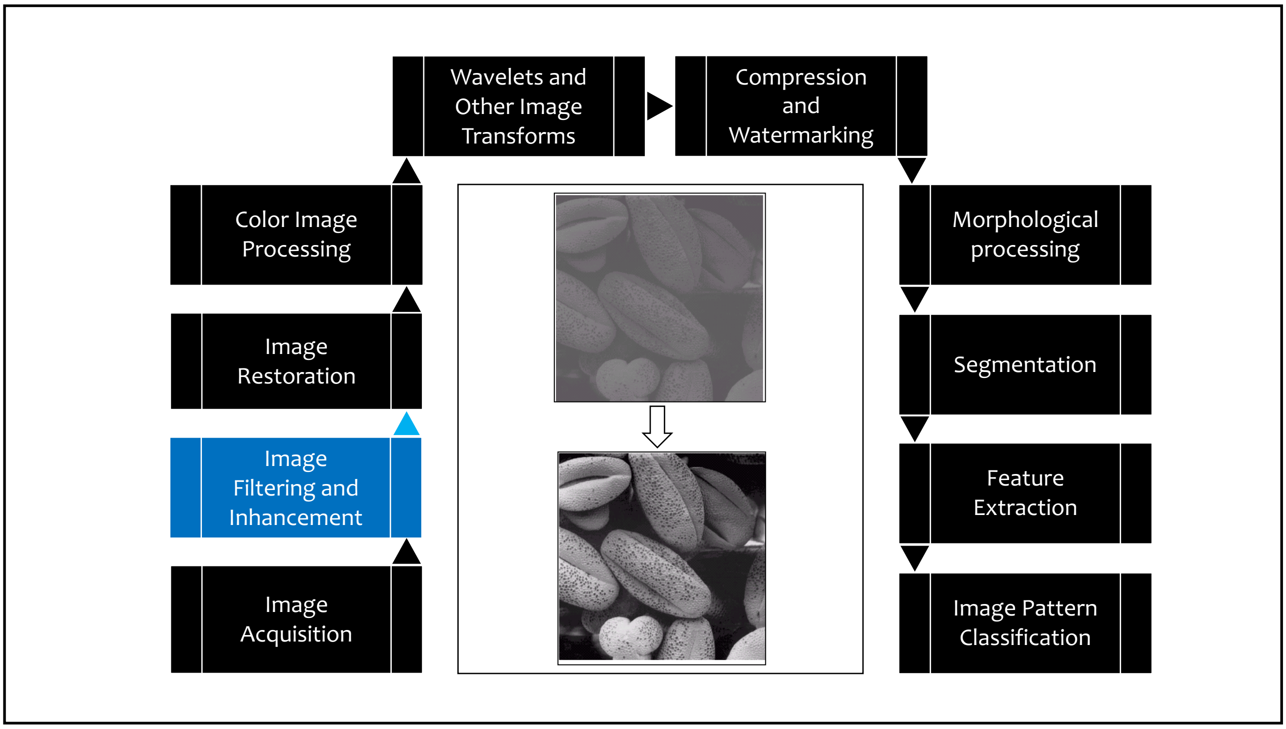
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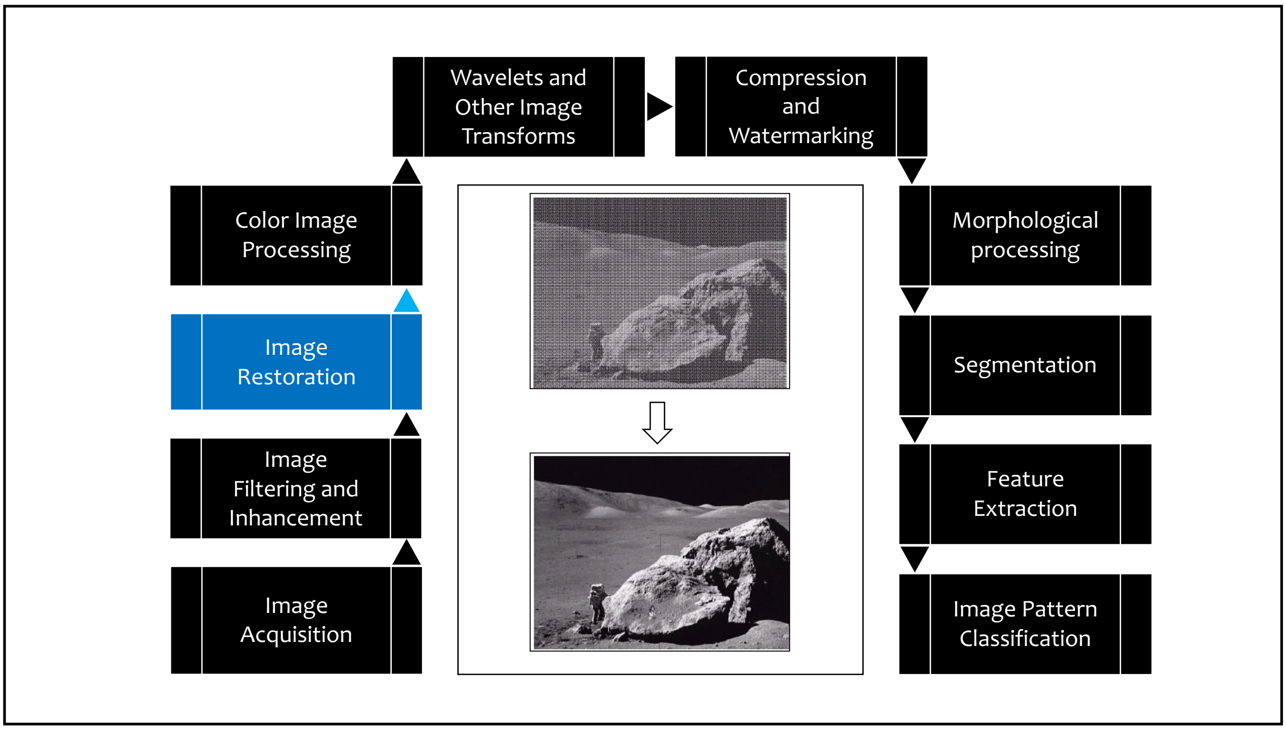
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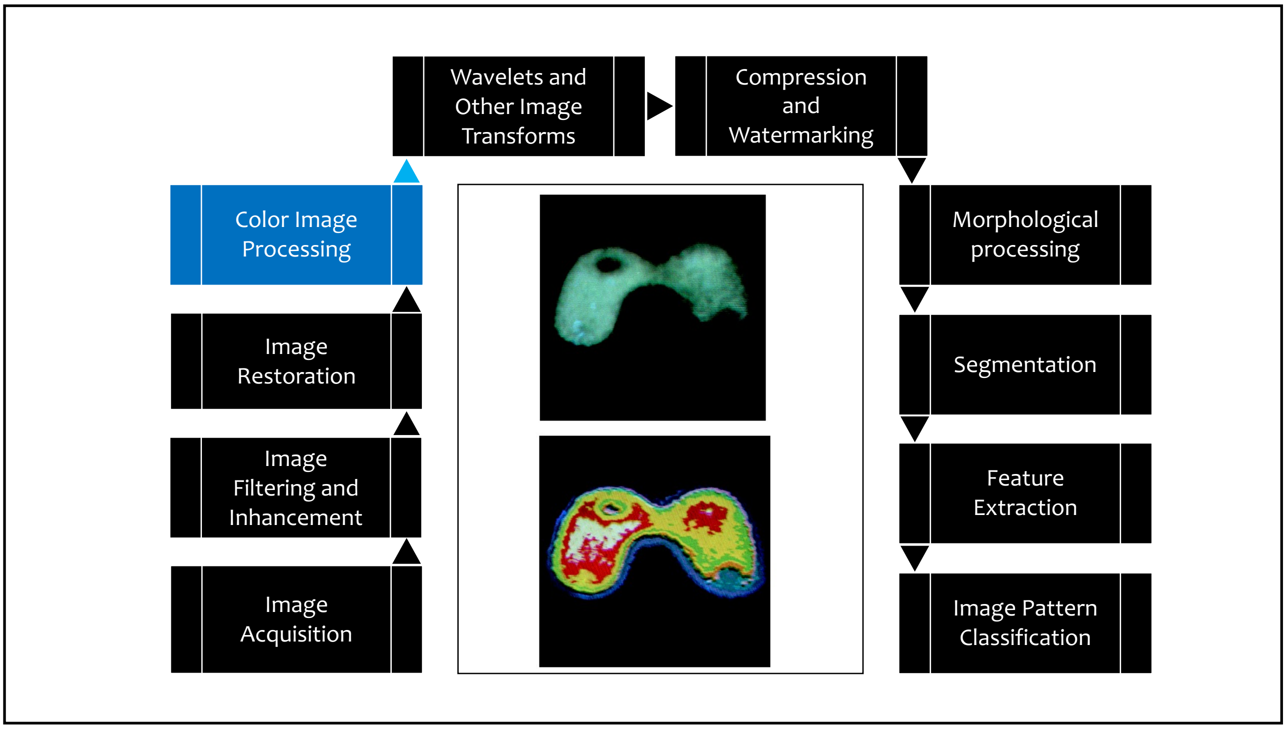
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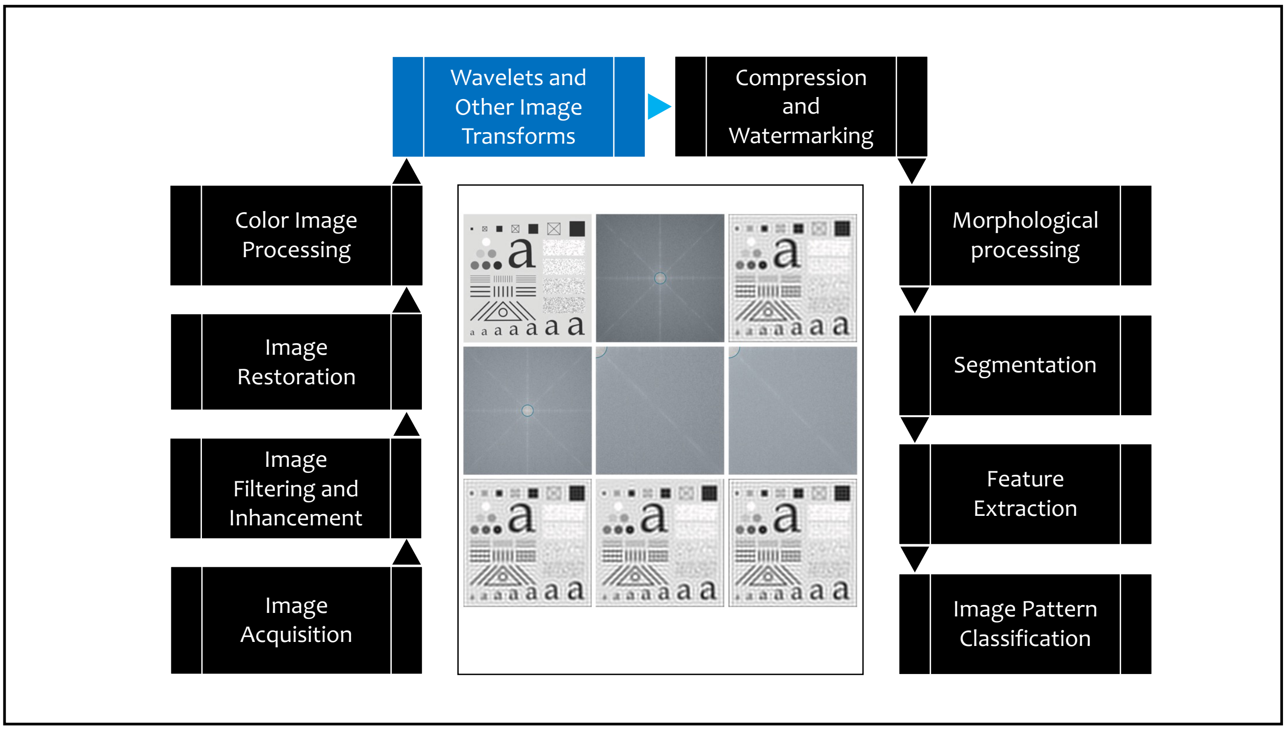
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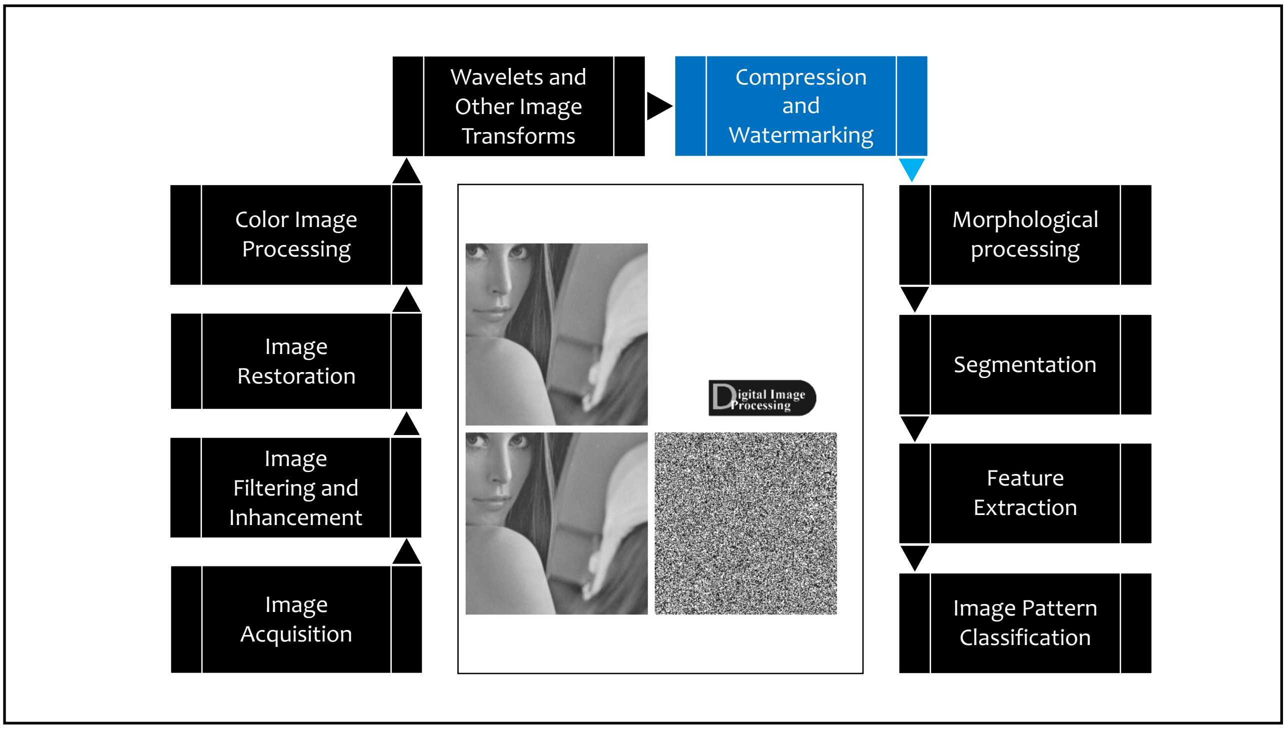
