Vivekananda
College of Engineering & Technology

Lecture Notes on

10CS762 /10IS762

Digital Image Processing

UNIT- 1 : THE DIGITIZED IMAGE AND ITS PROPERTIES

Contents

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1. Introduction to Digital Image Processing

1.1. General

- DIP refers to **Improvement** of pictorial information for **human** interpretation and **Processing** of image data for storage, transmission and representation for autonomous **machine** perception
- Humans Vision allows us to perceive and understand the world surrounding us. **Computer vision** aims to duplicate the effect of human vision by electronically perceiving and understanding an image.

1.2. Image, Digital Image

- Ideally, we think of an **image** as a 2D light intensity function f(x,y), where x and y are spatial coordinates. f at (x,y) is related to the brightness or color of the image at that point. Here x and y are to be continuous.
- A **digital image** is a 2D representation of a scene as a finite set of digital values, called picture elements or **pixels** or pels.

$$
f(x,y) = \begin{array}{cc} & \begin{array}{ccccc} 0 & 1 & 2 & & N-1 \end{array} \\ \begin{array}{c} 0 \\ 1 \\ \\ \\ \\ M-1 \end{array} & \begin{bmatrix} f(0,0) & f(0,1) & f(0,2) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & f(1,2) & \dots & f(1,N-1) \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ f(M-1,0) & & \dots & & f(M-1,N-1) \end{bmatrix} \end{array}
$$

Matrix Dimension = M x N

- A digital image can be considered a matrix whose row and column indices identify a **point** in the image and the corresponding matrix element value identifies the **gray level** at that point.
- Actual image is continuous. Convolution with the Dirac functions is used to sample the image.
- Digital image has a finite number of pixels and levels

	• **Define digital image processing. (2 Marks)** • **Briefly explain digital image and its representation (4 Marks)**

1.3. Levels of Image processing

- In order to simplify the task of computer vision understanding, three levels are usually distinguished; **low level**, **middle level** and **high level** image understanding.
    1. **Low level** methods usually use very little knowledge about the content of images. Low level processes involve primitive operations such as image preprocessing to reduce noise, contrast enhancement, and image sharpening. A low-level process is characterized by the fact that both its inputs and outputs are images.

2. **Mid-level processing** on images involves tasks such as segmentation (partitioning an image into regions or objects), description of those objects to reduce them to a form suitable for computer processing, and classification (recognition) of individual objects. A mid-level process is characterized by the fact that its inputs generally are images, but its outputs are attributes extracted from those images (e.g., edges, contours, and the identity of individual objects).
3. **High level processing** is based on knowledge, goals, and plans of how to achieve those goals. Artificial intelligence (AI) methods are used in many cases. High level computer vision tries to imitate human cognition and the ability to make decisions according to the information contained in the image. Higher-level processing involves "making sense" of an ensemble of recognized objects, as in image analysis, and, in addition, encompasses processes that extract attributes from images, up to and including the recognition of individual objects.

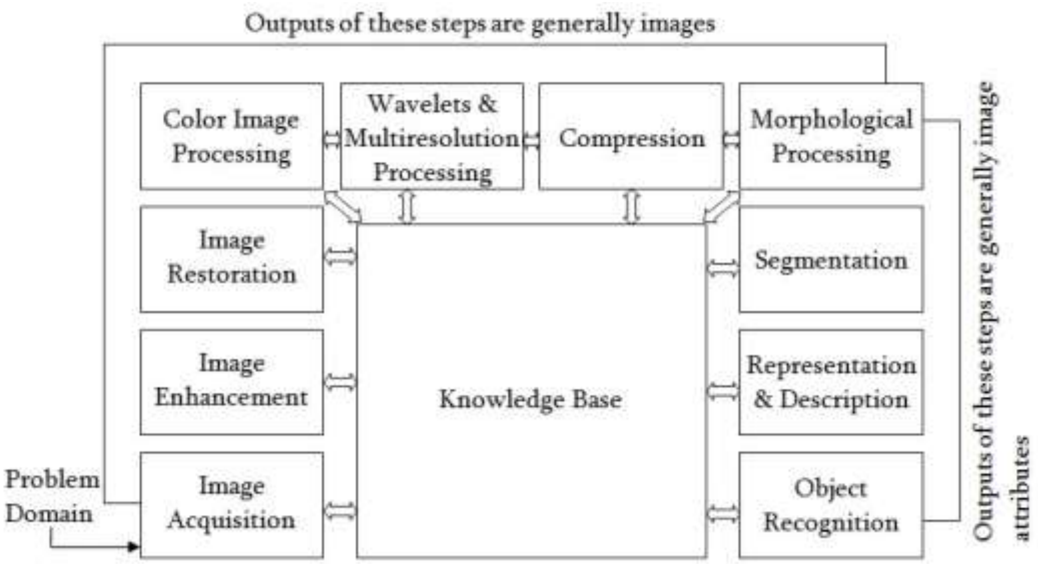
- This course (10CS762) deals almost exclusively with **low/middle level image processing.** Low level computer vision techniques overlap almost completely with digital image processing, which has been practiced for decades.
- As a simple illustration to clarify these concepts,

  Consider the area of automated analysis of text. The processes of acquiring an image of the area containing the text, preprocessing that image, extracting (segmenting) the individual characters, describing the characters in a form suitable for computer processing, and recognizing those individual characters are in the scope of what we call digital image processing.

