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NAVI MUMBAI

Subject Name: Pattern Recognition

Module No: 1

Module Name: Digital Image Fundamentals

Faculty Name : Mrs. Namita Pulgam

Lecture No: 1
Introduction to Image Processing Systems

Image Processing

- Image processing is a method of manipulating or altering an image to achieve a desired result, typically for improving its visual quality or extracting useful information from it.

- It involves a variety of techniques and algorithms to modify or analyze images, and it is a fundamental component of computer vision, artificial intelligence, and many other fields.

- Image Processing involves processing images obtained by a camera.

- Images from a camera are fed into a computer where algorithms are written to process these images.

History of Digital Image Processing

Early 1920s: One of the first applications of digital imaging was in the news-paper industry

- The Bartlane cable picture transmission service
- Images were transferred by submarine cable between London and New York
- Pictures were coded for cable transfer and reconstructed at the receiving end on a telegraph printer

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

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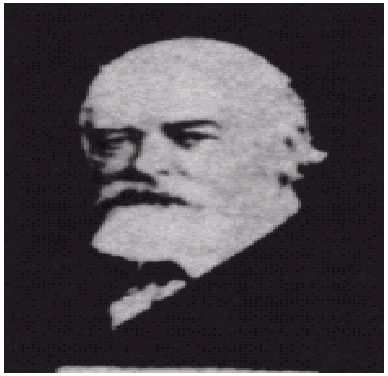
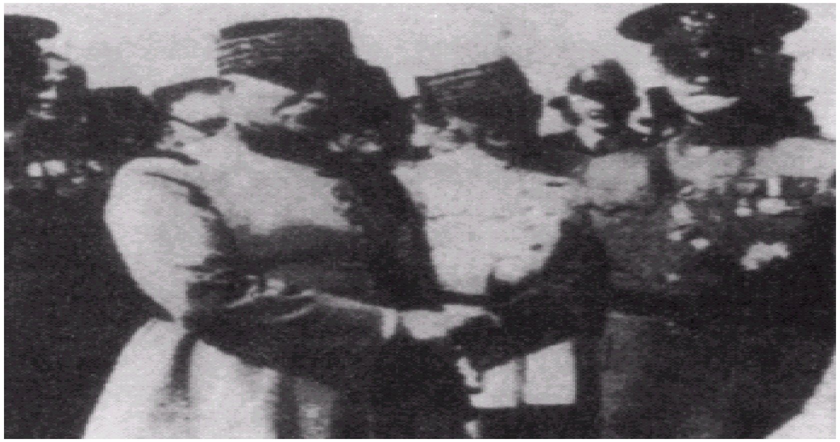
History of Digital Image Processing

Mid to late 1920s: Improvements to the Bartlane system resulted in higher quality images

1. News reproduction processes based on photographic techniques
2. Increased number of tones in reproduced images





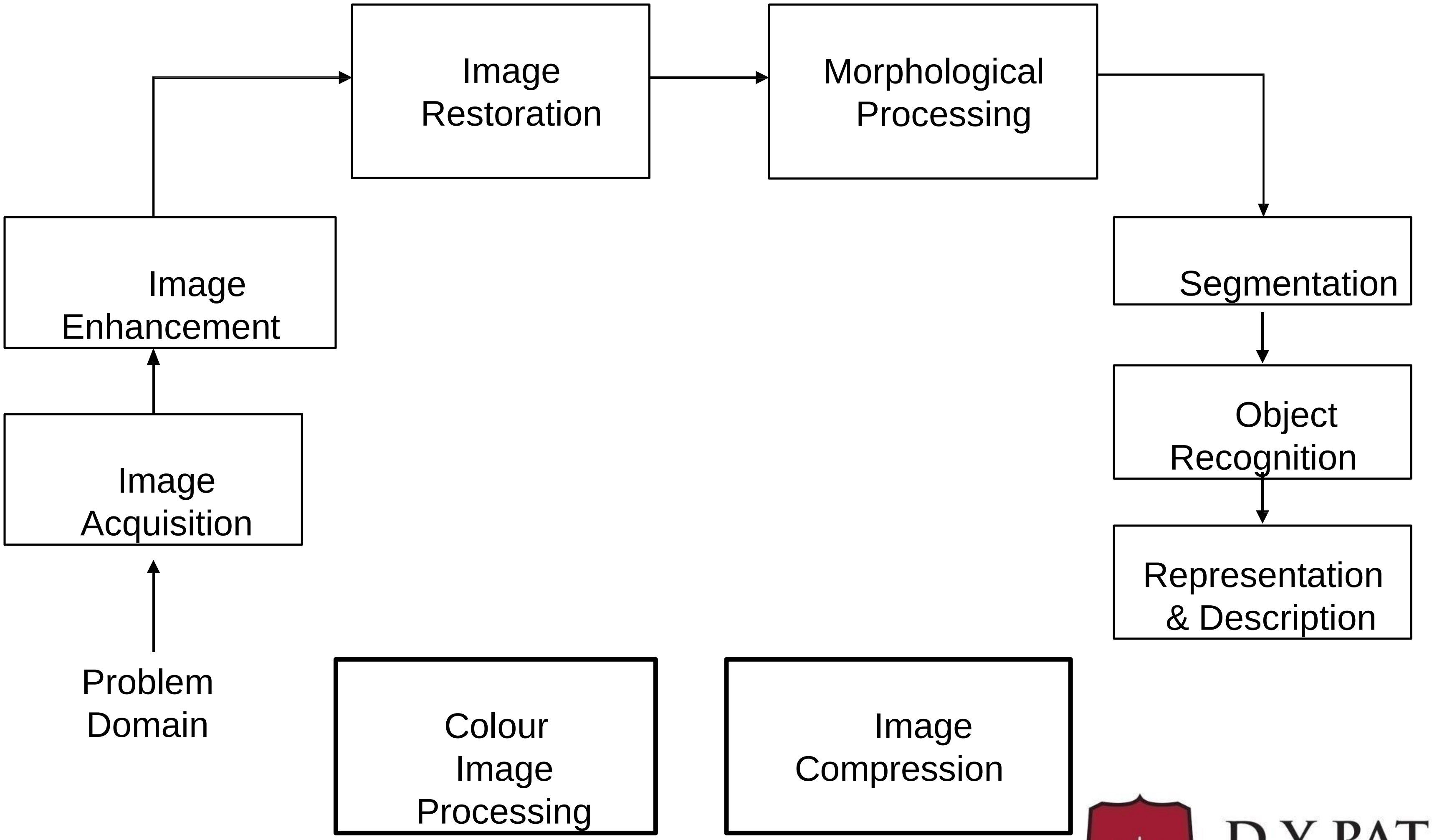
Early 15 tone digital image

Key Stages of Image Processing System

Various stages involved in image processing system are :

1. Image Acquisition
2. Image Enhancement
3. Image Restoration
4. Morphological Processing
5. Segmentation Processing
6. Representation and Description
7. Object Recognition and Interpretation
8. Color Image Processing
9. Image Compression

Key Stages of Image Processing System



Overview of Image Processing System

- **Image Acquisition:** The process starts with acquiring an image using devices like digital cameras, scanners, or sensors. The quality and resolution of the acquired image are crucial.