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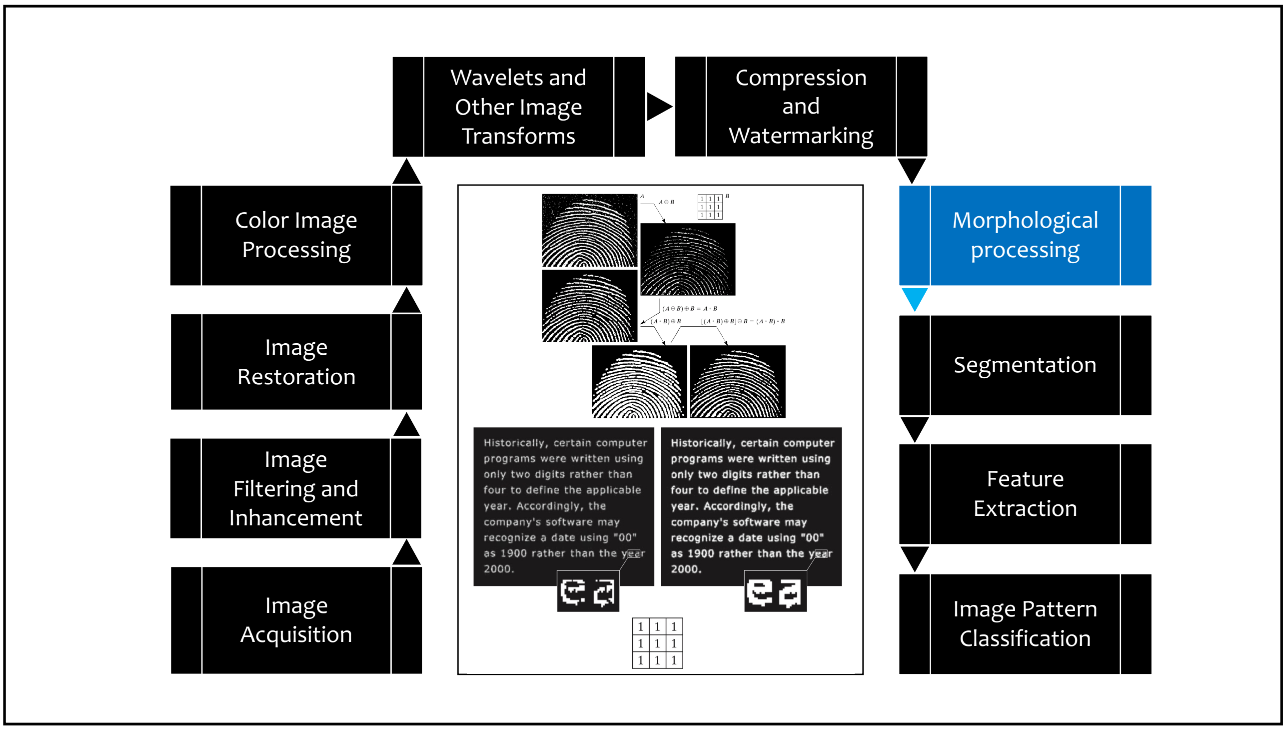
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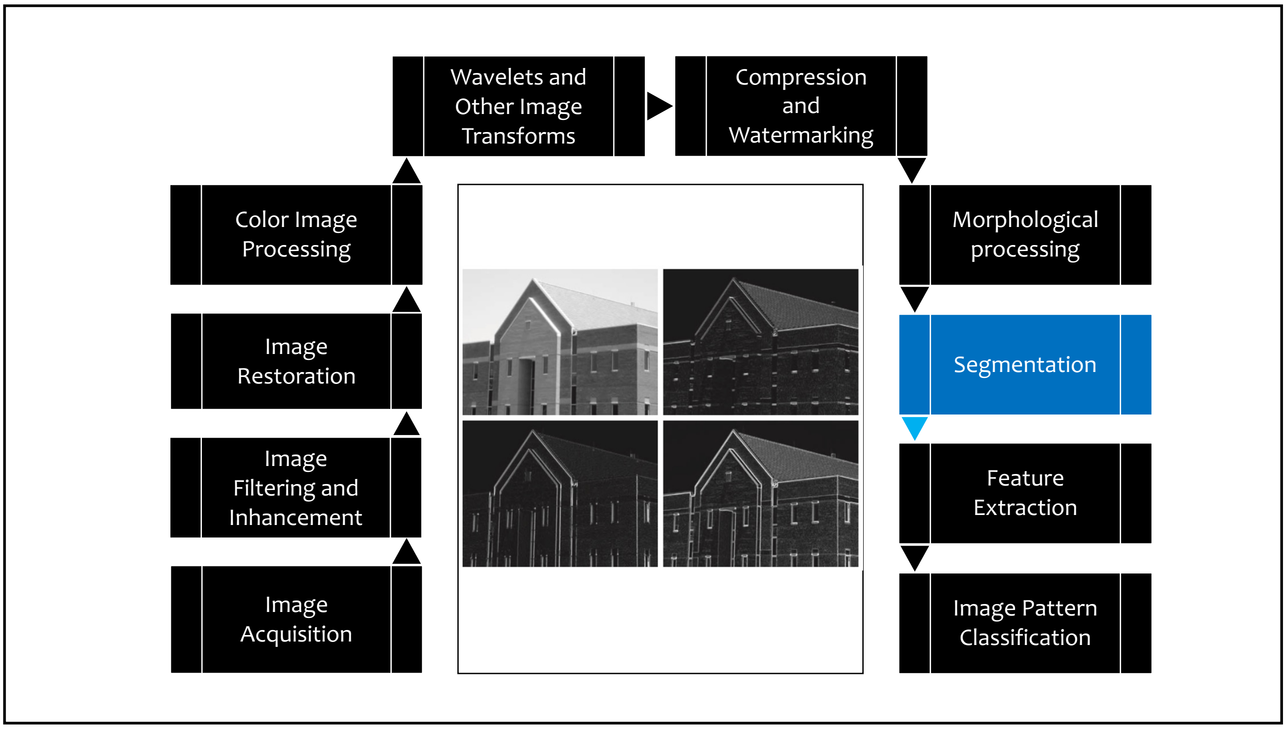
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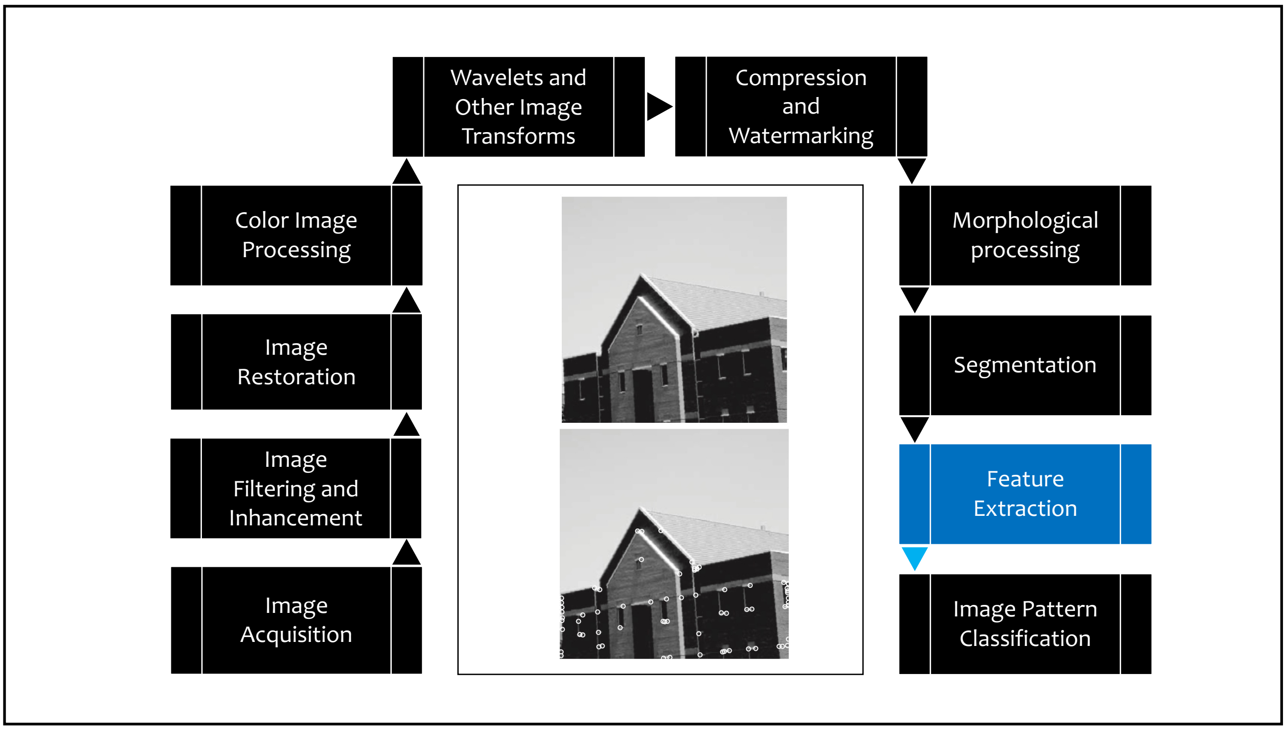
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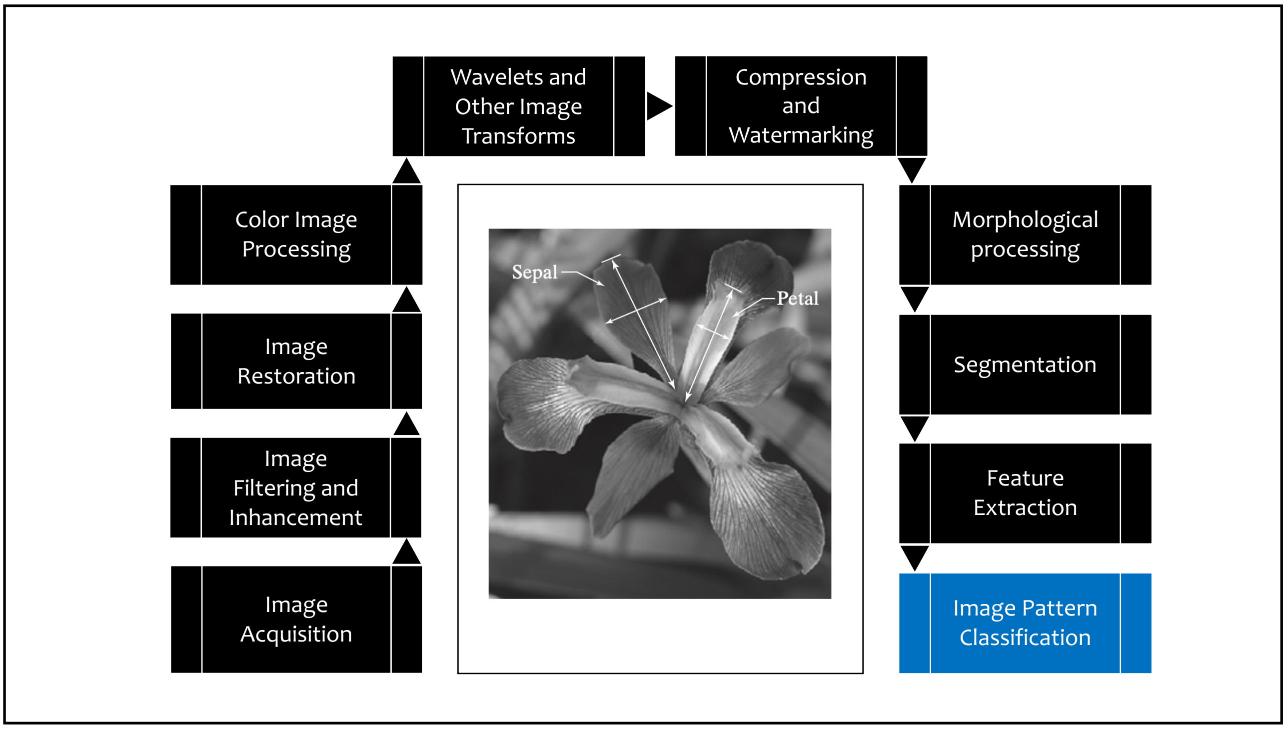
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Feature Extraction
Image Acquisition
Image Pattern Classification
Sepal
Petal

