JAVA INTERVIEW NOTES

Deep & Easy Edition — Core Java to Concurrency & Java 8

Compiled from personal study notes

Format: Simple Everyday Analogy → Full Technical Depth → Example with Output → Interview Tip → Common Interview Q&A

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1. Variables in Java

Variable Types: Static, Instance, Local

In simple words:

Think of a school. A static variable is like the school's name on the gate – there's only ONE, and every student/teacher shares that same one. An instance variable is like a student's own roll number – every student has their own, different from everyone else's. A local variable is like a note you scribble on scratch paper during one exam – once the exam (method) ends, that paper is thrown away.

The technical detail:

A variable is a named piece of memory that holds a value. Java variables are classified by SCOPE and LIFETIME – where they can be accessed from, and how long they stay alive.

STATIC VARIABLE (class variable): declared with 'static' inside a class but outside any method. It belongs to the CLASS itself, not to any object. Memory for it is allocated ONCE, in the method area (metaspace), when the class is first loaded by the classloader. Every object of that class shares the exact same copy – change it through one object and every other object sees the new value. It is destroyed only when the class is unloaded (usually JVM shutdown).

INSTANCE VARIABLE (non-static field): declared inside a class but outside any method, WITHOUT 'static'. Each object gets its own independent copy, allocated on the HEAP as part of the object at the moment 'new' runs. It gets a default value automatically if not explicitly initialized (0 for numbers, false for boolean, null for objects) – unlike local variables. Lives as long as the object is reachable; reclaimed by GC once the object becomes garbage.

LOCAL VARIABLE: declared inside a method, constructor, or block (including for-loop headers, catch blocks). Allocated on the calling thread's STACK as part of that method's stack frame. Has NO default value – Java forces you to assign it before first use, or it will not compile. It only exists while that method/block is executing; once the method returns, its stack frame (and the local variable) is discarded.

```
class Counter {
    static int totalObjects = 0;   // ONE copy, shared, lives in method area
    int id;                        // per-object copy, lives on heap

    Counter() {
        int localVar = 10;         // exists only during this constructor call
        totalObjects++;            // shared counter increments for ALL objects
        id = totalObjects;
    }
}

Counter a = new Counter();   // totalObjects=1, a.id=1
Counter b = new Counter();   // totalObjects=2, b.id=2
System.out.println(a.totalObjects); // Output: 2 (same shared copy, accessed via 'a')
System.out.println(b.totalObjects); // Output: 2 (identical - it's the SAME variable)
```

Interview tip: *Interview trap: static variables are initialized once at class load; instance variables reset per object; local variables have NO default value – compiler error if used uninitialized. Accessing a static field through an instance (a.totalObjects) works but is misleading – IDEs warn 'static member accessed via instance reference' because it implies per-object state that doesn't exist.*

Common interview questions:

Q: Can a static method access an instance variable directly?

A: No. A static method belongs to the class and runs without any particular object existing, so 'this' has no meaning there. It can only access instance variables through an explicit object reference.

Q: Where do static variables live in memory?

A: In the Method Area / Metaspace (part of non-heap memory), not inside individual objects on the heap.

Q: Why does Java force initialization of local variables but not instance variables?

A: Instance variables are always zeroed out by the JVM as part of object allocation, so there's no risk of reading garbage. Local variables live on the stack where old frame data could leak through, so the compiler enforces definite assignment as a safety check.

2. Classes, Objects & Methods

Class vs Object vs Concrete Instance

In simple words:

> *A class is like a cookie CUTTER – it defines the shape, but it isn't a cookie itself. An object is an actual COOKIE made using that cutter – you can make many cookies (objects) from one cutter (class), and each cookie is separate; eating one doesn't affect the others.*

The technical detail:

A CLASS is a compile-time blueprint: it defines what fields (state) and methods (behavior) something will have, but by itself occupies no memory for 'instances' – only its own metadata (Class object) is loaded once by the classloader.

An OBJECT is a runtime entity created from a class using the 'new' keyword. 'new' does three things: (1) allocates memory on the heap sized to hold the class's instance fields, (2) initializes those fields to defaults then runs the constructor, (3) returns a reference (memory address) to that block, which you store in a reference variable.

'CONCRETE INSTANCE' simply emphasizes that this object is a fully realized, instantiated thing in memory – as opposed to an abstract class or interface TYPE, which describes a category but can never itself be instantiated directly (you can only instantiate a concrete subclass of it).

```
class Car {                    // blueprint - no memory used for 'instances' yet
    String model;
    int speed;
}

Car c1 = new Car();             // heap allocation #1, c1 -> address A
Car c2 = new Car();             // heap allocation #2, c2 -> address B (different!)
c1.model = "Tesla";
c2.model = "BMW";
System.out.println(c1.model);   // Output: Tesla
System.out.println(c2.model);   // Output: BMW  (completely separate memory)
```

Common interview questions:

Q: What exactly does 'new' do, step by step?
A: 1) Allocates zeroed memory on the heap for the object's fields. 2) Runs field initializers and instance initializer blocks top-to-bottom. 3) Runs the constructor body. 4) Returns the reference (address) to the caller.

Q: Can two reference variables point to the same object?
A: Yes. Car c3 = c1; makes c3 point to the SAME heap object as c1 – modifying via c3 is visible via c1 too, since there's only one object.

Method

In simple words:

A method is like a recipe in a cookbook. Writing the recipe down doesn't cook anything by itself – food only gets made when someone actually FOLLOWS (calls) that recipe.

The technical detail:

A method is a named, reusable block of code attached to a class that defines a unit of behavior. It has a signature (name + parameter types), an optional return type, a body, and runs ONLY when explicitly invoked (called) – unlike a static/instance initializer block which runs automatically. Methods can be instance methods (need an object, can use 'this') or static methods (called on the class, cannot use 'this').

```
int add(int a, int b) {
    return a + b;         // executes only when add(x, y) is called
}
System.out.println(add(2, 3));   // Output: 5
```

Method Overloading

In simple words:

Imagine one person named 'Order' who can take your food order differently depending on how you ask – order("pizza"), order("pizza", "large"), order(2, "pizza"). Same name, but the restaurant (compiler) looks at exactly what you handed over and picks the matching version, before the order even starts.

The technical detail:

Overloading means defining MULTIPLE methods with the SAME NAME in the same class, but with different parameter lists – different number of parameters, different parameter types, or different parameter order. The compiler decides WHICH version to call by matching the arguments at the call site – this decision is made at COMPILE TIME, which is why overloading is called compile-time (static) polymorphism.

Resolution rules when multiple overloads could match: Java prefers (1) an exact type match, then (2) widening primitive conversion (int→long), then (3) autoboxing (int→Integer), then (4) varargs – in that priority order.

```
void print(int a) { System.out.println("int: " + a); }
void print(double a) { System.out.println("double: " + a); }
void print(String a) { System.out.println("String: " + a); }

print(5);       // Output: int: 5        (exact match)
print(5.5);     // Output: double: 5.5   (exact match)
print("hi");    // Output: String: hi    (exact match)
```

Interview tip: *Return type ALONE cannot distinguish overloads – 'int f()' and 'double f()' with no parameter difference is a compile error, because the compiler picks a method by argument types, not by what you do with the return value.*

Common interview questions:

Q: Is overloading resolved at compile time or runtime?
A: Compile time – the compiler looks at the declared/static types of the arguments at the call site and bakes in which overload to call.

Q: What happens if you pass null to two overloaded methods, print(String) and print(Object)?
A: The compiler picks the MOST SPECIFIC applicable type – print(String) wins because String is more specific than Object.

Method Overriding

In simple words:

> *Think of 'make a sound' as a general instruction. A Dog and a Cat both know how to 'make a sound', but each does it their OWN way – a dog barks, a cat meows. You don't find out which sound happens until you actually see which animal you're dealing with (at runtime), even if you just call it a generic 'Animal'.*

The technical detail:

Overriding means a SUBCLASS provides its OWN implementation of a method it inherited from its superclass, using the EXACT SAME method signature (name + parameter types). Which version actually executes is decided at RUNTIME, based on the ACTUAL object type the reference points to (not the reference's declared type) – this is runtime (dynamic) polymorphism, implemented internally via a mechanism called dynamic method dispatch (the JVM looks up the method in the object's actual class's vtable).

Rules enforced by the compiler: (1) same name and parameter list, (2) return type must be the same or a covariant (subtype) of the original, (3) access modifier cannot be MORE restrictive than the parent's (can widen: protected -> public, but not narrow public -> private), (4) cannot override a method marked final, static, or private in the parent (static 'overriding' is actually hiding, see note below), (5) can only throw the same, fewer, or narrower checked exceptions.

```
class Animal {
    void sound() { System.out.println("Some generic sound"); }
}
class Dog extends Animal {
    @Override
    void sound() { System.out.println("Bark"); }
}
class Cat extends Animal {
    @Override
    void sound() { System.out.println("Meow"); }
}

Animal a = new Dog();     // reference type Animal, ACTUAL object type Dog
a.sound();                 // Output: Bark  (decided by actual object, at runtime)
a = new Cat();
a.sound();                 // Output: Meow  (same call site, different output!)
```

Interview tip: *Static methods CANNOT be overridden – if a subclass declares a static method with the same signature, that is METHOD HIDING, not overriding, and it is resolved at COMPILE TIME based on the reference type, not the object type. This is a classic interview gotcha.*

Common interview questions:

Q: What is dynamic method dispatch?

A: The JVM mechanism where, for an overridden instance method, the actual method executed is looked up in the runtime (actual) class of the object via its virtual method table, not the compile-time reference type.

Q: Why can't private or static methods be overridden?

A: Private methods aren't inherited/visible to subclasses at all, so there's nothing to override – a same-named private method in the subclass is just a separate, unrelated method. Static methods belong to the class, not an object instance, so there's no object polymorphism to dispatch on – the call is resolved by the reference's compile-time type instead.

Q: @Override is optional - why use it?

A: It's not required by the compiler, but it makes the compiler VERIFY you are actually overriding a real superclass method (matching signature). Without it, a typo in the method name silently creates a new, unrelated overloaded method instead of overriding – a very common bug @Override catches.

3. The Four Pillars of OOP

Encapsulation

In simple words:

> *Think of a medicine capsule – the actual medicine (data) is sealed inside, and you can only take it the intended way (through the capsule's shell/methods), not by poking the raw powder directly. This keeps the medicine safe and the dose correct.*

The technical detail:

Encapsulation means bundling an object's data (fields) together with the methods that operate on that data into a single unit (the class), and then restricting direct outside access to the internal state – typically by marking fields 'private' and exposing controlled access through public getter/setter methods. This lets the class enforce invariants (validation rules) every time the state changes, and lets the internal representation be changed later without breaking code that uses the class (the public getter/setter contract stays stable even if internal storage changes).

This is sometimes called 'data hiding', though encapsulation is broader than just hiding – it is about controlling and validating ALL access to state through a defined interface.

```
class Account {
    private double balance;             // hidden - can't be touched directly

    public double getBalance() { return balance; }

    public void deposit(double amt) {
        if (amt <= 0) throw new IllegalArgumentException("Invalid amount");
        balance += amt;                  // only path to modify state - validated
    }
}

Account acc = new Account();
acc.deposit(100);
// acc.balance = -500;    // COMPILE ERROR - balance is private, cannot bypass validat
ion
System.out.println(acc.getBalance());   // Output: 100.0
```

Common interview questions:

Q: Is encapsulation just about using private fields?
A: No – making fields private is the mechanism, but encapsulation is the broader design principle of exposing behavior (methods) instead of raw state, so the class controls how its data can be changed and stays internally consistent.

Inheritance

In simple words:

> *Think of a family recipe passed down from parent to child. The child automatically knows the family recipe (inherited methods) without being taught again, but can also learn their own new recipes, or tweak the family one to taste (override it).*

The technical detail:

Inheritance lets one class (the SUBCLASS/child) acquire the fields and methods of another class (the SUPERCLASS/parent) using the 'extends' keyword, establishing an IS-A relationship (a Car IS-A Vehicle). The subclass automatically gets all non-private members of the parent, can add new members, and can override existing behavior. This enables code reuse (write common logic once in the parent) and is the foundation that makes runtime polymorphism possible.

Java supports SINGLE inheritance for classes – a class can extend only ONE direct superclass (avoids the 'diamond problem' of ambiguous inherited state) – but MULTIPLE inheritance for interfaces, since interfaces (pre-Java 8) had no state, only method signatures, so there was no ambiguity to resolve. Every class in Java implicitly extends Object if no other superclass is specified.

```
class Vehicle {
    int speed;
    void start() { System.out.println("Vehicle starting"); }
}
class Car extends Vehicle {          // Car IS-A Vehicle
    void honk() { System.out.println("Beep!"); }
}

Car c = new Car();
c.start();     // Output: Vehicle starting  (inherited, not redefined)
c.honk();       // Output: Beep!             (Car's own method)
```

> ***Interview tip:*** *Composition ('has-a', e.g. a Car HAS-A Engine field) is often preferred over inheritance for code reuse when there's no true IS-A relationship, because it avoids tight coupling to a parent's implementation details (the well-known 'favor composition over inheritance' principle).*

Common interview questions:

Q: Why doesn't Java allow multiple inheritance of classes?
A: To avoid the diamond problem: if class B and class C both extend class A and override the same method differently, and class D extends both B and C, the compiler cannot unambiguously decide which version D should inherit. Java sidesteps this entirely by allowing only one direct parent class.

Q: How do interfaces achieve multiple inheritance without the diamond problem?
A: Pre-Java 8 interfaces had no method bodies, so there was nothing to conflict. Since Java 8, interfaces CAN have default methods, and if a class implements two interfaces with the same default method, the compiler forces you to explicitly override it and resolve the conflict yourself – it will not compile silently.

Polymorphism

In simple words:

> *Think of a TV remote's 'power' button. Pressing it does the SAME action name ('turn on/off') but the actual result is completely different depending on which brand of TV it's pointed at – the button doesn't need to know the internal wiring of each TV brand.*

The technical detail:

Polymorphism ('many forms') means the same method call or operator can behave differently depending on context. Java has two kinds:
• Compile-time (static) polymorphism – method overloading. The compiler decides which method runs, based on argument types, before the program even executes.
• Runtime (dynamic) polymorphism – method overriding. The JVM decides which version runs based on the actual object type, while the program is executing.