- **Preprocessing:** This stage involves cleaning up the image, removing noise, correcting distortions, and enhancing its quality. Common preprocessing techniques include image denoising, contrast adjustment, and image resizing.

- **Image Enhancement:** Enhancement techniques aim to improve the visual quality of an image. These methods can sharpen edges, adjust brightness and contrast, and highlight certain features within the image.

Overview of Image Processing System (cont..)

- **Image Restoration:** Restoration techniques are used to recover or improve the original image from a degraded or damaged version. This can be useful in scenarios such as restoring old photographs or removing scratches and stains.

- **Image Segmentation:** Segmentation involves dividing an image into meaningful regions or objects. It is commonly used in object detection, medical image analysis, and more.

- **Feature Extraction:** In this step, relevant information is extracted from the image. This may include extracting specific patterns, shapes, or features for further analysis.

Overview of Image Processing System (cont..)

- **Object Recognition:** Object recognition techniques are used to identify and classify objects within an image. This is fundamental in applications like facial recognition, object tracking, and autonomous vehicles.

- **Pattern Matching:** Image processing can be used to find patterns or templates within an image, which can be useful in various fields such as character recognition or fingerprint analysis.

Applications of Image Processing System

- **Medical Imaging:** Image processing plays a crucial role in medical diagnostics, including X-ray analysis, MRI, CT scans, and identifying abnormalities in medical images.
- **Remote Sensing:** Analyzing satellite images for environmental monitoring, disaster management, and land use planning.
- **Computer Vision:** Image processing is the backbone of computer vision applications, including facial recognition, object detection, and gesture recognition.
- **Security and Surveillance:** It's used for video surveillance, analyzing CCTV footage, and facial recognition in security applications.
- **Entertainment:** In the film and gaming industry, image processing is used for special effects, image editing, and enhancing visual quality.

Applications of Image Processing System (cont..)

- **Industrial Automation:** Image processing is used for quality control, defect detection, and robotics in manufacturing.
- **Document Analysis:** OCR (Optical Character Recognition) relies on image processing to convert printed or handwritten text into machine-readable text.
- **Astronomy:** Analyzing and enhancing astronomical images to study celestial objects and phenomena.

Benefits of Image Processing

- **Improved Image Quality**: Image processing can enhance image quality, making images sharper, clearer, and more visually appealing.
- **Automation**: It allows for the automation of tasks that would be time-consuming and error-prone if done manually, such as object recognition or defect detection.
- **Information Extraction**: It enables the extraction of valuable information from images, which can be used for decision-making and analysis.
- **Medical Diagnostics**: In the medical field, image processing aids in early disease detection and non-invasive diagnostics.
- **Cost Savings**: It can lead to cost savings in various industries by reducing the need for manual labor and improving the efficiency of processes.
- **Scientific Research**: Image processing is critical in scientific research, allowing researchers to analyze and visualize data effectively.
- **Enhanced Security**: It enhances security through facial recognition, fingerprint analysis, and object tracking.
- **Creative Expression**: In the arts and entertainment industry, it enables creative expression and the development of visually stunning effects.

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Module No 1: Digital Image Fundamentals

Lecture No: 2
Image Sensing and Acquisition

Basic

- Image sensing and Image formation are in the sequence in the digital image formation pipeline.
- The output of the image sensing/image formation model is the continuous voltage/ frequency and then digitizes that single into a digital image.

Elements of Visual Perception

- The main elements of the human visual system are the eye and the brain and the connection between is done through the nerves.
- The human eye acts as the camera and the brain acts as a computer system that processes the image captured by the human eye also the connection cables are the verves.
- The human eye detects the electromagnetic rays emitted by light to sense the object the color (hue value) of these rays represents the wavelength of rays and the brightness is the intensity of light.

Image Sensing

- Images can be generated by the combination of an illuminating source and reflection or absorption of energy from that source by the elements of the scene being imaged.
- The waves that are received by the sensors reflected by the object in different bands are then converted into a voltage.
- The output of the sensing process is then digitized to construct a digital image.
- The illuminating source could be sun or any other source of electromagnetic energy such as radar, IR rays or X-ray energy.

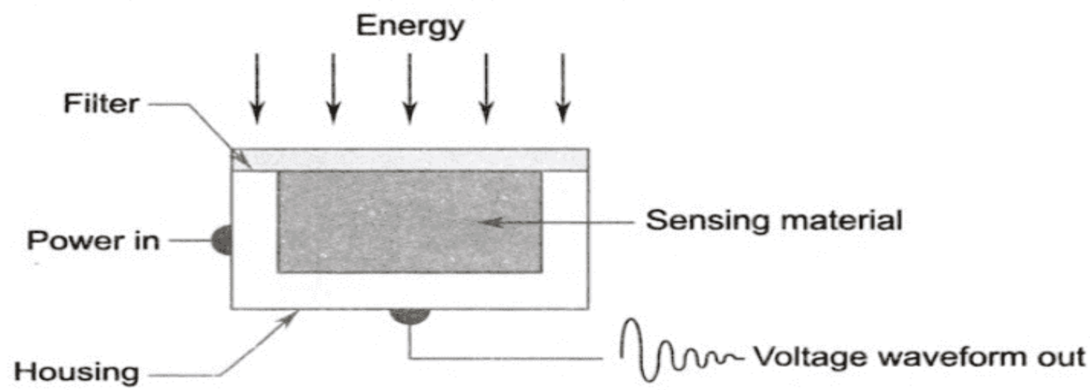
Image Acquisition

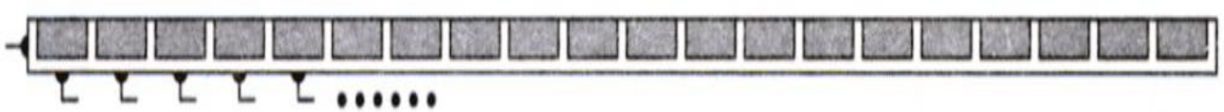
- In image processing, it is defined as the action of retrieving an image from some source, usually a hardware-based source for processing.
- It is the first step in the workflow sequence.
- The image that is acquired is completely unprocessed.
- The incoming energy is transformed into a voltage by the combination of input electrical power and sensor material that is responsive to a particular type of energy being detected.
- The output voltage waveform is the response of the sensor(s) and a digital quantity is obtained from each sensor by digitizing its response.