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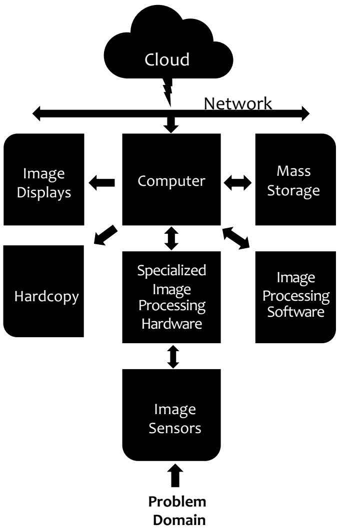
Elements of Digital Image Processing Systems[1/4]

Image sensors:
- Physical sensor responds to the energy radiated by the object we wish to image.

Specialized Image processing Hardware:
- Digitizer is a device for converting the output of the physical sensing device into digital form.
- GPU perform intensive matrix operations
- Arithmetic logic unit (ALU) performs arithmetic and logical operations



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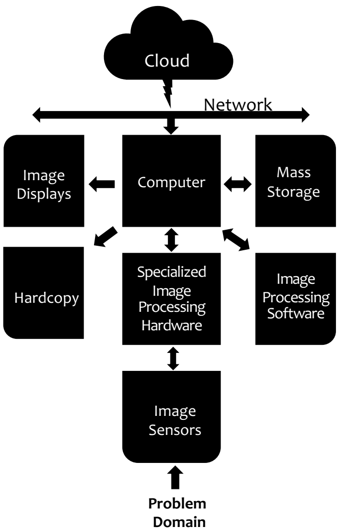
Elements of Digital Image Processing Systems[2/4]

Computers:
- General-purpose computer can range from a PC to a supercomputer suitable for off-line image processing tasks.

Image Processing Software:
- Software packages consists of specialized modules that perform specific tasks and general-purpose software commands from at least one computer language. E.g. MATLAB



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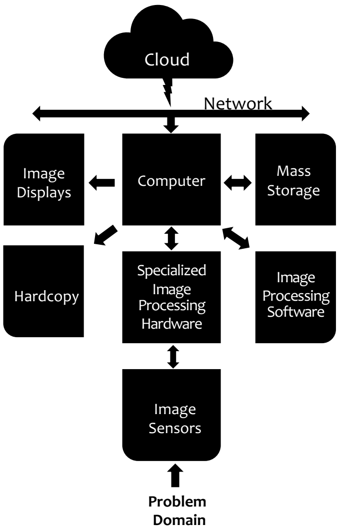
Elements of Digital Image Processing Systems[3/4]

Mass Storage:
- Short-term storage for use during processing; frame buffer
- On-line storage for relatively fast recall; magnetic disks or optical-media storage
- Archival storage characterized by infrequent access; Magnetic tapes and optical disks housed in "jukeboxes"

Image displays:
- Color, flat screen monitors.



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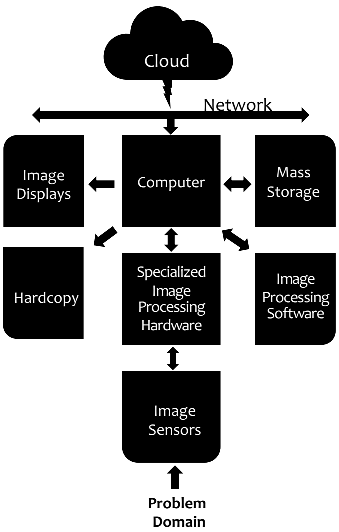
Elements of Digital Image Processing Systems[4/4]

Hardcopy devices:
- Used for recording images include laser printers, film cameras, heat sensitive devices, ink-jet units, and digital units, such as optical and CD-ROM disks.
- Either presented through projectors or printed into papers.

Networking and cloud communication:
- large amount of data inherent in image processing applications.
- Image data compression continues to play a major role in the transmission of large amounts of image data.



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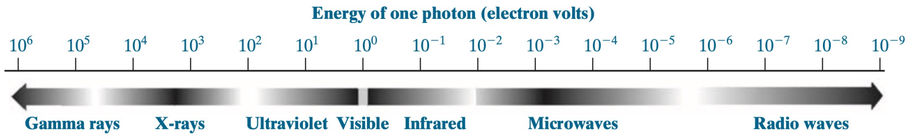
EM spectrum.

- Application of image processing can be categorize according to their source (e.g., X-ray, visual, infrared, and so on).
- The principal energy source for images is the electromagnetic energy spectrum.
- If spectral bands are grouped according to energy per photon, we obtain the spectrum ranging from gamma rays (highest energy) at one end to radio waves (lowest energy) at the other.



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Fields that use - Gamma ray imaging

- Major uses of imaging based on gamma rays include nuclear medicine and astronomical observations.
  - A radioactive isotope is injected to a patient which emits gamma rays as it decays. Images are produced from the emissions collected by gamma-ray detectors.
  - Used to locate sites of bone pathology, such as infections or tumors.

Figure : Bone scan obtained by using gamma-ray imaging

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Figure: Positron emission tomography (PET) shows a tumor in the brain and another in the lung, easily visible as small white masses.

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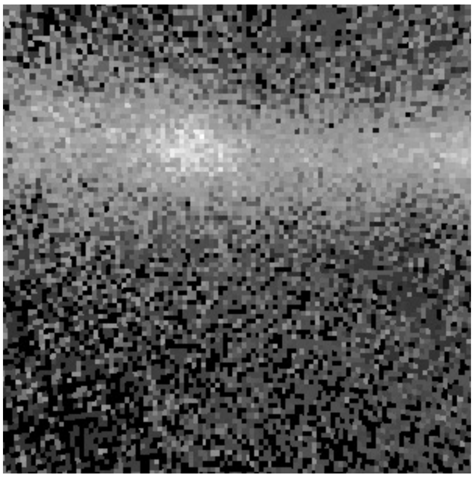

Figure: A star in the constellation of Cygnus exploded about 15,000 years ago, generating a superheated, stationary gas cloud (known as the Cygnus Loop) that glows in a spectacular array of colors.

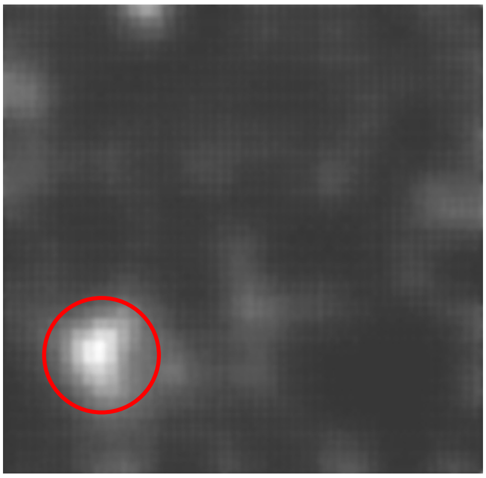

Figure: image of gamma radiation from a valve in a nuclear reactor.
An area of strong radiation is seen in the lower left side of the image.

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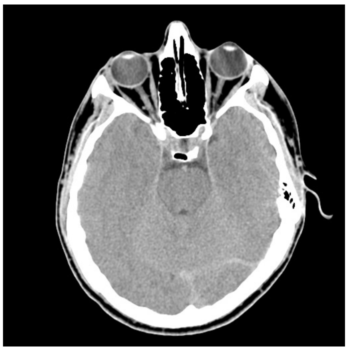
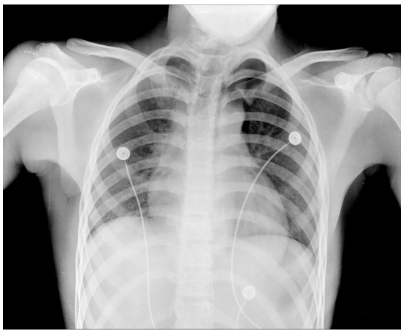
Area of use - X ray imaging

- X-ray images are widely used among medical diagnostics, industrial imagining and other fields like astronomy.



Img: Head CT.



Img: Chest X-ray.

Img: Aortic angiogram

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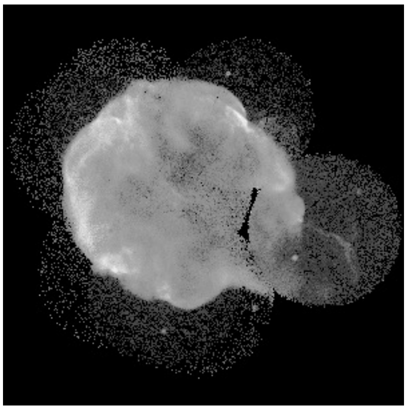
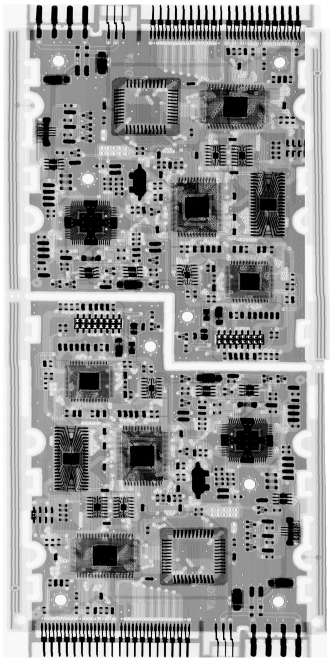


Img: Cygnus Loop.



Img: Circuit boards.

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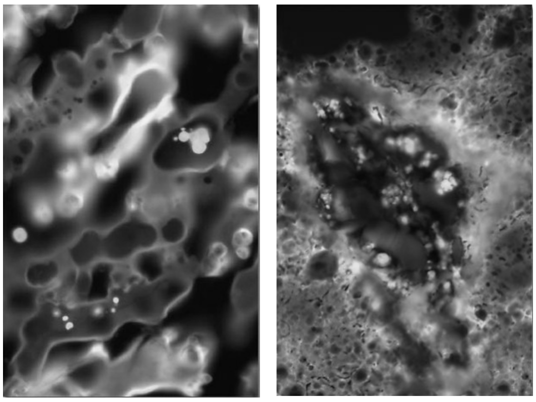
Area of use - Ultraviolet range

- Ultraviolet imaging is being used in various fields such as lithography, industrial inspection, microscopy, lasers, biological imaging, and astronomical observations.
- Ultraviolet light is used in fluorescence microscopy,
  - The ultraviolet light itself is not visible, but when a photon of ultraviolet radiation collides with an electron in an atom of a fluorescent material, it elevates the electron to a higher energy level. Subsequently, the excited electron relaxes to a lower level and emits light in the form of a lower-energy photon in the visible (red) light region.



Examples of Ultraviolet imaging;
(a) Normal corn. (b) Corn infected by smut.

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Area of use - Visible and infrared band

- Major area of visible and infrared band processing are
  - light microscopy,
  - astronomy,
  - remote sensing,
  - industry, and
  - law enforcement.

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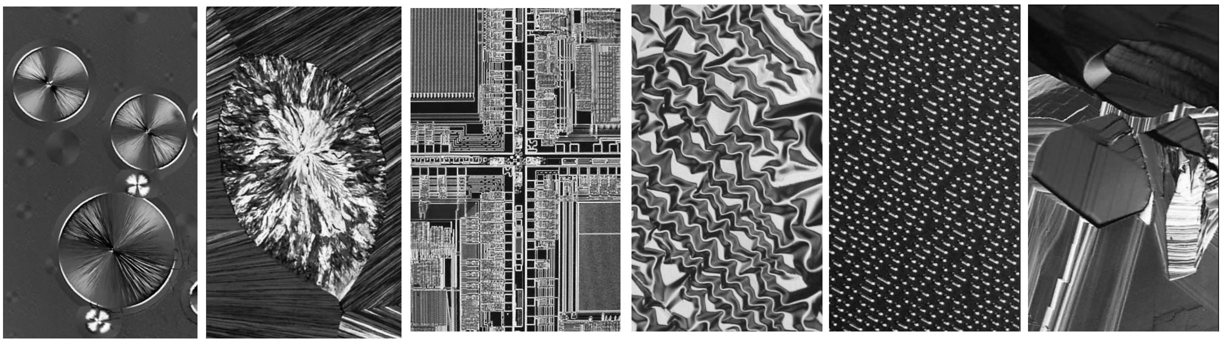
Images obtained with a light microscope.
The examples range from pharmaceuticals
and microinspection to materials characterization.



Examples of light microscopy images. [a-f]
(a) Taxol (anticancer agent), magnified 250 (b) Cholesterol 40 (c) Microprocessor 60 (d) Nickel oxide thin film600
(e) Surface of audio CD 1750 (f) Organic superconductor 450

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- Another major area of visual processing is remote sensing, which usually includes several bands in the visual and infrared regions of the spectrum.
- Table shows the so-called thematic bands in NASA's LANDSAT satellites.
- 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.

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

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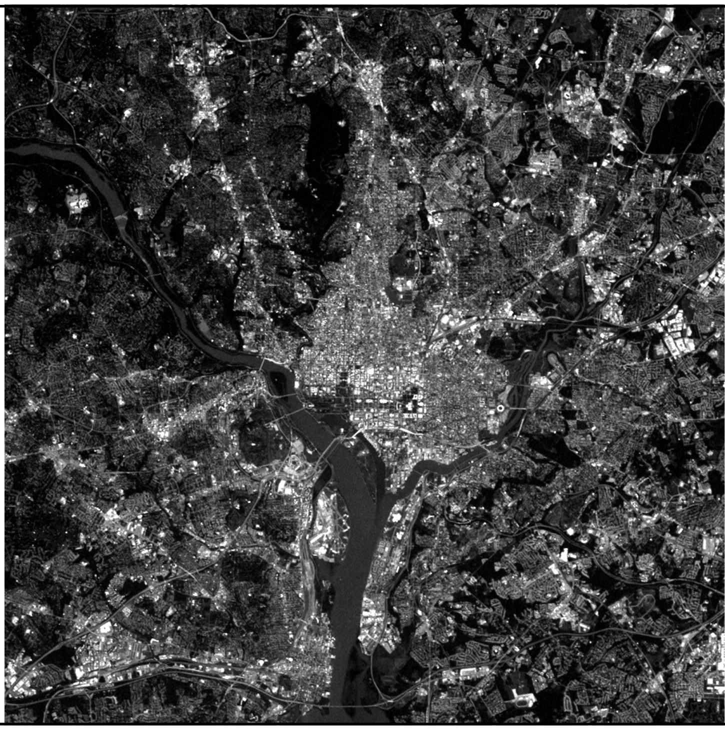
LANDSAT satellite images of the Washington, D.C. area.

