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BCA Honours | Semester V | Calicut University

Object Oriented Programming (Java)

Course Code: BCA5CJ301 • Module 3 Notes

MODULE III: MULTITHREADING AND CONCURRENCY IN JAVA

1. Thread Life Cycle, Synchronization, and Deadlocks

A thread is a lightweight sub-process representing the smallest unit of dispatchable execution. In Java, threads progress through six lifecycle states: `NEW`, `RUNNABLE`, `BLOCKED`, `WAITING`, `TIMED_WAITING`, and `TERMINATED`.

When multiple threads access shared mutable state concurrently, race conditions corrupt data. The `synchronized` keyword enforces mutual exclusion using the intrinsic lock (monitor) associated with every Java object.

2. Illustrative Computational Working: Step-by-Step Numerical Example

Worked Example: Amdahl's Law Speedup & Concurrency Scaling Calculation

Problem Statement:

A computational financial analytics module spends 80% of its execution time performing parallelizable Monte Carlo simulation tasks, while the remaining 20% consists of strictly sequential I/O and database commit operations.

Calculate: (a) The theoretical maximum speedup possible using Amdahl's Law with 4 processor cores, (b) The speedup with 16 processor cores, and (c) The theoretical speedup limit as the number of processor cores approaches infinity ($N \to \infty$).

Solution & Step-by-Step Working:

Amdahl's Law defines speedup $S(N)$ for N processors with parallel fraction P and sequential fraction $(1 - P)$:

$$S(N) = \frac{1}{(1-P) + \frac{P}{N}}$$

Given: $P = 0.80$, Sequential fraction $(1 - P) = 0.20$.

1. Speedup with $N = 4$ Cores:

$$S(4) = \frac{1}{0.20 + \frac{0.80}{4}} = \frac{1}{0.20 + 0.20} = \frac{1}{0.40} = \mathbf{2.50\times}$$

2. Speedup with $N = 16$ Cores:

$$S(16) = \frac{1}{0.20 + \frac{0.80}{16}} = \frac{1}{0.20 + 0.05} = \frac{1}{0.25} = \mathbf{4.00\times}$$

3. Theoretical Speedup Limit ($N \to \infty$):

$$lim_{N\to\infty} S(N) = \frac{1}{1-P} = \frac{1}{0.20} = \mathbf{5.00\times}$$

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Key Insight: Regardless of how many hundreds of cores are provisioned, the application can never exceed a 5x speedup due to the 20% sequential execution bottleneck.

Advanced Architectural Extensions & Industrial Systems Synthesis

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1. Contemporary Engineering Dilemmas and Architectural Solutions

Engineering teams designing software systems centered around Object Oriented Programming (Java) must systematically navigate critical technical trade-offs:

- **Execution Throughput versus Memory Footprint:** In high-performance computational pipelines related to Multithreading and Concurrent Architecture, aggressive caching, in-memory collections, and uncompressed intermediate data structures drastically reduce CPU cycle overhead and latency, but expand physical RAM footprint. Conversely, compact serialized representations conserve memory at the cost of continuous decompression overhead. High-throughput architectures deploy off-heap memory buffers and zero-copy data pipelines.
- **Synchronous Simplicity versus Reactive Concurrency:** While synchronous blocking execution models offer straightforward debugging and predictable stack traces, they quickly exhaust thread pool limits under heavy concurrent traffic. Contemporary enterprise frameworks adopt reactive, non-blocking asynchronous architectures (event loops, coroutines, reactive streams) that handle millions of concurrent connections with minimal context switching.
- **Monolithic Cohesion versus Distributed Microservices:** Decomposing large codebases into independently deployable microservices isolates failure domains and enables autonomous team scaling, but introduces network latency, distributed transaction complexities, and eventual consistency challenges.

2. Empirical Comparative Framework

A structured comparative assessment clarifies operational distinctions across conventional and contemporary paradigms in Object Oriented Programming (Java):

Evaluation Dimension	Conventional Traditional Approach	Contemporary Integrated Paradigm	Strategic Impact Metric
Runtime Execution	Interpreted or single-threaded execution with manual memory management.	Adaptive Just-In-Time (JIT) compilation with generational garbage collection and hardware SIMD acceleration.	High-throughput operational execution with minimal latency jitter.
Data Access Architecture	Direct relational database queries with heavy connection creation latency.	Connection pooling, asynchronous Object-Relational Mapping (ORM), and multi-tier distributed caching (Redis).	Sub-millisecond query responses and resilient database load protection.
Deployment Pipeline	Manual server provisioning and periodic	Containerized continuous integration and deployment	Zero-downtime continuous deployment

Evaluation Dimension	Conventional Traditional Approach	Contemporary Integrated Paradigm	Strategic Impact Metric
	scheduled deployment windows.	(CI/CD) with automated canary rollouts and automated rollbacks.	and instantaneous bug remediation.
Security Hardening	Perimeter network firewalls and basic session authentication.	Zero-Trust Architecture (ZTA), OAuth2 / JWT stateless token authentication, and continuous runtime security monitoring.	Complete mitigation of credential compromise and lateral attack propagation.

3. Step-by-Step Implementation and Operational Governance Roadmap

Executing enterprise-grade implementations of Object Oriented Programming (Java) requires an organized four-phase execution roadmap:

- **Phase I: Architectural Assessment & Baseline Telemetry:** Conducting diagnostic audits of baseline throughput, memory access patterns, and I/O bottlenecks to establish empirical performance benchmarks.
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Industrial Risk Governance, Statutory Compliance & Failure Mode Analysis

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Risk Category	Primary Sources of Vulnerability	Diagnostic Warning Indicators	Mitigation Protocol & Internal Controls
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	Request Forgery (CSRF), deserialization attacks.	patterns, unexpected privilege elevation logs.	Security Policy (CSP), anti-CSRF tokens.
Statutory & Regulatory Risk	Violations of data privacy standards (DPDP Act, GDPR), unencrypted customer data storage.	Unencrypted database backups, audit logging gaps during user credential changes.	End-to-end data encryption (AES-256), strict role-based access control, automated regulatory compliance auditing.

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