Types of Image Sensors

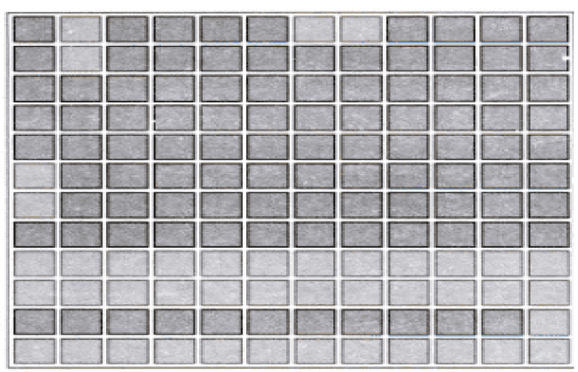
There are 3 principal sensor arrangements (produce an electrical output proportional to light intensity).

(i) Single imaging Sensor →





← (ii) Line sensor



← (iii) Array sensor

Image Acquisition using a Single Sensor Element

- The most common sensor of this type is the photodiode, which is constructed of silicon materials and whose output voltage waveform is proportional to light.
- The use of a filter in front of a sensor improves selectivity. For example, a green (pass) filter in front of a light sensor favours light in the green band of the color spectrum.
- As a consequence, the sensor output will be stronger for green light than for other components in the visible spectrum.
- In order to capture the 2D image we need this single sensor to have displacement in both the x and y direction of the image to sense for that we have a mechanical motion-based setup.

Image Acquisition using a Single Sensor Element

- An arrangement used in high precision scanning, where a film negative is mounted onto a drum whose mechanical rotation provides displacement in one dimension.
- The single sensor is mounted on a lead screw that provides motion in the perpendicular direction.
- Since mechanical motion can be controlled with high precision, this method is an inexpensive (but slow) way to obtain high-resolution images.

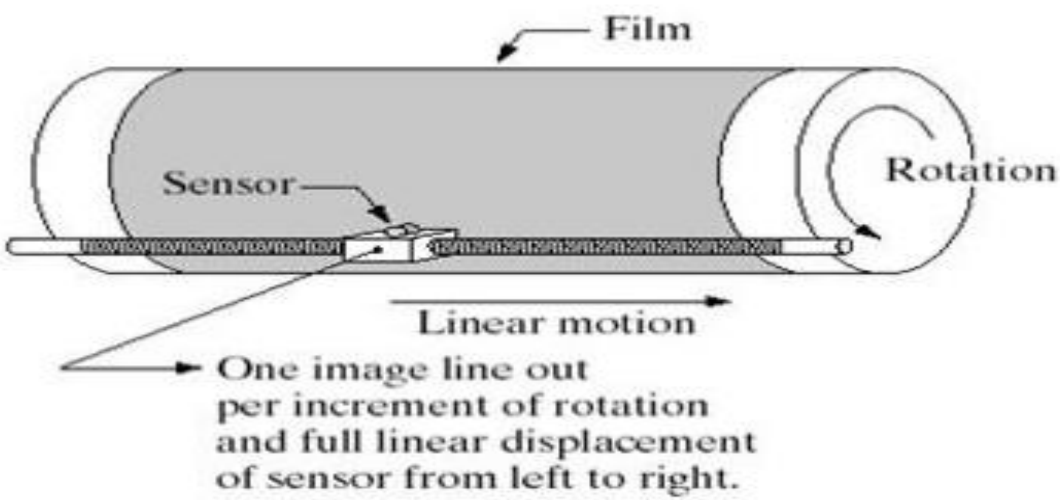


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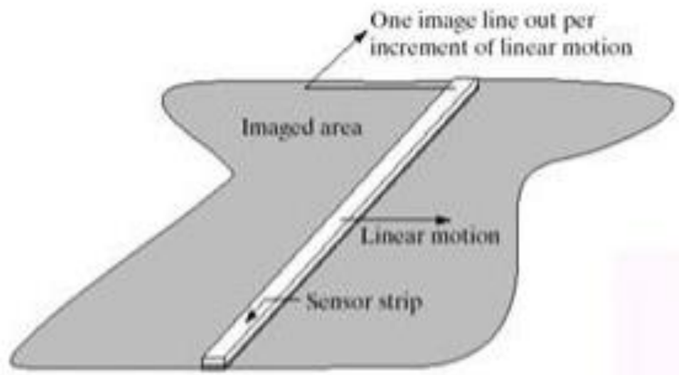
Image Acquisition using Sensor Strips

- In this the strip provides imaging elements in one direction.
- Motion perpendicular to the strip provides imaging in the other direction.
- This is the type of arrangement used in most flatbed scanners.



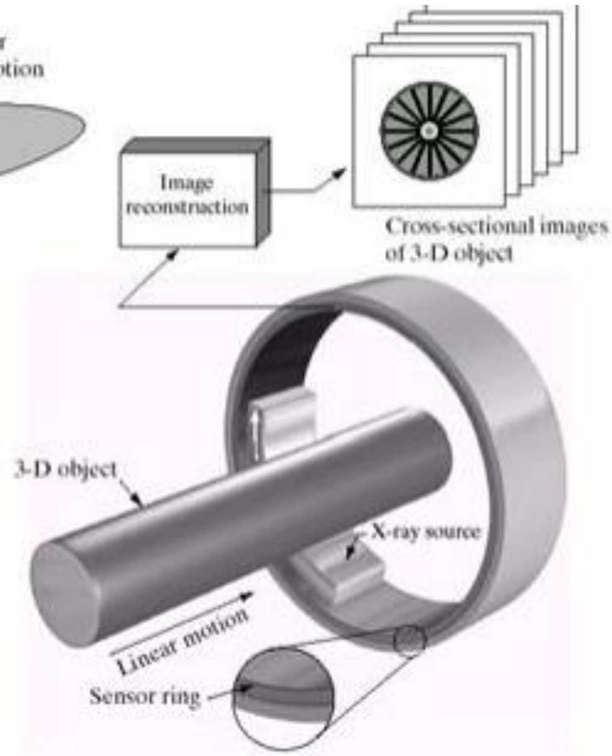


Image Acquisition using Sensor Strips (cont..)