The practical power of runtime polymorphism: you can write code against a general parent type/interface, and it will correctly invoke the specialized behavior of whatever concrete subclass is actually passed in – this is what lets you loop over a List<Shape> containing Circles, Squares, and Triangles, calling shape.draw() on each, with each one drawing itself correctly without any if-else type checking.

```
abstract class Shape { abstract void draw(); }
class Circle extends Shape { void draw() { System.out.println("Drawing circle"); } }
class Square extends Shape { void draw() { System.out.println("Drawing square"); } }

List<Shape> shapes = List.of(new Circle(), new Square());
for (Shape s : shapes) s.draw();
// Output:
// Drawing circle
// Drawing square
// (no type-checking code needed - each object knows how to draw itself)
```

Common interview questions:

Q: Give a real interview one-liner distinguishing the two types.

A: Overloading = same class, same name, different parameters, resolved at compile time. Overriding = parent-child classes, same signature, resolved at runtime based on the object's actual type.

Abstraction

In simple words:

> *Think of driving a car. You just need to know 'press the accelerator to go faster' – you don't need to understand the engine's internal combustion process to drive. The car exposes simple controls (WHAT you can do) and hides the complicated engineering (HOW it actually happens).*

The technical detail:

Abstraction means exposing only the essential, relevant details of an object's behavior to the outside world, while hiding the internal implementation complexity. It answers 'WHAT can this thing do' without forcing the caller to know 'HOW it does it'.

Java achieves abstraction via:
• Abstract classes – partial abstraction (0% to 100%); can mix abstract and concrete methods.
• Interfaces – historically 100% abstraction; since Java 8 they can also carry default/static method bodies, but the core idea (defining a contract of WHAT without prescribing internal state) remains.

This is different from encapsulation: encapsulation hides DATA (state) via access modifiers; abstraction hides IMPLEMENTATION (logic) via abstract types.

```
abstract class Shape {
    abstract double area();          // WHAT: every shape can compute area
    void describe() {                 // shared concrete behavior
        System.out.println("Area = " + area());
    }
}
class Circle extends Shape {
    double r;
    Circle(double r) { this.r = r; }
    double area() { return Math.PI * r * r; }   // HOW: hidden inside subclass
}

new Circle(2).describe();   // Output: Area = 12.566370614359172
```

Common interview questions:

Q: Encapsulation vs abstraction - what's the actual difference?
A: Encapsulation hides DATA using access modifiers (protects state from invalid change). Abstraction hides IMPLEMENTATION DETAILS using abstract classes/interfaces (lets you use something without knowing its internal logic). A class can be encapsulated without being abstract, and vice versa.

4. Abstract Class vs Interface

Abstract Class

In simple words:

> *Think of a half-finished recipe card that says 'Step 3: cook the filling (exact method depends on the dish)' but already has fixed Steps 1 and 2 filled in for you. You must fill in the missing step yourself, but you don't have to rewrite the whole recipe from scratch.*

The technical detail:

Declared with the 'abstract' keyword; cannot be instantiated directly (new AbstractThing() is a compile error) but CAN have a constructor – invoked implicitly when a concrete subclass is instantiated, to initialize inherited fields. Can freely mix abstract methods (no body, must be implemented by the first concrete subclass) and concrete methods (with a body, shared/reused by all subclasses). Can declare instance variables of ANY access modifier (private, protected, public), unlike interfaces where fields are always constants. Use when a family of related classes shares common state and some common implementation, but each needs to specialize part of the behavior.

```
abstract class Employee {
    protected String name;                        // real instance state allowed
    Employee(String n) { this.name = n; }          // constructor allowed
    abstract double salary();                      // must be implemented by subclass
    void greet() { System.out.println("Hi, I'm " + name); }  // shared concrete method
}
class Manager extends Employee {
    Manager(String n) { super(n); }
    double salary() { return 90000; }
}

Employee e = new Manager("Ravi");
e.greet();                    // Output: Hi, I'm Ravi
System.out.println(e.salary()); // Output: 90000.0
```

Interface

In simple words:

> *Think of a job description/contract: 'must be able to drive, must be able to cook.' It doesn't say HOW you learned to drive or cook – it just lists what you must be capable of doing. Anyone (any class) who can do all the listed things qualifies, no matter how differently they learned it.*

The technical detail:

A pure behavioral contract. All fields declared in an interface are implicitly 'public static final' (i.e. compile-time constants shared across all implementers, not real per-object state). All abstract methods are implicitly 'public abstract' – you never need to write those keywords. Since Java 8: 'default' methods provide a method body that implementing classes inherit automatically (used to add new methods to an interface without breaking every existing implementation), and 'static' methods belong to the interface itself, callable as InterfaceName.method(). Since Java 9: 'private' methods allow code sharing between default methods inside the interface without exposing it. A single class CAN implement MULTIPLE interfaces – this is how Java achieves multiple inheritance of TYPE (behavior contracts) while still forbidding multiple inheritance of STATE (instance fields) from classes.

```
interface Payable {
    double TAX_RATE = 0.18;               // implicitly public static final
    double calculate();                   // implicitly public abstract
    default void printInfo() {            // Java 8+ - shared default behavior
        System.out.println("Payable amount: " + calculate());
    }
    static Payable zero() {               // Java 8+ static factory method
```

```
        return () -> 0.0;
    }
}
class Invoice implements Payable {
    public double calculate() { return 100 * (1 + TAX_RATE); }
}

new Invoice().printInfo();    // Output: Payable amount: 118.0
```

Interview tip: *Interview one-liner: use abstract class for an 'is-a' relationship needing shared state + partial implementation; use interface for a 'can-do' capability contract and to allow a class to satisfy multiple unrelated roles (e.g. a class can be Comparable AND Serializable AND Runnable simultaneously, but can only extend one abstract class).*

Common interview questions:

Q: If a class implements two interfaces with the same default method signature, what happens?
A: The compiler throws an error demanding you explicitly override that method in the implementing class to resolve the ambiguity yourself – Java refuses to silently guess which default implementation to use.

Q: Can an interface have a constructor?
A: No – interfaces cannot be instantiated on their own, and they have no instance state to initialize, so a constructor is meaningless there.

Q: Since Java 8 interfaces can have method bodies - so what's the difference from an abstract class now?
A: Still no instance fields (only constants), no constructors, and a class can implement many interfaces but extend only one abstract class – the core single-inheritance-of-state rule remains unchanged.

5. Key Keywords: this, super, static, final

this vs super

In simple words:

Think of a son with the same name as his father, living in the same house. 'this' means 'talking about ME (the son)', 'super' means 'talking about my FATHER specifically' – useful when you need to be clear about which one you mean.

The technical detail:

'this' is an implicit reference every non-static method/constructor receives, pointing to the CURRENT object the method is running on. Common uses: (1) disambiguating an instance field from a same-named constructor/method parameter, (2) passing the current object as an argument to another method, (3) calling another constructor in the SAME class via this(...) as the first statement (constructor chaining).

'super' refers to the IMMEDIATE PARENT class's portion of the current object. Common uses: (1) calling the parent's constructor via super(...) as the first statement of a subclass constructor – if omitted, Java silently inserts a no-arg super() call, which fails to compile if the parent has no no-arg constructor, (2) explicitly invoking a parent's version of a method that the subclass has overridden, (3) accessing a parent's field that is shadowed (hidden) by a same-named field in the subclass.

```
class Parent {
    int x = 10;
    Parent() { System.out.println("Parent constructor"); }
    void show() { System.out.println("Parent.show()"); }
```

```
}
class Child extends Parent {
    int x = 20;                       // shadows Parent's x, doesn't replace it
    Child() {
        super();                       // explicit call to Parent() - optional here
        System.out.println("Child constructor");
    }
    void show() {
        System.out.println(this.x);    // Output: 20 (Child's own field)
        System.out.println(super.x);   // Output: 10 (Parent's shadowed field)
        super.show();                  // Output: Parent.show()
    }
}

new Child().show();
// Output:
// Parent constructor
// Child constructor
// 20
// 10
// Parent.show()
```

Common interview questions:

Q: What order do constructors run in an inheritance chain?

A: Always parent-first, child-last – every constructor's first action (explicit or compiler-inserted) is a call up to its superclass constructor, so the chain unwinds from Object all the way down to the most derived class before any subclass constructor body runs.

Q: Can this() and super() both appear in one constructor?

A: No – whichever you use must be the very first statement, so a constructor can only chain to ONE of: another constructor in the same class (this(...)), or the parent constructor (super(...)), never both.

static keyword

In simple words:

> *Think of a shared office printer – it belongs to the whole office (the class), not to any one employee (object). Everyone uses the SAME printer; there isn't a personal printer copy sitting inside each employee's desk.*

The technical detail:

'static' marks a member (variable, method, nested class, or initializer block) as belonging to the CLASS rather than to any individual object. Static members are allocated once, when the class is first loaded by the classloader (triggered by first active use: instantiation, static method call, or static field access).

A static METHOD has no implicit 'this' – it cannot directly reference instance (non-static) fields or call instance methods, because there is no guaranteed object to operate on. It can be called without ever creating an object: ClassName.method().

A static BLOCK ('static { ... }') runs exactly once, in source order relative to other static members, at class-loading time – before main() runs and before any object of that class is created. Commonly used for one-time setup of static resources.

```
class MathUtil {
    static int callCount = 0;
    static { System.out.println("MathUtil class loaded"); }   // runs once
```

```
    static int square(int n) {
        callCount++;                // OK - accessing another static member
        return n * n;
    }
}

System.out.println(MathUtil.square(5));  // Output: MathUtil class loaded
                                         //         25
System.out.println(MathUtil.callCount);   // Output: 1
```

Common interview questions:

Q: Can you call a static method using an object reference like obj.staticMethod()?

A: Syntactically yes, but it's discouraged – the call is still resolved at compile time via the reference's declared TYPE, not the object, and most style guides/IDEs flag it because it misleadingly suggests instance-level behavior.

final keyword

In simple words:

Think of engraving something in stone versus writing it in pencil. A final variable is engraved – once set, it cannot be changed. A final class is like a locked recipe that no one is allowed to modify or extend into a new version.

The technical detail:

'final' means 'cannot be changed further', applied in three distinct contexts:
• final VARIABLE – once assigned, its reference/value cannot be reassigned. For primitives this locks the value itself; for object references it locks WHICH object the variable points to (the object's internal state can still change unless the object itself is immutable).
• final METHOD – cannot be overridden by any subclass; used to lock down critical logic that must not be altered (e.g. security-sensitive code).
• final CLASS – cannot be extended/subclassed at all; used when a class's behavior must remain exactly as designed (String, Integer, and all other wrapper classes are final for this reason – it's part of what makes them safely immutable and cacheable).

```
final class Constants {
    static final double PI = 3.14159;      // constant - reassignment = compile error
}
// class MoreConstants extends Constants { }   // COMPILE ERROR - Constants is final

final List<String> names = new ArrayList<>();
names.add("Ravi");           // OK! the LIST CONTENTS can still change
// names = new ArrayList<>();  // COMPILE ERROR - can't repoint a final reference
```

Interview tip: *Common trap: 'final' on an object reference does NOT make the object immutable – it only freezes which object the variable points to. To make a class truly immutable you need the pattern in Section 18.*

Common interview questions:

Q: Does 'final' improve performance?

A: It can enable the JIT compiler to make certain optimizations (e.g. inlining final method calls since they can't be overridden), but its primary purpose is expressing design intent and safety, not raw speed.

finalize()

In simple words:

> *Think of a cleaning crew that MIGHT show up before a house gets demolished, but you can never be sure exactly when they'll arrive, or if they'll show up at all – which is why nobody responsible relies on them for anything important anymore.*

The technical detail:

A protected method inherited from Object, historically called by the Garbage Collector just before it reclaims an object's memory, intended for last-chance cleanup (e.g. releasing native resources). It has been DEPRECATED since Java 9 because its execution timing is unpredictable (the GC decides when, or IF, to ever call it), it can resurrect objects unexpectedly, and it can silently swallow exceptions. Modern Java code uses try-with-resources (Section 7) or the java.lang.ref.Cleaner API instead for deterministic cleanup.

```
@Override
protected void finalize() throws Throwable {
    System.out.println("About to be garbage collected");
    super.finalize();
}
// Avoid relying on this in real code - use try-with-resources instead.
```

6. Arrays, Strings & Number Systems

Array

In simple words:

> *Think of a row of numbered lockers in a school hallway, all bolted to the wall in a fixed row – you decide how many lockers there are when they're installed, and that number can never change afterward. You reach any locker instantly by its number (index).*

The technical detail:

An array is a FIXED-SIZE, contiguous block of memory on the heap holding elements of a single declared type, accessed by a zero-based integer index. The size is decided at creation time and can never grow or shrink afterward (this is precisely why the Collections framework – ArrayList etc. – exists, to give you resizable, richer alternatives). Length is read via the '.length' FIELD (no parentheses) – not a method, unlike String's .length(). Arrays can be single or multi-dimensional (arrays of arrays).

```
int[] nums = new int[5];         // 5 ints, default-initialized to 0
String[] names = {"A", "B"};    // array literal, length 2
int[][] grid = new int[3][3];     // 2D array - array of arrays

System.out.println(nums.length);   // Output: 5  (field, not a method call)
System.out.println(nums[10]);      // Output: ArrayIndexOutOfBoundsException at runtim
e
```

> ***Interview tip:*** *Arrays are covariant and reified at runtime (an Object[] array actually 'remembers' if it's really a String[] at runtime and throws ArrayStoreException on a bad write) – this differs from Generics, where type information is erased at compile time (Section 15).*

Common interview questions:

Q: Why does '.length' have no parentheses but '.length()' on String does?
A: On an array, length is a plain public final FIELD baked in at array creation. On String, length() is a METHOD, because String is a full class with encapsulated internal representation – exposing a method keeps that representation free to change internally.