- **Explain 3 levels of Image processing (6 Marks)**

1.4. Fundamental Stages

- The following are the **fundamental image processing steps**.



i. **Image Acquisition:** This is the first fundamental steps of digital image processing. An image is captured by a sensor (such as digital camera) and digitized. The image that is acquired is completely unprocessed and is the result of whatever sensor was used to generate it. The sensors generally use electromagnetic energy spectrum, acoustic or ultrasonic signals.

ii. **Image Enhancement:** The idea behind enhancement techniques is to bring out detail that is hidden, or simply to highlight certain features of interest in an image. Such as, changing brightness & contrast etc. Image enhancement is among the simplest and most appealing areas of digital image processing.

iii. **Image Restoration:** Image restoration is an area that also deals with improving the appearance of an image. However, unlike enhancement, which is subjective, image restoration is objective, in the sense that restoration techniques tend to be based on mathematical or probabilistic models of image degradation.

iv. **Color Image Processing:** This may include color modeling and processing in a digital domain etc. Color image processing is an area that has been gaining its importance because of the significant increase in the use of digital images over the Internet.

v. **Compression:** Compression deals with techniques for reducing the storage required to save an image or the bandwidth to transmit it. Particularly in the uses of internet it is very much necessary to compress data.

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

vii. **Segmentation:** Segmentation procedures partition an image into its constituent parts or objects. It extracts required potion of the image. In general, automatic segmentation is one of the most difficult tasks in digital image processing. A rugged segmentation procedure brings the process a long way toward successful solution of imaging problems that require objects to be identified individually.

viii. **Representation and Description:** Representation and description almost always follow the output of a segmentation stage, which usually is raw pixel data, constituting either the boundary of a region or all the points in the region itself. Choosing a representation is only part of the solution for transforming raw data into a form suitable for subsequent computer processing. Description deals with extracting attributes that result in some quantitative information of interest or are basic for differentiating one class of objects from another.

ix. **Object recognition:** Recognition is the process that assigns a label, such as "vehicle" to an object based on its descriptors.

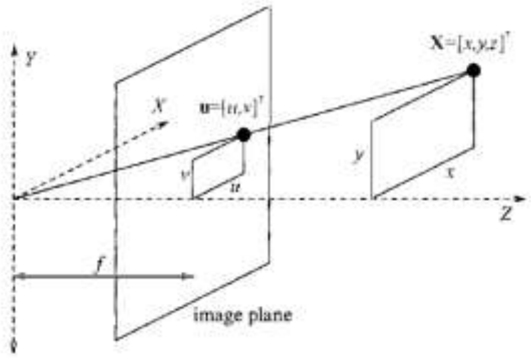
x. **Knowledge Base**: Knowledge may be as simple as detailing regions of an image where the information of interest is known to be located, thus limiting the search that has to be conducted in seeking that information. The knowledge base also can be quite complex, such as an interrelated list of all major possible defects in a materials inspection problem or an image database containing high-resolution satellite images of a region in connection with change-detection applications.

- **With a neat block diagram describe the various phases or fundamental stages of typical image processing system. (10 Marks)**

2. Basic Concepts

2.1. Image functions

- The **image** can be modeled by a continuous function of two or three variables; in the simple case arguments are co-ordinates x, y in a plane, while if images change in time a third variable t might be added.
- The image function values correspond to the brightness at image points. The **brightness** integrates different optical quantities.
- The image on the human eye retina or on a TV camera sensor is intrinsically 2D. We shall call such a 2D image bearing information about brightness points an **intensity image**.
- The real world which surrounds us is intrinsically 3D. The 2D intensity image is the result of a perspective projection of the 3D scene, which is modelled by the image captured by a pin-hole camera.