BAND-1

- Visible blue
- 0.45– 0.52 µm
- Maximum water penetration



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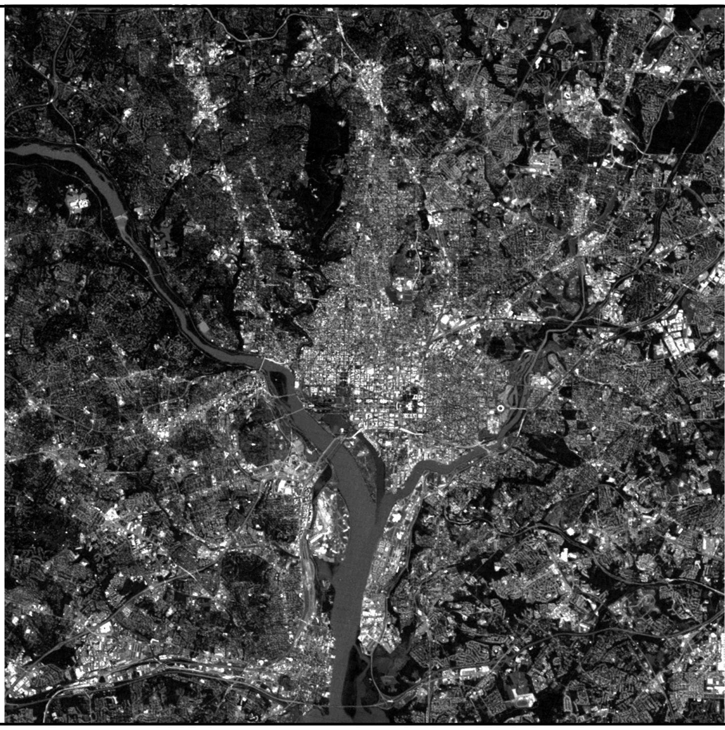
LANDSAT satellite images of the Washington, D.C. area.

BAND-2

- Visible green
- 0.53– 0.61 µm
- Measures plant vigor



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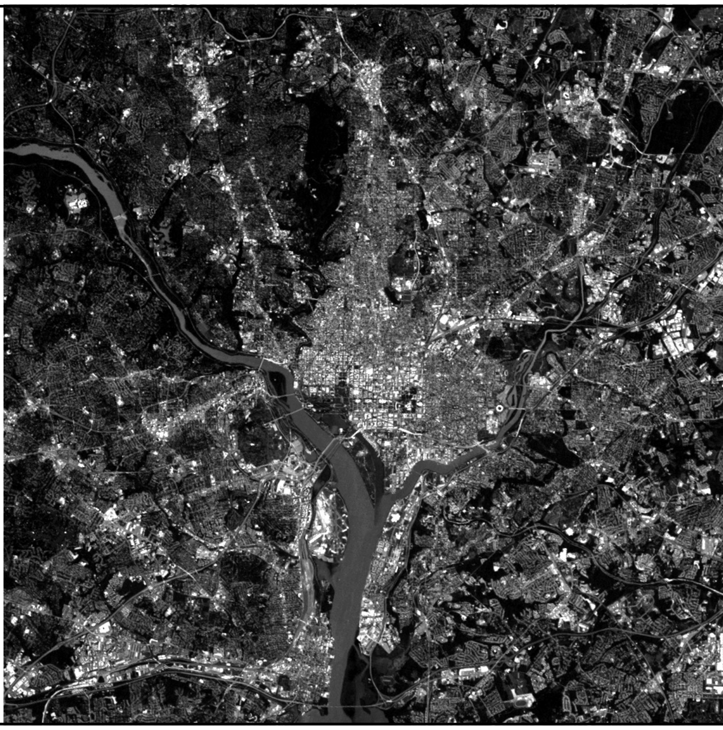
LANDSAT satellite images of the Washington, D.C. area.

BAND-3

- Visible red
- 0.63– 0.69 μm
- Vegetation discrimination



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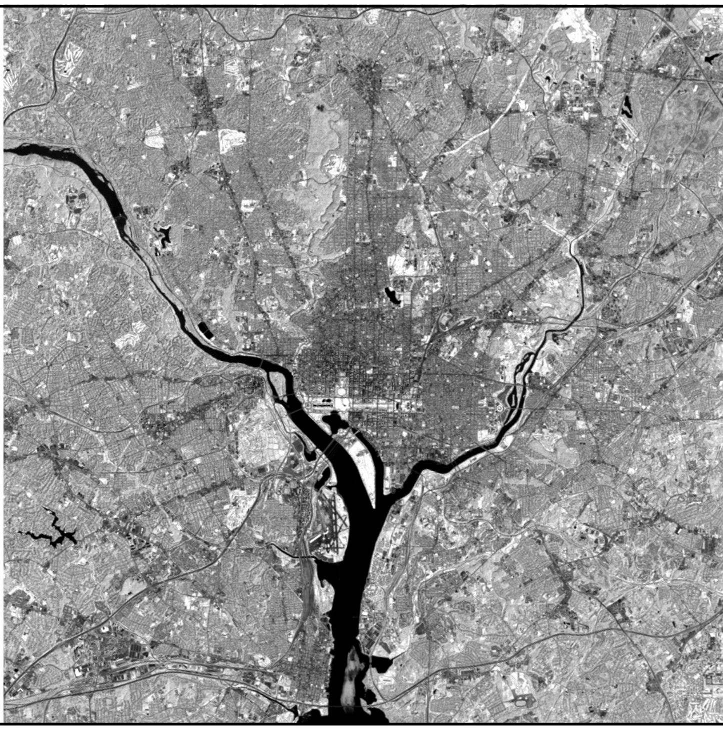
LANDSAT satellite images of the Washington, D.C. area.

BAND-4

- Near infrared
- 0.78– 0.90 μm
- Biomass and shoreline mapping



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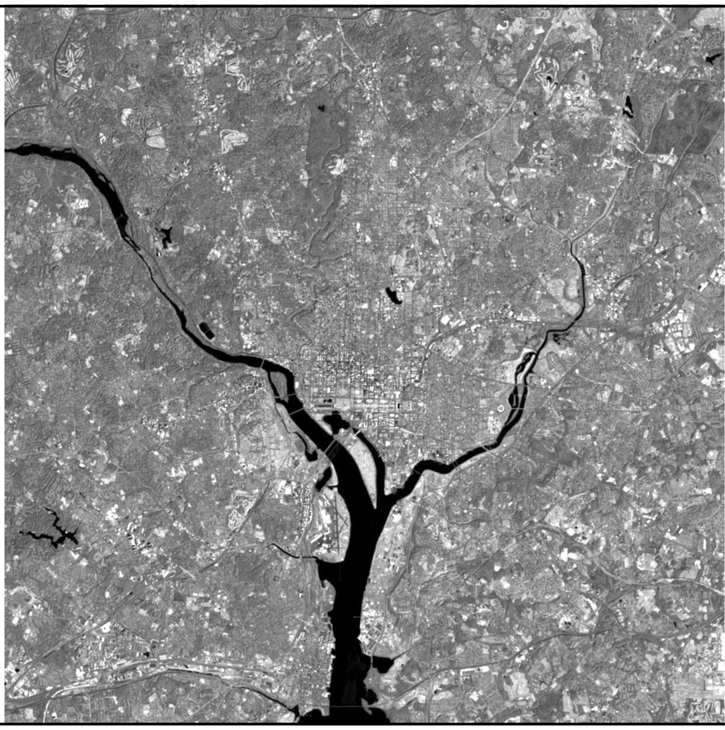
LANDSAT satellite images of the Washington, D.C. area.

BAND-5

- Middle infrared
- 1.55–1.75 µm
- Moisture content: soil/vegetation



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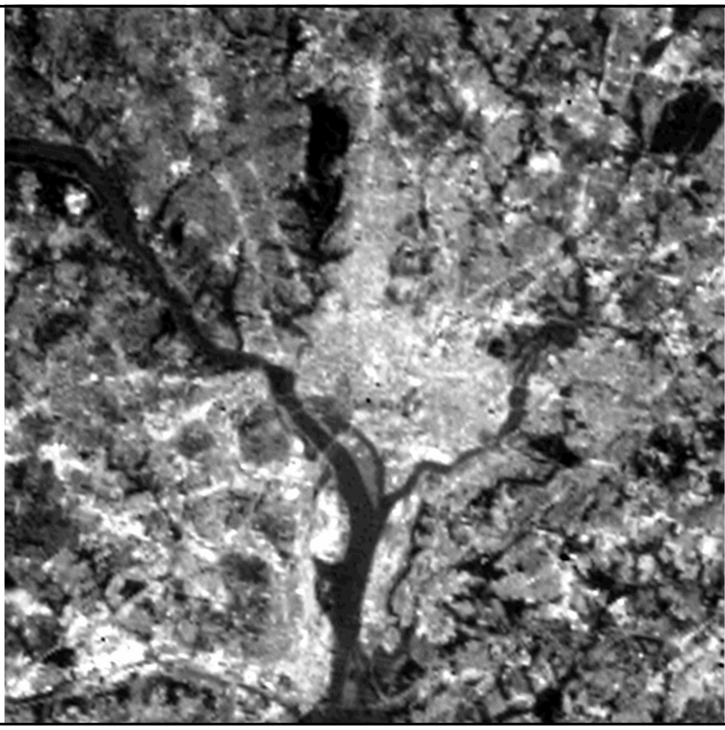
LANDSAT satellite images of the Washington, D.C. area.

BAND-6

- Thermal infrared
- 10.4–12.5 µm
- Soil moisture; thermal mapping



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LANDSAT satellite images of the Washington, D.C. area.

BAND-7

- Short-wave infrared
- 2.09–2.35 μm
- Mineral mapping

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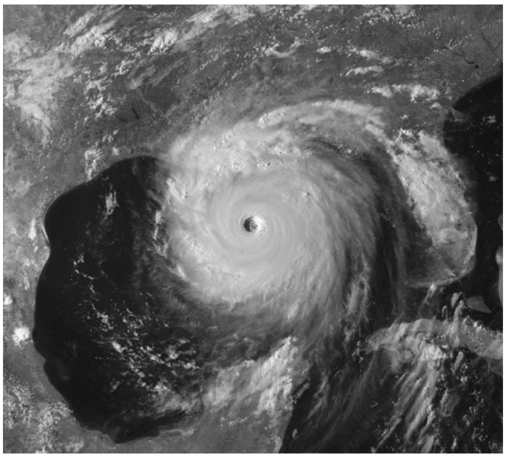
- Weather observation and prediction also are major applications of multispectral imaging from satellites.



an image of Hurricane Katrina, one of the most devastating storms in recent memory in the Western Hemisphere. This image was taken by a National Oceanographic and Atmospheric Administration (NOAA) satellite using sensors in the visible and infrared bands.

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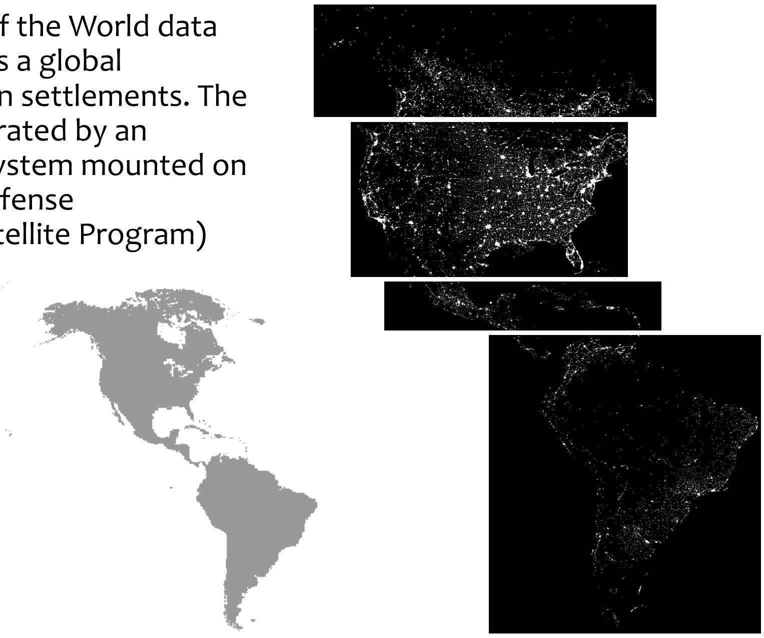
- Nighttime Lights of the World data set, which provides a global inventory of human settlements. The images were generated by an infrared imaging system mounted on a NOAA/DMSP (Defense Meteorological Satellite Program) satellite.



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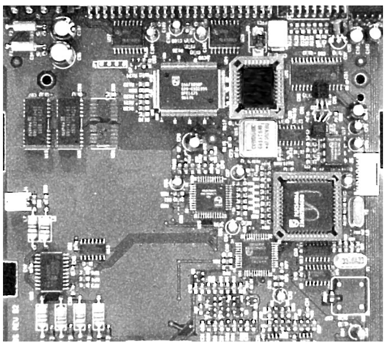
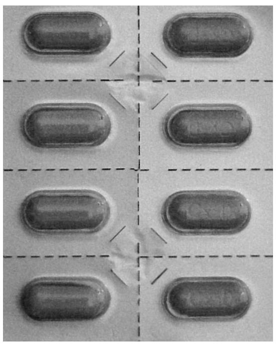
- Imaging in the visible spectrum is in automated visual inspection of manufactured goods.



a controller board for
a CD-ROM drive.
inspect them for missing parts.



an imaged pill container.
machine look for missing,
incomplete, or deformed pills.

