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BCA Honours | Semester VI | BCA6EJ304(1)

Applied Digital Image Processing

Module 1 Comprehensive Notes

Module 1: Medical Image Processing and Diagnostic Radiography

Medical image processing applies digital filtering, tissue segmentation, and multi-modal registration to diagnostic radiology, aiding clinical decision-making and computer-assisted interventions.

1.1 Medical Imaging Modalities and Physical Acquisition Principles

- **Computed Tomography (CT):** Employs rotating X-ray tube and detector arrays. The **Radon Transform** captures projection line integrals across angles θ. **Filtered Back-Projection (FBP)** reconstructs slice cross-sections calibrated in **Hounsfield Units (HU)**, where water $= 0$ HU, air $= -1000$ HU, and bone $\approx +1000$ HU.
- **Magnetic Resonance Imaging (MRI):** Aligns hydrogen proton nuclear spins in a strong static magnetic field B_0. Radio-frequency pulses excite spins; relaxation times (T_1 longitudinal spin-lattice and T_2 transverse spin-spin relaxation) are encoded in k-space via gradient magnetic fields and reconstructed via 2D inverse Fourier transformation.
- **Diagnostic Ultrasound:** Transmits high-frequency acoustic waves ($2–15$ MHz) via piezoelectric transducers, measuring reflected pulse-echo time delays and acoustic impedance mismatches between tissues. Prone to multiplicative speckle noise.

1.2 Pre-processing and Contrast Enhancement in Diagnostic Radiography

Medical images require contrast tuning for tissue differentiation. In CT imaging, **Windowing (Window Level and Window Width)** maps selected sub-ranges of Hounsfield units to 8-bit display brightness, highlighting soft tissue, lung parenchyma, or bone structures.

1.3 Anatomical Segmentation and Computer-Aided Diagnosis (CAD)

Automated clinical segmentation isolates pathological lesions from healthy anatomy:

- **Brain Tumor Segmentation:** Delineating glioblastoma boundaries from multi-sequence MRI (T_1, T_2, FLAIR) using deep convolutional architectures (such as the 3D U-Net).
- **Retinal Vessel Segmentation:** Tracking blood vessels in fundus camera imagery for diabetic retinopathy screening using Gabor wavelet filters and ridge tracking.

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- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 1 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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