Perspective projection geometry

- When 3D objects are mapped into the camera plane by perspective projection a lot of information disappears as such a transformation is not one-to-one.
- How to understand image brightness? The only information available in an intensity image is brightness of the appropriate pixel, which is dependent on a number of independent factors such as object surface reflectance properties (given by the surface material, microstructure and marking), illumination properties, and object surface orientation with respect to a viewer and light source.
- Some scientific and technical disciplines work with 2D images directly; for example, an image of the flat specimen viewed by a microscope with transparent illumination, a character drawn on a sheet of paper, the image of a fingerprint, etc.
- Many basic and useful methods used in digital image analysis do not depend on whether the object was originally 2D or 3D.
- Image processing often deals with static images, in which time t is constant.
- A monochromatic static image is represented by a continuous image function f(x,y) whose arguments are two co-ordinates in the plane.
- The domain of the image function is a region R in the plane

$$R = \{(x, y),\ 1 \le x \le x_m,\ 1 \le y \le y_n\},$$

where x_m , y_n represent the maximal image co-ordinates.

- Computerized image processing uses digital image functions which are usually represented by matrices, so co-ordinates are integer numbers.
- The customary orientation of co-ordinates in an image is in the normal Cartesian fashion (horizontal x axis, vertical y axis), although the (row, column) orientation used in matrices is also quite often used in digital image processing.

2.2. The Dirac distribution and convolution

- An ideal **impulse** is an important input signal; for appreciating the use of linear mathematical theory in considering image function. The ideal impulse in the image plane is defined using the Dirac distribution $\delta(x, y)$,

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\delta(x,y)\,dx\,dy = 1 \quad \text{and} \quad \delta(x, y) = 0 \text{ for all } (x, y) \neq 0.$$

- The following equation is called the **'sifting property'** of the Dirac distribution; it provides the value of the function f(x , y) at the point (λ,μ)

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x-\lambda, y-\mu)\,dx\,dy = f(\lambda,\mu)$$

- The 'sifting equation' can be used to describe the sampling process of a continuous image function f(x,y).
- We may express the **image function** as a linear combination of Dirac pulses located at the points a, b that cover the whole image plane; samples are weighted by the image function f (x, y)

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(a,b)\delta(a-x, b-y)\,da\,db = f(x,y)$$

- **Convolution** is an important operation in the linear approach to image analysis. The convolution g of 2D functions f and h is denoted by f*h, and is defined by the integral

$$\begin{aligned} g(x,y) &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(a,b)h(x-a),y-b)\,da\,db \\ &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x-a),y-b)\,h(a,b)da\,db \\ &= (f*h)(x,y) = (h*f)(x,y) \end{aligned}$$

- In digital image analysis, the discrete convolution is expressed using sums instead of integrals. A digital image has a limited domain on the image plane. The convolution expresses a linear filtering process using the filter h; linear filtering is often used in local image pre-processing and image restoration.
- Linear operations calculate the resulting value in the output image pixel g(i,j) as a linear combination of image intensities in a local neighborhood *O* of the pixel f(i,j) in the input image. The contribution of the pixels in the neighborhood *O* is weighted by coefficients h

$$f(i,j) = \sum_{(m,n)\in O} h(i-m, j-n)g(m,n)$$

- Above Equation is equivalent to discrete convolution with the kernel h, which is called a **convolution mask**. Rectangular neighborhoods *O* arc often used with an odd number of pixels in rows and columns, enabling specification of the central pixel of the neighborhood.

2.3. The Fourier transform

- An image f(x,y) is a function of two parameters in a plane. The Fourier transform uses harmonic functions for the decomposition of the images.
- 2D Fourier transform is defined as,

$$F(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)e^{-2\pi i(xu+yu)}dx\,dy$$

  The inverse 2D – FT is defined as

$$f(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} F(u,v)e^{2\pi i(xu+yu)}du\,dv$$

- Parameters (x,y) denote coordinates and (u,v) are called spatial frequencies.
- Denoting FT by an operator, it can be denoted as $\mathcal{F}\{f(x,y)\} = F(u,v)$
- The following properties of the FT are interesting from the image processing point of view.
  - Linearity: $\mathcal{F}\{af_1(x,y) + bf_2(x,y)\} = aF_1(u,v) + bF_2(u,v)$
  - Shift of the origin in the image domain
  - Shift of the origin in the image domain
  - Symmetry: If f(x,y) is real valued, F(-u,-v)=F*(u,v)
  - Duality of the Convolution

3. Image digitization

- An image captured by a sensor is expressed as a continuous function f(x,y) of two co-ordinates in the plane.
- Image digitization means that the function f(x,y) is **sampled** into a matrix with M rows and N columns.
- The image **quantization** assigns to each continuous sample an integer value.
- The continuous range of the image function f(x,y) is split into K intervals.
- The finer the sampling (i.e., the larger M and N) and quantization (the larger K) the better the approximation of the continuous image function f(x,y).
- Two questions should be answered in connection with image function sampling:
  - First, the sampling period should be determined - the distance between two neighbouring sampling points in the image
  - Second, the geometric arrangement of sampling points (sampling grid) should be set.