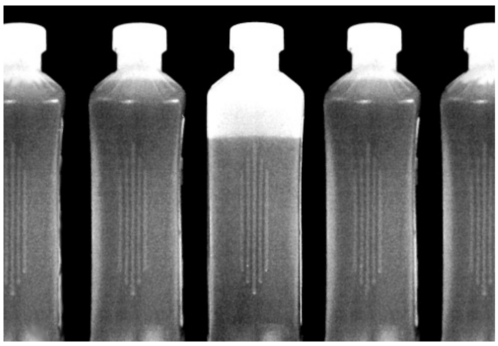


image processing is used to
look for bottles that are not filled
up to an acceptable level.

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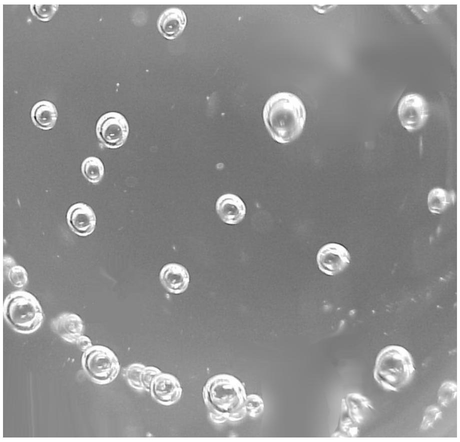
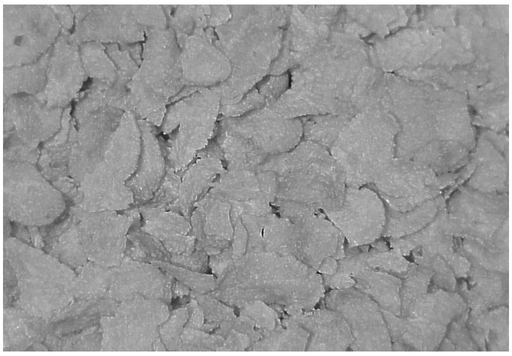


a clear plastic part with an unacceptable of air pockets in it.



a batch of cereal during inspection for color and the presence of anomalies such as burned flakes.

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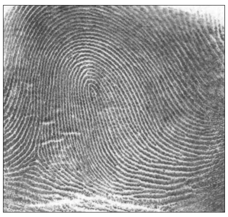

- a thumb print.
- enhance them or to find features that aid in the automated search of a database for potential matches.

- image of paper currency.
- automated counting and, in law enforcement, the reading of the serial number for the purpose of tracking and identifying currency bills.

- automated license plate reading

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Area of use - Microwave band

- Microwave band is used in radar technology, because of its ability to collect data over virtually any region at any time, regardless of weather or ambient lighting conditions.
- Radar waves are used to explore inaccessible regions of the Earth's surface.
- Instead of a camera lens, a radar uses an antenna and digital computer processing to record its images.
- In a radar image, one can see only the microwave energy that was reflected back toward the radar antenna.

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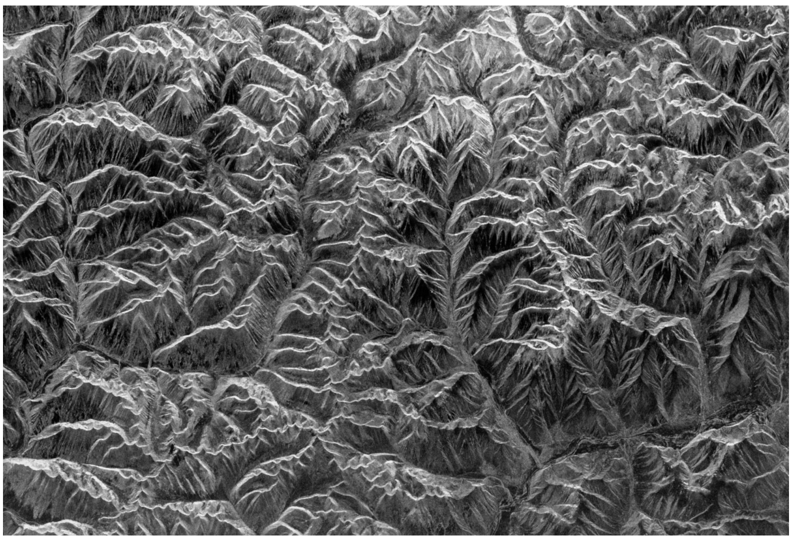

Figure: Spaceborne radar image of mountainous region in southeast Tibet. (Courtesy of NASA.)

Note: the clarity and detail of the image, unencumbered by clouds or other atmospheric conditions that normally interfere with images in the visual band.

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Area of use - Radio band

- The major applications of imaging in the radio band are in medicine and astronomy.
  - In medicine, radio waves are used in magnetic resonance imaging (MRI).

Figure: MRI images of a human (a) knee, and (b) spine.

In MRI patient is placed in a powerful magnet and passes radio waves through the individual's 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 image of a section of the patient.

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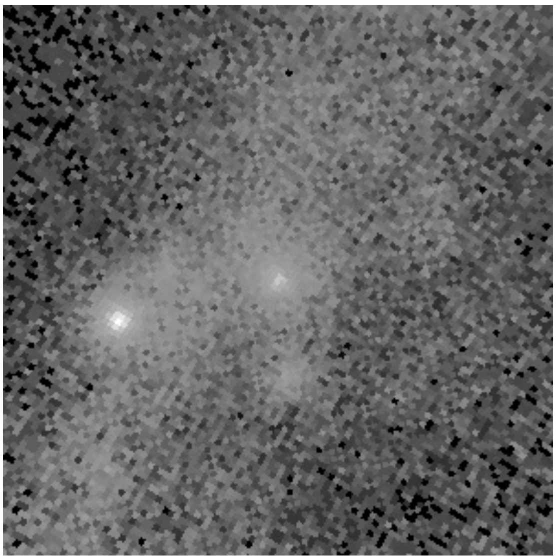
Images of the Crab Pulsar, a nebula star covering the electromagnetic spectrum.

Gamma



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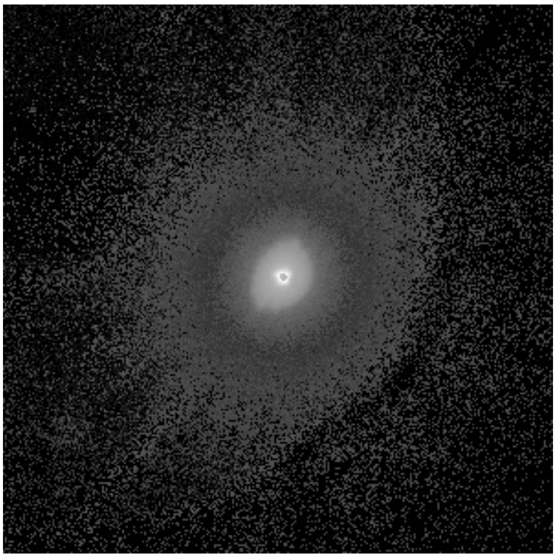
Images of the Crab Pulsar, a nebula star covering the electromagnetic spectrum.

X-ray



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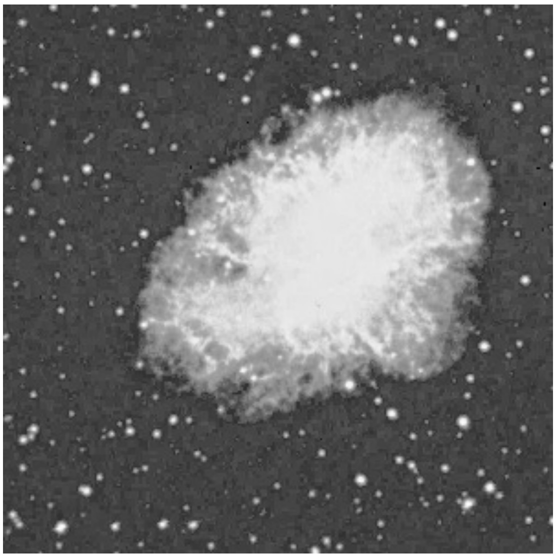
Images of the Crab Pulsar, a nebula star covering the electromagnetic spectrum.

Optical



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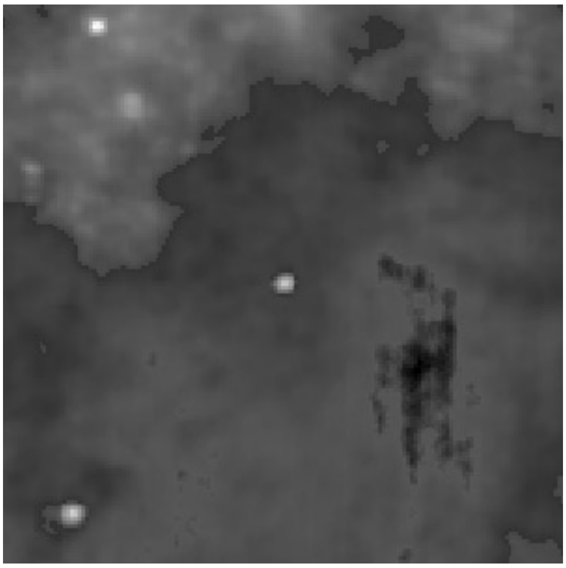
Images of the Crab Pulsar, a nebula star covering the electromagnetic spectrum.

Infrared



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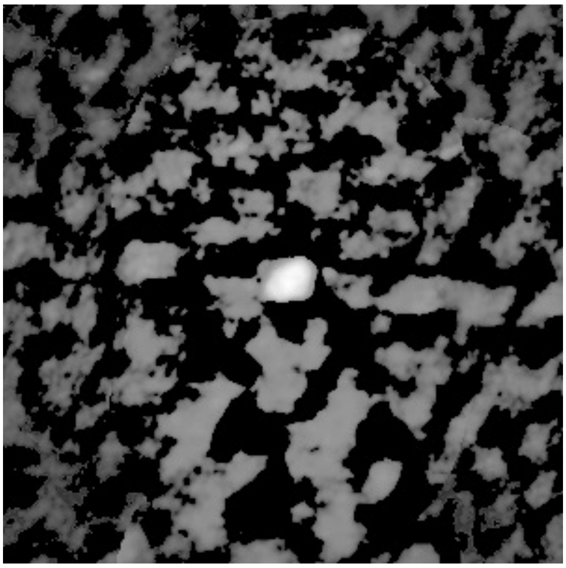
Images of the Crab Pulsar, a nebula star covering the electromagnetic spectrum.

Radio



50

Other imaging modalities

- Acoustic imaging
- Electron microscopy
- Synthetic (computer-generated) imaging

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Acoustic imaging

- Imaging using "sound" is used in geological exploration, industry, and medicine.
- Geological applications use sound in the low end of the sound spectrum (hundreds of Hz) while imaging in other areas use ultrasound (millions of Hz).
- In geology such imaging is used in mineral and oil exploration, marine image acquisition.
- Ultrasound imaging is used in medical field such as finding the sex of the baby.

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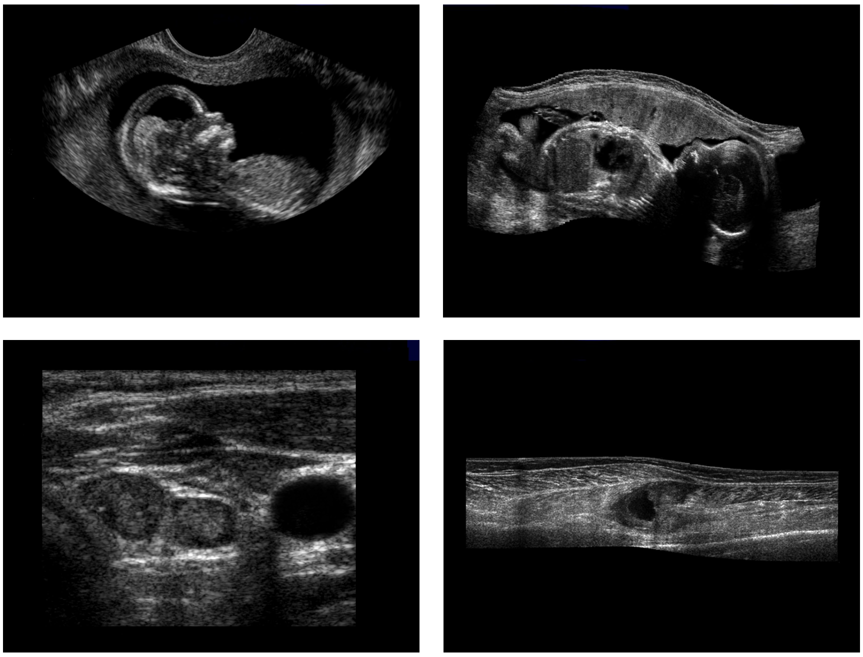

Figure: Ultrasound imaging.
(a) A fetus.
(b) Another view of the fetus.
(c) Thyroids.
(d) Muscle layers showing lesion.
(Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

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Watch it.

Electron microscopy

- Basic steps:
  - A stream of electrons is produced by an electron source and accelerated toward the specimen using a positive electrical potential.
  - This stream is confined and focused using metal apertures and magnetic lenses into a thin, monochromatic beam.
  - This beam is focused onto the sample using a magnetic lens. Interactions occur inside the irradiated sample, affecting the electron beam.
  - These interactions and effects are detected and transformed into an image, much in the same way that light is reflected from, or absorbed by, objects in a scene.
- Transmission electron microscope (TEM) and Scanning electron microscope (SEM) are two types of electron microscopes.

