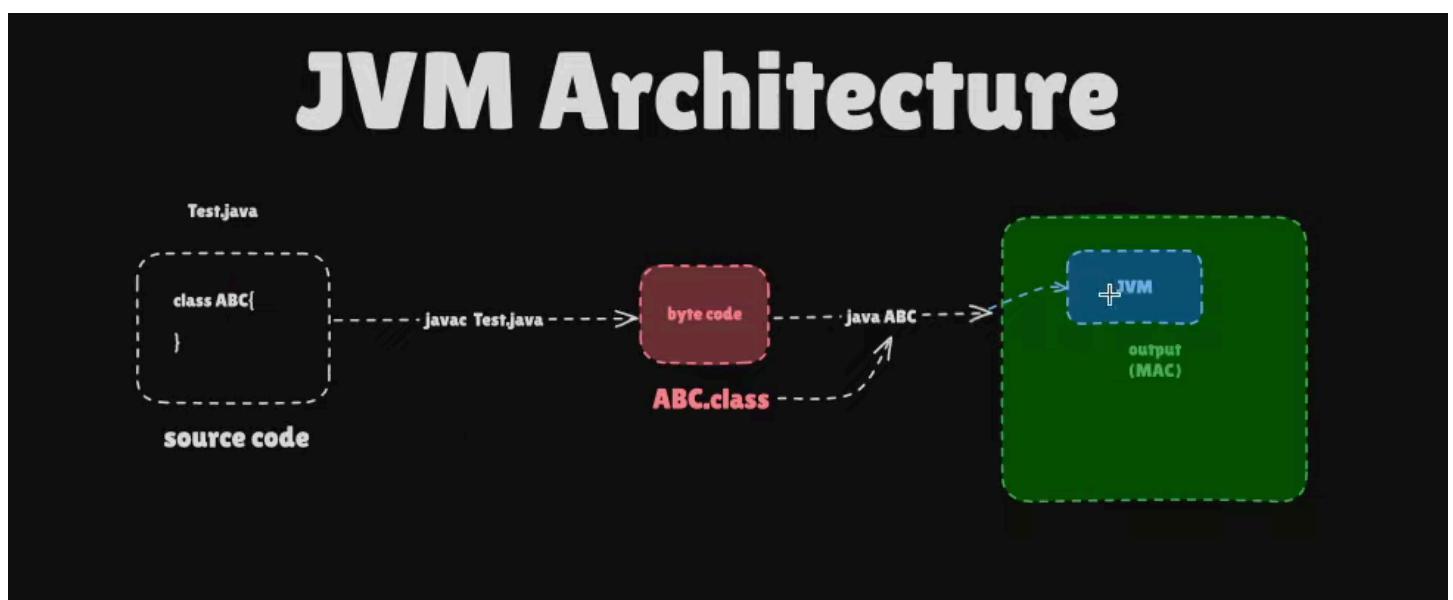


JAVA Internal Working (JVM)

Here is a clear English summary of the video transcript on **JVM Architecture** (Java Virtual Machine), covering how Java programs run and the internal structure of the JVM (with emphasis on changes from Java 8 onward):

How a Java Program Runs (Basic Flow)

1. You write **source code** (.java file) in a high-level language.
2. The **javac** compiler compiles it into **bytecode** (.class file) – platform-independent intermediate code that humans can't easily read, but the JVM understands.
3. To run the program: `java ClassName` → The JVM (part of JRE – Java Runtime Environment) loads and executes this bytecode.
4. The JVM provides a virtual/abstract machine that makes Java "write once, run anywhere" by handling platform-specific details.