Number Systems

In simple words:

> *Think of the same amount of money being written in different currencies (dollars, rupees, or 'ten' spelled out in words) – different notation, but identical actual value underneath. int dec, bin, oct, hex here are all just different ways of WRITING the exact same number 10.*

The technical detail:

Integer literals in Java can be expressed in four bases, all interpreted as the same underlying binary value by the compiler: decimal (default, no prefix), binary (0b or 0B prefix, added in Java 7), octal (leading 0), and hexadecimal (0x or 0X prefix). Since Java 7, underscores can be inserted between digits purely for human readability – they are stripped by the compiler and have zero effect on the value.

```
int dec = 10;
int bin = 0b1010;         // binary for 10
int oct = 012;            // octal for 10  (leading zero = octal, common trap!)
int hex = 0xA;             // hex for 10
int million = 1_000_000;   // same as 1000000, just easier to read

System.out.println(dec == bin && bin == oct && oct == hex);  // Output: true
```

> ***Interview tip:*** *Interview trap: a leading zero on an int literal (e.g. 012) is parsed as OCTAL, not decimal – 012 equals 10 in decimal, not 12. This has bitten many developers zero-padding numbers by habit.*

7. Exception Handling

Exception Hierarchy Overview

In simple words:

> *Think of a hospital's triage system: 'Throwable' is any medical problem at all. 'Error' cases are so severe (like a building collapse) that regular staff shouldn't even attempt to treat them on their own. 'Exception' cases are things doctors (your code) are expected to actually be able to treat/handle.*

The technical detail:

All exception/error classes descend from Throwable, which splits into two branches: Error (serious problems like OutOfMemoryError or StackOverflowError, not meant to be caught/handled by application code – usually unrecoverable JVM-level issues) and Exception (conditions a program can reasonably catch and handle). Exception itself splits again: RuntimeException and its subclasses are UNCHECKED; everything else under Exception is CHECKED.

```
Throwable
  ■■ Error (OutOfMemoryError, StackOverflowError - don't catch these)
  ■■ Exception
        ■■ RuntimeException (unchecked: NullPointerException, ArithmeticException...)
        ■■ IOException, SQLException, etc. (checked)
```

Checked vs Unchecked Exceptions

In simple words:

> *Checked exceptions are like a warning label the LAW forces you to acknowledge before doing something risky ('you MUST wear a helmet before riding') – the compiler won't let you proceed without addressing it. Unchecked exceptions are like everyday mistakes (tripping over your own feet) – nobody legally forces you to plan for them in writing, but they can still happen if you're careless.*

The technical detail:

CHECKED exceptions are verified by the COMPILER at compile time – if a method can throw one, it must either handle it (try/catch) or declare it in its signature with 'throws', otherwise the code will not compile. They extend Exception but NOT RuntimeException, e.g. IOException, SQLException, ClassNotFoundException. They represent RECOVERABLE conditions largely outside the program's own control (a missing file, a dropped network connection) that the caller is expected to anticipate and handle.

UNCHECKED exceptions extend RuntimeException. The compiler does NOT force you to catch or declare them – code compiles fine even if they might be thrown. Examples: NullPointerException, ArrayIndexOutOfBoundsException, ArithmeticException, ClassCastException, IllegalArgumentException. They typically signal PROGRAMMING BUGS (a logic error) rather than expected external failure conditions, which is why forcing every caller to handle them everywhere would just add noise.

```
// CHECKED - must declare 'throws' or wrap in try/catch, or compile fails
void readFile() throws IOException {
    FileReader f = new FileReader("x.txt");
}

// UNCHECKED - compiles fine, but crashes at runtime if triggered
int[] arr = new int[2];
System.out.println(arr[5]);
// Output: Exception in thread "main" java.lang.ArrayIndexOutOfBoundsException:
//         Index 5 out of bounds for length 2
```

Common interview questions:

Q: Give a memory trick for checked vs unchecked.

A: Checked = compiler CHECKS you handled it (extends Exception, not RuntimeException) – usually caused by external/environmental factors. Unchecked = extends RuntimeException, no compiler enforcement – usually caused by a bug in your own logic.

Q: Is Error checked or unchecked?

A: Neither is typically 'caught' in practice, but technically Error does NOT extend RuntimeException, so by the Java Language Spec's literal rule Error is treated like a checked-style class for the throws clause, yet by convention nobody declares or catches Errors – they represent conditions like OutOfMemoryError that application code usually cannot recover from.

throw vs throws

In simple words:

> *'throws' on a method is like a warning sign outside a shop: 'may run out of stock' – just a heads-up of what COULD happen. 'throw' is the actual moment the shopkeeper says 'sorry, we ARE out of stock right now' – the real event happening.*

The technical detail:

'throw' is a STATEMENT that actually raises/triggers a specific exception OBJECT at a precise point in the code – you can only throw one exception at a time, and execution immediately stops at that line and unwinds up the call stack looking for a matching catch block.

'throws' is a DECLARATION in a method's SIGNATURE, listing the checked exception TYPES that method might propagate to its caller if something goes wrong internally, without necessarily handling it itself – it's a compile-time contract, not an action.

```
class InsufficientFundsException extends Exception {
    InsufficientFundsException(String msg) { super(msg); }
}

void withdraw(double amt) throws InsufficientFundsException {   // declares (throws)
    if (amt > balance)
        throw new InsufficientFundsException("Not enough balance");  // raises (throw)
    balance -= amt;
}
```

finally block

In simple words:

> *Think of turning off the stove after cooking – whether the dish turned out great, burned, or you got interrupted halfway, you ALWAYS turn off the stove at the end no matter what happened. 'finally' is that guaranteed last step.*

The technical detail:

A block attached to try/catch that is GUARANTEED to execute after the try (and any catch) completes – whether the try succeeded, an exception was thrown and caught, an exception was thrown and NOT caught (finally still runs before the exception propagates further up), or even if the try/catch executes a 'return' statement (finally runs before the method actually returns). The only ways to skip finally are System.exit() or the JVM crashing/being killed. Primary use: guaranteed resource cleanup (closing files, connections) even when something goes wrong.

```
try {
    System.out.println("try block");
    throw new RuntimeException("boom");
} catch (Exception e) {
    System.out.println("caught: " + e.getMessage());
} finally {
    System.out.println("finally always runs");
}
// Output:
// try block
// caught: boom
// finally always runs
```

Common interview questions:

Q: If both try and finally have a return statement, which wins?
A: finally's return WINS and overrides the try block's return value – this is considered bad practice precisely because it silently discards the original result and surprises readers.

Custom Exception

In simple words:

> *Think of writing your own specific warning label instead of using a generic one – instead of a vague 'Error!' sticker, you write 'Warning: Battery Low', a name that tells you exactly what went wrong.*

The technical detail:

A user-defined class representing a domain-specific error condition, typically extending Exception (to force callers to handle it – checked) or RuntimeException (to make it optional to handle – unchecked), giving it a meaningful, descriptive name instead of relying on generic built-in exceptions. Best practice: always provide a constructor that accepts a message (and often the original cause) and passes it to super(...), so the exception preserves a useful stack trace and message.

```
class InsufficientFundsException extends Exception {
    public InsufficientFundsException(String message) {
        super(message);              // preserves message + stack trace behavior
    }
    public InsufficientFundsException(String message, Throwable cause) {
        super(message, cause);       // preserves original root-cause exception too
    }
}
```

try-with-resources

In simple words:

> *Think of a hotel room key that automatically locks itself and shuts off the lights the moment you leave – you don't have to remember to do it manually every single time, and it happens even if you leave in a hurry.*

The technical detail:

Introduced in Java 7. A try statement that declares one or more resources inside parentheses – any object implementing the AutoCloseable (or its subtype Closeable) interface. Java AUTOMATICALLY calls .close() on each resource, in REVERSE order of declaration, at the end of the block – whether it completed normally or an exception was thrown – eliminating the classic verbose 'close it in a finally block' boilerplate and the risk of forgetting to close a resource on an exception path.

```
try (BufferedReader br = new BufferedReader(new FileReader("a.txt"));
     FileWriter fw = new FileWriter("b.txt")) {
    System.out.println(br.readLine());
}  // fw.close() then br.close() called automatically, even if an exception occurs
// no finally block needed at all
```

Common interview questions:

Q: What interface must a resource implement to be used in try-with-resources?
A: AutoCloseable (or Closeable, which extends it and narrows the thrown exception type to IOException). Its single required method is close().

Q: In what order are multiple resources closed?
A: Reverse of declaration order – the last resource opened is the first one closed, similar to unwinding a stack.

8. String Handling

String, StringBuffer, StringBuilder

In simple words:

String is like a printed photograph – to 'change' it, you must print a whole NEW photo; the original never gets altered. StringBuilder/StringBuffer are like a whiteboard – you erase and rewrite parts of the SAME board directly, which is much faster than reprinting a new photo every time.

The technical detail:

STRING is IMMUTABLE – once created, its internal character sequence can never change. Every apparent 'modification' (concatenation, replace, substring) actually creates and returns a BRAND NEW String object, leaving the original untouched. This makes String inherently thread-safe (no synchronization needed – nothing ever changes) and cacheable in the String Pool, but wasteful if you build up a string through many concatenations in a loop (each '+' creates a new object, and the old one becomes garbage).

STRINGBUFFER is MUTABLE – its internal character array can grow and change in place without creating new objects on every operation. Its methods (append, insert, delete...) are 'synchronized', making it THREAD-SAFE, but that synchronization overhead makes it slower than StringBuilder when thread-safety isn't actually needed.

STRINGBUILDER is also MUTABLE, with the exact same API as StringBuffer, but its methods are NOT synchronized – faster, and the right choice for single-threaded string building (which is the overwhelming majority of real-world use, e.g. building output inside a loop).

```
// String - wasteful in a loop, creates N-1 throwaway objects
String s = "";
for (int i = 0; i < 3; i++) s = s + i;   // 3 intermediate String objects created
System.out.println(s);   // Output: 012

// StringBuilder - efficient, modifies ONE internal buffer in place
StringBuilder sb = new StringBuilder();
for (int i = 0; i < 3; i++) sb.append(i);
System.out.println(sb.toString());   // Output: 012 (same result, far fewer objects)
```

Interview tip: *Interview tip: prefer StringBuilder in loops/single-threaded code; use StringBuffer only when multiple threads genuinely mutate the SAME buffer concurrently; String immutability is exactly what makes the String Pool (next topic) safe to implement.*

Common interview questions:

Q: Why is String immutable by design?

A: Security (Strings are used for class names, file paths, network connections – immutability prevents them being altered mid-use), thread-safety (safe to share across threads with zero synchronization), and enabling the String Pool (safe to let many references share one object only because that object can never change underneath them), plus it lets hashCode() be computed once and cached.

String Pool

In simple words:

> *Think of a library with only ONE copy of a popular book. If ten people ask for 'Harry Potter' (the same literal text), the library hands out the SAME physical copy each time instead of printing ten new books – saving huge amounts of space.*

The technical detail:

The String Constant Pool is a special reserved area inside the heap (moved there from PermGen/Metaspace as of Java 7) where the JVM caches String LITERALS to save memory. When the compiler encounters a string literal, it checks the pool first: if an identical string already exists there, the new reference simply points to that EXISTING object instead of allocating a new one. Using 'new String(...)' explicitly BYPASSES the pool check and always creates a brand-new object on the heap, separate from any pooled copy – even if the content is identical. The String.intern() method can manually force a String into (or retrieve it from) the pool.

```
String a = "hello";
String b = "hello";
System.out.println(a == b);              // Output: true  - both point to the SAME poo
led object

String c = new String("hello");
System.out.println(a == c);              // Output: false - c is a distinct heap objec
t
System.out.println(a.equals(c));         // Output: true  - content is equal

String d = c.intern();                    // forces lookup/insertion into the pool
System.out.println(a == d);              // Output: true  - now points to the pooled o
bject
```

Common interview questions:

Q: Why does the String Pool exist?
A: Strings are used constantly and often repeated (class names, keys, config values) – reusing identical literals instead of duplicating them saves significant memory, and it's only safe BECAUSE String is immutable (a shared object can never be corrupted by one holder changing it under another holder's feet).

equals() vs ==

In simple words:

> *Think of twins wearing identical clothes. '==' asks 'are you looking at the exact SAME person?' while '.equals()' asks 'do you two LOOK the same?' Two different twins can look equal (.equals() = true) while clearly being two separate people (== false).*

The technical detail:

'==' compares REFERENCES for objects – asking 'do these two variables point to the exact same memory location/object?' For primitives, '==' compares actual VALUES since primitives aren't objects at all.

'.equals()' compares LOGICAL/CONTENT equality, as DEFINED by the class. The default Object.equals() implementation just falls back to '==' (reference comparison) unless a class explicitly overrides it – String, Integer, and most wrapper/collection classes override it sensibly to compare actual content.

```
String x = new String("cat");
String y = new String("cat");
```

```
System.out.println(x == y);        // Output: false - different objects in memory
System.out.println(x.equals(y));   // Output: true  - same character content

Integer i1 = 500, i2 = 500;
System.out.println(i1 == i2);        // Output: false - outside Integer cache range
System.out.println(i1.equals(i2));   // Output: true  - value equality
```

hashCode()

In simple words:

> *Think of a library's shelf-numbering system based on a book's title. If two copies of the exact same book get assigned DIFFERENT shelf numbers by mistake, the second copy will never be found when someone searches for it – that's exactly what breaks if equals() and hashCode() disagree.*

The technical detail:

Returns an int 'signature' for an object, used by hash-based collections (HashMap, HashSet, Hashtable) to decide which internal bucket to place the object in for fast O(1) average lookup. THE CONTRACT (must never be violated): if two objects are equal according to .equals(), they MUST return the SAME hashCode(). The reverse is not required – unequal objects MAY share a hashCode (a 'collision'; the collection handles that correctly by also checking .equals() within a bucket), but equal objects with different hashCodes will BREAK HashMap/HashSet – the object could be inserted into one bucket but looked up in a different, wrong bucket, making 'contains' or 'get' silently fail to find it.

```
class Person {
    int id; String name;
    @Override
    public boolean equals(Object o) {
        if (this == o) return true;
        if (!(o instanceof Person p)) return false;
        return id == p.id && name.equals(p.name);
    }
    @Override
    public int hashCode() { return Objects.hash(id, name); }   // consistent with equa
ls
}

Set<Person> set = new HashSet<>();
set.add(new Person(1, "Amit"));
System.out.println(set.contains(new Person(1, "Amit")));
// Output: true - ONLY works because equals() AND hashCode() are both overridden consi
stently
```

> ***Interview tip:*** *Golden rule: whenever you override equals(), you MUST override hashCode() too – forgetting this is one of the most common real-world Java bugs, and it silently breaks HashMap/HashSet lookups without any compile error or obvious symptom.*

Common interview questions:

Q: What breaks if you override equals() but NOT hashCode()?

A: The default Object.hashCode() (based on memory address) still applies, so two 'equal' objects can land in different hash buckets – a HashSet can then contain what look like duplicate entries, and .contains() on a logically-equal-but-different-instance object can wrongly return false.