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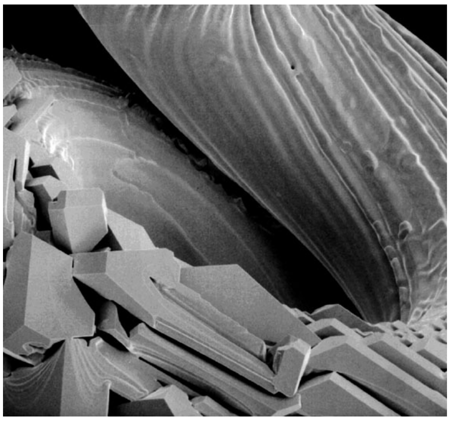
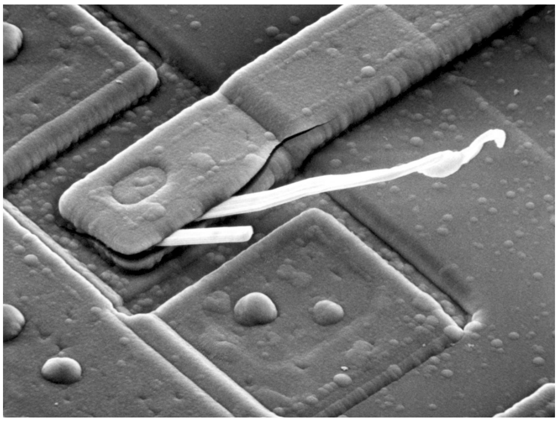


250× SEM image of a tungsten filament following thermal failure (note the shattered pieces on the lower left).



2500× SEM image of a damaged integrated circuit. The white fibers are oxides resulting from thermal destruction.

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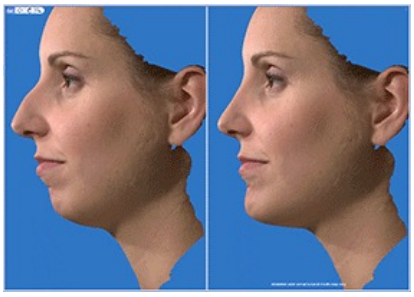
Synthetic imaging

- Generated by computers.
  - Fractals: iterative reproduction of a basic pattern according to some mathematical rules.
  - 3-D Imaging: images can be generated in any perspective from plane projections of the 3-D volume.



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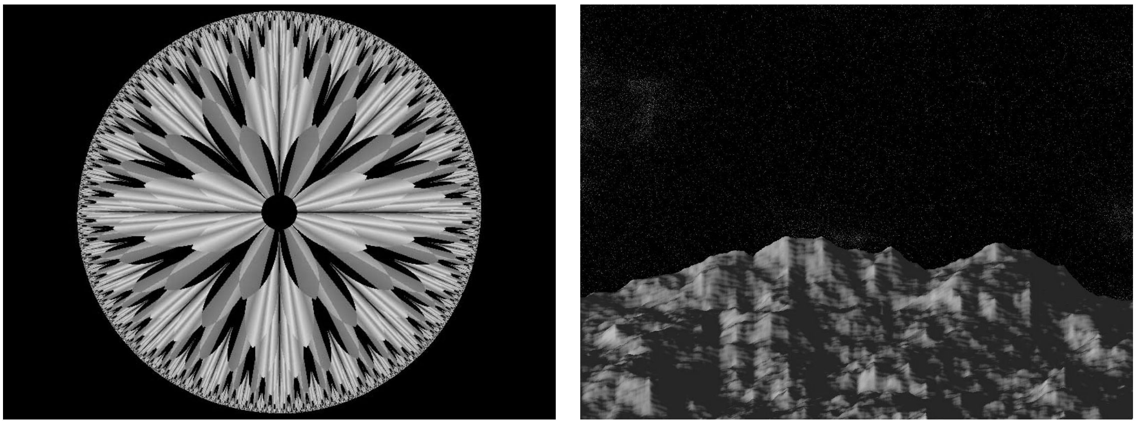

Figure: Fractal images.

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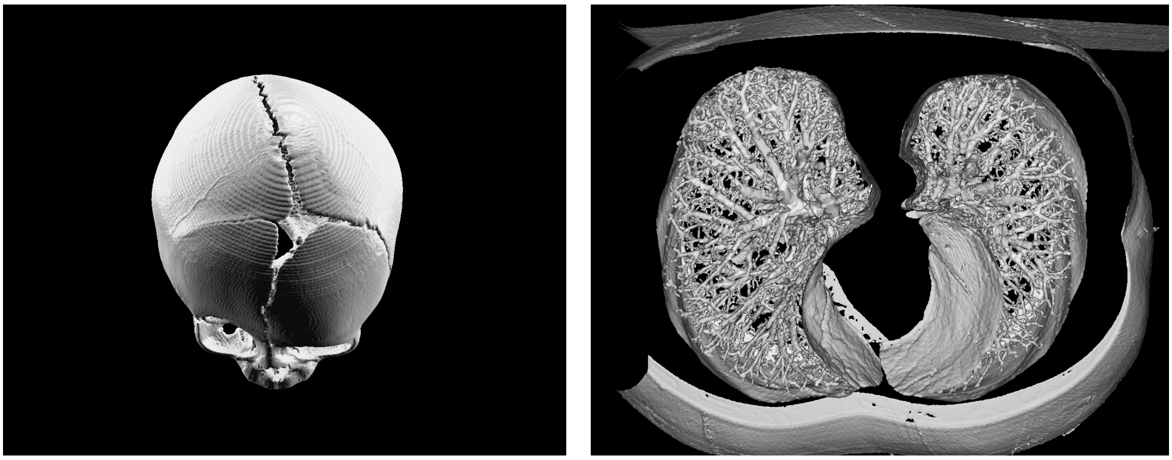

Figures: Images generated from 3-D computer models of the objects shown.

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Discussions and Classwork

- Discuss:
  - Importance of digital image processing
  - Role of EM spectrum in image sensing
  - Image generation vs Image processing
- Quickly Notes:
  - Define Digital Imang and Digital Image Processing.
  - Write down the short notes on the steps involved in digital image processing.

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Lecture – 02

Harimohan Khatri

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In this lecture…

i. Elements of Visual Perception
ii. Image Sensing and Acquisition
iii. Image Sampling and Quantization
iv. Neighbors, Connectivity, Distance Measures between pixels

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Structure of the Human Eye

- The lens focuses light from objects onto the retina
- The retina is covered with light receptors called *cones* (6-7 million) and *rods* (75-150 million)
- Cones are concentrated around the fovea and are very sensitive to colour
- Rods are more spread out and are sensitive to low levels of illumination

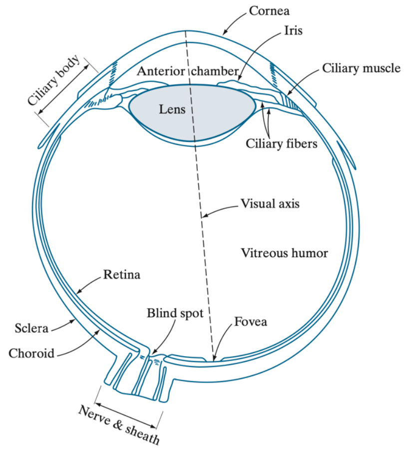

Figure: Structure of human eye.

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Photoreceptors density across retina

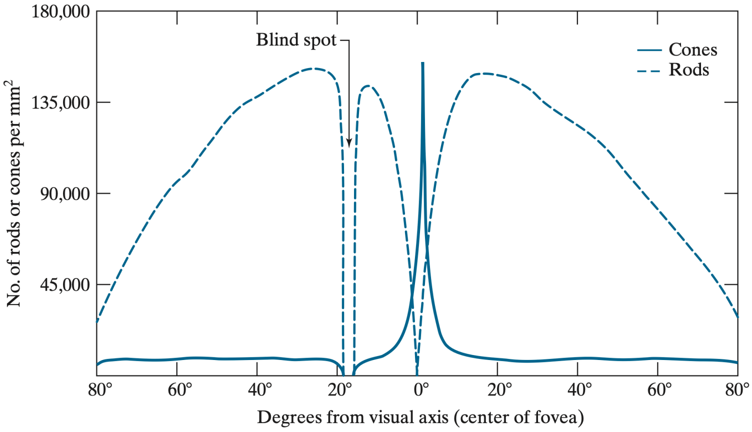

Figure: Distribution of rods and cones in the retina.

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The Blind Spot Experiment

Draw an image similar to that below on a piece of paper (the dot and cross are about 6 inches apart)

Close your right eye and focus on the cross with your left eye.

Hold the image about 20 inches away from your face and move it slowly towards you.

The dot should disappear!

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Image Formation in the Eye.

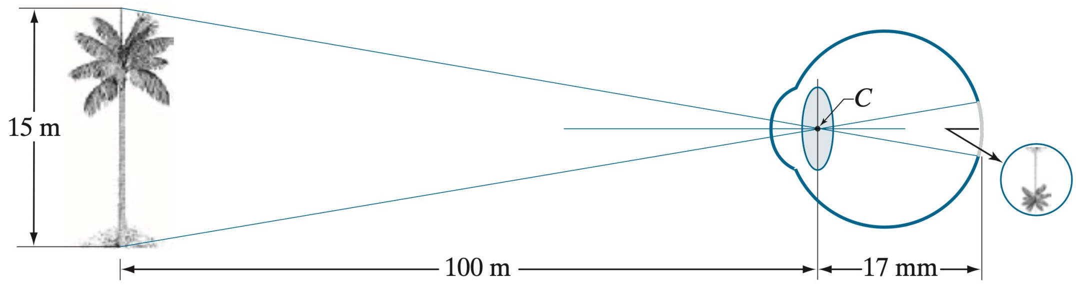

Figure: Formation of an image in the eye.

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Elements of visual perception

- Two phenomena demonstrate that perceived brightness is not a simple function of intensity.
  - i. The visual system tends to undershoot or overshoot around the boundary of regions of different intensities.
  - ii. Simultaneous contrast, is that a region's perceived brightness does not depend only on its intensity.

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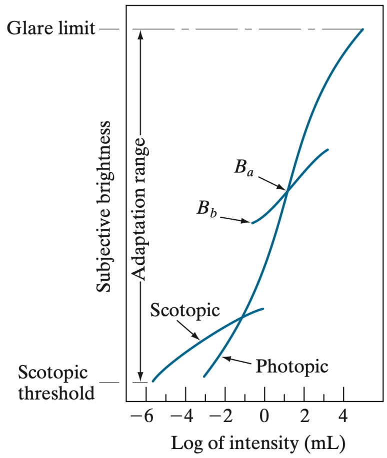
Brightness Adaptation and Discrimination

- Eyes see light on a log scale, adjusting to an average level (red dot). They see a range between glare limit and scotopic threshold, but not all at once. Low light looks black, bright light looks white.
- Weber Ratio (ΔI/I) measures how well eyes detect light changes.
  - Small ΔI/I = good discrimination (small change noticed); large ΔI/I = poor (big change needed).
- Experiment: Background light (I) with a flash (ΔI). If ΔI is noticeable, you say "yes"; if not, "no."



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Weber Ratio ΔI/I

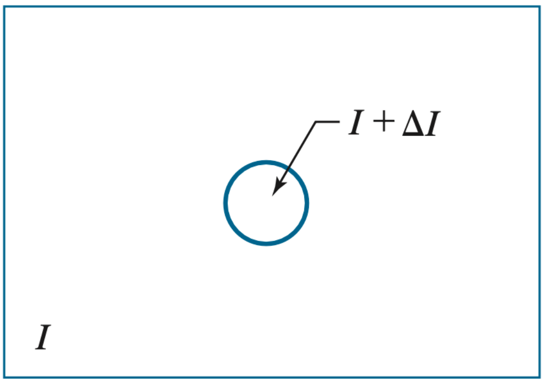
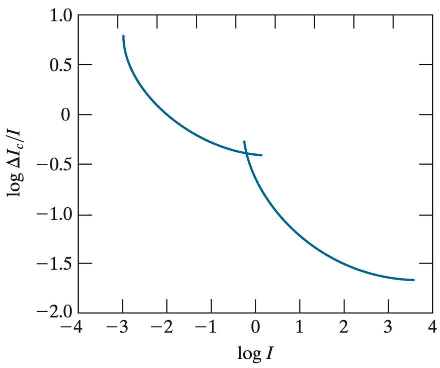


Figure: Basic experimental setup used to characterize brightness discrimination.



This curve shows that brightness discrimination is poor at low levels of illumination, and it improves significantly as background illumination increases.

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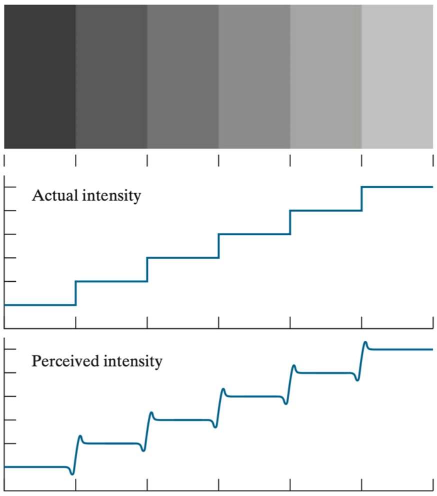
Brightness Adaption in Mach Bands

Although the intensity of the stripes is constant, we actually perceive a brightness pattern that is strongly scalloped near the boundaries.

These perceived scalloped bands are called Mach bands after Ernst Mach.



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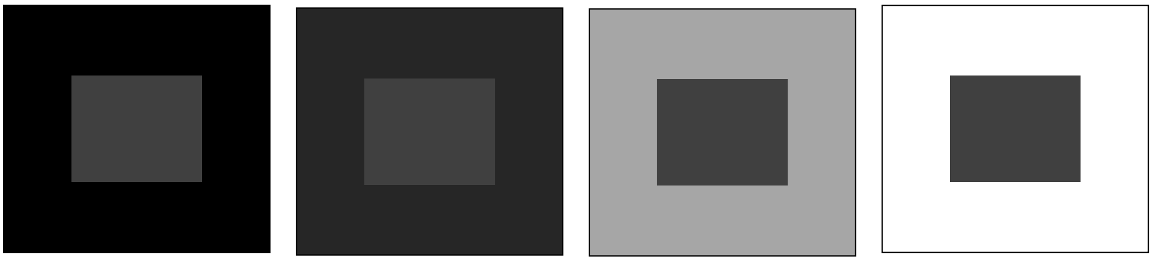
Simultaneous Contrast

Simultaneous contrast refers to the way in which two adjecent intensities affect each other.