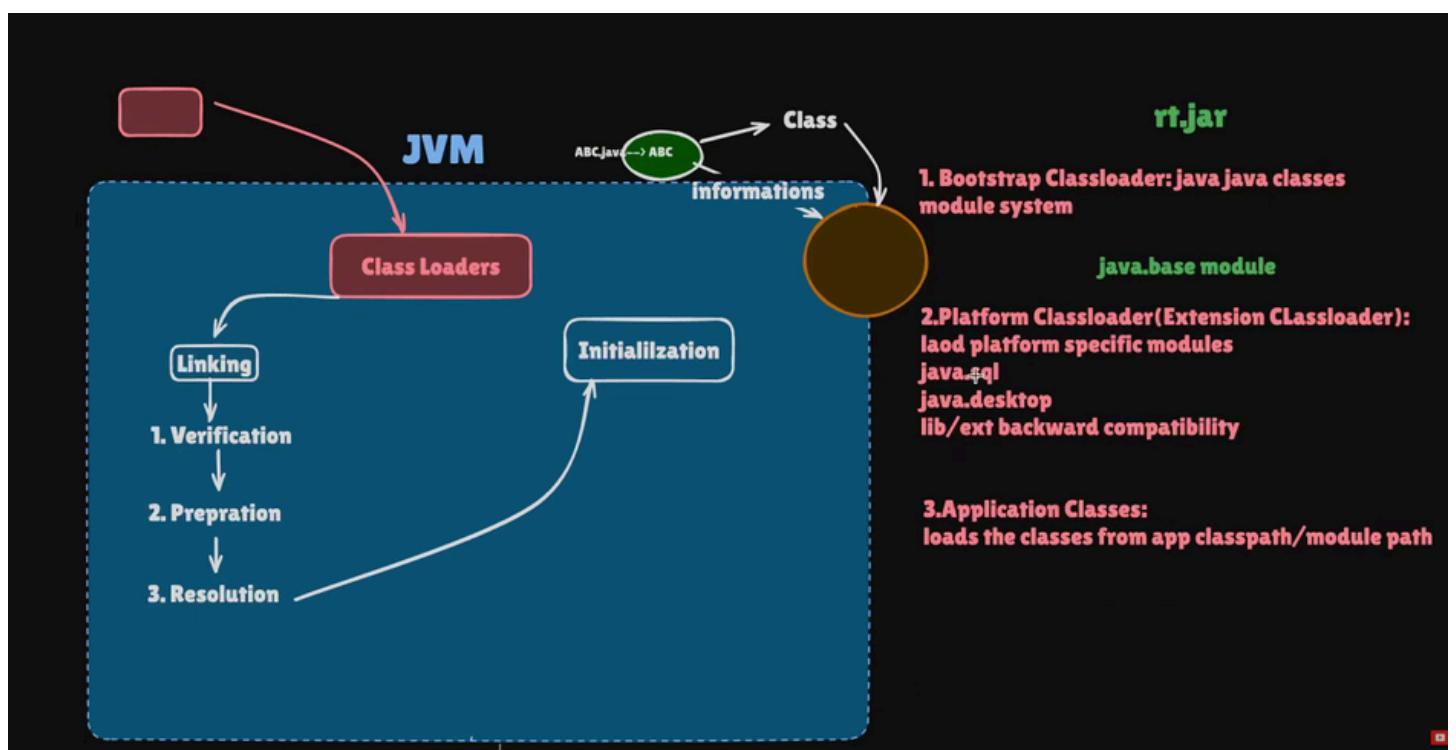


Main Components of JVM Architecture

The JVM has three primary subsystems:

1. **Class Loader Subsystem**

- Loads .class files into memory.
- Three main types of class loaders (with changes in Java 9+):
 - **Bootstrap ClassLoader** (primordial, native code) → Highest priority. Loads core Java classes (from **java.base** module in Java 9+; earlier from rt.jar).
 - **Platform ClassLoader** (Java 9+) → Replaced the old **Extension ClassLoader**. Loads platform-specific modules (e.g., java.desktop) and maintains backward compatibility (loads from ext/ folder if needed).
 - **Application ClassLoader** (also called System ClassLoader) → Loads your application's classes from the classpath or module path.
- Loading process includes:
 - **Loading** → Read bytecode into memory.
 - **Linking**:
 - Verification → Check bytecode is valid and follows JVM specs (security).
 - Preparation → Allocate memory for static variables and set default values.
 - Resolution → Convert symbolic references (e.g., method/class names) to direct references. - **Initialization** → Execute static blocks, assign static variable values (static initialization happens here).



2. **Runtime Data Areas (Memory Areas)**

JVM divides memory into several regions:

- **Method Area / Class Area** (non-heap):

- Stores class metadata (class name, fields, methods, constants, annotations, etc.).
- Also stores bytecode of methods (including static and instance methods, constructors).
- **Java 8 change**: Replaced **Permanent Generation (PermGen)** (fixed-size, part of heap, caused OutOfMemoryError easily) with **Metaspace** (native memory, dynamically resizable, grows automatically, better performance and fewer OOM errors).
- Metaspace holds class metadata, method bytecode, annotations, reflection info, etc.