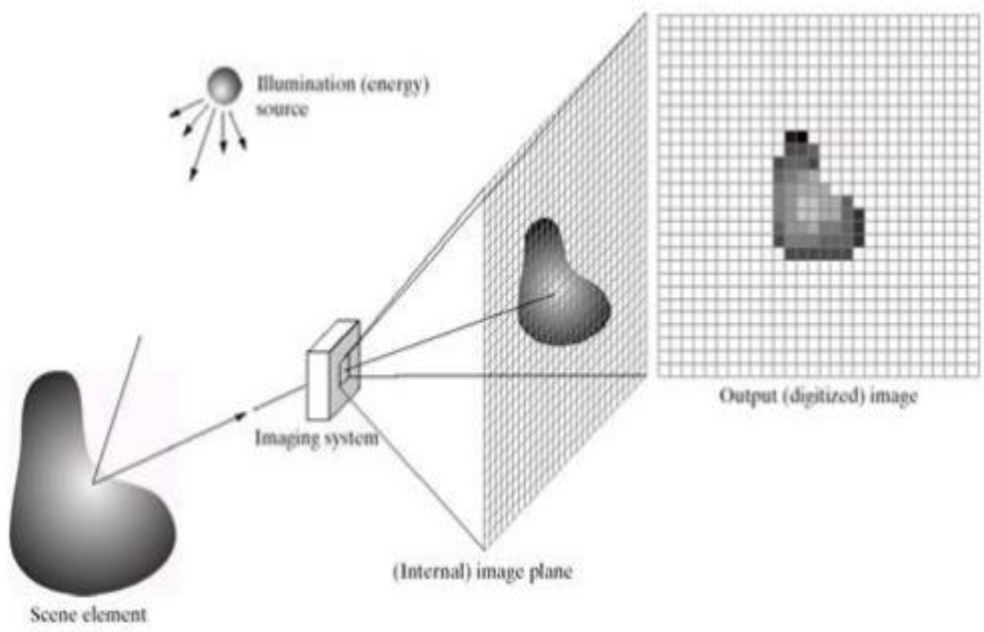
- In-line sensors are used routinely in airborne imaging applications, in which the imaging system is mounted on an aircraft that flies at a constant altitude and speed over the geographical area to be imaged.
- One-dimensional imaging sensor strips that respond to various bands of the electromagnetic spectrum are mounted perpendicular to the direction of flight.
- The imaging strip gives one line of an image at a time, and the motion of the strip completes the other dimension of a two-dimensional image.
- Sensor strips mounted in a ring configuration are used in medical and industrial imaging to obtain crosssectional (“slice”) images of 3-D objects.
- A rotating X-ray source provides illumination and the portion of the sensors opposite the source collect the X-ray energy that pass through the object.

Image Acquisition using Sensor Arrays

- This type of arrangement is found in digital cameras.
- A typical sensor for these cameras is a CCD array, which can be manufactured with a broad range of sensing properties and can be packaged in rugged arrays of 4000 * 4000 elements or more.
- CCD sensors are used widely in digital cameras and other light sensing instruments.
- The response of each sensor is proportional to the integral of the light energy projected onto the surface of the sensor, a property that is used in astronomical and other applications requiring low noise images.
- The first function performed by the imaging system is to collect the incoming energy and focus it onto an image plane.

Image Acquisition using Sensor Arrays (cont..)

- If the illumination is light, the front end of the imaging system is a lens, which projects the viewed scene onto the lens focal plane.
- The sensor array, which is coincident with the focal plane, produces outputs proportional to the integral of the light received at each sensor.



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Module No 1: Digital Image Fundamentals

Lecture No: 3
Image Definition and Relationship between Pixels

Image Definition

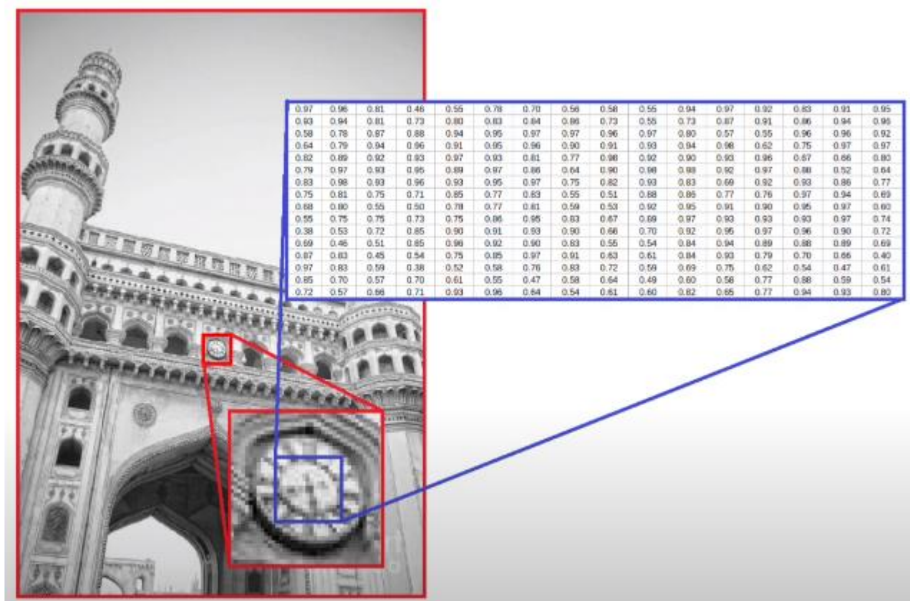
- An image is a visual representation of something, while a digital image is a binary representation of visual data.
- These images can be in the form of photographs, graphics and individual video frames.
- For this purpose, an image is a picture that was created or copied and stored in electronic form.

Representation of an Image

- There are various ways by which an image can be represented.

1. Image as a matrix

- The simplest way to represent the image is in the form of a matrix.



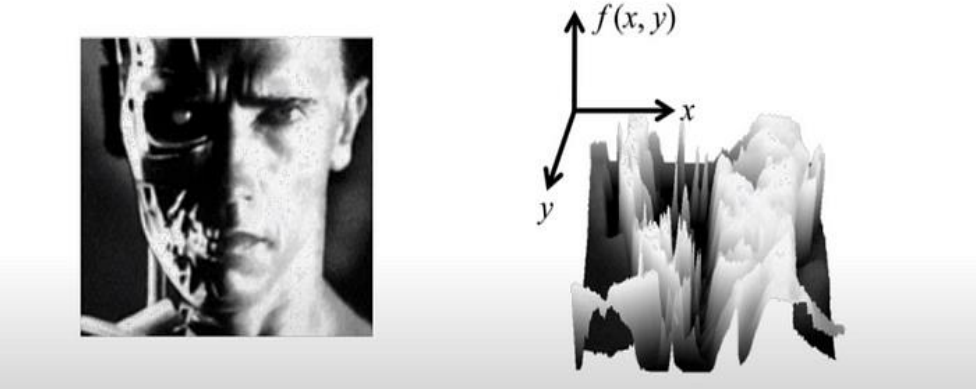
Representation of an Image (cont..)

- A byte is used to represent every pixel of the image.
- These have values between 0 to 255 which represents the intensity for each pixel in the image where 0 is black and 255 is white.
- For every color channel in the image, one such matrix is generated.
- For some applications pixel values are normalized between 0 and 1.

Representation of an Image (cont..)

2. Image as a function

- An image can also be represented as a function.
- An image (grayscale) can be thought of as a function that takes in a pixel coordinate and gives the intensity at that pixel.
- It can be written as function f: $\mathbb{R}^2 \rightarrow \mathbb{R}$ that outputs the intensity at any input point (x,y).
- The value of intensity can be between 0 to 255 or 0 to 1 if values are normalized.