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Some Optical Illusions

The eye fills in non existing details or wrongly perceives geometrical properties of objects.

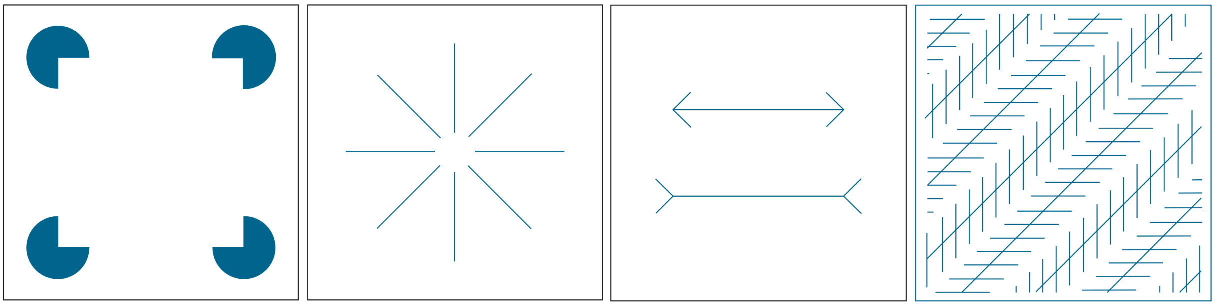

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Image Sensing and Acquisition

- Most of the images are generated by the combination of an "illumination" source and the reflection or absorption of energy from that source by the elements of the "scene" being imaged.
- The illumination may originate from a source of electromagnetic energy, such as a radar, infrared, or X-ray system, or ultrasound or even a computer-generated illumination pattern.
- Incoming energy is transformed into a voltage by a combination of the input electrical power and sensor material that is responsive to the type of energy being detected. The output voltage waveform is the response of the sensor, and a digital quantity is obtained by digitizing that response.

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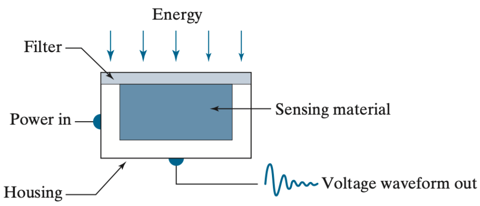
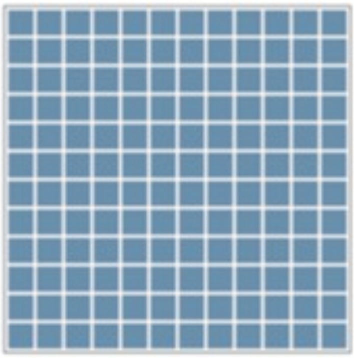
Image Sensors



Single sensing element.

Line sensor.



Array sensor.

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Image Acquisition using Single Sensing Element

- High-resolution images because mechanical motion can be controlled with high precision.
- Slow and not readily portable.

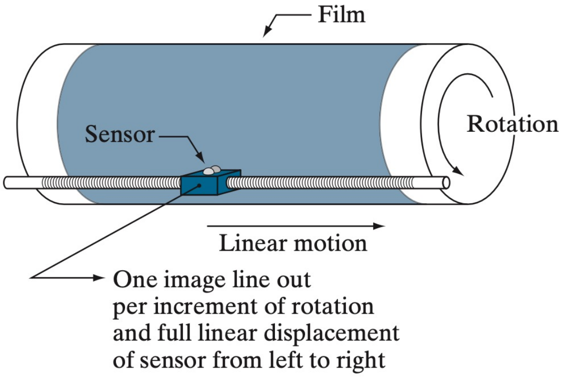

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Image Acquisition using Sensor Strips

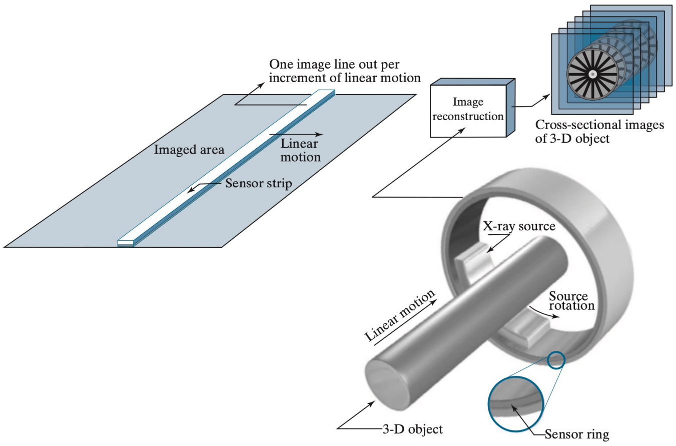

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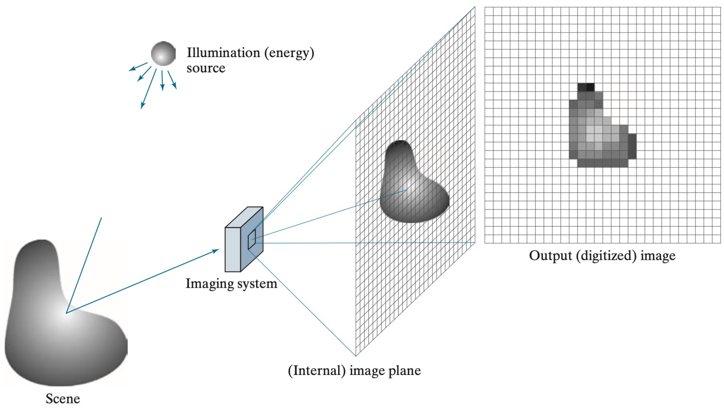
Image Acquisition using Sensor Arrays

Electromagnetic and ultrasonic sensing devices frequently are arranged in form of 2D array.



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A Simple Image Formation Model

- Image is defined as 2D light intensity function f(x,y).
- As, light is a form of energy f(x,y) must be nonnegative and finite;
  $0 \leq f(x,y) \leq \infty$
- f (x,y) is characterized by two components:
  $f(x,y) = i(x,y)\, r(x,y)$
  where, i(x,y) is the illumination: $0 < i(x,y) < \infty$
  and r(x,y) is the reflectance: $0 < r(x,y) < 1$
  - r(x,y)=0 implies total absorption
  - r(x,y)=1 implies total reflectance

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A Simple Image Formation Model

- The intensity of a monochrome image f at (x,y) is the gray level (l) of the image at that point

$$L_{min} \leq l \leq L_{max}$$

- In practice $L_{min}=i_{min}\, r_{min}$ and $L_{max}=i_{max}\, r_{max}$
- The interval $[L_{min}, L_{max}]$ is called the gray scale
- Common practice is to shift the interval to $[0,L]$ where $l=0$ is considered black and $l=L$ is considered white. All intermediate values are shades of gray

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Image Sampling and Quantization

- The output of most sensors is a continuous voltage waveform.
- To convert the continuous sensed data into a digital format. This requires two processes:
  - Sampling and
  - Quantization.
- To digitize a image, we have to sample the function in both coordinates and in amplitude.
  - Digitizing the coordinate values is called sampling.
  - Digitizing the amplitude values is called quantization.

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Image Sampling and Quantization

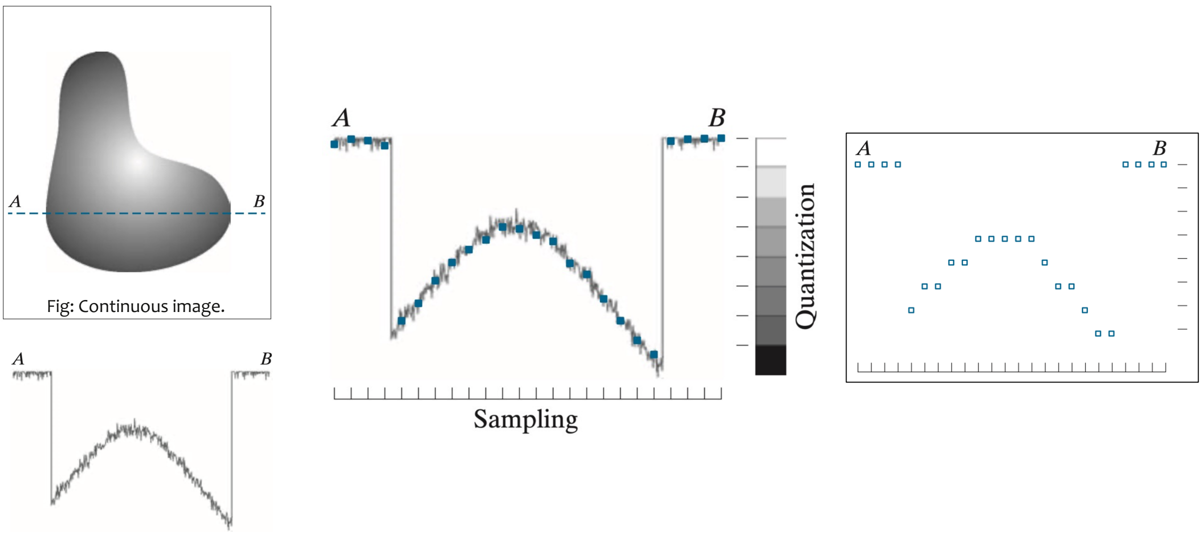

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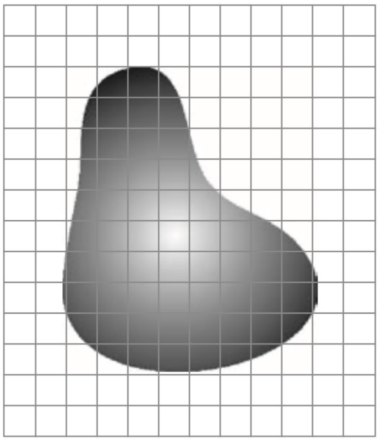
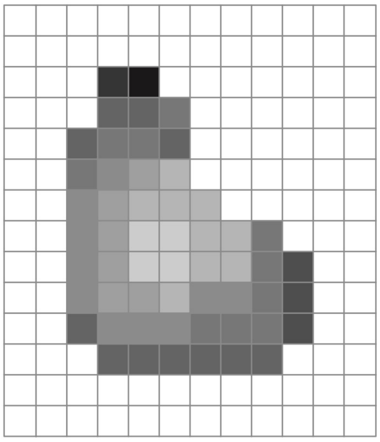
Image Sampling and Quantization



Continuous image projected onto a sensor array.



Result of image sampling and quantization.

The quality of a digital image is determined by the number of samples and discrete intensity levels used in sampling and quantization.

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Digital Image Representataion

- f(x,y) is approximated by equally spaced samples in the form of an NxM array where each element is a discrete quantity.

x = 0,1,2,… M-1 and y = 0,1,2,… N-1

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}$$

- The value of a digital image at any coordinates (x,y) is denoted f(x y).
- The section of the real plane spanned by the coordinates of an image is called the spatial domain, with x and y being referred to as spatial variables or spatial coordinates.

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Digital Image Representataion

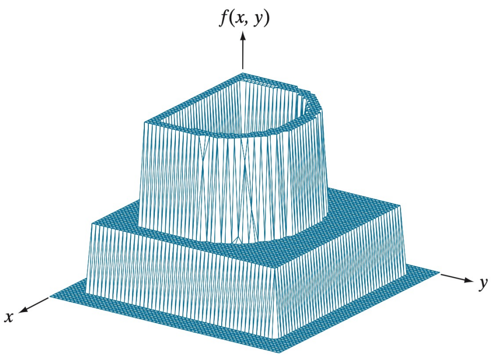

Fig: Image plotted as a surface.

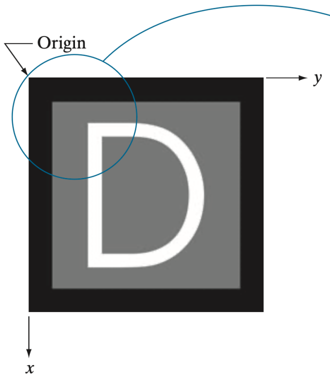

Fig: Image displayed as a visual intensity array.

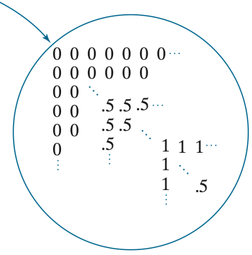

Fig: Image shown as a 2-D numerical array.
(The numbers 0, .5, and 1 represent
black, gray, and white, respectively.)

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Digital Image Representataion

- Common practice is to let N and M be powers of two; $N=2^n$ and $M=2^m$
- And $G=2^k$ where G denotes the number of gray levels
- The assumption here is that gray levels are equally space in the interval [0,L]
- The number of bits, b, necessary to store the image is then

  b = M*N*k

  for M=N

  $b = N^2k$
- For example, a 128x128 image with 64 gray levels would require 98,304 bits of storage.

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Resolution

- Spatial Resolution: measure of the smallest discernible detail in an image.
  - Example, line pairs per unit distance, and dots (pixels) per unit distance.
  - Measures of spatial resolution must be stated with respect to spatial units. For example, to say that an image has a resolution of 1024*1024 pixels is not a meaningful statement without stating the spatial dimensions encompassed by the image.
- Intensity Resolution: smallest discernible change in intensity level.
  - For example, an image whose intensity is quantized into 256 levels has 8 bits of intensity resolution.
- NOTE: Discernible changes in intensity are influenced also by noise and saturation values, and by the capabilities of human perception to analyze and interpret details in the context of an entire scene

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Effects of Change in Spatial Resolution

Pixel replication occurs as resolution is decreased.