- **Heap Area** (main runtime memory):

- Stores all objects and their instance variables.

- **Static variables** are stored here (in the Class object) from Java 8 onward (earlier in PermGen/Method Area).

- When a class is loaded, JVM creates a **Class** object (of type `java.lang.Class`) in the heap to represent that class → this holds static variables and class info.

- Heap is divided for garbage collection efficiency:

- **Young Generation** (Eden + Survivor spaces) → New/short-lived objects.

- **Old Generation** (Tenured) → Long-lived/promoted objects.

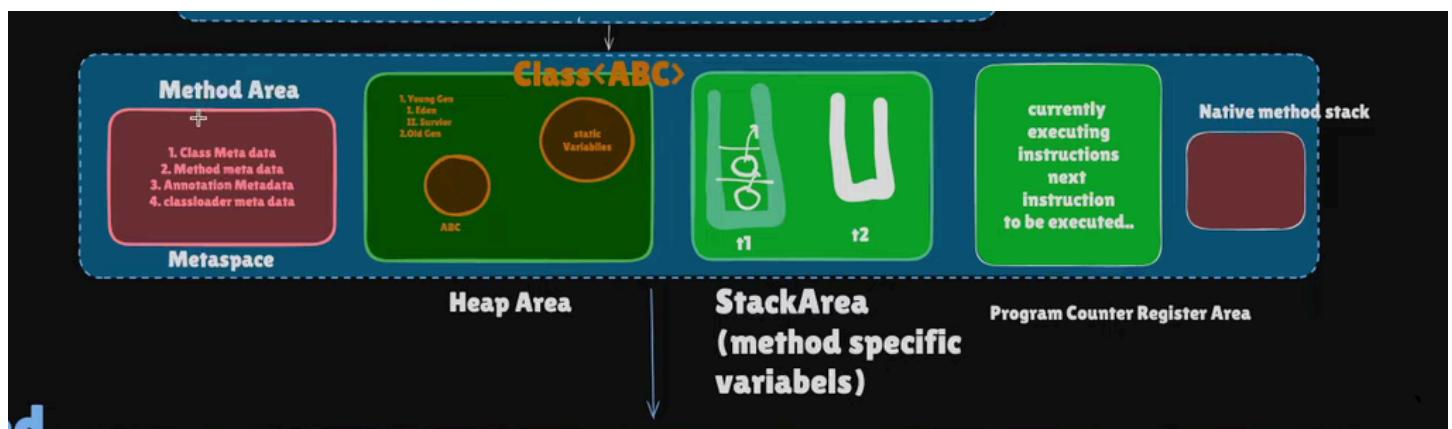
- **Java Stacks** (one per thread):

- Stores frames for each method call (local variables, parameters, intermediate results, operand stack).

- Each thread has its own private stack.

- Method calls push/pop frames (LIFO structure).

- **PC Register** (Program Counter Register) – one per thread:
 - Tracks the address of the currently executing instruction and the next one.
 - Very important for thread execution control.
- **Native Method Stack**:
 - For native (non-Java) methods (e.g., written in C/C++).



3. **Execution Engine**

- Executes the bytecode.
- Key components:
 - **Interpreter** → Executes bytecode line-by-line (converts to machine code on the fly) → Slow for repeated code.
 - **JIT Compiler** (Just-In-Time) → Identifies "hotspots" (frequently executed code/loops) → Compiles them once to native machine code → Caches it for faster repeated execution → Greatly improves performance.
 - **Garbage Collector (GC)** → Automatically reclaims memory from unreachable objects (mainly in heap) → Manages memory efficiently (e.g., Young/Old Gen collectors).
 - **Java Native Interface (JNI)** → Allows Java to call native code (C/C++) and use native libraries (e.g., OS-specific features, .dll/.so files).