3.1. Sampling

- A continuous image function f(x,y) can be sampled using a discrete grid of sampling points in the plane.
- The image is sampled at points x = j Δx, y = k Δy
- Two neighbouring sampling points are separated by distance Δx along the x axis and Δy along the y axis. Distances Δx and Δy are called the **sampling interval** and the matrix of samples constitutes the discrete image.
- The ideal sampling s(x,y) in the regular grid can be represented using a collection of Dirac distributions (Eq. 2.31)

$$s(x,y) = \sum_{j=1}^{M}\sum_{k=1}^{N} \delta(x - j\Delta x,\, y - k\Delta y) \qquad (2.31)$$

- The sampled image is the product of the continuous image f(x,y) and the sampling function s(x,y) (Eq. 2.32)

$$\begin{aligned} f_s(x,y) &= (f\,s)(x,y) \\ &= \sum_{j=1}^{M}\sum_{k=1}^{N} f(x,y)\,\delta(x - j\Delta x, y - k\Delta y) \\ &= f(x,y)\sum_{j=1}^{M}\sum_{k=1}^{N} \delta(x - j\Delta x, y - k\Delta y) \qquad (2.32) \end{aligned}$$

- The collection of Dirac distributions in equation 2.32 can be regarded as periodic with period x, y and expanded into a Fourier series (assuming that the sampling grid covers the whole plane (infinite limits)). (Eq. 2.33)

$$\sum_{j=-\infty}^{\infty}\sum_{k=-\infty}^{\infty} \delta(x - j\Delta x, y - k\Delta y) = \sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty} a_{mn}\, e^{2\pi i\left(\frac{mx}{\Delta x}+\frac{ny}{\Delta y}\right)} \qquad (2.33)$$

where the coefficients of the Fourier expansion can be calculated as given in Eq. 2.34

$$a_{mn} = \frac{1}{\Delta x\,\Delta y}\int_{-\frac{\Delta x}{2}}^{\frac{\Delta x}{2}}\int_{-\frac{\Delta y}{2}}^{\frac{\Delta y}{2}} \sum_{j=-\infty}^{\infty}\sum_{k=-\infty}^{\infty} \delta(x - j\Delta x, y - k\Delta y)\, e^{-2\pi i\left(\frac{mx}{\Delta x}+\frac{ny}{\Delta y}\right)} dx\,dy \qquad (2.34)$$

- Noting that only the term for j=0 and k=0 in the sum is nonzero in the range of integration, the coefficients are in Eq. 2.35

$$a_{mn} = \frac{1}{\Delta x\,\Delta y}\int_{-\frac{\Delta x}{2}}^{\frac{\Delta x}{2}}\int_{-\frac{\Delta y}{2}}^{\frac{\Delta y}{2}} \delta(x,y)\, e^{-2\pi i\left(\frac{mx}{\Delta x}+\frac{ny}{\Delta y}\right)} dx\,dy \qquad (2.35)$$

- Noting that the integral in equation 2.35 is uniformly equal to one the coefficients can be expressed as given in Eq. 2.36 and 2.32 can be rewritten as Eq. 2.37. In frequency domain then Eq. 2.38.

$$a_{mn} = \frac{1}{\Delta x \, \Delta y} \tag{2.36}$$

$$f_s(x,y) = f(x,y) \frac{1}{\Delta x \, \Delta y} \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} e^{2\pi i \left(\frac{mx}{\Delta x} + \frac{ny}{\Delta y}\right)} \tag{2.37}$$

$$F_s(u,v) = \frac{1}{\Delta x \, \Delta y} \sum_{j=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} F\left(u - \frac{j}{\Delta x}, v - \frac{k}{\Delta y}\right) \tag{2.38}$$

- Thus the Fourier transform of the sampled image is the sum of periodically repeated Fourier transforms F(u,v) of the image.
- Periodic repetition of the Fourier transform result F(u,v) may under certain conditions cause distortion of the image which is called **aliasing**; this happens when individual digitized components F(u,v) overlap.
- There is no aliasing if the image function f(x,y) has a band limited spectrum ... its Fourier transform F(u,v)=0 outside a certain interval of frequencies |u| > U; |v| > V.
- As you know from general sampling theory, overlapping of the periodically repeated results of the Fourier transform F(u,v) of an image with band limited spectrum can be prevented if the sampling interval is chosen according to Eq. 2.39

$$\Delta x < \frac{1}{2U}, \; \Delta y < \frac{1}{2V} \tag{2.39}$$

- This is the **Shannon sampling theorem** that has a simple physical interpretation in image analysis: The sampling interval should be chosen in size such that it is less than or equal to half of the smallest interesting detail in the image.
- The sampling function is not the Dirac distribution in real digitizers - narrow impulses with limited amplitude are used instead.
- As a result, in real image digitizers a sampling interval about ten times smaller than that indicated by the Shannon sampling theorem is used - because the algorithms for image reconstruction uses only a step function.
- Practical examples of digitization using a flatbed scanner and TV cameras help to understand the reality of sampling.
- A continuous image is digitized at sampling points.
- These sampling points are ordered in the plane and their geometric relation is called the **grid**.
- Grids used in practice are mainly square or hexagonal (Figure 2.4).