Substring

In simple words:

> *Think of cutting out a section of a sentence with scissors, keeping only the piece between two chosen points, while the original sentence you cut from remains a separate, whole sentence.*

The technical detail:

Returns a NEW String object containing characters from a start index (inclusive) up to an end index (exclusive) – if the end index is omitted, it defaults to the end of the string. Since Java 7u6, substring copies the relevant characters into a new backing char array (earlier versions shared the original array, which could cause memory leaks by keeping a huge original string alive just because of a small substring reference).

```
String s = "HelloWorld";
System.out.println(s.substring(5));       // Output: World  (index 5 to end)
System.out.println(s.substring(0, 5));    // Output: Hello  (index 0 up to, not includ
ing, 5)
System.out.println(s.substring(2, 2));    // Output: (empty string, start == end is va
lid)
```

Constructor & Constructor Chaining

In simple words:

> *Think of filling out a simplified form that auto-fills the rest of a longer, more detailed form for you, instead of you re-typing everything from scratch every single time.*

The technical detail:

A constructor is a special block that initializes a newly created object; it shares the class's name and has NO return type (not even void). If you don't write any constructor, Java auto-generates a public no-arg DEFAULT constructor – but as soon as you write ANY constructor yourself, that automatic default one disappears.

CONSTRUCTOR CHAINING means one constructor calls another to avoid duplicating initialization logic: this(...) chains to another constructor in the SAME class (must be the first statement); super(...) chains to a constructor in the PARENT class (also must be first statement, and Java inserts an implicit no-arg super() automatically if you write neither).

```
class Box {
    int w, h;
    Box() { this(1, 1); }                        // chains to the 2-arg constructor
    Box(int side) { this(side, side); }           // chains to the 2-arg constructor
    Box(int w, int h) { this.w = w; this.h = h; } // does the actual work, once
}

Box b = new Box();
System.out.println(b.w + " " + b.h);   // Output: 1 1
```

9. Access Modifiers, Casting & Wrapper Classes

Access Modifiers

In simple words:

> *Think of rooms in a house: private = your own locked bedroom (only you), default = rooms open to family living in the same house (package), protected = rooms open to family plus close relatives visiting (subclasses), public = the front porch, open to anyone walking by.*

The technical detail:

Control the VISIBILITY of classes, fields, methods, and constructors, from most to least restrictive:
• private – visible only inside the declaring class itself. Not even subclasses can see it directly.
• default / package-private (no keyword written) – visible to any class in the SAME package, regardless of inheritance.
• protected – visible within the same package PLUS to subclasses in ANY package (via inheritance).
• public – visible from anywhere, no restriction.

```
public class Demo {
    private int a;      // this class only
    int b;                // package only (default)
    protected int c;     // package + subclasses everywhere
    public int d;         // everywhere, unrestricted
}
```

Common interview questions:

Q: Can a top-level class be declared private or protected?
A: No – a top-level (non-nested) class can only be public or default(package-private). private/protected are only valid on members (fields, methods, constructors) or on NESTED classes.

Type Casting: Widening vs Narrowing

In simple words:

> *Widening is like pouring a small cup of water into a big bucket – it always fits safely, nothing spills. Narrowing is like pouring a big bucket of water into a small cup – you might have to accept that some water spills out (data is lost), so you have to deliberately choose to do it.*

The technical detail:

WIDENING (implicit / automatic conversion): converting a smaller primitive type to a larger one, in the order byte → short → int → long → float → double. The compiler does this automatically because the larger type can always represent every value the smaller one could, so there's no possible data loss (though converting int/long to float/double can lose PRECISION, not magnitude).

NARROWING (explicit / manual conversion): converting a larger type to a smaller one, which the compiler will NOT do automatically because information could be lost – you must write an explicit cast '(targetType) value' to acknowledge you accept that risk.

```
int i = 100;
long l = i;                 // widening - implicit, always safe
double d = 9.99;
int j = (int) d;             // narrowing - explicit cast REQUIRED, j = 9 (fraction tr
uncated)

int big = 130;
byte b = (byte) big;          // narrowing - byte range is -128..127
System.out.println(b);        // Output: -126 (silent overflow/wraparound - no excepti
on!)
```

> ***Interview tip:*** *Narrowing does NOT throw an exception on overflow – it silently wraps around using integer overflow rules, which can produce very surprising, hard-to-spot bugs if not intentional.*

Autoboxing & Unboxing

In simple words:

> *Think of a primitive value as loose cash, and a Wrapper object as that same cash sealed inside an envelope. Autoboxing is sealing the cash into an envelope automatically; unboxing is tearing the envelope back open to get the cash out – Java does this sealing/unsealing for you behind the scenes.*

The technical detail:

AUTOBOXING: the compiler automatically wraps a primitive value into its corresponding Wrapper object when an object is required (e.g. adding an int into a List<Integer>, since generics only work with objects, never primitives). UNBOXING: the reverse – automatically extracting the primitive value back out of a Wrapper object when a primitive is expected (e.g. using an Integer in an arithmetic expression). Both happen silently, inserted by the compiler, without you writing explicit conversion code.

```
List<Integer> list = new ArrayList<>();
list.add(5);                 // autoboxing: int 5 -> new Integer(5) behind the scenes
int x = list.get(0);          // unboxing: Integer -> int, extracting .intValue()

Integer sum = 0;
for (int i = 1; i <= 3; i++) sum += i;   // unboxes sum, adds, reboxes - each iteratio
n!
System.out.println(sum);      // Output: 6
```

> ***Interview tip:*** *Danger: unboxing a NULL Integer (or any wrapper) throws NullPointerException – e.g. 'Integer x = map.get(missingKey); int y = x;' crashes if the key wasn't found and get() returned null.*

Common interview questions:

Q: Why is repeated autoboxing in a loop a performance concern?
A: Each box/unbox cycle can allocate a new Wrapper object (outside the small cached range), creating unnecessary garbage under heavy iteration – prefer primitive accumulator variables (int, not Integer) in hot loops.

Wrapper Classes

In simple words:

> *Think of a coin (primitive) versus that same coin sealed inside a labeled display case (Wrapper object) so it can be shown in a museum exhibit (a collection) that only accepts display cases, never loose coins.*

The technical detail:

Object representations of Java's 8 primitive types: byte→Byte, short→Short, int→Integer, long→Long, float→Float, double→Double, char→Character, boolean→Boolean. They exist because generics, collections (List, Map, Set), and anything requiring an Object cannot work with raw primitives directly. All wrapper classes are IMMUTABLE (like String) and FINAL (cannot be subclassed). For performance, Java caches and reuses Integer objects for the range -128 to 127 (and similar small caches for Short, Long, Byte, Character ≤127, and both Boolean values) – autoboxing a value in that range returns the SAME cached object every time, which is why '==' can misleadingly appear to work for small numbers.

```
Integer a = 100, b = 100;
System.out.println(a == b);        // Output: true  - both come from the cache (-128..
127)

Integer c = 200, e = 200;
System.out.println(c == e);        // Output: false - outside the cache, two new objec
```

```
ts
System.out.println(c.equals(e));   // Output: true  - always use equals() for wrapper
comparison
```

Interview tip: *Never compare Wrapper objects with '==' – it works 'by accident' for small cached values and silently breaks for larger ones. Always use .equals() (or unbox both to primitives first).*

10. Collections Framework

Collection Hierarchy Overview

In simple words:

Think of different types of containers in a kitchen: a List is like a labeled spice rack where order matters and you can have duplicates; a Set is like a set of unique house keys (no two are the same); a Map is like a phonebook, pairing a name (key) to a phone number (value).

The technical detail:

The framework has two separate root interfaces: Collection<E> (single elements) and Map<K,V> (key-value pairs – NOT a Collection, a separate hierarchy). Under Collection: List (ordered, index-accessible, allows duplicates – ArrayList, LinkedList, Vector), Set (no duplicates, membership-focused – HashSet, LinkedHashSet, TreeSet), and Queue/Deque (ordered for processing, typically FIFO or priority-based – LinkedList, PriorityQueue, ArrayDeque). Under Map: HashMap, LinkedHashMap, TreeMap, ConcurrentHashMap, Hashtable.

```
Collection<E>                    Map<K,V>
  ■■ List (ArrayList, LinkedList)     ■■ HashMap
  ■■ Set (HashSet, TreeSet)           ■■ LinkedHashMap
  ■■ Queue/Deque (PriorityQueue)      ■■ TreeMap
```

ArrayList vs LinkedList

In simple words:

ArrayList is like a row of numbered parking spots – you can jump straight to spot #47 instantly, but squeezing a new car into the middle means every car after it has to shuffle over. LinkedList is like a treasure-hunt chain, where each clue only tells you where the NEXT clue is – inserting a new clue in the middle is easy (just repoint two links), but finding clue #47 means walking through every clue before it.

The technical detail:

ARRAYLIST is backed by a dynamically resizable ARRAY. Random access via get(index) is O(1) – direct memory offset calculation. Insertion/deletion in the MIDDLE is O(n) – every subsequent element must physically shift over. When the backing array fills up, it's reallocated (typically 1.5x growth) and all elements copied – an occasionally expensive O(n) operation, though amortized O(1) per add() on average.

LINKEDLIST is backed by a DOUBLY LINKED LIST of nodes, each holding data plus references to the previous and next node. Random access via get(index) is O(n) – must walk the chain from the nearer end. Insertion/deletion at a KNOWN node (e.g. the head/tail, or via an Iterator's cursor position) is O(1) – just relinking pointers, no shifting. LinkedList also implements the Deque interface, giving it efficient queue/stack operations (addFirst, addLast, pollFirst, pollLast).

```
List<String> al = new ArrayList<>();
al.add("a"); al.add("b"); al.add("c");
```

```
System.out.println(al.get(1));       // Output: b - O(1) fast random access

List<String> ll = new LinkedList<>();
ll.add("a"); ll.add("b"); ll.add("c");
((LinkedList<String>) ll).addFirst("z");   // O(1) - just relinks head pointer
System.out.println(ll);                    // Output: [z, a, b, c]
```

Interview tip: *Rule of thumb: mostly reading by index -> ArrayList. Mostly inserting/removing at the ends or via an iterator, or need queue/deque behavior -> LinkedList. In practice ArrayList is the default choice for most everyday code because CPU cache locality makes it faster in practice even for many 'should favor LinkedList' scenarios.*

Common interview questions:

Q: Why is ArrayList often faster than LinkedList even for insertions in real benchmarks?
A: Arrays have excellent CPU cache locality (elements sit contiguously in memory), while LinkedList nodes are scattered across the heap, causing cache misses that often outweigh the theoretical O(1) vs O(n) advantage for typical list sizes.

Set: HashSet vs LinkedHashSet vs TreeSet

In simple words:

HashSet is like tossing unique marbles into a bag – no duplicates allowed, but you can't predict what order you'll pull them out in. LinkedHashSet is the same bag, but marbles are strung on a thread in the order you added them. TreeSet is like a marble sorter that always arranges the marbles from smallest to largest automatically.

The technical detail:

HASHSET: backed internally by a HashMap (elements stored as keys). No duplicates (uses equals()/hashCode() to detect them), NO guaranteed iteration order (can even change between runs), O(1) average time for add/remove/contains.

LINKEDHASHSET: extends HashSet but ALSO maintains a doubly-linked list running through all entries, so iteration order matches INSERTION order – slightly more memory overhead than HashSet for that guarantee, still O(1) average operations.

TREESET: backed by a Red-Black tree (a self-balancing binary search tree). Elements are always kept in SORTED order – either their natural order (via Comparable) or a supplied Comparator. Operations are O(log n), slower than the hash-based sets but you get sorted iteration for free, plus range operations like headSet/tailSet/ceiling/floor.

```
Set<Integer> hs = new HashSet<>(List.of(3, 1, 2));
System.out.println(hs);     // Output: [1, 2, 3] or any order - NOT guaranteed

Set<Integer> lhs = new LinkedHashSet<>(List.of(3, 1, 2));
System.out.println(lhs);    // Output: [3, 1, 2] - always matches insertion order

Set<Integer> ts = new TreeSet<>(List.of(3, 1, 2));
System.out.println(ts);     // Output: [1, 2, 3] - always sorted
```

Queue

In simple words:

> *Think of a queue (line) at a ticket counter – first person in line is generally the first one served (FIFO). A PriorityQueue is more like an emergency room – the most urgent patient gets seen first, regardless of who arrived earliest.*

The technical detail:

An interface modeling elements held for PROCESSING, typically FIFO (first-in-first-out), though implementations can vary that ordering. Core methods come in two families: offer/poll/peek (return special values like null/false on failure) vs add/remove/element (throw exceptions on failure) – offer/poll/peek are generally preferred since they avoid unnecessary exception handling for expected 'empty queue' cases. Common implementations: LinkedList (basic FIFO), PriorityQueue (orders elements by natural order or a Comparator – NOT insertion order; smallest/highest-priority element is always at the head), ArrayDeque (fast resizable-array-backed double-ended queue, usually the best general-purpose Deque/stack choice. faster than LinkedList for that role).

```
Queue<Integer> q = new LinkedList<>();
q.offer(1); q.offer(2); q.offer(3);
System.out.println(q.poll());   // Output: 1 (removes & returns the head - FIFO)

Queue<Integer> pq = new PriorityQueue<>();
pq.offer(5); pq.offer(1); pq.offer(3);
System.out.println(pq.poll());  // Output: 1 - smallest element first, NOT insertion o
rder
```

HashMap vs LinkedHashMap vs TreeMap

In simple words:

> *A HashMap is a phonebook where entries are scattered randomly for fast lookup by name. A LinkedHashMap is the same phonebook, but it also remembers the exact order you wrote entries in. A TreeMap is a phonebook that's always kept alphabetically sorted automatically.*

The technical detail:

HASHMAP: stores key-value pairs using a hash table internally (array of 'buckets', each bucket a linked list or, since Java 8, a balanced tree once a bucket gets crowded – turning worst-case O(n) lookups into O(log n)). No ordering guarantee. Permits ONE null key and multiple null values. O(1) average time for get/put, computed via the key's hashCode().

LINKEDHASHMAP: extends HashMap, additionally maintaining a doubly-linked list of entries – default iteration order is INSERTION order, but it can be configured (via a constructor flag) to use ACCESS order instead, which is the standard building block for implementing an LRU (Least-Recently-Used) cache.

TREEMAP: implements SortedMap/NavigableMap, backed by a Red-Black tree, keeping KEYS always in sorted order (natural or Comparator-defined). O(log n) operations. Does NOT permit null keys (throws NullPointerException) since it must be able to compare every key.

```
Map<String,Integer> hm = new HashMap<>();
hm.put("b", 2); hm.put("a", 1);
System.out.println(hm);        // Output: order not guaranteed, e.g. {a=1, b=2} or oth
er

Map<String,Integer> lhm = new LinkedHashMap<>();
lhm.put("b", 2); lhm.put("a", 1);
System.out.println(lhm);        // Output: {b=2, a=1} - always insertion order
```

```
Map<String,Integer> tm = new TreeMap<>();
tm.put("b", 2); tm.put("a", 1);
System.out.println(tm);         // Output: {a=1, b=2} - always sorted by key
```

Common interview questions:

Q: How does HashMap resolve collisions internally, and how did that change in Java 8?
A: Before Java 8, each bucket was a simple linked list of entries with the same hash bucket index – worst case (many collisions) degraded to O(n) lookups. Since Java 8, if a single bucket's linked list grows beyond a threshold (8 entries, and the table is large enough), that bucket converts into a balanced Red-Black tree, capping worst-case lookup at O(log n).