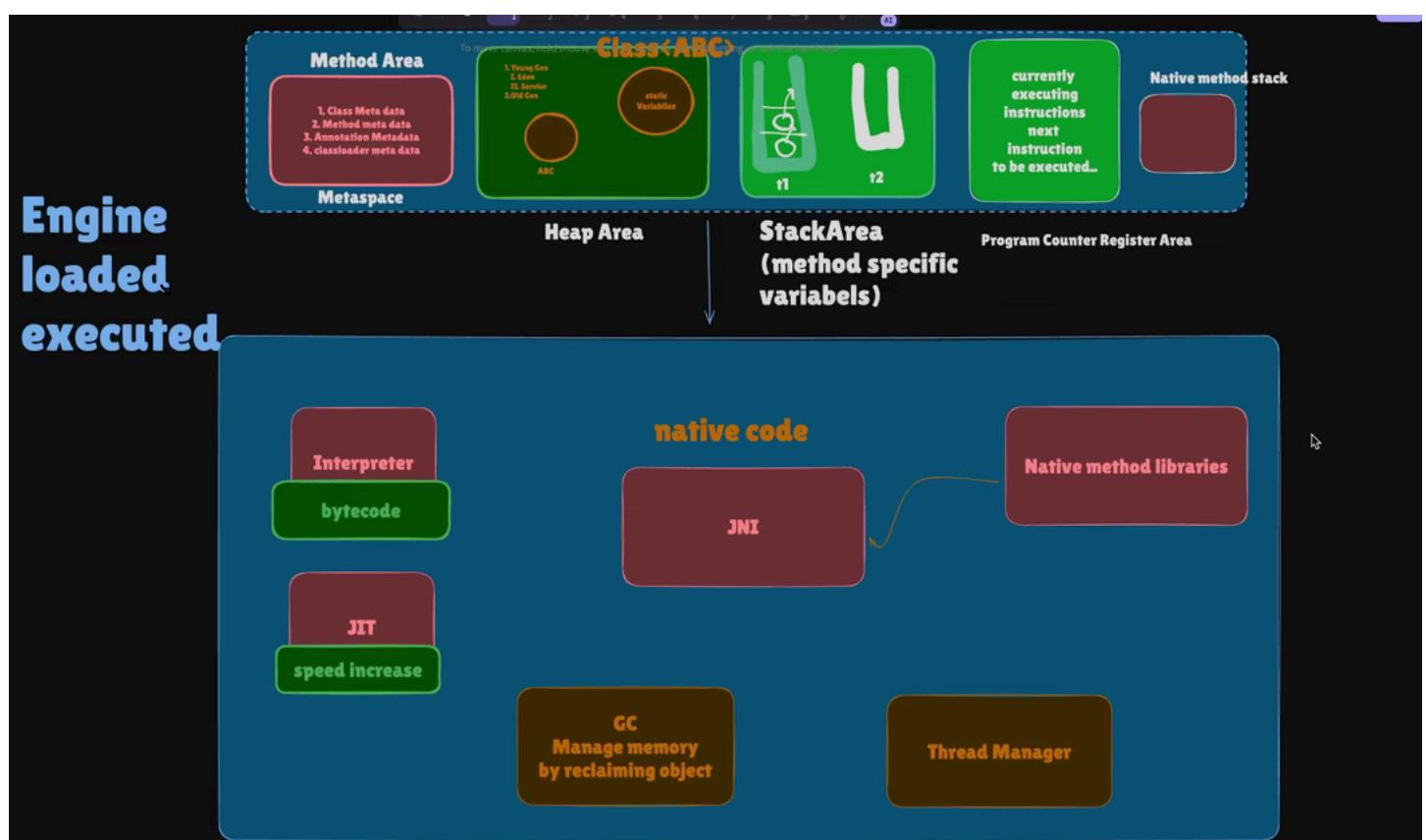
- Other helpers: Thread manager, etc.

Key Java Version Changes Mentioned

- **Java 8**: Replaced PermGen with Metaspace → Removed fixed-size issues, moved class metadata to native memory.
- **Java 9+**: Modular system (java.base, etc.) replaced rt.jar → Platform ClassLoader handles modules instead of extensions folder.

This architecture makes Java secure, portable, performant (thanks to JIT + GC), and memory-managed automatically.

The video emphasizes this topic is very important for interviews and explains every step in detail with examples.



Heap Area (main runtime memory):

* Stores all objects and their instance variables., so like what is meta data of the class , like my confusion is if we have a class , what will be stored in meta data storage area , , what will be stored in Class class object ,what will be stored in heap ? of a class

Let's clear up your confusion step by step with a concrete example.