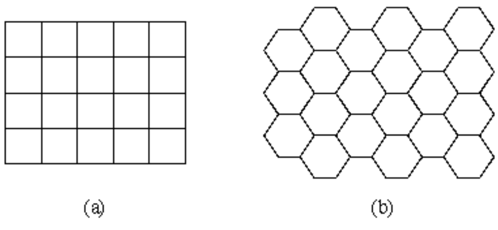


Figure 2.4 *(a) Square grid, (b) hexagonal grid.*

- One infinitely small sampling point in the grid corresponds to one picture element (pixel) in the digital image.
- The set of pixels together covers the entire image. Pixels captured by a real digitization device have finite sizes. The pixel is a unit which is not further divisible, sometimes pixels are also called points.

3.2 Quantization

- A magnitude of the sampled image is expressed as a digital value in image processing.
- Digitizing the amplitude values is called quantization
- It is related to number of gray/color values. Usually decided by the number of bits used to store the values
- The transition between continuous values of the image function (brightness) and its digital equivalent is decided during quantization.
- The number of quantization levels should be high enough for human perception of fine shading details in the image.
- Most digital image processing devices use quantization into k equal intervals.
- If b bits are used, the number of brightness levels is $k=2^b$.
- Eight bits per pixel are commonly used; specialized measuring devices use twelve and more bits per pixel.

The quality of a digital image grows in proportion to the spatial, radiometric, spectral and time resolution.

- The spatial resolution is given by the proximity of image samples in the image plane. (sampling)
- The radiometric resolution corresponds to the number of distinguishable gray levels. (Quantization)
- The spectral resolution is given by the bandwidth of the light frequencies captured by the sensor.
- The time resolution is given by the interval between time samples at which images are captured. Image processing often deals with static images, in which time t is constant.

3.3 Color images

- Color is a property of enormous importance to human visual properties. Human color perception adds a subjective layer on top of underlying objective physical properties- - the wavelength of electromagnetic radiation. Consequently, color may be considered a psychophysical phenomenon.
- Colors can be represented as combinations of the primary colors, e.g., red, green, and blue, which for the purposes of standardization have been defined as 700 nm, 546.1 nm, and 435.8nm, respectively
- The intensity of irradiation for different wavelengths λ usually changes. This variation is expressed by a power spectrum
- Sometimes, intensities measured in several narrow bands of wavelengths are collected in a vector describing each pixel. Each spectral band is digitized independently and is represented by an individual digital image function as if it were a monochromatic image. In this way, **multispectral images** are created. Multispectral images are commonly used in remote sensing from satellites, airborne sensors and in industry.
- Several different primary colors and corresponding color spaces are used in practice, and these spaces can be transformed into each other.

- The **RGB** color space has its origin in color television where Cathode Ray Tubes (CRT) were used.

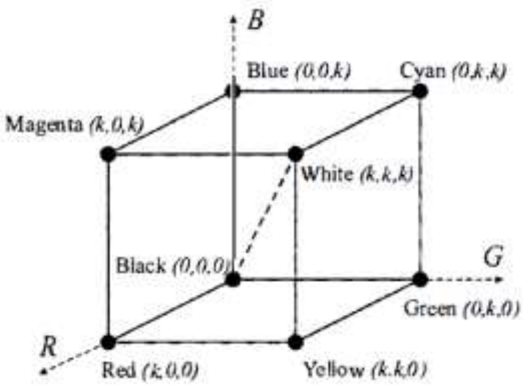


Figure 2.32: RGB color space with primary colors red, green, blue and secondary colors yellow, cyan, magenta. Gray-scale images with all intensities lie along the dashed line connecting black and white colors in RGB color space.

- The RGB model may be thought of as a 3D co-ordinatization of color space secondary colors which are combinations of two pure primaries
- The US and Japanese color television formerly used YIQ color space. The Y component describes intensity and I, Q represent color. YIQ is another example of additive color mixing. This system stores a luminance value with two chrominance values, corresponding approximately to the amounts of blue and red in the color. The YIQ color model is useful since the Y component provides all that is necessary for a monochrome display; further, it exploits advantageous properties of the human visual system, in particular our sensitivity to luminance, the perceived energy of a light source.

$$\begin{pmatrix} Y \\ I \\ Q \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

- **HSI** - Hue, Saturation, and Intensity is often used by painters because it is closer to their thinking and technique. HSI decouples intensity information front color, while hue and saturation correspond to human perception, thus making this representation very useful for developing image processing algorithms.