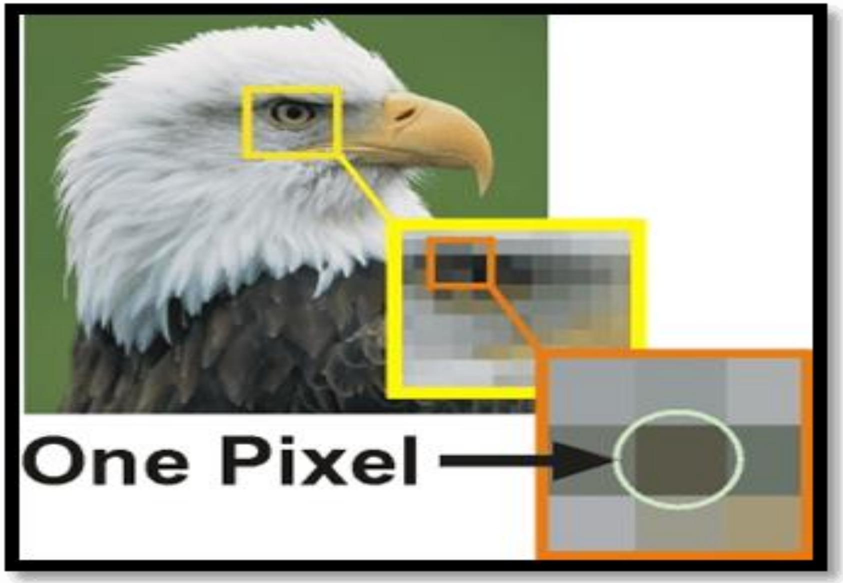


Concept of Pixel

- The full form of the pixel is "Picture Element."
- Pixel is the smallest element of an image on a computer display, whether they are LCD or CRT monitors.
- A screen is made up of a matrix of thousands or millions of pixels.
- A pixel is represented with a dot or a square on a computer screen.

Concept of Pixel (cont..)

- A pixel cannot be seen as they are very small which result in a smooth and clear image rather than "pixelated."
- Each pixel has a value, or we can say a unique logical address.
- It can have only one color at a time.
- Colour of a pixel is determined by the number of bits which is used to represent it.



Gray level

- The value of the minimum gray level is 0.
- The gray level depends on the depth of the image.

- **For example:**
- In an 8-bit image, gray level is 255.
- For a binary image, a pixel can only take value 0 or 255.
- In color image, it can choose values between 0 and 255.

- The formula for calculating gray level in a color image is as shown below:

Grey level = 0.299 * red component + 0.587 * green component + 0.114 * blue component

Pixel value(0)

- Each pixel has a unique value.
- 0 is a unique value that means the absence of light. (It means that 0 is used to denote dark.)
- **For example:**
- We have a matrix of 3X3 of an image, and each pixel is of value as shown

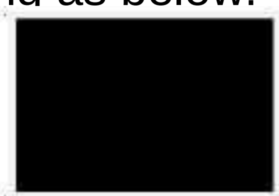
0	0	0
0	0	0
0	0	0

Total number of pixels = Number of rows X Number of columns

= 3 X 3

= 9.

- It means the image formed is of 9 pixels which are black.
- The image would be something as below:



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Types of Images

- There are three types of images.

1. Binary Images

2. Gray-scale Images

3. Colour Images

Binary Images

- It is the simplest type of image.
- It takes only two values i.e, Black and White or 0 and 1.
- The binary image consists of a 1-bit image and it takes only 1 binary digit to represent a pixel.
- Binary images are mostly used for general shape or outline.
- **For Example:** Optical Character Recognition (OCR).

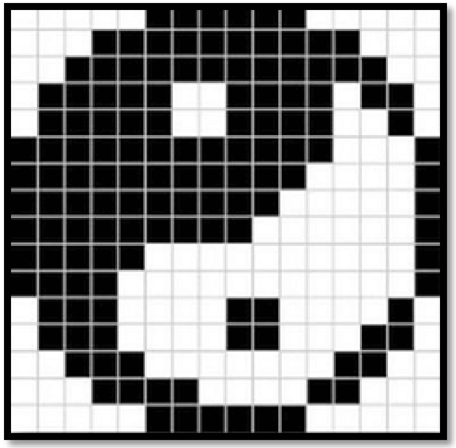

Fig. Binary image

- Binary images are generated using threshold operation.
- When a pixel is above the threshold value, then it is turned white('1') and which are below the threshold value then they are turned black('0')

Gray-scale Images

- Grayscale images are monochrome images, Means they have only one color.
- Grayscale images do not contain any information about color.
- Each pixel determines available different grey levels.
- A normal grayscale image contains 8 bits/pixel data, which has 256 different grey levels.
- In medical images and astronomy, 12 or 16 bits/pixel images are used.

Fig. Gray-scale image

Colour Images

- Colour images are three band monochrome images in which, each band contains a different color and the actual information is stored in the digital image.
- The images are represented as red, green and blue (RGB images).
- And each color image has 24 bits/pixel means 8 bits for each of the three color band(RGB).

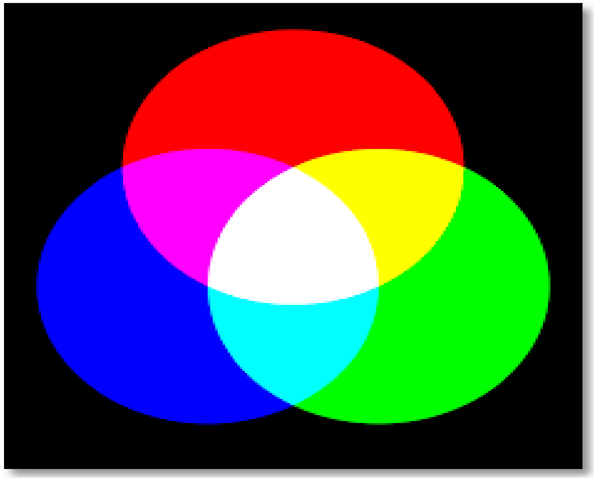

Fig. Colour image

8-Bit Colour Format

- 8-bit colour is used for storing image information in a computer's memory or in a file of an image.
- In this format, each pixel represents one 8 bit byte.
- It has 0-255 range of colours, in which 0 is used for black, 255 for white and 127 for gray colour.
- The 8-bit colour format is also known as a grayscale image.

