A COMPARATIVE STUDY OF GARBAGE COLLECTION IN C#, JAVASCRIPT, AND KOTLIN

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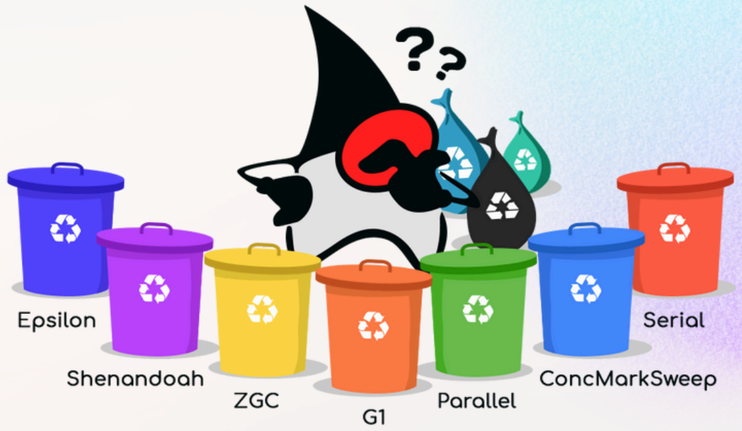
Introduction

What is it Garbage Collection?

- Garbage Collection (GC) = automatic memory management
- Frees memory from unused objects
- Prevents memory leaks & crashes
- Goal: Compare GC in C#, JavaScript, and Kotlin



Why These Languages?

JavaScript -

- Widely used, high-level language for web development
- Garbage collection handled by engines like V8
- Suited for event-driven, browser-based applications

Kotlin -

- Runs on the JVM and works seamlessly with Java
- Features safe and concise syntax
- Shows GC behavior in JVM-based apps

C# -

- Runs on .NET with generational garbage collection
- Statically typed and object-oriented
- Used in high-performance, enterprise applications

COMPARISON

Garbage Collection Strategy

JavaScript –

- Mark-and-Sweep algorithm with generational enhancements
- Incremental collection to keep UI responsive
- Handles circular references with ease

Kotlin –

- Uses JVM collectors (G1, ZGC, Shenandoah)
- Generational approach: short-lived vs long-lived objects
- Mark-and-Sweep / Mark-Compact under the hood

C# –

- Generational GC (Gen 0, 1, 2) with heap compaction
- Background & concurrent collection support
- Optimized for high-throughput enterprise systems

```javascript
function createCycle() {
    let a = {};
    let b = {};
    a.ref = b;
    b.ref = a;
    return null; // Both collectible once out of
}cope
```

```kotlin
class Node(var next: Node?)
fun main() {
    val a = Node(null)
    val b = Node(a)
    a.next = b
    // Both a and b are eligible for GC when unreachable
}
```

```csharp
class Node { public Node Next; }
void CreateCycle() {
    Node a = new Node();
    Node b = new Node();
    a.Next = b;
    b.Next = a;
    // Collected when no references remain
}
```

Manual vs Automatic Control

JavaScript –

- **Fully automatic; developer cannot trigger GC**
- **Browser engines manage memory behind the scenes**

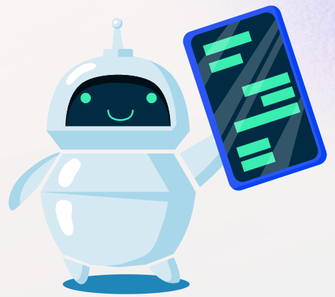
Kotlin –

- **Fully automatic; JVM decides when GC runs**
- **No API for manual GC calls**

C# –

- **Automatic by default**
- **Allows manual GC trigger with GC.Collect() (rarely recommended)**

```
// C# manual GC trigger
GC.Collect(); // Not recommended in most cases
```



Runtime Environments

JavaScript –

- Runs in browser engines (V8, SpiderMonkey)
- Also powers Node.js for server-side apps

Kotlin –

- Runs on JVM (Java Virtual Machine)
- Benefits from decades of JVM GC research

C# –

- Runs on .NET CLR (Common Language Runtime)
- Supports workstation and server GC modes

Performance Goals & Trade-offs

JavaScript –

- **Prioritizes smooth UI and low pause times**
- **May face memory pressure with long-lived apps**

Kotlin –

- **JVM collectors can be tuned (pause vs throughput)**
- **Aimed at Android/mobile performance balance**

C# –

- **Offers tuning for desktop (low latency) or server (high throughput)**
- **Background sweeping reduces pause impact**

Special Features & Tools

JavaScript –

- WeakMap, WeakSet for weak references
- WeakRef & FinalizationRegistry for advanced memory control

Kotlin –

- WeakReference & SoftReference (via JVM)
- JVM flags for choosing GC type (e.g., -XX:+UseG1GC)

C# –

- WeakReference<T>, GCSettings for fine tuning
- IDisposable & using for unmanaged resource cleanup

```javascript
let cache = new WeakMap();
(function() {
    let obj = { temp: true };
    cache.set(obj, "data");
    // 'obj' becomes collectible when out of scope
})();
```

```kotlin
val data = MyData("important")
val weak = WeakReference(data)
// 'data' is collectible when no strong refs remain
```

```javascript
var weak = new WeakReference<MyClass>(new MyClass());
// Object collectible when no strong reference exists
```

Memory Leak Risks

JavaScript –

- Closures holding unused variables
- DOM event listeners not removed
- Accidental globals in non-strict mode

Kotlin –

- Static or singleton references holding Activities
- Long-lived coroutines not canceled
- Observers or listeners not unregistered

C# –

- Event handler subscriptions left active
- Static fields holding objects indefinitely
- Unmanaged resources not disposed (IDisposable not used)

INSIGHTS

Implications for Learning and Productivity

- GC makes programming more accessible and speeds up prototyping
- Can lead to a false sense of memory safety and unnoticed leaks
- Highlights the need for better developer education and tooling

The Future: Smarter GC and Static Analysis

- Growing complexity demands smarter, adaptive GC algorithms
- Deeper static analysis should help identify leaks earlier
- Connecting analysis to memory patterns will improve application robustness

Trade-off Between Memory and Performance

- GC improves productivity but can impact performance
- High-performance apps combine GC with manual memory strategies
- Developers balance convenience and efficiency based on requirements

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THANK YOU