4. Digital image properties

4.1 Metric properties

- Some intuitively clear properties of continuous images have no straightforward analogy in the domain of digital images. **Distance** is an important example.
- The distance between two pixels in a digital image is a significant quantitative measure.
- The distance between points with co-ordinates (i,j) and (h,k) may be defined in several different ways;
    - the **Euclidean** distance is defined by

$$D_E\big((i,j),(h,k)\big) = \sqrt{(i-h)^2 + (j-k)^2}$$

    - **city block** distance is given by

$$D_4\big((i,j),(h,k)\big) = |i-h| + |j-k|$$

    - **chessboard** distance is given by

$$D_8((i,j),(h,k)) = max\ \{|i-h|,|j-k|\}$$

The Diagram (a) shows city block distance from central pixel to all other pixels in the neighborhood, whereas (b) shows chessboard distance.

4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

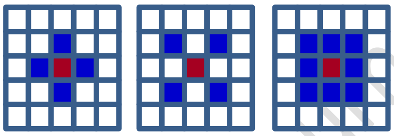
(a)

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

(b)

- **Explain different distance metrics used in image processing with example (9 marks)**

Neighbor of a Pixel: It can be four neighbor **N_4(p),** Diagonal neighbor **N_D(p)** or Eight neighbor **N_8(p)**



Adjacency

4-adjacency: Two pixels *p* and *q* with values from *V* are 4-adjacent if *q* is in the set $N_4(p)$.

8-adjacency: Two pixels *p* and *q* with values from *V* are 8-adjacent if *q* is in the set $N_8(p)$.

m-adjacency =(mixed): Two pixels *p* and *q* with values from *V* are m-adjacent if *q* is in $N_4(p)$ OR *q* is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixel whose values are from V (no intersection)

diagram

- It will become necessary to consider important sets consisting of several adjacent pixels - **regions**. Region is a contiguous set.
- Contiguity paradoxes of the square grid.

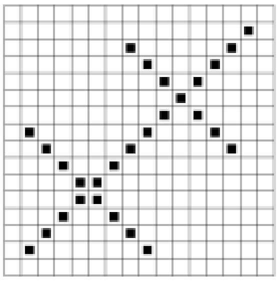


Figure 2.7 Digital line.

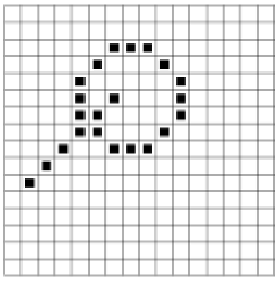


Figure 2.8 Closed curve paradox.

- These neighborhood and contiguity definitions on the square grid create paradoxes. Figure given above shows two digital line segments with 45° slope. If 4-connectivity is used, the lines are not contiguous at each of their points. An even worse conflict with intuitive understanding of line properties is also illustrated; two perpendicular lines do intersect in one case (upper right intersection) and do not intersect in another case (lower left), as they do not have any common point (i.e., their set intersection is empty) .

- One possible solution to contiguity paradoxes is to treat objects using 4-neighborhood and background using 8-neighborhood (or vice versa).
- A hexagonal grid solves many problems of the square grids ... any point in the hexagonal raster has the same distance to all its six neighbors.
- **Border** R is the set of pixels within the region that have one or more neighbors outside R ... **inner** borders, **outer** borders exist.
- **Edge** is a local property of a pixel and its immediate neighborhood --it is a vector given by a magnitude and direction.
- The **edge direction** is perpendicular to the gradient direction which points in the direction of image function growth.
- **Border and edge** ... the border is a global concept related to a region, while edge expresses local properties of an image function.
- **Crack edges** ... four crack edges are attached to each pixel, which are defined by its relation to its 4-neighbors. The direction of the crack edge is that of increasing brightness, and is a multiple of 90 degrees, while its magnitude is the absolute difference between the brightness of the relevant pair of pixels.

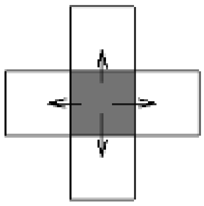


Figure 2.9 Crack edges.

4.2 Topological properties of digital images

- Topological properties of images are invariant to **rubber sheet transformations**.
- Stretching does not change contiguity of the object parts and does not change the number of holes in regions.
- One such image property is the Euler-Poincare characteristic defined as the difference between the number of regions and the number of holes in them.
- Convex hull is used to describe topological properties of objects.
- The convex hull is the smallest region which contains the object, such that any two points of the region can be connected by a straight line, all points of which belong to the region.