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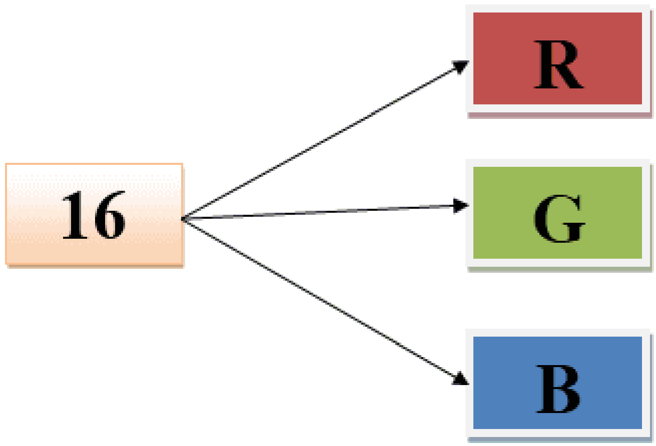
16-Bit Colour Format

- The 16-bit color format is also known as high color format.
- It has 65,536 different color shades.
- The 16-bit color format is further divided into three formats which are Red, Green, and Blue also known as RGB format.
- In RGB format, there are 5 bits for R, 6 bits for G, and 5 bits for B. One additional bit is added in green because in all the 3 colors green color is soothing to eyes.



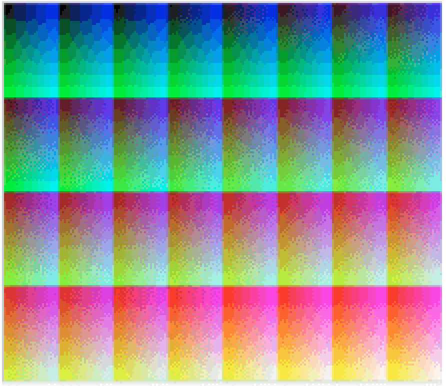


Fig: RGB 16 bits palette

Neighbors of a Pixel

- A pixel p at coordinates (x, y) has two horizontal and two vertical neighbors with coordinates (x+1,y), (x-1,y), (x,y+1) and (x,y-1).
- These are called the 4-neighbours of p : $N_4(p)$.
- The four diagonal neighbors of p have coordinates (x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1) and are denoted by $N_D(p)$.
- Diagonal neighbors together with the 4-neighbors are called the 8-neighbors of p, denoted by $N_8(p)$.

$$N_8(p) = N_4(p) + N_D(p)$$

- Neighbors of pixel are as shown below:

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

Adjacency between Pixels

- Let V be the set of intensity values used to define adjacency.
- In a binary image, V ={1} if we are referring to the adjacency of pixels with the value 1.
- In a gray-scale image, the idea is the same, but set V typically contains more elements.
- **For example:**
- In the adjacency of pixels with intensity values ranging from 0 to 255, set V might be any subset of these 256 values.

Types of Adjacency

- There are three types of adjacency:
- **4-adjacency:** Two pixels p and q with values from V are 4-adjacent if q is in the set N4(p).
- **8-adjacency:** Two pixels p and q with values from V are 8-adjacent if q is in the set N8(p).
- **m-adjacency (Mixed Adjaceny):** Two pixels p and q with values from V are m-adjacent if

  → q is in N4(p), or

  →q is in ND(p) and the set N4(p)∩N4(q) has no pixels whose values are from V.
- Mixed adjacency is a modification of 8-adjacency, and is introduced to eliminate the ambiguities that may result from using 8-adjacency.

Connectivity between Pixels

- Two pixels are said to be connected:

  → if they are adjacent in some sense (neighbour pixels,4/8/m-adjacency)

  → if their gray levels satisfy a specified criterion of similarity(equal intensity level)

- There are three types of connectivity on the basis of adjacency. They are:

  a) 4-connectivity: Two or more pixels are said to be 4-connected if they are 4-adjacent with each others.

  b) 8-connectivity: Two or more pixels are said to be 8-connected if they are 8-adjacent with each others.

Connectivity between Pixels (cont..)

c) m-connectivity: Two or more pixels are said to be m-connected if they are m-adjacent with each others.

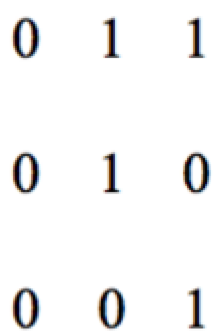


Fig: An arrangement of pixels

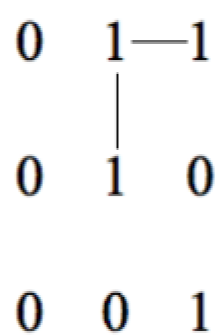


Fig: 4-connectivity of pixels

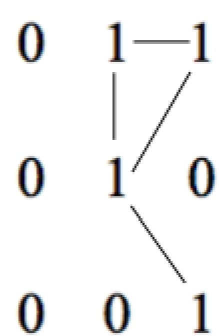


Fig: 8-connectivity of pixels

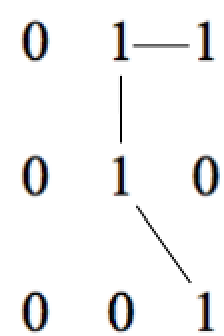


Fig: m-connectivity of pixels

Thank You

Module No 1: Digital Image Fundamentals

Lecture No: 4

Digitization – Sampling

Digitization

- Image processing can be applied on digital images only.
- To create a digital image, we need to convert the continuous sensed data into a digital format. This process is called as digitization.
- The process of digitization involves two steps:

    1. Sampling

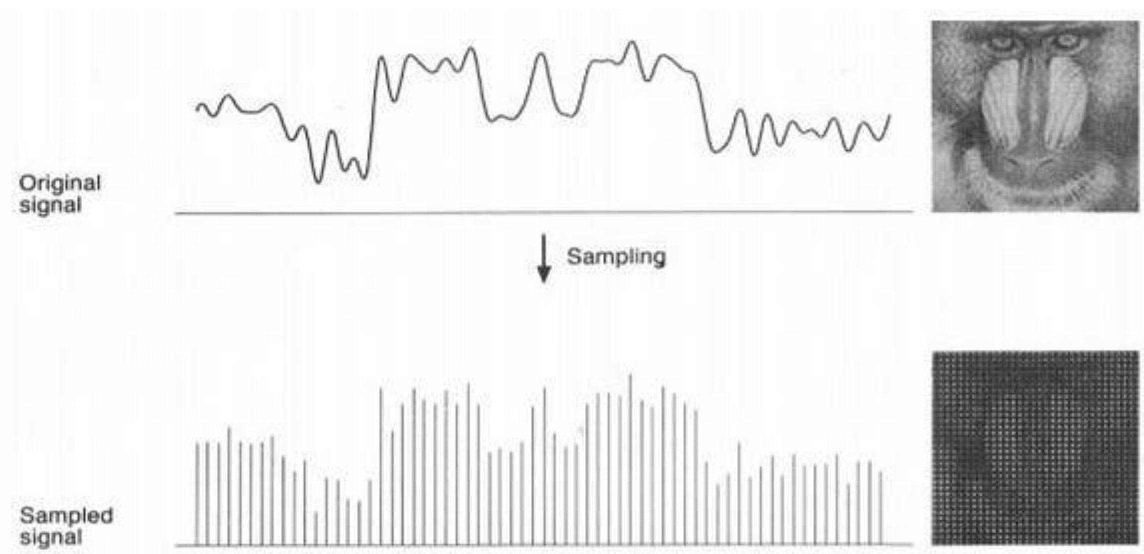
    2. Quantization

Digitization = Sampling + Quantization

- An image may be continuous with respect to x and y coordinates and amplitude.
- To digitize we have to sample the function in both coordinates and amplitude.
- Digitizing the coordinate value is called sampling.
- Digitizing the amplitude values is called quantization.