ConcurrentHashMap

In simple words:

Think of a big shared whiteboard split into many small separate sections. Multiple people can write on DIFFERENT sections at the same time without bumping into each other, instead of everyone having to take turns using one single marker for the entire board.

The technical detail:

A thread-safe implementation of Map designed for HIGH-CONCURRENCY access – unlike a plain HashMap wrapped with Collections.synchronizedMap() (which locks the ENTIRE map for every operation, serializing all threads), ConcurrentHashMap uses fine-grained internal locking (in modern versions, primarily per-bin/per-node CAS operations and synchronized blocks scoped to individual bins rather than the whole map), so multiple threads can read AND write different parts of the map truly simultaneously. Reads generally don't block at all. It does NOT permit null keys OR null values (a deliberate design choice, since a null return from get() would be ambiguous between 'key absent' and 'key mapped to null' in a concurrent context where you can't safely double-check).

```
Map<String,Integer> map = new ConcurrentHashMap<>();
map.put("count", 0);
// Safe to call from many threads at once without external synchronization:
map.compute("count", (k, v) -> v + 1);   // atomic read-modify-write
```

Iterator vs ListIterator

In simple words:

An Iterator is like walking through a museum in one direction only, able to remove an exhibit as you pass it. A ListIterator is like being able to walk BOTH forward and backward through the museum, and also swap out or add a new exhibit right where you're standing.

The technical detail:

ITERATOR: works on ANY Collection (List, Set, Queue). Traverses FORWARD ONLY. Supports remove() (safely deletes the current element during iteration). This is the safe way to remove elements while looping – modifying a collection directly during a for-each loop throws ConcurrentModificationException because the for-each loop uses an internal Iterator under the hood and detects the structural change.

LISTITERATOR: works ONLY on List implementations. Traverses BOTH directions (next() and previous()). Supports remove(), and ALSO set() (replace the last-returned element) and add() (insert a new element at the current cursor position) – capabilities plain Iterator lacks. It also exposes nextIndex()/previousIndex().

```
List<Integer> list = new ArrayList<>(List.of(1, 2, 3));
Iterator<Integer> it = list.iterator();
while (it.hasNext()) {
    if (it.next() == 2) it.remove();      // safe removal during iteration
}
System.out.println(list);   // Output: [1, 3]

ListIterator<Integer> lit = list.listIterator();
while (lit.hasNext()) lit.set(lit.next() * 10);   // in-place modification
System.out.println(list);   // Output: [10, 30]
```

Interview tip: *Interview trap: 'for (Integer i : list) { if (i == 2) list.remove(i); }' throws ConcurrentModificationException – you MUST use Iterator.remove() instead of the collection's own remove() while looping.*

Common interview questions:

Q: Why does removing directly during a for-each loop throw ConcurrentModificationException?
A: The for-each loop internally uses an Iterator and checks a 'modCount' (modification count) field on the collection each time next() is called. Calling list.remove() directly bumps modCount without the iterator knowing, so the mismatch is detected and the exception is thrown as a fail-fast safety check.

Comparable vs Comparator

In simple words:

Comparable is a person's own natural height, built into who they are – there's only ONE natural way to compare heights. Comparator is like handing someone a special measuring tape with custom rules ('sort by shoe size instead') – you can create as many different comparators as you like, without changing the person at all.

The technical detail:

COMPARABLE (java.lang package): implemented BY the class whose objects need ordering, via a SINGLE method compareTo(other) returning negative/zero/positive. This defines that class's ONE 'natural ordering' – there can only be one compareTo() implementation per class. Used automatically by Collections.sort(list) and TreeSet/TreeMap when no separate Comparator is supplied.

COMPARATOR (java.util package): a SEPARATE, standalone object (often a lambda) implementing compare(a, b), completely independent of the class being compared. Lets you define ANY NUMBER of different custom orderings for the same class WITHOUT modifying that class's source code at all – essential when you don't own the class, or need multiple different sort criteria (by name, then separately by age, then separately by salary).

```
class Person implements Comparable<Person> {
    String name; int age;
    Person(String n, int a) { name = n; age = a; }
    public int compareTo(Person p) { return this.age - p.age; }  // natural order: by
age
    public String toString() { return name + "(" + age + ")"; }
}

List<Person> people = new ArrayList<>(List.of(
    new Person("Ravi", 30), new Person("Amit", 25)));
Collections.sort(people);                              // uses compareTo -> by age
System.out.println(people);   // Output: [Amit(25), Ravi(30)]

Comparator<Person> byNameDesc = (p1, p2) -> p2.name.compareTo(p1.name);
people.sort(byNameDesc);                                // custom order, class unchang
ed
```

```
System.out.println(people);   // Output: [Ravi(30), Amit(25)]
```

Common interview questions:

Q: Can a class have multiple compareTo() implementations for different fields?
A: No – a class implementing Comparable can define only ONE compareTo() method, i.e. only one 'natural' ordering. For additional orderings, you write separate Comparator objects instead.

11. Multithreading & Concurrency

Thread Basics & Lifecycle

In simple words:

Think of a kitchen with several cooks working at once, each following their own recipe (their own path of execution), rather than one cook doing every single task one after another. A thread is one of those cooks.

The technical detail:

A Thread represents an independent path of execution that can run concurrently with other threads within the same process, sharing the same heap memory but having its own stack. Created either by extending Thread and overriding run() (less flexible, uses up your only superclass slot), or by implementing Runnable and passing it to a Thread's constructor (preferred – keeps the class free to extend something else, and separates 'what to run' from 'how it's run').

LIFECYCLE STATES (java.lang.Thread.State):
• NEW – Thread object created, start() not yet called.
• RUNNABLE – eligible to run (may be actually executing, or waiting for CPU time from the OS scheduler – Java doesn't distinguish these two).
• BLOCKED – waiting to acquire a lock (synchronized) held by another thread.
• WAITING – waiting indefinitely for another thread's explicit signal (e.g. after calling wait() with no timeout, or join() with no timeout).
• TIMED_WAITING – waiting for a bounded amount of time (sleep(ms), wait(ms), join(ms)).
• TERMINATED – run() has completed (normally or via an uncaught exception).

```
class Task implements Runnable {
    public void run() { System.out.println("Running on " + Thread.currentThread().getN
ame()); }
}
Thread t = new Thread(new Task(), "worker-1");
System.out.println(t.getState());   // Output: NEW
t.start();                            // NEW -> RUNNABLE ; JVM allocates a real OS thr
ead
// Output: Running on worker-1
```

Interview tip: *Calling run() directly (t.run()) instead of start() just executes it like a normal method call on the CURRENT thread – no new thread is ever created, and no concurrency happens at all. This is one of the most common multithreading beginner mistakes.*

Common interview questions:

Q: What's the real difference between calling t.start() and t.run()?
A: start() asks the JVM to allocate a new OS-level thread and THEN calls run() on that new thread. run() called directly just executes the method body synchronously on whichever thread called it – no new thread is created at all.

Synchronization

In simple words:

> *Think of a single-occupancy bathroom with a lock. Only one person (thread) can be inside at a time; everyone else has to wait outside (blocked) until the door unlocks, preventing chaos from two people using it at once.*

The technical detail:

A mechanism using the 'synchronized' keyword to ensure only ONE thread at a time can execute a given critical section, preventing RACE CONDITIONS (where the final result depends unpredictably on thread timing/interleaving). Internally, every Java object has an associated monitor lock; entering a synchronized method/block requires acquiring that object's lock, and no other thread can acquire the SAME lock until the first thread releases it (exits the block, normally or via exception).

'synchronized' on an INSTANCE method locks on 'this' (the current object). 'synchronized' on a STATIC method locks on the Class object itself (shared across ALL instances). 'synchronized(someObject) { ... }' as a BLOCK lets you lock on any chosen object, giving finer-grained control (locking only the minimal necessary code, not the whole method) for better performance under contention.

```
class Counter {
    private int count = 0;
    synchronized void increment() {   // locks on 'this' - only one thread at a time h
ere
        count++;                       // count++ is NOT atomic (read+increment+write)
    }
    int get() { return count; }
}

Counter c = new Counter();
Runnable task = () -> { for (int i = 0; i < 1000; i++) c.increment(); };
Thread t1 = new Thread(task), t2 = new Thread(task);
t1.start(); t2.start(); t1.join(); t2.join();
System.out.println(c.get());   // Output: 2000 - correct ONLY because of synchronized
```

> ***Interview tip:*** *Without 'synchronized', count++ is a classic race condition: it's actually THREE operations (read count, add 1, write count back) – two threads can both read the same old value before either writes back, silently losing an increment. Running the same code without 'synchronized' would unpredictably print something less than 2000.*

Common interview questions:

Q: What does a synchronized instance method actually lock on?

A: The intrinsic monitor lock of 'this' – the current object instance. Two different objects each have their own independent lock, so calling a synchronized method on two different Counter objects from two threads does NOT block each other at all.

volatile keyword

In simple words:

> *Think of a shared whiteboard note visible instantly to everyone in the office the moment it's updated, instead of everyone working from their own private, possibly outdated photocopy of the note taken earlier.*

The technical detail:

Applied to a field to guarantee VISIBILITY across threads: every read of a volatile variable always fetches the latest value from main memory (never a stale value cached in one CPU core's local cache/register), and every write is immediately flushed to main memory, visible to all other threads right away. It also prevents certain compiler/CPU instruction REORDERING optimizations around that variable.

CRITICALLY, volatile does NOT provide ATOMICITY – a compound operation like count++ on a volatile int is STILL a race condition (read, increment, write are three separate steps; two threads can still interleave them incorrectly), because volatile only guarantees each individual read/write step sees fresh data, not that a multi-step operation happens as one indivisible unit. For atomic counters, use java.util.concurrent.atomic.AtomicInteger instead.

```
private volatile boolean running = true;

// Thread A:
while (running) { /* do work */ }   // always re-checks the LATEST value

// Thread B:
running = false;                     // immediately visible to Thread A's next check

// Contrast - this is UNSAFE even if volatile:
private volatile int counter = 0;
counter++;   // STILL a race condition - not atomic, despite being volatile
```

Common interview questions:

Q: volatile vs synchronized - what's the precise difference?

A: volatile guarantees VISIBILITY only (fresh reads/writes to main memory) for a single variable, with no locking and no mutual exclusion. synchronized guarantees BOTH visibility AND atomicity/mutual exclusion for an entire block of code, at the cost of higher overhead (threads can block waiting for the lock).

wait(), notify(), notifyAll()

In simple words:

> *Think of a customer waiting patiently at a counter until the shopkeeper rings a bell (notify) to say 'ready for you now.' Until the bell rings, the customer just waits quietly instead of repeatedly bothering the shopkeeper.*

The technical detail:

Methods defined on Object (NOT Thread), used for INTER-THREAD COMMUNICATION/coordination. They must be called from WITHIN a synchronized block on the SAME object being waited/notified on, or they throw IllegalMonitorStateException at runtime.

wait() – releases the object's lock and puts the current thread into the WAITING state, pausing until another thread calls notify()/notifyAll() on the same object (or an optional timeout elapses). Crucially, it releases the lock WHILE waiting, so other threads can acquire it and make progress (unlike sleep(), which holds any locks it has).

notify() – wakes up ONE arbitrarily-chosen thread that is waiting on this object. notifyAll() – wakes up ALL threads waiting on this object; they then compete to re-acquire the lock one at a time. notifyAll() is usually the safer default choice to avoid missed-wakeup bugs when multiple different conditions/consumers might be waiting.

```
class Buffer {
    private final Object lock = new Object();
    private boolean dataReady = false;

    void produce() {
        synchronized (lock) {
            dataReady = true;
            lock.notifyAll();      // wake up any waiting consumers
        }
    }
    void consume() throws InterruptedException {
        synchronized (lock) {
            while (!dataReady) lock.wait();   // releases lock, pauses until notified
            System.out.println("Data consumed");
        }
    }
}
```

Common interview questions:

Q: Why must wait() be called inside a 'while' loop checking the condition, not just an 'if'?
A: Spurious wakeups can occur (the thread can wake up even without an explicit notify), and with notifyAll(), multiple waiting threads wake and race to recheck the condition – by the time this thread gets the lock back, another thread might have already consumed the resource. A while loop re-verifies the condition is STILL true after waking, before proceeding.

ExecutorService

In simple words:

> *Think of a taxi company with a fixed pool of drivers (threads) waiting to take ride requests, instead of hiring and firing a brand new driver for every single ride – much more efficient to just reuse the same pool of drivers.*

The technical detail:

A higher-level framework (java.util.concurrent) for managing a POOL of reusable worker threads, instead of manually creating and discarding a raw Thread object for every task – thread creation/teardown is relatively expensive, so pooling and reusing threads is far more efficient at scale. ExecutorService also manages task QUEUING (when all pool threads are busy, submitted tasks wait in an internal queue) and provides graceful shutdown control. Common factory methods: newFixedThreadPool(n) (fixed pool size), newCachedThreadPool() (grows/shrinks as needed), newSingleThreadExecutor() (one worker, tasks run sequentially, still off the calling thread).

```
ExecutorService pool = Executors.newFixedThreadPool(4);
for (int i = 0; i < 10; i++) {
    int taskId = i;
    pool.submit(() -> System.out.println("Task " + taskId + " on " + Thread.currentThr
ead().getName()));
}
pool.shutdown();   // stops accepting new tasks, lets already-submitted ones finish
```

Interview tip: *Always call shutdown() (or shutdownNow() for immediate termination) when done – an ExecutorService's threads are non-daemon by default, so a forgotten pool will keep the JVM process alive indefinitely even after main() finishes.*

Callable & Future

In simple words:

> *Think of dropping off laundry at a shop and getting a claim TICKET (Future) instead of waiting there in person. You can go do other things, and later use the ticket to collect your actual finished laundry (the result) whenever it's ready.*

The technical detail:

Runnable's run() method returns NOTHING (void) and cannot declare checked exceptions. Callable<V>'s call() method RETURNS a value of type V and CAN throw checked exceptions – useful whenever a background task needs to produce a result or might legitimately fail with a checked error.

