Digital Image Processing

Unit 1: Introduction

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A SIMPLE IMAGE FORMATION MODEL

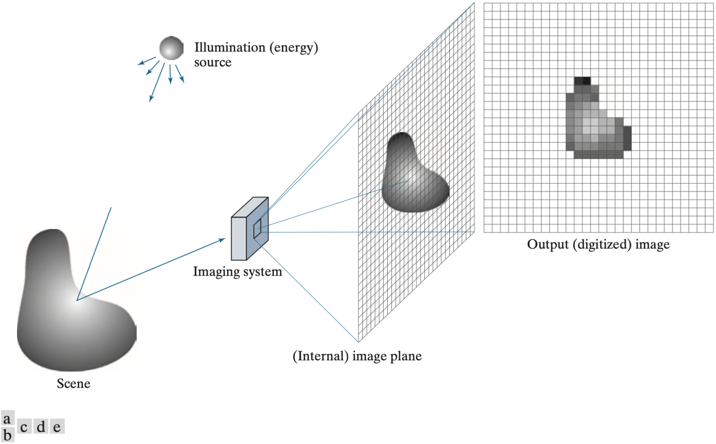


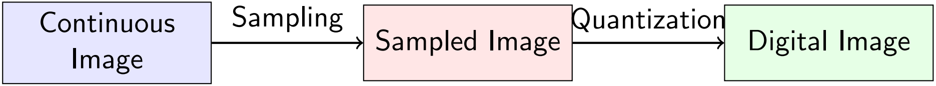
Figure: An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Basic Concepts in Sampling and Quantization

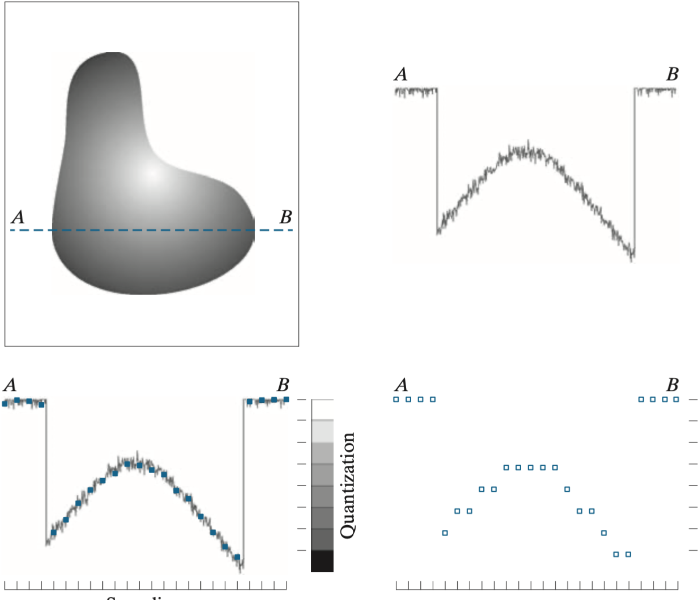
Digitization Process

Converting continuous images into digital form requires two operations:

1. **Sampling**: Digitizing spatial coordinates (x, y)
2. **Quantization**: Digitizing amplitude (intensity) values



SAMPLING AND QUANTIZATION



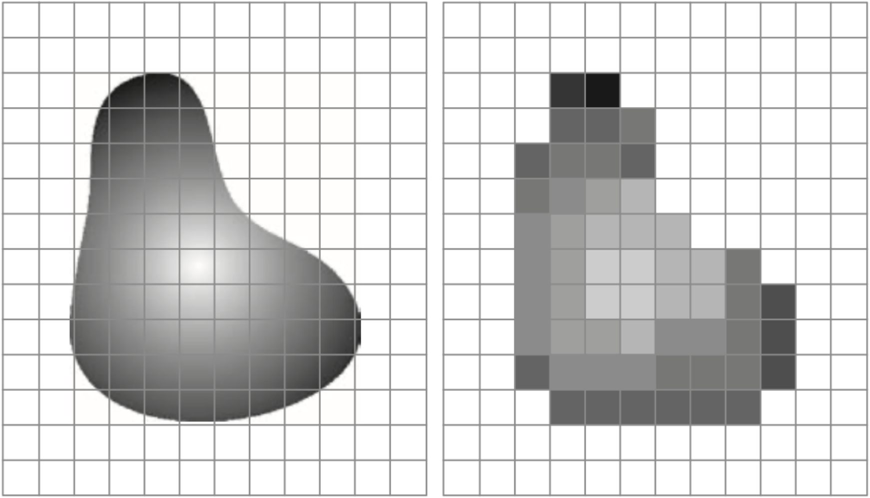


Figure: (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Spatial and Gray-Level Resolution