Sampling

- Sampling is the process of converting an analog signal into discrete values.
- Image sampling involves the process of selecting pixels from an original image to create a new one.
- This new image is referred to as the sample and is used to determine the resolution of an image.
- More samples will result in higher image quality of the digital image because of more pixels.



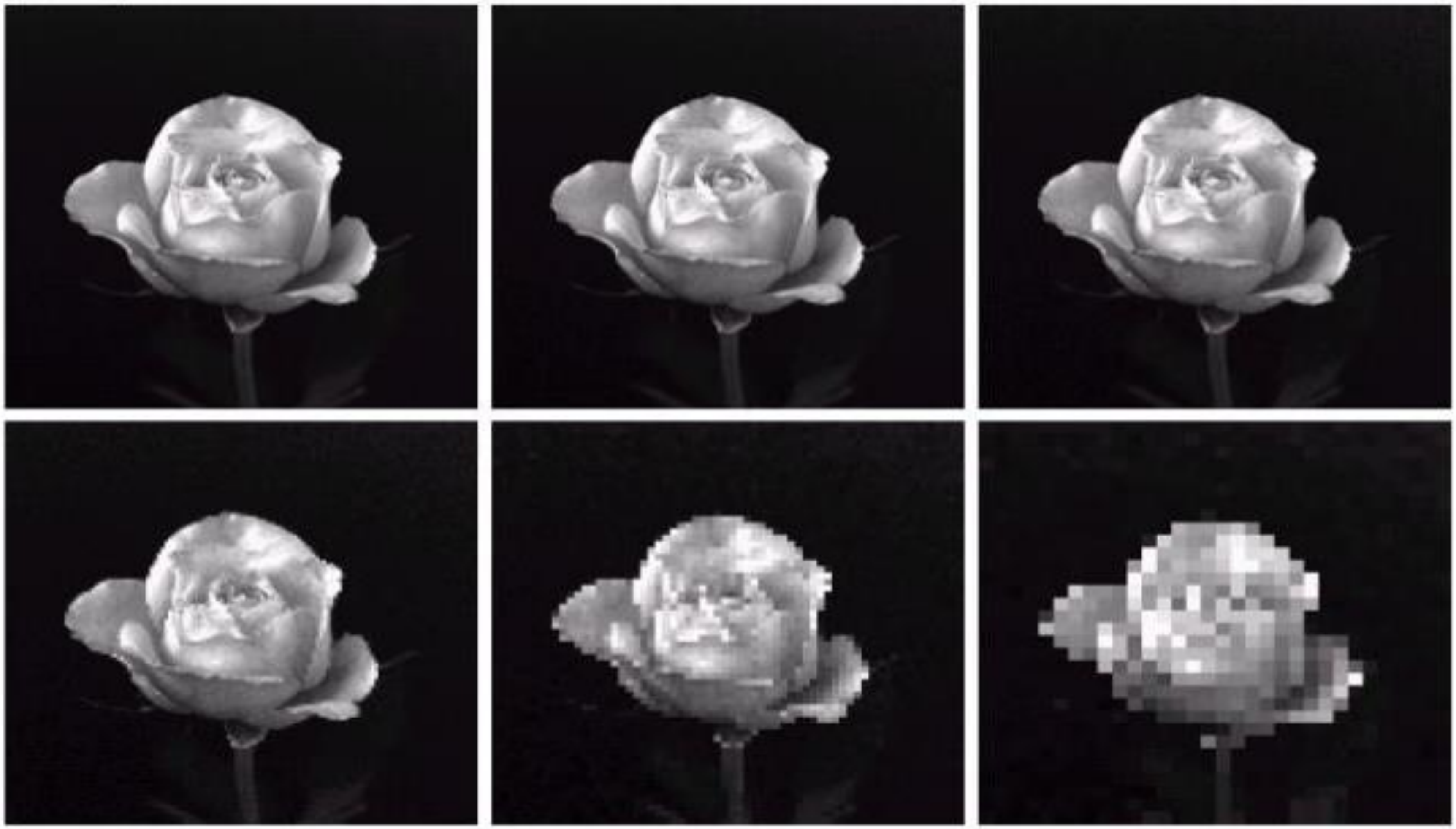
Sampling (cont..)

- Sampling is done in two ways: **Downsampling and Upsampling**
- **Downsampling** reduces the number of pixels in an image while **upsampling** increases the number of them.
- There are a variety of interpolation techniques that can be used for either process, such as nearest neighbour(pixel replication) or bilinear interpolation (zooming).
- Anti Aliasing filtering may also be used in order to reduce pixelation, which occurs when there are too few pixels in an image.
- Image sampling can drastically affect the perceived resolution of image by both increasing and decreasing their visual quality.

Sampling (cont..)

- If done properly with higher quality images, samples can easily be enlarged beyond their original resolution without losing much detail or sharpness.
- On the other hand, if low quality images are sampled and downscaled, it can significantly reduce their perceived resolution making them look fuzzy and distorted.
- Other than affecting resolution sampling allows for easier storage of large high resolution images while still retaining much of their original information such as colors, details and sharpness.
- **By adjusting the resolution of an image through sampling, it becomes possible to find the best balance between file size and image quality for different purposes and platforms.**