Suppose you have this simple class:

```
```java
public class Person {

 private String name; // instance variable
 private int age; // instance variable

 public static int count = 0; // static variable

 public Person(String name, int age) {
 this.name = name;
 this.age = age;
 count++;
 }

 public void sayHello() {
 System.out.println("Hi, I'm " + name);
 }
}
```

When the JVM loads this class (during class loading / linking / initialization), here's \*\*exactly\*\* what gets stored \*\*where\*\* (in modern JVMs, Java 8+):

### ### 1. Metaspace (Method Area / Class Metadata Area) – Native (off-heap) memory

This is \*\*not\*\* part of the Java heap. It stores the \*\*blueprint / structural description\*\* of the class (class metadata). This data is \*\*not\*\* a Java object – it's internal JVM data structures.

\*\*What is stored here for the `Person` class?\*\*

- Class name (`Person`)
- Superclass (`java.lang.Object`)
- Implemented interfaces (if any)
- Field metadata:
  - `name` → type `String`, access flags (private), etc.
  - `age` → type `int`, access flags (private), etc.
- Method metadata:
  - Constructor `<init>(String,int)` → bytecode, signature, access flags, exceptions, etc.
  - `sayHello()` → bytecode, signature, access flags, etc.
- Constant pool (literals, method/field references, strings like "Hi, I'm ", etc.)
- Annotations (if any)
- Method bytecode for \*\*all\*\* methods (including constructors and static methods)
- Other internal JVM info (e.g., vtable / itable for method dispatch, reflection data structures, etc.)

→ \*\*Important\*\*: This is \*\*per-class\*\* data. It's shared by \*\*all\*\* instances of `Person`. It lives as long as the class is loaded (usually until the classloader is GC'ed).

### ### 2. Heap – Where actual Java objects live

When the class is loaded and \*\*initialized\*\*, the JVM creates \*\*one special object\*\* in the heap:

- An instance of \*\*`java.lang.Class`\*\* that \*\*represents\*\* the `Person` class.

