Introduction to Computer Vision

Image Processing Fundamentals

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Lecture Outline

Computer Vision

- Computer Vision enables machines to **see, analyze, and understand images**
- Core tasks:
  - Image processing
  - Feature extraction
  - Object detection
  - Image classification

Image as a Matrix

- A grayscale image is a 2D matrix:

$$I(x, y) \in [0, 255]$$

$$\boldsymbol{I} = \begin{bmatrix} 52 & 55 & 61 \\ 63 & 59 & 55 \\ 70 & 61 & 64 \end{bmatrix}$$

- Each value represents pixel intensity
- Color images use 3 channels (RGB)

Color Images

$$\boldsymbol{I}(x, y) = \begin{bmatrix} R(x, y) \\ G(x, y) \\ B(x, y) \end{bmatrix}$$

- Each channel is a matrix
- Stored as a 3D array: height $\times$ width $\times$ 3

Image Filtering

- Filtering modifies pixel values using neighbors
- Used for:
  - Noise reduction
  - Smoothing
  - Edge enhancement

Convolution Operation

$$I'(x,y) = \sum_{i=-k}^{k} \sum_{j=-k}^{k} I(x+i, y+j)\, K(i,j)$$

- K is a kernel (filter)
- Applied to every pixel

Common Filters

Mean Filter

$$K = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Gaussian Filter

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Edges in Images

- Edges correspond to **intensity changes**
- Detected using image gradients

Image Gradient

$$\nabla I = \begin{bmatrix} \frac{\partial I}{\partial x} \\ \frac{\partial I}{\partial y} \end{bmatrix}$$

$$|\nabla I| = \sqrt{G_x^2 + G_y^2}$$

- High gradient magnitude $\Rightarrow$ edge

Sobel Operator

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

- Approximates image derivatives

What Is Image Classification?

- Assigning a label to an image
- Examples:
  - Cat vs Dog
  - Tumor vs Normal
  - Road sign recognition

Image as Feature Vector

- Image is flattened into a vector:

$$\boldsymbol{x} = [p_1, p_2, \ldots, p_n]$$

- Classifier learns mapping:

$$f(\boldsymbol{x}) = y$$

Classification Pipeline

1. Image acquisition
2. Preprocessing
3. Feature extraction
4. Classification model

Summary

- Images are numerical matrices
- Filtering modifies local neighborhoods
- Edges are detected via gradients
- Classification assigns semantic meaning