Effect of subsampling and resampling



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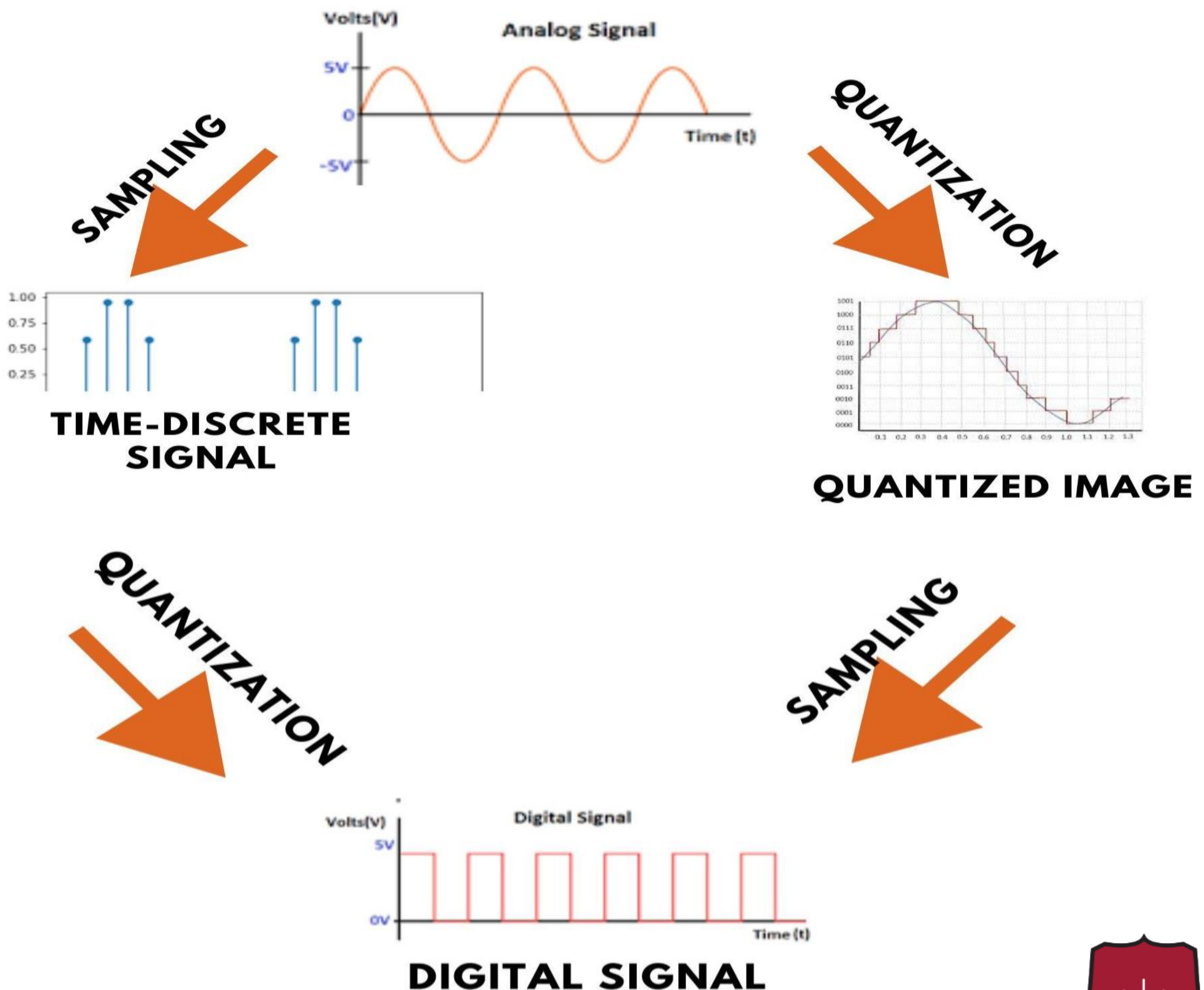
Lecture No: 5
Digitization – Quantization

Quantization

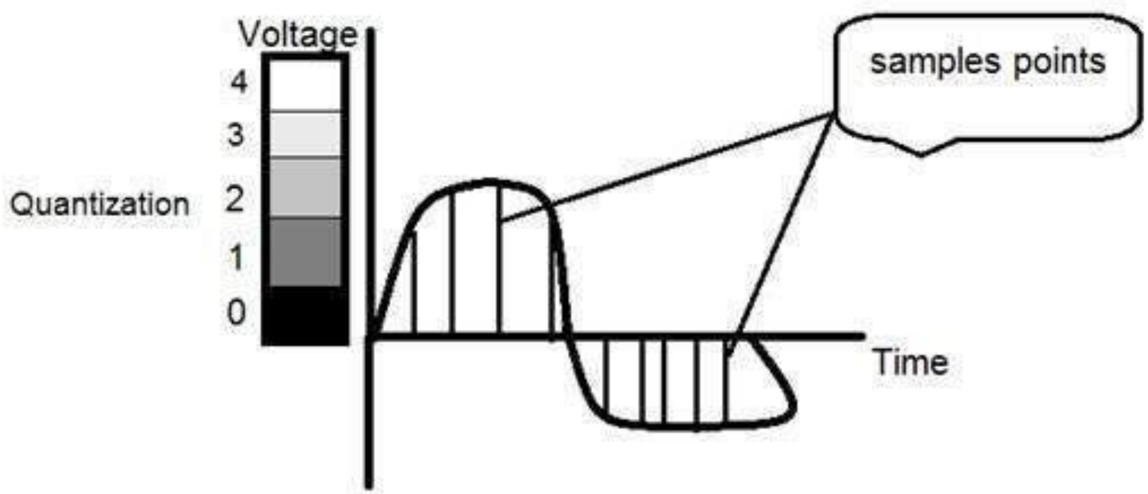
- Quantization is applied after sampling the analog signal.
- Quantization is opposite to sampling because it is done on “y axis” while sampling is done on “x axis”,
- Quantization is done by rounding off the amplitude of each sample and then assigning a different value according to its amplitude.
- Each value will represent a different color tone.
- In simple words, quantizing an image means dividing a signal into quanta(partitions).
- Bits are used to represent a pixel intensity, which is limited that is why quantization is needed.

Quantization (cont..)



Quantization (cont..)

- We can assign levels to the values generated by sampling process.
- In the image shown below, these vertically ranging values have been quantized into 5 different levels or partitions.
- Ranging from 0 black to 4 white.
- This level could vary according to the type of image.



Quantization (cont..)

- When we want to improve the quality of image, we can increase the levels assign to the sampled image.
- If we increase this level to 256, it means we have a gray scale image.
- Whatever the level which we assign is called as the gray level.
- If b-bits per pixel are used, then no. of quantization levels are calculated as,

No of Quantization levels, $k = 2^b$

Q. Need of Image Sampling and Quantization

- The output of image sensors is in the form of analog signal, hence we cannot apply digital image processing and image processing techniques on analog signals.
- Analog signal requires infinite memory to store a signal that can have infinite values.
- Thus we cannot store the output of image sensors.
- Hence we have to convert analog to digital signal and that is done by sampling followed by quantization.

Difference between Sampling and Quantization

Sampling	Quantization
Sampling establishes the number of pixels in a digital image.	Quantization establishes the color of each pixel.
Sampling digitalizes an analog signal's x-axis.	Quantization digitalizes its y-axis.
An analog signal's amplitude value is noted at predetermined intervals during sampling.	In quantization, the amplitude values are rounded off, and the values are given.
Sampling is carried out before quantization.	Quantization is carried out following sampling.
Expressed as pixels per inch (PPI) or dots per inch (DPI)	Usually measured in bits per channel (e.g., 8-bit color)
Sampling affects the sharpness and clarity of the image	Quantization affects the color richness of the image

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Thank You