Submitting a Callable to an ExecutorService immediately returns a Future<V> – a HANDLE/placeholder for a result that may not exist yet, since the task runs asynchronously in another thread. Calling future.get() BLOCKS the calling thread until the task completes, then returns its result (or throws ExecutionException wrapping any exception the task threw). future.get(timeout, unit) blocks with a maximum wait, throwing TimeoutException if exceeded. future.isDone()/isCancelled() let you check status without blocking.

```
ExecutorService pool = Executors.newFixedThreadPool(2);
Callable<Integer> task = () -> {
    Thread.sleep(1000);       // simulate slow work
    return 10 + 20;
};
Future<Integer> future = pool.submit(task);
System.out.println("Doing other work while task runs...");
Integer result = future.get();     // blocks here until the task finishes
```

```
System.out.println(result);         // Output: 30
pool.shutdown();
```

ThreadLocal

In simple words:

> *Think of each employee having their own personal locker at work, even though they all work in the same shared building – what's inside YOUR locker never mixes up with what's inside a coworker's locker.*

The technical detail:

Provides each individual thread with its OWN independent copy of a variable – reads/writes from one thread never affect the value seen by any other thread, even though they all reference the SAME ThreadLocal object. This avoids needing synchronization for state that is inherently per-thread (e.g. a database connection per request-handling thread, a date formatter, a 'current logged-in user' context in a web server). Internally, each Thread object carries its own small map (ThreadLocalMap) from ThreadLocal instances to their per-thread values.

```
ThreadLocal<SimpleDateFormat> fmt =
    ThreadLocal.withInitial(() -> new SimpleDateFormat("yyyy-MM-dd"));

Runnable task = () -> {
    SimpleDateFormat f = fmt.get();          // each thread gets its OWN instance
    System.out.println(Thread.currentThread().getName() + ": " + f.format(new Date()))
;
};
new Thread(task, "T1").start();
new Thread(task, "T2").start();
// each thread safely uses its own SimpleDateFormat, which is NOT thread-safe by itsel
f
```

> ***Interview tip:*** *In thread-pooled environments (like ExecutorService), always call remove() on a ThreadLocal when done – pooled threads are REUSED across many tasks, so a forgotten ThreadLocal value can leak stale data into the next unrelated task run on that same pooled thread.*

12. Java 8+ Modern Features

Lambda Expressions

In simple words:

> *Think of writing a short sticky note instead of a full formal memo just to say 'do this one small thing.' A lambda is that quick sticky note, used instead of writing a whole formal class just to define one small piece of behavior.*

The technical detail:

A concise, anonymous, inline way to represent a single unit of behavior as a VALUE that can be passed around, assigned to a variable, or passed as an argument – primarily used to implement FUNCTIONAL INTERFACES (interfaces with exactly one abstract method) without the verbose boilerplate of a full anonymous class. Syntax: (parameters) -> expression, or (parameters) -> { statements; return ...; } for multi-line bodies. Parameter types are usually inferred by the compiler from context, so they're normally omitted.

```
Runnable r = () -> System.out.println("Running");
Comparator<Integer> cmp = (a, b) -> a - b;
```

```
List<Integer> nums = List.of(1, 2, 3);
nums.forEach(n -> System.out.println(n * 2));
// Output:
// 2
// 4
// 6
```

Interview tip: *A lambda can only capture local variables that are final or 'effectively final' (never reassigned after initialization) – this is because the lambda may execute later/on a different thread, so it captures a snapshot COPY of the variable's value, and allowing reassignment afterward would create confusing inconsistency.*

Common interview questions:

Q: Why must variables captured by a lambda be effectively final?

A: The lambda body might run later, potentially on a different thread, after the enclosing method has already returned and its stack frame is gone. The lambda captures the variable's VALUE at creation time; allowing it to change afterward in the enclosing scope would create an inconsistency about which value the lambda 'should' see.

Functional Interface

In simple words:

Think of a job posting with exactly ONE required task listed ('must be able to answer the phone'). Because there's only one requirement, you can hire someone super quickly with a one-line agreement (a lambda) instead of a lengthy formal contract.

The technical detail:

An interface with EXACTLY ONE abstract method (default and static methods don't count toward this rule) – this single abstract method is the 'target' that a lambda expression implements. The optional @FunctionalInterface annotation isn't required, but tells the compiler to verify and enforce the single-abstract-method rule, causing a compile error if a second abstract method is accidentally added later. Built-in examples: Runnable (run()), Callable<V> (call()), Comparator<T> (compare()), and the java.util.function package: Function<T,R> (apply – transforms input to output), Predicate<T> (test – returns boolean), Supplier<T> (get – no input, produces a value), Consumer<T> (accept – takes input, returns nothing).

```
@FunctionalInterface
interface Calculator { int operate(int a, int b); }

Calculator add = (a, b) -> a + b;
Calculator multiply = (a, b) -> a * b;
System.out.println(add.operate(3, 4));        // Output: 7
System.out.println(multiply.operate(3, 4));   // Output: 12

Predicate<Integer> isEven = n -> n % 2 == 0;
System.out.println(isEven.test(4));            // Output: true
```

Stream API

In simple words:

> *Think of a factory assembly line: raw items go in one end, pass through a series of stations (filter out bad ones, paint them, package them), and finished products come out the other end. Nothing happens on the line until you actually switch the belt ON (the terminal operation).*

The technical detail:

A pipeline abstraction (java.util.stream) for processing SEQUENCES of elements (from a Collection, an array via Arrays.stream, a range via IntStream.range, etc.) in a DECLARATIVE, functional style – you describe WHAT transformation you want, not HOW to loop through it manually.

A stream pipeline has three parts: (1) a SOURCE, (2) zero or more INTERMEDIATE operations (filter, map, sorted, distinct, limit – each returns a NEW stream, and they are all LAZY, meaning nothing actually executes until a terminal operation is invoked), and (3) exactly one TERMINAL operation (collect, forEach, reduce, count, anyMatch – this triggers the entire pipeline to actually run, element by element, and produces a final result or side effect). Crucially, streams do NOT modify their source collection, and a stream can only be consumed ONCE (reusing an already-terminated stream throws IllegalStateException). parallelStream() runs the same pipeline across multiple threads automatically for large datasets, at the cost of coordination overhead.

```
List<String> names = List.of("Amit", "Bob", "Anita", "Zara");

List<String> result = names.stream()
    .filter(n -> n.startsWith("A"))     // intermediate: keep names starting with A
    .map(String::toUpperCase)           // intermediate: transform each
    .sorted()                           // intermediate: sort alphabetically
    .collect(Collectors.toList());      // terminal: trigger execution, gather res
ults
System.out.println(result);   // Output: [AMIT, ANITA]

long count = names.stream().filter(n -> n.length() > 3).count();
System.out.println(count);     // Output: 3 (Amit, Anita, Zara)
```

Interview tip: *Streams are lazy: writing '.filter(...).map(...)' with NO terminal operation does nothing at all – no exception, no output, the pipeline simply never executes. This surprises beginners who expect side effects inside filter/map to run immediately.*

Common interview questions:

Q: Why can a stream only be consumed once?

A: A stream isn't a data structure that stores elements – it's a one-time pipeline of computation over a source. Once a terminal operation runs it, the stream is considered 'closed'; calling another terminal operation on the same stream instance throws IllegalStateException. You'd call .stream() again on the source collection to get a fresh stream.

Optional

In simple words:

> *Think of a gift box that's clearly labeled 'may or may not contain a gift.' Because the label warns you upfront, you naturally check before reaching in, instead of blindly grabbing and being shocked to find it empty.*

The technical detail:

A container object explicitly representing 'a value that might be present, or might be absent' – designed to make the possibility of 'no value' visible in a method's RETURN TYPE itself, forcing callers to consciously handle the empty case instead of accidentally dereferencing a forgotten null and crashing with NullPointerException somewhere far from the actual root cause. Created via Optional.of(value) (throws immediately if value is null), Optional.ofNullable(value) (safely wraps a possibly-null value), or Optional.empty(). Consumed via orElse(default), orElseGet(supplier), orElseThrow(...), ifPresent(consumer), or map(...) to transform the contained value only if present.

```
Optional<String> opt = Optional.ofNullable(findUserEmail("id123"));

String email = opt.orElse("no-email@example.com");        // safe default
opt.ifPresent(e -> System.out.println("Found: " + e));    // only runs if present

String upper = opt.map(String::toUpperCase).orElse("N/A");
System.out.println(upper);   // Output: value uppercased, or "N/A" if absent
```

> ***Interview tip:*** *Optional is intended for RETURN TYPES, not for fields or method parameters – using it as a class field adds serialization overhead and complexity without real benefit, since fields can already just be properly null-checked internally within the class.*

DateTime API (java.time)

In simple words:

> *Think of a printed calendar page versus a whiteboard calendar. The old Date class was like a whiteboard anyone walking by could scribble changes on. The new java.time classes are like a printed page – to 'change the date' you get a brand NEW printed page; the original page never gets altered.*

The technical detail:

Java 8's complete replacement for the old java.util.Date and java.util.Calendar classes, which were notoriously MUTABLE (a shared Date object could be silently modified by any code holding a reference to it – not thread-safe) and had a confusing API (months indexed from 0, years offset from 1900). Every class in java.time (LocalDate, LocalTime, LocalDateTime, ZonedDateTime, Duration, Period, Instant) is IMMUTABLE and inherently THREAD-SAFE – every 'modifying' method (like plusDays()) returns a NEW instance rather than changing the original, following the same immutable pattern as String.

```
LocalDate today = LocalDate.now();
LocalDate future = today.plusDays(10);       // returns a NEW LocalDate, today unchang
ed
Period gap = Period.between(today, future);
System.out.println(gap.getDays());             // Output: 10

LocalDateTime dt = LocalDateTime.of(2026, 7, 17, 14, 30);
System.out.println(dt.getDayOfWeek());          // Output: FRIDAY
```

13. Memory Management: JVM, JRE, JDK & GC

JVM vs JRE vs JDK

In simple words:

> *Think of cooking: the JDK is the full kitchen with all tools, recipes, and a stove (everything to CREATE a dish). The JRE is just the dining setup needed to EAT a dish someone already cooked. The JVM is the stove itself – the actual engine that turns raw ingredients (bytecode) into a finished, running result.*

The technical detail:

JVM (Java Virtual Machine): the abstract execution engine that actually runs compiled Java BYTECODE (.class files), one platform-specific implementation per OS/architecture – this is what makes Java 'write once, run anywhere': the SAME bytecode runs unmodified on any platform that has a compatible JVM. Handles class loading, bytecode verification, memory management (heap allocation, garbage collection), and JIT (Just-In-Time) compilation of hot bytecode paths into native machine code for speed.

JRE (Java Runtime Environment): JVM PLUS the core standard class libraries (java.lang, java.util, java.io, etc.) needed to actually RUN a Java application. If you only need to EXECUTE Java programs (not write/compile them), the JRE alone used to be sufficient.

JDK (Java Development Kit): JRE PLUS development tooling – the compiler (javac), debugger (jdb), documentation generator (javadoc), and other build tools. Needed to WRITE and COMPILE Java source code into bytecode. (Note: since Java 11, Oracle stopped shipping a separate standalone JRE distribution – the JDK is now the standard thing everyone installs, even just to run programs.)

```
JDK  ⊃  JRE  ⊃  JVM
(write + compile + run)  (run only)  (execute bytecode)

javac MyProgram.java   // JDK tool: compiles .java source -> .class bytecode
java MyProgram          // JVM: loads and executes the .class bytecode
```

Common interview questions:

Q: If bytecode is platform-independent, why do we need different JVMs per OS?
A: The bytecode itself is universal, but the JVM that INTERPRETS/executes that bytecode must be compiled natively for each OS/CPU architecture, since it ultimately has to translate bytecode instructions into real machine instructions and interact with OS-level system calls for memory, I/O, and threading.

Heap vs Stack Memory

In simple words:

> *Think of a big shared warehouse (heap) that everyone in the company can access, versus each employee's own personal desk drawer (stack) that only they use, and which gets cleared out automatically the moment they leave for the day.*

The technical detail:

HEAP: a single shared memory region (per JVM process) where ALL objects and their instance variables are allocated, accessible by every thread. Managed automatically by the Garbage Collector – objects are reclaimed once no live reference points to them anymore. Generally larger but SLOWER to allocate/access than stack memory, and access must sometimes be coordinated across threads (since it's shared).

STACK: EACH THREAD gets its OWN separate stack. Every method call pushes a new 'stack frame' onto that thread's stack, holding that method's local variables, method parameters, and partial computation results. Frames are LIFO (last-in-first-out) – pushed on call, automatically popped/freed the instant the method returns, requiring no garbage collector involvement at all. Fast, but limited in size – exceeding it (e.g. via unterminated recursion) throws StackOverflowError.

```
void method() {
    int x = 5;                  // 'x' itself lives on the STACK
    Person p = new Person();     // reference variable 'p' on STACK,
                                   // actual Person OBJECT on the HEAP
}   // when method() returns, 'x' and 'p' vanish from the stack instantly;
     // the Person object on the heap becomes eligible for GC only if
     // nothing else still references it

void recurse(int n) { recurse(n + 1); }   // never terminates
recurse(0);   // Output: eventually throws StackOverflowError - stack frames exhausted
```

Common interview questions:

Q: Why is stack memory access faster than heap access?

A: Stack allocation/deallocation is just moving a single pointer up or down (push/pop) – extremely cheap, no bookkeeping needed. Heap allocation requires the JVM to find suitable free space and track object lifetimes for later garbage collection, which is inherently more complex and slower.

Garbage Collection

In simple words:

> *Think of a cleaning crew that walks through an office at night, throwing away only the things NOBODY is using or referencing anymore, and leaving everything still in active use completely untouched.*

The technical detail:

The JVM's automatic process of identifying and reclaiming heap memory occupied by objects that are no longer REACHABLE from any live reference (starting from 'GC roots' – active thread stacks, static fields, JNI references) – this frees Java developers from manually calling something like free()/delete() as required in C/C++, eliminating a huge class of memory leak and dangling-pointer bugs.

