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BCA Honours | Semester VI | BCA6EJ304(2)

Internet of Things

Module 4 Comprehensive Notes

Module 4: Embedded Platforms, Cloud Analytics, and IoT Security

IoT systems connect physical microcontrollers and single-board computers to cloud analytics engines while maintaining security against network vulnerabilities.

4.1 Hardware Prototyping Platforms: Arduino vs. Raspberry Pi

Evaluation Dimension	Arduino Platform (e.g., Uno)	Raspberry Pi Platform (e.g., Model 4B)
Processing Architecture	8-bit AVR Microcontroller (Atmega328P, 16 MHz)	64-bit Quad-Core ARM Cortex-A72 Microprocessor (1.5 GHz)
Operating System	None (Bare-metal firmware execution)	Full Linux OS (Raspberry Pi OS / Ubuntu)
Memory	2 KB SRAM, 32 KB Flash memory	2 GB to 8 GB LPDDR4 SDRAM, MicroSD storage
Optimal Use Case	Real-time analog sensor reading, motor control, simple loops.	Computer vision, edge AI inference, IoT gateway coordination.

4.2 IoT Security Vulnerabilities and Mitigation Best Practices

- **Common Attack Vectors:** Hardcoded default credentials, unencrypted network communications, lack of firmware integrity verification, and physical device tampering.
- **Security Frameworks:** Transport Layer Security (TLS/DTLS) for network encryption, hardware Root of Trust (secure boot, TPM chips), authenticated over-the-air (OTA) cryptographic firmware updates, and mutual client-certificate authentication.

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1. Architectural Trade-offs and Computational Complexity

Software architects and systems engineers designing scalable computational pipelines centered on Internet of Things must methodically navigate core trade-offs:

- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 4 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.

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- **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 Internet of Things:

Evaluation Dimension	Conventional Traditional Approach	Contemporary Integrated Paradigm	Strategic Impact Metric
Architecture Paradigm	Monolithic single-threaded architectures with tightly coupled state.	Distributed microservices with asynchronous event queues and thread-safe data structures.	Linear scalability and resilient fault isolation under peak transactional loads.
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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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- **State Immutability and Event Sourcing:** Maintaining an append-only log of immutable state changes guarantees verifiable auditability, eliminates data race hazards, and facilitates seamless system recovery.
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