```java

```
Class<Person> clazz = Person.class; // This is the reference to that heap object
```

```

\*\*What is stored inside this `java.lang.Class` object (in the heap)?\*\*

- This is a normal Java object of type `java.lang.Class<Person>`.
- It contains \*\*references\*\* and runtime data that Java code can access via reflection, such as:
  - `getName()` → returns "Person"
  - `getFields()`, `getMethods()`, `getConstructors()` → returns `Field[]`, `Method[]`, etc.
  - `getDeclaredFields()` etc.
- The static field values (like `Person.count`)
- Other reflection-related caches

→ \*\*Crucially\*\*: The \*\*actual values\*\* of \*\*static variables\*\* (like `count = 0`) are stored \*\*inside this `Class` object\*\* in the heap (not in Metaspace).

So:

- `Person.count` lives inside the heap object `Person.class`
- But the \*\*description\*\* of the field `count` (name, type=int, static, etc.) lives in Metaspace.

### 3. Summary Table: One Class → Where Things Live

What	Location	Why / Notes	
Class structure & description (name, fields list, methods list, signatures, constant pool, bytecode of methods, annotations, vtable, etc.)	**Metaspace**	Internal JVM metadata (native memory, not Java objects). Shared for all instances.	
Bytecode of all methods	**Metaspace**	Stored once per class (including static & instance methods).	
The `java.lang.Class` object representing this class ('Person.class')	**Heap**	Normal Java object. Used for reflection.	
Values of **static variables** ('count', static references, etc.)	**Heap** (inside the 'Class' object)	Static fields belong to the class itself → stored in its 'Class' instance.	
Instances of the class ('new Person(...)')	**Heap**	Each object gets its own copy of instance variables ('name', 'age').	
Instance variables ('name', 'age')	**Heap** (inside each 'Person' object)	Per-instance data.	

### ### Quick Mental Model

- \*\*Metaspace\*\* = The \*\*blueprint / recipe\*\* of the class (structure, code). Think: class file parsed into efficient internal format.
- \*\*Heap → `java.lang.Class` object\*\* = The \*\*living representative\*\* of the class in the Java world (holds static state + reflection API).
- \*\*Heap → Your objects\*\* = The actual things you create with `new`.

So when people say "Metaspace stores class metadata", they mean the \*\*structural / descriptive\*\* metadata (not the runtime static values).

This separation (metadata in native Metaspace, static values in heap 'Class' object) has been the case since Java 8.

Hope this resolves the confusion – let me know if you want a diagram explanation or more examples! Let's clear up your confusion step by step with a concrete example.

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Yes, your understanding is \*\*mostly correct\*\*, and you're very close to how it actually works in practice (especially in modern HotSpot JVM, Java 8+). Let me clarify it precisely and remove any remaining confusion.

### ### Two Different Kinds of "Metadata" / Class Information

#### 1. \*\*Internal JVM Class Metadata\*\* (what lives in \*\*Metaspace\*\*)

- This is \*\*native (off-heap) data structures\*\* managed entirely by the JVM.
- It includes:
  - Class name, superclass, interfaces
  - Field descriptors (names, types, access flags for both instance & static fields)
  - Method descriptors (names, signatures, bytecode, access flags)
  - Constant pool
  - Annotations
  - vtables/itables (for method dispatch)
  - Other runtime structures needed for verification, linking, reflection support, etc.
- \*\*This data is not a Java object\*\* – it's internal JVM bookkeeping.
- \*\*Purpose\*\*: The JVM uses this directly during execution (creating objects, calling methods, verifying bytecode, etc.). Your program \*\*cannot\*\* access this raw form.

## 2. \*\*The `java.lang.Class` object\*\* (lives in the \*\*Heap\*\*)

- When a class is loaded and initialized, the JVM creates \*\*exactly one\*\* instance of `java.lang.Class` in the \*\*heap\*\* to represent that class.
- Example: `Person.class` or `Class.forName("com.example.Person")` returns this heap object.
- This is a \*\*real Java object\*\* (of type `java.lang.Class<Person>`).
- It acts as the \*\*public, reflection-friendly gateway\*\* to the class.
- What it contains / exposes:
  - References to `Field[]`, `Method[]`, `Constructor[]` objects (these are also heap objects)
  - The \*\*actual values\*\* of static fields (e.g., `Person.count` is stored inside this object or in structures directly associated with it)
- Methods like `getFields()`, `getConstructors()`, `getMethods()`, `newInstance()`, etc.
- \*\*Purpose\*\*: This is what \*\*your Java code\*\* uses when doing reflection or accessing statics. It's the bridge between your program and the internal metadata.

### ### How They Connect (Your Key Insight)

- The `java.lang.Class` object in the heap \*\*references / points to\*\* much of the internal metadata stored in Metaspace.
- When you call `Person.class.getConstructors()`:
  - The JVM looks at the heap `Class` object.
  - It uses pointers/references from that object to the \*\*Metaspace metadata\*\*.
  - It constructs `java.lang.reflect.Constructor` objects (heap objects) on the fly based on the Metaspace data.
  - Returns them to your code.
- Similarly:
  - `getFields()` → creates `Field` objects from Metaspace field descriptors.
  - Static field access (`Person.count`) → reads/writes the value stored in/associated with the heap `Class` object (not in Metaspace).

### ### Quick Summary Table

Aspect	Stored In	Accessible From Java Code?	Used For Execution?
Example Content			
Raw class structure & bytecode	**Metaspace** Bytecode, constant pool, field/method descriptors	No (internal only)	Yes (by JVM)
Reflection API objects	**Heap** 'Method', 'Field', 'Constructor' instances	Yes	No (reflection overhead)
Static field **values**	**Heap** (tied to 'Class' object) `Person.count = 42` value	Yes	Yes
`java.lang.Class` instance itself	**Heap**	Yes (`Person.class`)	Indirectly The entry point for reflection & statics

### ### Bottom Line

- \*\*For JVM execution\*\* (normal method calls, object creation, etc.) → JVM directly uses \*\*Metaspace metadata\*\* (fast, native).
- \*\*For your program / user code\*\* (especially reflection, introspection, or static access) → everything routes through the \*\*heap `java.lang.Class` object\*\*, which acts as a facade/proxy to the Metaspace data.

So yes – metadata (the detailed blueprint) is in Metaspace for fast JVM-internal use, but to \*\*access or use it from our code\*\* (via reflection or statics), we go through the 'Class' object in the heap.

This design gives the best of both worlds: efficient runtime + safe, reflective access from Java. Great question – you nailed the distinction! If you want code examples showing reflection vs normal access, let me know. Yes, your understanding is \*\*mostly correct\*\*, and you're very close to how it actually works in practice (especially in modern HotSpot JVM, Java 8+). Let me clarify it precisely and remove any remaining confusion.

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