GENERATIONAL GC (the standard strategy, based on the empirical observation that most objects die young): the heap is split into a YOUNG GENERATION (further split into Eden + two Survivor spaces, where new objects are created and most quickly become garbage) and an OLD GENERATION (holds long-lived objects that have survived several young-gen collection cycles). Minor GC cleans the young generation frequently and cheaply; Major/Full GC cleans the old generation, less often but more expensively (can pause the application briefly – 'stop-the-world').

```
Person p = new Person();
p = null;    // the Person object is now UNREACHABLE -> eligible for GC
             // (not necessarily collected immediately - GC runs on its own schedule)

System.gc();  // only a HINT/SUGGESTION to the JVM to run GC - not a guarantee
```

Interview tip: *GC timing is non-deterministic by design – System.gc() merely SUGGESTS a collection cycle; the JVM is completely free to ignore it. Never rely on GC timing for program correctness (e.g. don't depend on finalize() running promptly, or ever).*

Common interview questions:

Q: What makes an object eligible for garbage collection?
A: It becomes UNREACHABLE – no active reference chain exists from any GC root (running thread's stack, static field, etc.) down to that object. Simply setting a reference to null is one common way to make an object unreachable, but it's the reachability, not the null assignment itself, that actually matters.

14. Serialization & Marker Interfaces

Serialization / Deserialization

In simple words:

> *Think of packing a fully-built piece of furniture (an object) flat into a cardboard box (a byte stream) to ship it, and then unpacking and reassembling it into the same furniture again at the destination.*

The technical detail:

SERIALIZATION: converting a live object's in-memory state into a linear byte stream, so it can be persisted (saved to a file/database) or transmitted (sent over a network to another JVM).
DESERIALIZATION: the reverse process – reconstructing a live object from that byte stream. A class must implement the Serializable marker interface to be eligible; attempting to serialize a non-Serializable object throws NotSerializableException at runtime. The 'serialVersionUID' field (a long, ideally declared explicitly) acts as a version identifier – if it doesn't match between the serialized bytes and the currently-loaded class definition, deserialization fails with InvalidClassException, protecting against loading incompatible old data into a changed class structure.

```
class User implements Serializable {
    private static final long serialVersionUID = 1L;   // explicit version - best prac
tice
    String name;
    transient String password;      // deliberately excluded, see below
}

User u = new User(); u.name = "Ravi"; u.password = "secret123";
try (ObjectOutputStream out = new ObjectOutputStream(new FileOutputStream("u.ser"))) {
    out.writeObject(u);        // serialize to disk
}
try (ObjectInputStream in = new ObjectInputStream(new FileInputStream("u.ser"))) {
    User loaded = (User) in.readObject();  // deserialize back into an object
    System.out.println(loaded.name);        // Output: Ravi
    System.out.println(loaded.password);     // Output: null - transient field is NOT
restored
}
```

Common interview questions:

Q: What happens if you deserialize a class whose fields have changed since it was serialized?
A: If serialVersionUID matches, Java attempts a best-effort mapping (missing fields get default values, extra serialized fields are ignored). If serialVersionUID does NOT match (or wasn't explicitly declared and gets auto-computed differently due to the structural change), deserialization fails immediately with InvalidClassException.

Marker Interface

In simple words:

> *Think of a plain sticker with no words on a suitcase that just says 'fragile handling allowed' – it doesn't DO anything by itself, but airport staff (the JVM) specifically check for that sticker before deciding how to treat the suitcase.*

The technical detail:

An interface with ZERO methods declared – it exists purely to 'TAG' or 'mark' a class with a piece of metadata that the JVM or a framework checks at runtime via 'instanceof', triggering special built-in behavior for instances of that class, without requiring the class to implement any actual method. Two classic JVM-recognized examples:
• Serializable – tells ObjectOutputStream 'this object is allowed to be serialized'.
• Cloneable – tells Object.clone() 'it's safe to make a field-by-field copy of this object'; WITHOUT implementing Cloneable, calling clone() throws CloneNotSupportedException even if you override clone() yourself, because the JVM explicitly checks for this marker inside Object's native clone() implementation. (Modern alternative style: annotations like @FunctionalInterface serve a similar 'marking' role but are checked by the COMPILER rather than at runtime.)

```
class Point implements Cloneable {       // marker - no methods to implement here
    int x, y;
    @Override
    public Point clone() throws CloneNotSupportedException {
        return (Point) super.clone();     // shallow copy via Object's native clone()
    }
}

Point p1 = new Point(); p1.x = 5;
Point p2 = p1.clone();
p2.x = 99;
System.out.println(p1.x);   // Output: 5  - p1 and p2 are independent objects
```

transient keyword

In simple words:

> *Think of deliberately leaving your wallet at home before mailing a personal package to someone – some things are just never meant to be included in what gets sent.*

The technical detail:

Marks an instance field to be SKIPPED entirely during the serialization process – its value is simply not written to the byte stream at all. Typical uses: sensitive data that shouldn't be persisted or transmitted (passwords, security tokens), fields holding non-serializable objects (like a live Thread or database Connection reference, which can't meaningfully be serialized anyway), or purely derived/cached values that can be cheaply recomputed after deserialization instead of being stored. Upon deserialization, a transient field is automatically reset to its type's DEFAULT value (0/0.0/false for primitives, null for object references) – it is never restored to whatever value it held before serialization.

```
class Session implements Serializable {
    String username;
    transient String authToken;    // sensitive - never written to disk/network
}
// after deserializing a Session, session.authToken will always be null,
// regardless of what it was set to before serialization
```

strictfp keyword

In simple words:

> *Think of a recipe that must produce the EXACT same taste no matter which kitchen (which computer/CPU) it's cooked in – no regional variations allowed at all.*

The technical detail:

Forces all floating-point (float/double) arithmetic within a marked class or method to strictly conform to the IEEE 754 standard's exact precision rules, guaranteeing bit-for-bit IDENTICAL results for the same calculation across every platform/CPU architecture/JVM implementation. Without it, the JVM was historically permitted limited extra intermediate precision on some hardware, which could (rarely) produce tiny result differences between platforms. Largely a historical/legacy keyword now – since Java 17 (JEP 306), ALL floating-point computations are strictfp by default everywhere, and the keyword itself became unnecessary (though still legal to write, with no effect).

```
strictfp class Physics {
    double compute(double a, double b) { return a / b; }   // guaranteed IEEE 754 prec
ision
}
// Since Java 17, this keyword is redundant - it's the default behavior everywhere.
```

15. Design Patterns, Generics & Enums

Singleton Class

In simple words:

> *Think of a country having only ONE sitting president at any given time. No matter how many different offices or people ask 'who is the president?', they all get pointed to the exact same single person.*

The technical detail:

A creational design pattern that guarantees a class has EXACTLY ONE instance for the entire application's lifetime, with one well-known GLOBAL access point to reach it. Achieved by: (1) making the constructor PRIVATE so external code cannot call 'new' on the class directly, (2) holding the sole instance in a private static field, (3) exposing a public static method (commonly getInstance()) that creates the instance on first call and returns the SAME one on every subsequent call.

In a MULTI-THREADED environment, naive lazy initialization is a race condition – two threads could both see 'instance == null' simultaneously and each create a separate object, violating the entire point of the pattern. The DOUBLE-CHECKED LOCKING idiom (shown in the example) fixes this efficiently: it only pays the synchronization cost on the FIRST call (when the instance might not exist yet), while all later calls skip the lock entirely because the outer null-check already passes.

```
class Singleton {
    private static volatile Singleton instance;   // volatile - crucial for visibility
    private Singleton() { }                        // blocks external 'new Singleton()
'

    public static Singleton getInstance() {
        if (instance == null) {                    // 1st check - avoids locking over
head
            synchronized (Singleton.class) {
                if (instance == null) {             // 2nd check - avoids a race insi
```

```
de the lock
                    instance = new Singleton();
                }
            }
        }
        return instance;
    }
}

Singleton s1 = Singleton.getInstance();
Singleton s2 = Singleton.getInstance();
System.out.println(s1 == s2);   // Output: true - always the exact same object
```

Interview tip: *The 'volatile' keyword on the instance field is essential here – without it, another thread could observe a PARTIALLY CONSTRUCTED object due to instruction reordering (the reference gets assigned before the constructor has fully finished initializing all fields), causing subtle and hard-to-reproduce bugs.*

Common interview questions:

Q: Why is double-checked locking needed instead of just synchronizing the whole getInstance() method?

A: Synchronizing the ENTIRE method would force every single call, forever, to acquire the lock – even though after the very first call the instance already exists and no further synchronization is actually needed. Double-checked locking pays that cost only once.

Q: What's a simpler thread-safe Singleton alternative?

A: An 'eager initialization' Singleton (create the instance immediately as a static field, relying on the JVM's guaranteed thread-safe class loading), or the 'enum singleton' pattern (a single-element enum, which the JLS guarantees is inherently serialization-safe and thread-safe with no extra code needed).

Generics

In simple words:

Think of a labeled storage box that says 'Books Only' on the outside. Anyone can immediately see, before even opening it, exactly what type of thing is allowed inside – no need to check every item individually after pulling it out.

The technical detail:

Lets classes, interfaces, and methods be written to operate on a TYPE PARAMETER specified by the caller at compile time (e.g. Box<T>, List<E>), instead of being hard-coded to one specific type or forced to use the unsafe, un-typed Object and require manual casting everywhere. Benefits: COMPILE-TIME type safety (the compiler rejects List<String> list = ...; list.add(42); before the program even runs), and eliminates explicit casting when retrieving elements.

TYPE ERASURE: generic type information exists only at COMPILE TIME for checking; the compiler 'erases' it afterward, replacing type parameters with their bound (Object, if unbounded) in the actual compiled bytecode, and automatically inserting the necessary casts. This is why List<String> and List<Integer> are the SAME class at runtime (both just 'List'), and why you cannot do 'new T()' or check 'obj instanceof List<String>' – that generic type detail simply doesn't exist anymore at runtime.

```
class Box<T> {
    private T value;
    void set(T v) { value = v; }
    T get() { return value; }
}

Box<String> b = new Box<>();
b.set("hello");
```

```
String s = b.get();          // no cast needed - compiler already knows the type is St
ring
// b.set(42);                // COMPILE ERROR - caught before the program even runs

// Bounded type parameter - T must be a Number or subtype:
class NumberBox<T extends Number> {
    T value;
    double doubled() { return value.doubleValue() * 2; }
}
```

Common interview questions:

Q: What is type erasure, and what problem does it cause in practice?

A: The compiler removes all generic type parameter information after compile-time checking, replacing them with Object (or their bound) in the actual .class bytecode. This means you cannot create an array of a generic type (new T[10]), cannot use instanceof with a parameterized type, and cannot overload two methods that differ only in generic type argument (they'd have identical erased signatures).

Enum

In simple words:

> *Think of the days of the week – there are exactly seven fixed options, and nobody can suddenly invent an eighth day. An enum locks a variable down to only a fixed, known set of valid choices.*

The technical detail:

A special reference type representing a FIXED, known set of constants (e.g. days of the week, directions, states of a workflow). Far more powerful than C/C++ enums – in Java, an enum is actually implemented as a full CLASS (implicitly extending java.lang.Enum) that can have its own FIELDS, CONSTRUCTORS (always implicitly private – you cannot 'new' an enum constant yourself, only the fixed set declared in the enum body), and METHODS, and individual constants can even provide their own method-body OVERRIDES for constant-specific behavior. Enums are inherently type-safe, comparable with '==' (each constant IS a genuine singleton instance), and work directly in switch statements.

```
enum Planet {
    MERCURY(3.3e23), EARTH(5.97e24), JUPITER(1.9e27);   // calls the constructor below

    private final double mass;                              // per-constant field
    Planet(double mass) { this.mass = mass; }              // enum constructor - impli
citly private
    double getMass() { return mass; }
}

for (Planet p : Planet.values()) {                          // built-in values() metho
d
    System.out.println(p + ": " + p.getMass());
}
// Output:
// MERCURY: 3.3E23
// EARTH: 5.97E24
// JUPITER: 1.9E27
```

Common interview questions:

Q: Can an enum implement an interface?
A: Yes – an enum can implement interfaces (though it can't EXTEND another class, since it already implicitly extends java.lang.Enum, and Java only allows single class inheritance).

Q: Are enum values() and switch statement support unique to enums?
A: values() (returns all constants as an array) and valueOf(String) are auto-generated by the compiler for every enum. Native switch statement support without needing the enum's fully-qualified name in each case label is also enum-specific syntax sugar.

16. Annotations & Reflection

Annotation

In simple words:

> *Think of a sticky note attached to a form saying 'URGENT – process first.' The note itself doesn't process anything, but whoever handles the form (the framework) sees the note and treats that form specially because of it.*

The technical detail:

A form of METADATA attached to code elements (classes, methods, fields, parameters) using '@Name' syntax – it does not directly change the annotated code's own runtime logic, but is READ by the compiler and/or by frameworks and tools (often via Reflection) to trigger external behavior, generate code, or perform checks. Built-in examples: @Override (compiler verifies a real superclass method is being overridden), @Deprecated (marks an API as discouraged, compiler emits warnings on use), @SuppressWarnings (tells the compiler to hide specific warning categories), @FunctionalInterface (compiler enforces single-abstract-method rule). Custom annotations are declared with '@interface' and given a RETENTION POLICY (SOURCE – discarded after compilation; CLASS – kept in .class file but not visible at runtime; RUNTIME – available via Reflection while the program runs, which is what frameworks like Spring/JUnit rely on).

```
@Override
void run() { }        // compiler CHECKS this actually overrides a parent method

@Retention(RetentionPolicy.RUNTIME)      // must be RUNTIME to be readable via Reflect
ion
@Target(ElementType.METHOD)
@interface Test {                          // custom annotation, e.g. like JUnit's @Te
st
    String value() default "";
}

class MyTests {
    @Test(value = "basic check")
    void checkAddition() { }
}
```

Reflection

In simple words:

> *Think of being able to open up and inspect the internal gears of a sealed watch while it's still ticking, and even reach in and adjust a gear directly – something you normally aren't allowed to do from outside the watch case.*

The technical detail:

The java.lang.reflect API that lets a running program INSPECT and MANIPULATE classes, methods, fields, and constructors AT RUNTIME – even PRIVATE members, by calling setAccessible(true) to bypass normal access-control checks. This is the mechanism that makes many frameworks possible without you writing manual boilerplate: Spring uses it for Dependency Injection (creating objects and wiring their fields automatically), Hibernate/JPA uses it for Object-Relational Mapping (reading/writing entity fields to build SQL), and JUnit uses it to discover and invoke @Test-annotated methods automatically. Trade-offs: noticeably SLOWER than direct code (extra runtime lookup/checks), bypasses normal compile-time type safety, and can break encapsulation if misused.

```
Class<?> cls = Class.forName("com.example.User");            // load class metadata by
 name
Object userObj = cls.getDeclaredConstructor().newInstance();   // create instance refl
ectively

Field nameField = cls.getDeclaredField("name");               // even if private
nameField.setAccessible(true);                                 // bypass private acce
ss check
nameField.set(userObj, "Ravi");                                // set the field's val
ue

Method getName = cls.getDeclaredMethod("getName");
getName.setAccessible(true);
Object result = getName.invoke(userObj);                       // call the method dyn
amically
System.out.println(result);   // Output: Ravi
```

Common interview questions:

Q: Why is Reflection considered slower than normal method calls?

