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BCA Honours | Semester VI | BCA6EJ304(1)

Applied Digital Image Processing

Module 2 Comprehensive Notes

Module 2: Document Image Analysis and Optical Character Recognition (OCR)

Document Image Analysis (DIA) transforms physical scanned paper documents, engineering blueprints, and historical manuscripts into editable, searchable digital formats.

2.1 Document Pre-processing and Adaptive Binarization

Scanned documents frequently suffer from non-uniform illumination, ink bleed-through, and paper aging. Global thresholding (Otsu) fails in the presence of illumination gradients, requiring **Local Adaptive Binarization**:

- **Sauvola's Adaptive Thresholding:**

$$T(x,y) = m(x,y)\,[1 + k\,(\frac{s(x,y)}{R} - 1)]$$

Where: $m(x, y)$ and $s(x, y)$ are local mean and standard deviation in a local window, R is dynamic range of standard deviation, and $k \approx 0.2 - 0.5$.

Where: σ (or s) = Standard deviation (square root of variance), measuring dispersion of data relative to the mean.

2.2 Skew Detection and Page Layout Analysis

- **Skew Correction:** Document pages rotated during scanning are corrected using the Radon Transform or Projection Profile method: calculating horizontal pixel projection histograms across angles and selecting the angle that maximizes projection variance.
- **Page Layout Decomposition:** Segmenting the document into semantic functional zones (titles, columns, paragraphs, tables, images) using the **Run-Length Smearing Algorithm (RLSA)** and Recursive X-Y Cut partitioning.

2.3 The Optical Character Recognition (OCR) Engine

The OCR pipeline extracts text line baselines, isolates individual glyphs, extracts invariant geometrical features (topological loops, stroke crossings, zoning matrices), and classifies characters using deep neural networks (CNN-LSTM networks with Connectionist Temporal Classification loss in modern Tesseract 5.0 engines).

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- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 2 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 Applied Digital Image Processing:

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Resilience & Failover	Manual failover mechanisms requiring operator intervention and scheduled downtime.	Automated self-healing clusters with dynamic health checking and zero-downtime rolling deployments.	Continuous availability meeting strict 99.999% Service Level Agreements (SLAs).
System Telemetry & Auditing	Passive log file aggregation with retrospective forensic analysis.	Distributed tracing, structured metrics collection, and real-time observability telemetry.	Proactive bottleneck resolution and sub-second mean time to detection (MTTD).

3. Production Implementation Patterns and Resilience Engineering

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