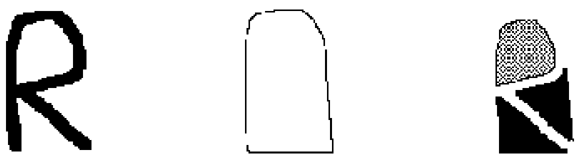


Figure 2.10 *Description using topological components: (a) An 'R' object, (b) its convex hull, (c) lakes and bays.*

- **Write a note on topological properties of an image. (6 Marks)**

4.3 Histogram

Brightness histogram provides the frequency of the brightness value z in the image. Histograms may have many local maxima. To remove this, histogram smoothing can be done.

Algorithm

1. Assign zero values to all elements of the array h.
2. For all pixels (x,y) of the image f, increment h(f(x,y)) by one.

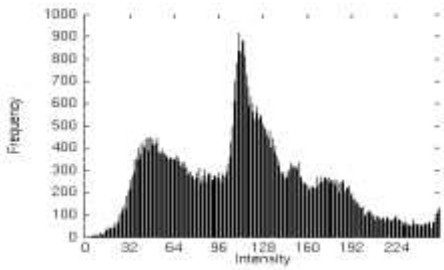


Figure 2.11 A brightness histogram.

4.4 Visual perception of the image

Anyone who creates or uses algorithms or devices for digital image processing should take into account the principles of human image perception. Humans will find objects in images only if they may be distinguished effortlessly from the background.

<u>Contrast</u>

- Contrast is the local change in brightness and is defined as the ratio between average brightness, of the object and the background.
- The sensitivity of human senses is roughly logarithmically proportional to the intensity of all input signal.
- Apparent Brightness depends very much on the brightness of the local surroundings; this effect is called conditional contrast.

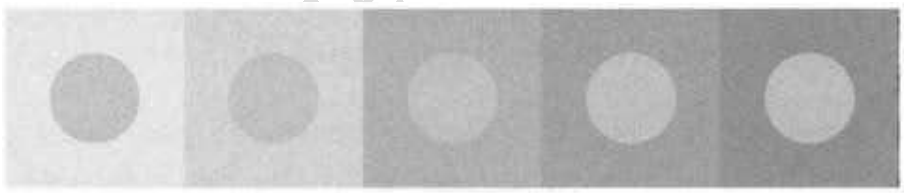


Figure: Conditional contrast effect. Circles inside squares have the same brightness and are perceived as having different brightness value.

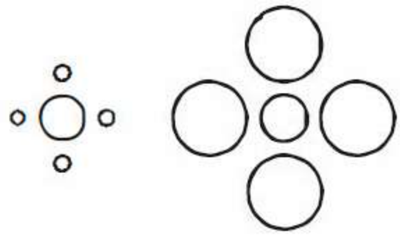
(Note: Do not try to draw above figure in the examination!!!)

<u>Acuity</u>

- Acuity is the ability to detect details in an image.
- The human eye is less sensitive to slow and fast changes in brightness in the image plane but is more sensitive to intermediate changes. Acuity also decreases with increasing distance from the optical axis.
- Resolution in an image is firmly bounded by the resolution ability of the human eye; there is no sense in representing visual information with higher resolution than that of the viewer. Resolution in optics is defined as the inverse value of a maximum viewing angle between the viewer and two proximate points which humans cannot distinguish, and so fuse together.

<u>Object borders</u>

- Object borders carry a lot of information for humans. Boundaries of objects and simple patterns such as blobs or lines enable adaptation effects similar to conditional contrast, mentioned above. The **Ebbinghaus illusion** is a well-known example. Two circles of the same diameter in the center of images appear to have different diameters. See the diagram.



Colors

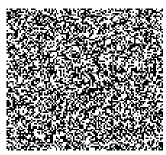
- Color is very important for perception, since under normal illumination conditions the human eye is more sensitive to color than to brightness.

- **Explain visual perception of image. (6 Marks)**

- An image might be degraded during capture, transmission, or processing, and measures of image quality can be used to assess the degree of degradation. The quality required naturally depends on the purpose for which an image is used. Methods for assessing image quality can be divided into two categories: subjective and objective.
- **Subjective methods** are often used in television technology, where the ultimate criterion is the perception of a selected group of professional and lay viewers. They appraise an image according to a list of criteria and give appropriate marks.
- In **objective quantitative** method the quality of the image I(x, y) is usually estimated by comparison with a known reference image g(x, y). A synthesized image is often used for this purpose.
- Another class measures the resolution of small or proximate objects in the image. An image consisting of parallel black and white stripes is used for this purpose; then the number of black and white pairs per millimeter gives the resolution.
- Measures of image similarity are also important since they are used in assisting retrieval from image databases.

4.6 Noise in images

- Images are often degraded by random noise. Noise can occur during image capture, transmission or processing, and may be dependent on or independent of image content. During image transmission, noise which is usually independent of the image signal occurs.