A: Normal calls are resolved and can be optimized/inlined by the JIT compiler at compile/run time based on known static types. Reflective calls go through extra layers – name lookup, access checks, argument boxing/unboxing – at every invocation, which the JIT historically could optimize far less aggressively (modern JVMs have improved this significantly, but it's still generally slower than direct calls).

17. Inner Classes

Inner (Member) Class

In simple words:

> *Think of a car's engine – it can't exist floating on its own; it's always tied to a specific car and can freely access that particular car's other parts (even ones a stranger walking by can't touch).*

The technical detail:

A NON-STATIC class defined inside another (outer) class. Every instance of an inner class implicitly holds a hidden reference to the specific OUTER OBJECT that created it, which is why an inner class can freely access ALL members of the outer class – including PRIVATE ones – as if they were its own. Because of that outer-object link, you cannot create an inner class instance without first having (or creating) an outer class instance: the syntax is 'outerInstance.new InnerClass()'.

```
class Outer {
    private int x = 10;
    class Inner {                          // non-static - tied to an Outer instance
        void show() { System.out.println("x = " + x); }   // accesses private outer fi
eld
    }
}

Outer o = new Outer();
Outer.Inner in = o.new Inner();             // needs an existing Outer instance
in.show();   // Output: x = 10
```

Static Nested Class

In simple words:

> *Think of a spare-parts box sold alongside a car but that isn't actually installed inside any particular car – it's just packaged and labeled together with the car brand for organization, without being physically attached to any one specific vehicle.*

The technical detail:

A class declared 'static' inside another class – it does NOT hold any implicit reference to an outer class instance, and therefore can ONLY access the outer class's STATIC members directly (it needs an explicit outer object reference to reach instance members, just like any other unrelated class would). Functionally it behaves like an ordinary top-level class, just logically namespaced/grouped inside the outer class for organizational purposes (commonly used for Builder pattern helper classes, or small data-holder classes tightly related to the outer class).

```
class Outer {
    static int shared = 100;
    static class Nested {
        void show() { System.out.println("shared = " + shared); }  // OK - static memb
er
    }
}

Outer.Nested n = new Outer.Nested();        // NO outer instance needed at all
n.show();   // Output: shared = 100
```

Local Class

In simple words:

> *Think of a temporary tool you build just for one specific job in your garage, then immediately throw away once that one job is finished – it was never meant to be reused for anything else.*

The technical detail:

A class defined ENTIRELY INSIDE a method body (or any block, e.g. an if-block). Its scope is strictly limited to that enclosing block – it cannot be referenced or instantiated from outside it at all. It CAN access the local variables of its enclosing method, but ONLY if they are final or effectively final (same restriction as lambda captures, and for the same underlying reason – the local class instance might outlive the method call itself).

```
void process() {
    int multiplier = 3;                          // effectively final
    class Helper {                                 // scoped to this method only
        void assist(int val) {
            System.out.println(val * multiplier);   // captures enclosing local variab
le
        }
    }
    new Helper().assist(5);   // Output: 15
}
```

Anonymous Class

In simple words:

> *Think of hiring a one-time temp worker for a single afternoon task, without bothering to formally name or register them as a permanent employee – they do the one job and that's it.*

The technical detail:

A class with NO NAME AT ALL, declared and instantiated together in a single expression – typically used to provide a ONE-OFF implementation of an interface or extend an abstract/concrete class right at the point of use, when you'll never need that implementation again elsewhere. Before Java 8 lambdas existed, this was the standard (if verbose) way to implement single-method interfaces like Runnable or event listeners inline.

```
Runnable r = new Runnable() {                   // anonymous class implementing Runnab
le
    @Override
    public void run() { System.out.println("Anonymous run"); }
};
r.run();   // Output: Anonymous run

// Since Java 8, for SINGLE-abstract-method interfaces, a lambda is far more concise:
Runnable r2 = () -> System.out.println("Lambda run");   // equivalent, less boilerplat
e
```

> ***Interview tip:*** *A lambda can ONLY replace an anonymous class implementing a functional interface (exactly one abstract method). Anonymous classes are still necessary for abstract classes, or interfaces with MULTIPLE abstract methods, or when you need to declare extra fields/state inside the implementation itself.*

18. Immutable Classes

Immutable Class

In simple words:

> *Think of a sealed, tamper-proof bottle. Once it's sealed at the factory, nobody – not even the factory itself – can reach in and change what's inside; if you want a 'different' version, you must get a whole new bottle.*

The technical detail:

A class whose object state can NEVER change after construction – String, Integer (and all wrapper classes), and the java.time classes are all real-world examples. To design one yourself, follow this recipe: (1) declare the class 'final' so it cannot be subclassed into a mutable variant, (2) make every field 'private final', (3) provide NO setter methods whatsoever, (4) fully initialize all fields inside the constructor, and (5) for any field holding a MUTABLE object (arrays, Date, collections), return a DEFENSIVE COPY from getters (and store a defensive copy in the constructor too), rather than the original reference – otherwise external code holding that reference could still mutate the 'immutable' object's internal state indirectly.

Why this matters practically: immutable objects are automatically THREAD-SAFE (no synchronization ever needed – there's nothing to race on, since nothing ever changes after construction), safe to freely SHARE and CACHE (as the String Pool does), and safe to use as HashMap keys (their hashCode can never change after being inserted, which avoids a nasty class of bugs where a mutable key's hashCode changes after insertion, making it unfindable in its own bucket).

```
final class ImmutablePoint {
    private final int x, y;
    ImmutablePoint(int x, int y) { this.x = x; this.y = y; }
    int getX() { return x; }
    int getY() { return y; }
    // no setters at all -> object state can never change post-construction
}

// Handling a MUTABLE field correctly with a defensive copy:
final class ImmutableEvent {
    private final Date date;
    ImmutableEvent(Date date) { this.date = new Date(date.getTime()); }   // defensive
 copy IN
    Date getDate() { return new Date(date.getTime()); }                    // defensiv
e copy OUT
}
```

> ***Interview tip:*** *Skipping the defensive copy is a very common real bug: 'this.date = date;' directly, without copying, lets ANY external code that kept a reference to the original Date object silently mutate the supposedly 'immutable' object's internal state from outside.*

Common interview questions:

Q: Why does an immutable object need to be declared 'final' as a class?
A: Without 'final' on the class, a subclass could override methods (or expose new setters) to introduce mutability, silently breaking the immutability guarantee that code relying on the parent type expects.

19. Object Class Methods

toString(), equals(), hashCode(), clone()

In simple words:

> *Think of toString() as a name tag showing who you are at a glance, equals() as answering 'are we the same person', hashCode() as a claim-check number tied to that identity, and clone() as photocopying yourself – though a quick photocopy might not copy everything you're carrying in your pockets, just the outer appearance (shallow copy).*

The technical detail:

Every class in Java implicitly extends java.lang.Object (directly or transitively), inheriting several fundamental methods:

• toString() – the DEFAULT implementation returns 'ClassName@hexHashcode' (not human-friendly). Overriding it provides a readable string representation, automatically used whenever the object is printed (System.out.println(obj)), concatenated with a String (" + obj), or logged.
• equals(Object o) – the DEFAULT implementation is identical to '==' (pure reference comparison). Override it to define logical/content equality appropriate for the class (see Section 8 for the full rules).
• hashCode() – returns an int identity code; MUST be overridden consistently whenever equals() is overridden (see Section 8's contract).
• clone() – creates and returns a copy of the object. The class must implement the Cloneable marker interface, or Object's native clone() implementation throws CloneNotSupportedException. The default clone() performs a SHALLOW copy – primitive fields are copied by value, but any OBJECT-reference fields are copied by reference, meaning the original and the clone still point to (and share) the SAME nested objects unless you manually deep-copy them yourself inside an overridden clone().

```
class Point {
    int x, y;
    Point(int x, int y) { this.x = x; this.y = y; }
    @Override public String toString() { return "(" + x + "," + y + ")"; }
}

Point p = new Point(3, 4);
System.out.println(p);                // Output: (3,4)  - uses overridden toString()
System.out.println(p.toString());      // Output: (3,4)  - same thing, called explici
tly

// Without overriding toString(), the default would print something like:
// Point@1b6d3586  (class name + '@' + hex hashcode - not useful for debugging)
```

Common interview questions:

Q: What's the difference between a shallow copy and a deep copy?
A: A shallow copy (Object's default clone()) copies primitive fields by value but object-reference fields by REFERENCE, so the original and the copy still share the same nested mutable objects – modifying a nested object through the clone also affects the original. A deep copy recursively creates independent copies of every nested mutable object too, achieving true full independence between original and copy.

20. File Handling

File Create, Open, Read

In simple words:

> *Think of a mailing address. Just writing down an address (creating a File object) doesn't mean a house exists there yet – you separately need to actually build the house (create it) and then walk in and look around (open and read it).*

The technical detail:

java.io.File represents an ABSTRACT PATH NAME on the filesystem – creating a File object does NOT actually create or open anything on disk by itself; it's just a reference to a path, with methods like exists(), createNewFile(), delete(), mkdir() that trigger real filesystem operations. Actual READING is done through separate stream/reader classes: FileReader/BufferedReader (efficient buffered text reading, line by line), FileInputStream (raw binary byte reading). Since Java 7, java.nio.file.Files offers modern, much simpler ONE-LINER utility methods (readAllLines, readString, write) for common cases, built on the newer java.nio.file.Path API which is generally preferred over the older File class in modern code.

```
File f = new File("data.txt");                        // just a path reference so far
if (!f.exists()) f.createNewFile();                       // actually creates it on di
sk

try (BufferedReader br = new BufferedReader(new FileReader(f))) {   // opens for readi
ng
    String line;
    while ((line = br.readLine()) != null) System.out.println(line);  // read line by
line
}   // auto-closed via try-with-resources

// Modern one-liner alternative (java.nio.file):
List<String> lines = Files.readAllLines(Path.of("data.txt"));
String whole = Files.readString(Path.of("data.txt"));    // Java 11+ - entire file as
one String
```

21. Control Flow

if-else, else-if, loops

In simple words:

> *if/else is like choosing a road at a fork based on a sign. A for loop is like doing 10 push-ups – a fixed, known count. A while loop is like 'keep walking WHILE there's still road ahead' – you might stop immediately if there's no road at all. A do-while is like 'taste the soup, then decide if you need more salt' – you always taste it at least once before checking.*

The technical detail:

if / else-if / else: branches execution based on boolean conditions, evaluated top to bottom – the FIRST branch whose condition is true runs, and the rest are skipped entirely, even if a later condition would also have been true.

for loop: best when you know (or can compute) a fixed number of iterations up front – init; condition; update, all declared together.

while loop: repeats WHILE its condition remains true, checked BEFORE every iteration (including the very first) – the body may run ZERO times if the condition is false from the start.

do-while loop: identical to while, except the condition is checked AFTER the body runs – guarantees the body executes AT LEAST ONCE, even if the condition is false immediately.

for-each (enhanced for) loop: iterates directly over the elements of an array or any Iterable (Collection), without manual index management – internally uses an Iterator behind the scenes for Collections.

```
for (int i = 0; i < 3; i++) System.out.print(i);       // Output: 012  (fixed count)

int i = 0;
while (i < 3) { System.out.print(i); i++; }               // Output: 012  (condition-f
irst)

int j = 5;
do { System.out.print(j); j++; } while (j < 3);            // Output: 5    (runs once,
 even though 5 < 3 is false)

for (String s : List.of("a", "b", "c")) System.out.print(s);  // Output: abc
```

Conditional / Logical Operators

In simple words:

> *Think of asking two questions in a row: 'Do you have a ticket AND are you on the guest list?' If the answer to the FIRST question is already 'no', there's no point even checking the guest list – that's short-circuiting in action.*

The technical detail:

&& (logical AND) – SHORT-CIRCUITS: if the left operand is false, the right operand is never even evaluated, since the overall result is already guaranteed false. || (logical OR) – also SHORT-CIRCUITS: if the left operand is true, the right operand is never evaluated, since the result is already guaranteed true. This short-circuiting is not just an optimization – it's routinely relied upon to safely GUARD against errors, e.g. checking 'obj != null && obj.field > 0' safely skips the field access entirely when obj is null.
! (logical NOT) – inverts a boolean value.
?: (ternary conditional operator) – a compact expression form of if/else that evaluates to a VALUE: 'condition ? valueIfTrue : valueIfFalse'.

```
String name = null;
if (name != null && name.length() > 0) { }   // safe - length() never called if name i
s null,
                                                  // thanks to && short-circuiting

int score = 65;
String grade = (score >= 50) ? "Pass" : "Fail";
System.out.println(grade);   // Output: Pass
```

Interview tip: *Java also has non-short-circuiting bitwise-style logical operators '&' and '|' when applied to booleans – they ALWAYS evaluate both sides regardless. Using them by mistake instead of && / || silently removes the short-circuit safety guard, occasionally causing a NullPointerException that && would have safely prevented.*

Common interview questions:

Q: Why is 'a != null && a.foo()' safe but 'a != null & a.foo()' potentially dangerous?
A: '&&' short-circuits: if 'a != null' is false, 'a.foo()' is never evaluated at all. The single '&' bitwise/logical form always evaluates BOTH sides regardless of the first result, so 'a.foo()' would still run even when a is null, throwing NullPointerException.

return statement

In simple words:

Think of raising your hand and saying 'I'm done, here's my answer' in the middle of a group task – you immediately stop working and hand back your result, and everything you would have done after that point simply never happens.

The technical detail:

Immediately terminates execution of the CURRENT method and, for non-void methods, sends a value back to the caller. Execution jumps straight back to the caller at that instant – any code after the return statement within that same method call is never reached. A method declared with a non-void return type must guarantee (as verified by the compiler through static reachability analysis) that EVERY possible execution path returns a value – missing a return on some path is a compile error, not a runtime one.

```
int max(int a, int b) {
    if (a > b) return a;    // exits the method HERE if true; 'return b' below never r
uns
    return b;                 // only reached if a > b was false
}
System.out.println(max(7, 3));   // Output: 7
```