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BCA Honours | Semester VI | BCA6EJ303(1)

Advanced Digital Image Processing and Computer Vision

Module 3 Comprehensive Notes

Module 3: Morphological Image Processing and Image Segmentation

Morphological operations extract structural components using mathematical set theory, while image segmentation partitions an image into constituent regions or objects.

3.1 Mathematical Morphology and Structuring Elements

Binary morphological operations process an image A using a compact probe geometry called a **Structuring Element (SE)** B:

- **Dilation ($A \oplus B$):** Expands boundaries of foreground regions:

$$A \oplus B = \{z \mid (\hat{B})_z \cap A \mathrel{!}= \emptyset\}$$

- **Erosion ($A \ominus B$):** Shrinks boundaries of foreground regions, eliminating protrusions and small noise:

$$A \ominus B = \{z \mid (B)_z \subseteq A\}$$

- **Opening ($A \circ B = (A \ominus B) \oplus B$):** Erosion followed by dilation. Smooths object contours, breaks thin isthmuses, and removes small protrusions.
- **Closing ($A \cdot B = (A \oplus B) \ominus B$):** Dilation followed by erosion. Smooths contours, fuses narrow breaks, and fills small holes.

3.2 Image Segmentation Techniques

1. Edge Detection: The Canny Edge Detector

The Canny detector is an optimal edge detection algorithm consisting of five multi-stage steps:

1. **Gaussian Smoothing:** Convolve image with a 2D Gaussian filter to suppress noise.
2. **Gradient Computation:** Compute gradient magnitude $M(x,y) = \sqrt{G_x^2 + G_y^2}$ and direction $\theta(x,y) = \arctan(G_y/G_x)$ using Sobel operators.
3. **Non-Maximum Suppression (NMS):** Thin broad edge ridges by preserving only local gradient maxima along the gradient direction.
4. **Double Thresholding:** Classify pixels using high threshold T_{high} (strong edges) and low threshold T_{low} (weak edges).
5. **Hysteresis Edge Tracking:** Retain weak edge pixels if and only if they are connected to strong edge pixels.

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2. Global Optimal Thresholding: Otsu's Method

Otsu's algorithm automatically determines an optimal global threshold k^* that maximizes between-class variance $\sigma_B^2(k)$ between foreground and background pixels:

$$\sigma_B^2(k) = \frac{[m_G P_1(k) - m(k)]^2}{P_1(k)[1 - P_1(k)]}$$

Where: *P_1(k)* is cumulative class probability, *m(k)* is cumulative mean, and *m_G* is global image mean.

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1. Architectural Trade-offs and Computational Complexity

Software architects and systems engineers designing scalable computational pipelines centered on Advanced Digital Image Processing and Computer Vision must methodically navigate core trade-offs:

- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 3 Core Concepts and Methods, pre-computing intermediate lookup tables, spatial indices, and hashing structures achieves near-instantaneous $O(1)$ query latency, but inflates the physical memory footprint. Conversely, in-place algorithms minimize RAM utilization at the cost of higher CPU cycle counts. Modern architectures dynamically calibrate memory allocations using memory-mapped files and cache-aware structures.
- **Concurrency Scalability versus Thread Contention:** While multi-core hardware allows horizontal execution, concurrent modifications to shared state structures create severe lock contention, thread synchronization bottlenecks, and cache line invalidation storms. High-performance frameworks deploy lock-free algorithms, optimistic concurrency control, and atomic compare-and-swap (CAS) primitives.
- **Algorithmic Determinism versus Heuristic Scalability:** Exact mathematical algorithms frequently encounter NP-hard combinatorial barriers as problem dimensions scale. Contemporary systems bridge this gap by deploying bounded approximation algorithms and meta-heuristics that produce near-optimal solutions within guaranteed execution time windows.

2. Empirical Comparative Framework

A structured comparative assessment clarifies operational distinctions across conventional paradigms and modern production implementations in Advanced Digital Image Processing and Computer Vision:

Evaluation Dimension	Conventional Traditional Approach	Contemporary Integrated Paradigm	Strategic Impact Metric
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3. Production Implementation Patterns and Resilience Engineering

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