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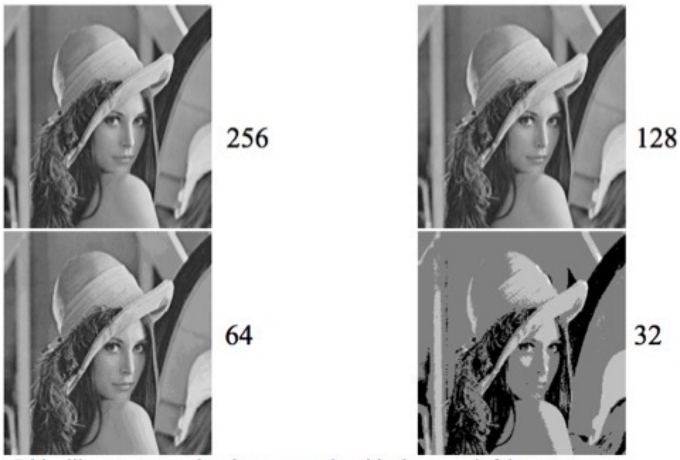
Effects of Change in Intensity Resolution



Ridgelike structures develop as gray level is decreased: false contours

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Effects of Change in Intensity Resolution

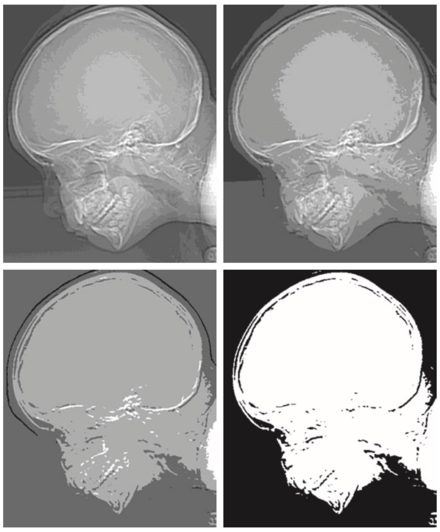

Image displayed in 16, 8, 4, and 2 intensity levels.

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Relationship Between Pixels

Neighbors of a pixel:

(x-1,y+1)	(x,y+1)	(x+1,y+1)
(x-1,y)	P(x,y)	(x+1,y)
(x-1,y-1)	(x,y+1)	(x+1,y-1)

4-Neighbours of P or $N_4(P)$

(x-1,y+1)	(x,y+1)	(x+1,y+1)
(x-1,y)	P(x,y)	(x+1,y)
(x-1,y-1)	(x,y+1)	(x+1,y-1)

Diagonal neighbours of P or $N_D(P)$

(x-1,y+1)	(x,y+1)	(x+1,y+1)
(x-1,y)	P(x,y)	(x+1,y)
(x-1,y-1)	(x,y+1)	(x+1,y-1)

8-Neighbours of P or $N_8(P)$

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Relationship Between Pixels

Adjacency of a pixel: (two neighboring pixels with same gray levels)

- Let V be the set of values used to determine adjacency
  - For example, in a binary image, V={1} for the connectivity of pixels with a value of 1
  - In a gray scale image, for the adjacency of pixels with a range of intensity values of, say, 32 to 64, it follows that V={32,33,...,63,64}
- Consider three types of adjacency
  - 4-adjacency: Pixels p and q with values from V are 4-adjecent if q is in the set $N_4(p)$
  - 8-adjacency: Pixels p and q with values from V are 8-adjecent if q is in the set $N_8(p)$
  - m-adjacency (mixed): Pixels p and q with values from V are m-adjacent if
    - q is in the set $N_4(p)$,or
    - q is in the set $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ is empty

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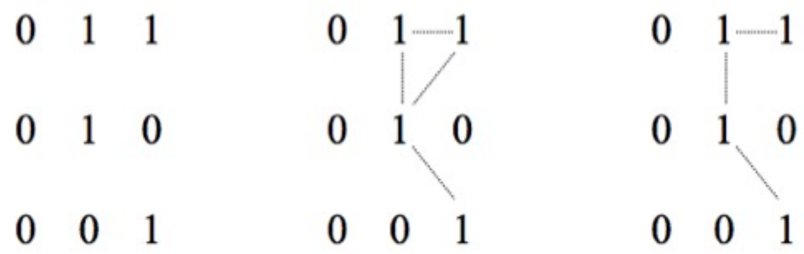
Relationship Between Pixels



An arrangement of pixels

8-connectivity of the pixels V={1}

m-connectivity of the pixels V={1}

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Relationship Between Pixels

Path between the pixels:

- A digital path from pixel ‘p’ with coordinates (x_0,y_0) to pixel ‘q’ with coordinates (x_n,y_n) is a sequence of distinct pixels with coordinates

  $(x_0,y_0), (x_1,y_1),\dots,(x_n,y_n)$

  where points (x_i,y_i) and (x_{i-1},y_{i-1}) are adjacent for $1 \le i \le n$.
- In this case, n is the length of the path.
- If $(x_0,y_0) = (x_n,y_n)$ the path is a closed path.
- We can define 4-, 8-,or m-paths, depending on the type of adjacency specified.

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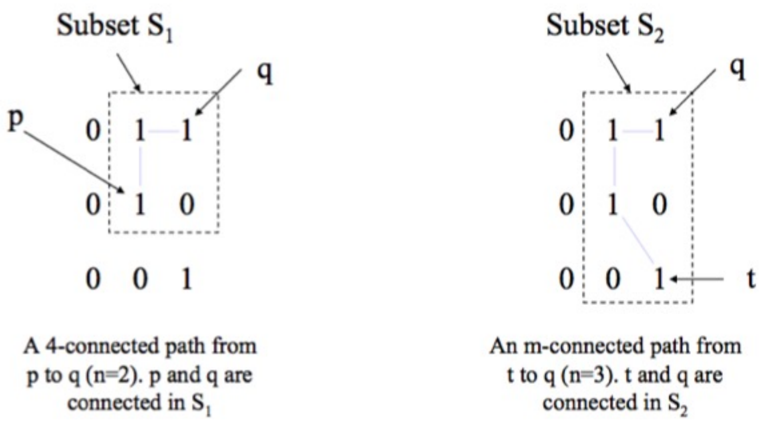
Relationship Between Pixels



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Relationship Between Pixels

Connectivity of a pixel:

- Let S represent a subset of pixels in an image.
- Two **pixels p and q are said to be connected in S if there exists a path between them consisting entirely of pixels in S.**
- For any pixel p in S, the set of pixels that are connected to it in S is called a connected component of S.
- If it only has one component, and that component is connected, then S is called a connected set.

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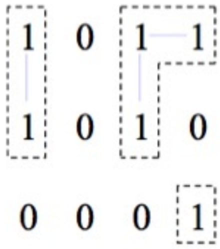
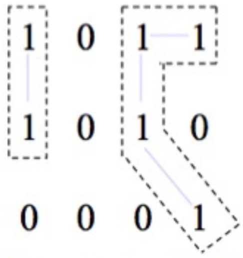
Relationship Between Pixels

Connectivity of a pixel:



3 4-connected components of S



2 m-connected components of S

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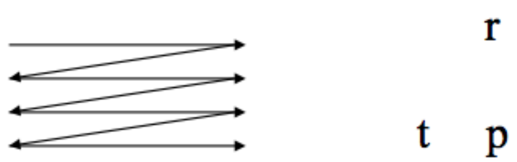
Relationship Between Pixels

Labeling 4-Connected Components:

- Consider scanning an image pixel by pixel from left to right and top to bottom



- Assume, for the moment, we are interested in 4-connected components
- Let p denote the pixel of interest, and r and t denote the upper and left neighbors of p, respectively
- The nature of the scanning process assures that r and t have been encountered (and labeled if 1) by the time p is encountered

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Relationship Between Pixels

Labeling 4-Connected Components:

Consider the following procedure

- if p = 0 continue to the next position
- if p = 1:
  - if r=t=0 assign a new label to p (L_n)
  - if r=t=1 and they have the same label, assign that label to p
  - if only one of r and t are 1, assign its label to p
  - if r=t=1 and they have different labels, assign one label to p and note that the two labels are equivalent (that is r and t are connected through p)
- At the end of the scan, sort pairs of equivalent labels into equivalence classes and assign a different label to each class

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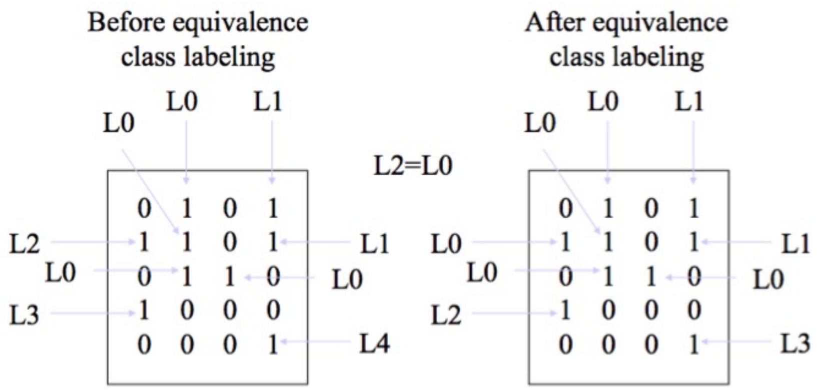
Relationship Between Pixels

Labeling 4-Connected Components:



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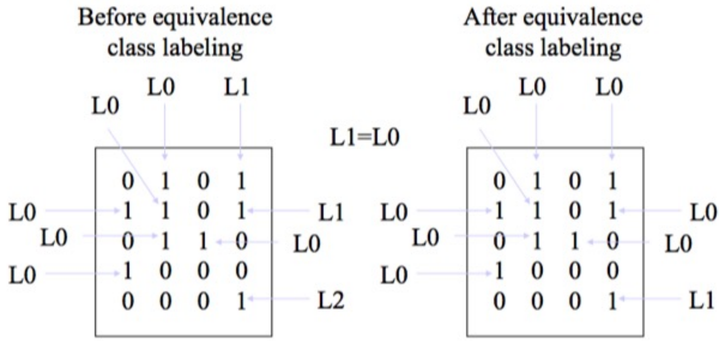
Relationship Between Pixels

Labeling 8-Connected Components:

- Proceed as in the 4-connected component labeling case, but also examine two upper diagonal neighbors (q and s) of p.



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Relationship Between Pixels

Labeling in non-binary images:

- The 4-connected or 8-connected labeling schemes can be extended to gray level images
- The set V may be used to connect into a component only those pixels within a specified range of pixel values

000	000	000	000	000
000	000	128	000	000
000	128	255	128	000
000	128	255	128	000
000	000	128	000	000
000	000	000	000	000

L0
L0 L1 L0
L0 L1 L0
L0

100

Distance Measures

- Given pixels p, q, and z at (x,y), (s,t) and (u,v) respectively, D is a distance function (or metric) if:
  - D(p,q) ≥ 0 (D(p,q)=0 iff p=q),
  - D(p,q) = D(q,p), and
  - D(p,z) ≤ D(p,q) + D(q,z).
- The Euclidean distance between p and q is given by:

$$D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

- The pixels having distance less than or equal to some value r from (x,y) are the points contained in a disk of radius r centered at (x,y)

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Distance Measures

- The D_4 distance (also called the *city block distance*) between *p* and *q* is given by:

$$D_4(p,q) = |x-s| + |y-t|$$

- The pixels having a D_4 distance less than some *r* from (x,y) form diamond centered at (x,y)
- Example: pixels where $D_4 \le 2$

$$\begin{array}{ccccc} & & 2 & & \\ & 2 & 1 & 2 & \\ 2 & 1 & 0 & 1 & 2 \\ & 2 & 1 & 2 & \\ & & 2 & & \end{array}$$

Note: Pixels with D_4=1 are the 4-neighbors of (x,y)

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Distance Measures

- The D8 distance (also called the chessboard distance) between p and q is given by:

$$D_8(p,q) = \max(|x-s|, |y-t|)$$

- The pixels having a D8 distance less than some r from (x,y) form a square centered at (x,y)
- Example: pixels where D8 ≤ 2

```
2 2 2 2 2
2 1 1 1 2
2 1 0 1 2
2 1 1 1 2
2 2 2 2 2
```

Note: Pixels with D_8=1 are the 8-neighbors of (x,y)

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Distance Measures and Connectivity

- The D_4 distance between two points *p* and *q* is the shortest 4-path between the two points.
- The D_8 distance between two points *p* and *q* is the shortest 8-path between the two points.
- D_4 and D_8 may be considered, regardless of whether a connected path exists between them, because the definition of these distances involves only the pixel coordinates.
- For *m-connectivity*, the value of the distance (the length of the path) between two points depends on the values of the pixels along the path.

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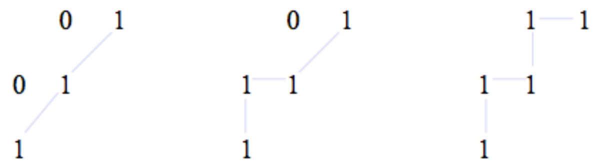
Distance Measures and Connectivity

- Consider the given arrangement of pixels and assume
  - p, p2 and p4 =1
  - p1 and p3 can be 0 or 1
- If V={1} and p1 and p3 are 0, the m-distance (p, p4) is 2 If either p1 or p3 are 1, the m-distance (p, p4) is 3 If p1 and p3 are 1, the m-distance (p, p4) is 4

$$\begin{matrix} & p_3 & p_4 \\ p_1 & p_2 & \\ p & & \end{matrix}$$



m-distance$(p,p_4)=2$ *m-distance*$(p,p_4)=3$ *m-distance*$(p,p_4)=4$

Discussions and Classwork

- Write down the difference between Sampling and Quantization.
- Label following image using 4- connected and 8- connected approach.

a)

1	0	1	1	0
0	1	1	0	1
0	0	1	1	0
0	1	0	0	1
0	1	0	1	0

b)

0	0	1	0	1
0	0	1	0	0
0	1	0	1	0
0	1	0	1	1
0	0	1	0	1

Discussions and Classwork

- Calculate Euclidean distance, city block distance and chessboard distance between pixels ‘p’ and ‘q’ in given images:

a)

1	0	1	1	0
0	1	1	q	1
0	0	1	1	0
0	p	0	0	1
0	1	0	1	0

b)

0	p	1	0	1
0	0	1	0	0
0	1	0	1	0
0	1	0	1	1
0	0	q	0	1