Spatial Resolution:

- Determined by the number of samples in the image
- Measured in pixels per inch (ppi) or dots per inch (dpi)
- Higher resolution = more detail captured
- Common resolutions: 256×256, 512×512, 1024×1024, 1920×1080

Gray-Level Resolution:

- Determined by the number of bits used to represent intensity
- 1 bit = 2 levels (binary), 8 bits = 256 levels, 16 bits = 65,536 levels
- More bits = smoother intensity transitions
- Typical: 8 bits per pixel for grayscale images

Representing Digital Images

An $M \times N$ digital image can be represented as:

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

- M rows, N columns
- Each element $f(x,y)$ is the intensity at position (x,y)
- For 8-bit grayscale: $f(x,y) \in [0,255]$
- Total storage: $M \times N \times b$ bits (where $b =$ bits per pixel)

Pixel Neighbors

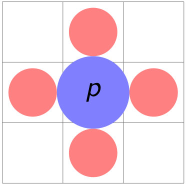
4-Neighbors (N_4):
Horizontal and vertical neighbors

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

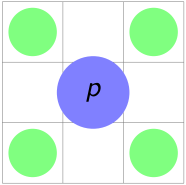
Diagonal Neighbors (N_D):
Diagonal neighbors

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

4-neighbors



Diagonal neighbors



8-Neighbors (N_8): $N_4(p) \cup N_D(p)$

Adjacency

Two pixels are adjacent if they satisfy two conditions:

1. They are neighbors
2. Their gray levels satisfy a specified criterion of similarity

Types of Adjacency:

- **4-adjacency**: Two pixels p and q are 4-adjacent if $q \in N_4(p)$
- **8-adjacency**: Two pixels p and q are 8-adjacent if $q \in N_8(p)$
- **m-adjacency (mixed)**: $q \in N_4(p)$, or $q \in N_D(p)$ and $N_4(p) \cap N_4(q)$ has no pixels with values from V

Used to avoid ambiguities in path definitions and region connectivity.

Connectivity

Definition

A path from pixel p with coordinates (x, y) to pixel q with coordinates (s, t) is a sequence of distinct pixels with coordinates:

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

where $(x_0, y_0) = (x, y)$, $(x_n, y_n) = (s, t)$, and pixels (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 \leq i \leq n$.

Connected Components:

- A region is connected if there is a path between any two pixels in the region
- Two regions are adjacent if they share a boundary

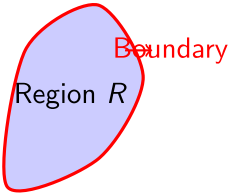
Regions and Boundaries

Region R:

- A connected set of pixels
- Can be defined by property P
- All pixels in R satisfy P

Boundary (Border, Contour):

- Set of pixels in region with neighbors outside region
- Inner boundary: inside the region
- Outer boundary: outside the region



Foreground and Background:

- Foreground: region of interest
- Background: complement of foreground

Distance Measures Between Pixels

For pixels p, q, and z with coordinates (x, y), (s, t), and (u, v):

Euclidean Distance:

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

City-Block (Manhattan) Distance:

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

Chessboard Distance:

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

These distances satisfy standard metric properties: $D(p, q) \geq 0$, $D(p, q) = D(q, p)$, $D(p, z) \leq D(p, q) + D(q, z)$

Key Takeaways from Unit 1

1. **Digital Image**: 2D function $f(x, y)$ with discrete values
2. **Image Processing System**: Acquisition $\rightarrow$ Processing $\rightarrow$ Analysis $\rightarrow$ Output
3. **Human Vision**: Eye structure, adaptation, and perception principles
4. **Digitization**: Sampling (spatial) and quantization (intensity)
5. **Image Representation**: Matrix form with $M \times N$ pixels
6. **Pixel Relationships**:
   - Neighbors: 4-connected, 8-connected
   - Adjacency and connectivity
   - Regions and boundaries
   - Distance measures

Learning Objectives Achieved

Upon completion of this unit, you should be able to:

- ✓ Understand the concept of a digital image
- ✓ Know the fundamentals of the electromagnetic spectrum
- ✓ Understand the definition and scope of digital image processing
- ✓ Have a broad overview of the historical underpinnings
- ✓ Be aware of different fields where DIP is applied
- ✓ Be familiar with basic image processing processes
- ✓ Be familiar with components of a general-purpose DIP system
- ✓ Understand visual perception elements

Questions?