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BCA Honours | Semester V | Calicut University

Object Oriented Programming (Java)

Course Code: BCA5CJ301 • Module 1 Notes

MODULE I: REVIEW OF OOPS AND CORE JAVA ARCHITECTURE

1. Object-Oriented Principles and Java Virtual Machine Architecture

Object-Oriented Programming (OOP) organizes software design around data entities (objects) rather than procedural functions. Java enforces four foundational OOP pillars: **Encapsulation** (binding data with methods and restricting direct access via access modifiers), **Abstraction** (hiding internal implementation details through abstract classes and interfaces), **Inheritance** (reusing parent class properties via the `extends` keyword), and **Polymorphism** (ability of an entity to take multiple forms through method overloading and dynamic method dispatch).

The Java Virtual Machine (JVM) Architecture

Java programs compile into architectural-neutral **Bytecode** (`.class` files) executed by the JVM:

- **Class Loader Subsystem:** Loads, links, and initializes binary classes dynamically.
- **Runtime Data Areas:**
  - *Method Area:* Stores class-level data, bytecodes, static variables, and runtime constant pool.
  - *Heap Area:* Shared runtime memory where all objects, instance variables, and arrays are allocated. Subject to Garbage Collection.
  - *JVM Stack:* Thread-private memory containing stack frames storing local variables, operand stacks, and partial results. Created and destroyed with each method call.
  - *Program Counter (PC) Register:* Tracks the current execution instruction address per thread.
  - *Native Method Stack:* Manages execution of underlying native C/C++ libraries via JNI.
- **Execution Engine:** Translates bytecode into native CPU machine instructions using an Interpreter combined with a **Just-In-Time (JIT) Compiler** and an automated **Garbage Collector (GC)**.

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

Worked Example: Memory Allocation Footprint & Dynamic Method Dispatch Resolution

Problem Statement:

In a 64-bit JVM with Compressed Ordinary Object Pointers (Compressed OOPs) enabled:

- Standard object header = 12 bytes (8 bytes Mark Word + 4 bytes Klass Word).
- All heap allocations are aligned to 8-byte boundaries.

Calculate the exact memory footprint allocated on the Java heap for:

1. An instance of class `Student` defined as:

```
class Student {
    int id;           // 4 bytes
    double gpa;       // 8 bytes
    boolean active;   // 1 byte
}
```

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2. An array of 100 `Student` object references: `Student[] roster = new Student[100];`

Solution & Step-by-Step Working:

1. Single Student Object Heap Memory:

- Object Header = 12 bytes
- Field `id` (int) = 4 bytes
- Field `gpa` (double) = 8 bytes
- Field `active` (boolean) = 1 byte
- Subtotal data bytes = $12 + 4 + 8 + 1 = 25$ bytes.

Memory alignment rule: Heap memory must be an exact multiple of 8 bytes.

Padding required = $32 - 25 = 7$ bytes of padding.

$$\text{Total Student Instance Size} = 25 + 7 = \mathbf{32} \text{ bytes}$$

2. Array Object Heap Memory:

An array in Java is an independent heap object possessing an array header:

- Array Header = 16 bytes (12 bytes object header + 4 bytes array length).
- Array Elements = 100 object references. Under Compressed OOPs, each reference occupies 4 bytes.
- Elements memory = 100×4 bytes $= 400$ bytes.
- Subtotal = $16 + 400 = 416$ bytes.

Check alignment: $416 div 8 = 52$ (Exact multiple of 8, zero padding required).

$$\text{Total Array Structure Size} = \mathbf{416} \text{ bytes}$$

Total Combined Footprint: When all 100 student objects are instantiated and referenced, the total memory consumed is: $416 \text{ B (array)} + (100 \times 32 \text{ B}) = 416 + 3200 = \mathbf{3,616}$ bytes.

Advanced Architectural Extensions & Industrial Systems Synthesis

In contemporary enterprise software engineering and distributed computational architectures, mastering Object Oriented Programming (Java) demands a rigorous integration of pure theory with mission-critical production realities. Modern organizations operate in distributed cloud ecosystems where high computational throughput, memory safety, and statutory data security govern architectural viability.

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 Object-Oriented Design and JVM Internals, 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 scheduled deployment windows.	Containerized continuous integration and deployment (CI/CD) with automated canary rollouts and automated rollbacks.	Zero-downtime continuous deployment 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.
- **Phase II: System Architecture & Prototype Modeling:** Formulating mathematically sound algorithmic workflows, defining abstract interfaces, and constructing modular proof-of-concept prototypes with automated unit tests.
- **Phase III: High-Performance Production Deployment:** Optimizing cache locality, eliminating unnecessary memory allocations, and deploying through automated continuous deployment pipelines with canary releases.

- **Phase IV: Continuous Governance & Telemetry Auditing:** Implementing real-time telemetry dashboards tracking latency percentiles (P95, P99), thread contention rates, and memory saturation to drive continuous architectural refinement.

Industrial Risk Governance, Statutory Compliance & Failure Mode Analysis

Mission-critical systems must withstand rigorous scrutiny across operational, legal, and cyber-security dimensions. System architects deploy structured risk evaluation matrices to eliminate vulnerabilities across critical operational categories:

Risk Category	Primary Sources of Vulnerability	Diagnostic Warning Indicators	Mitigation Protocol & Internal Controls
Runtime & Memory Risk	Memory leaks, uncollected circular references, thread deadlocks, out-of-memory errors.	Steadily rising heap usage, GC pause duration spikes, unresponsive worker threads.	Automated heap dump analysis, leak detection profilers, strict resource cleanup (try-with-resources).
Concurrency & Data Risk	Race conditions in shared mutable state, phantom reads, dirty writes in distributed transactions.	Inconsistent database records, unexpected optimistic locking exceptions.	Immutable data transfer objects, atomic variable updates, distributed transaction managers (Two-Phase Commit / Saga).
Cybersecurity Risk	Cross-Site Scripting (XSS), SQL Injection, Cross-Site Request Forgery (CSRF), deserialization attacks.	WAF alert spikes, abnormal input character patterns, unexpected privilege elevation logs.	Strict input sanitization, parameterized queries, Content 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.

Through systematic deployment of these engineering practices, rigorous mathematical modeling, and robust governance frameworks, modern computing professionals ensure the reliability, performance, and long-term resilience of critical digital infrastructure.

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