- Noise is usually described by its probabilistic characteristics.
- **White noise -** constant power spectrum (its intensity doesn't decrease with increasing frequency); It is a very crude approximation of image noise
- **Gaussian noise** is a very good approximation of noise that occurs in many cases
  - probability density of the random variable is given by the Gaussian curve;
  - 1D Gaussian noise - μ is the mean and is the standard deviation of the random variable.

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

- Noise may be **additive**, noise v and image signal g are independent $$f(x,y) = g(x,y) + \nu(x,y)\,,$$

  multiplicative, noise is a function of signal magnitude

  $$f = g + \nu g = g(1+\nu) \approx g\nu$$

  impulse noise (saturated = salt and pepper noise)

  An image with salt and pepper noise.


- **Define noise. Describe various noise models. (6/8 Marks)**

  OR
- **Explain any two models of noise that can distort an image and by which the quality of an image can be assessed. (6 marks)**

Questions and Answers

1. Define image. Explain the steps involved in image digitization. OR Discuss the procedure of sampling and quantization

- A **digital image** is a 2D representation of a 3D image or a scene as a finite set of digital values, called picture elements or pixels or pels. DIP refers to **Improvement** of pictorial information for **human** interpretation and Processing of image data for storage, transmission and representation for autonomous **machine** perception.
- A digital image can be considered a matrix whose row and column indices identify a **point** in the image and the corresponding matrix element value identifies the **gray level** at that point.
- Image digitization means that the function f(x,y) is **sampled** into a matrix with M rows and N columns. The image **quantization** assigns to each continuous sample an integer value.

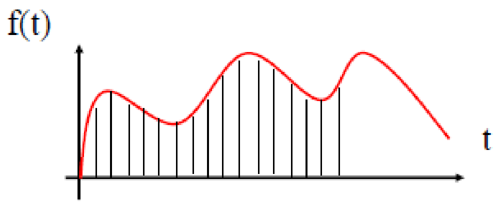
$$
f(x,y) = \begin{array}{c|ccccc|}
 & 0 & 1 & 2 & & N-1 \\
\hline
0 & f(0,0) & f(0,1) & f(0,2) & \dots & f(0,N-1) \\
1 & f(1,0) & f(1,1) & f(1,2) & \dots & f(1,N-1) \\
 & \vdots & & & & \vdots \\
M-1 & f(M-1,0) & & \dots & & f(M-1,N-1)
\end{array}
$$

Matrix Dimension = M x N

Sampling

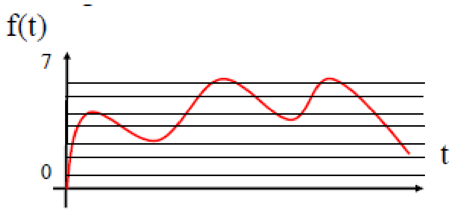
- Digitizing the coordinate values is called sampling. Actual image coordinates are continuous. Convolution with the Dirac functions is used to sample the image.
- The spacing between the pixels are determined during sampling
- This also defines No. of pixels per unit area i.e. Resolution of the image. Sampling rate determines - How many samples are taken in unit dimension

- Different cameras will capture same scene with different size/sampling rate. Higher the size, more resolution, more quality
- Sampling of 1D signal is shown here.



Quantization

- Digitizing the amplitude values is called quantization. The transition between continuous values of the image function (brightness) and its digital equivalent is decided during quantization.
- It is related to number of gray/color values used in the image. The number of quantization levels should be high enough for human perception of fine shading details in the image.
- Most digital image processing devices use quantization into k equal intervals. If b bits are used. The number of brightness levels is $k=2^b$.
- Suppose if we use 8-bit per pixel, 2^8 = 256 gray values (0-255) can be used to represent the image.
- Quantization of 1D signal into 7 levels is shown here.



2. Write an algorithm for generation of additive zero mean Gaussian noise.

Algorithm 2.3: Generate additive, zero mean Gaussian noise

1. Select a value for σ; low values generate less noise effect.
2. If the image gray-level range is $[0, G-1]$, calculate
$$p[i] = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-i^2}{2\sigma^2}} \qquad i = 0, 1, \ldots, G-1$$
3. For each pixel (x, y), of intensity $g(x, y)$, generate a random number q_1 in the range $[0, 1]$. Determine
$$j = \operatorname{argmin}_i (q_1 - p[i])$$
4. Generate a random number (sign) q_2 from the set $\{-1,1\}$. Set $f^*(x, y) = g(x, y) + q_2 j$.
5. Set
$$\begin{aligned} f(x,y) &= 0 && \text{if } f^*(x,y) < 0 \\ f(x,y) &= G-1 && \text{if } f^*(x,y) > G-1 \\ f(x,y) &= f^*(x,y) && \text{otherwise} \end{aligned} \tag{2.47}$$
6. Go to 3 until all pixels have been scanned.

*****