Java ExecutorService

Complete Guide to Concurrent Programming

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1. Introduction & Overview

ExecutorService is Java's high-level concurrency framework that manages thread pools, making multithreading easier, safer, and more efficient than manual thread management.

💡 **Key Benefits**

- Thread reuse instead of expensive creation/destruction
- Built-in task queue management
- Graceful exception handling
- Controlled thread lifecycle
- Memory leak prevention

2. Why ExecutorService?

Problems with Manual Thread Management

```
// ❌ Old way - Manual thread management
Thread thread = new Thread(() -> {
// Heavy computation
    processLargeDataset();
});
thread.start();
thread.join(); // Wait for completion
```

⚠️ Issues with Manual Threads

- No thread reuse (expensive creation/destruction)
- No built-in task queue management
- Difficult to handle exceptions
- Hard to control thread lifecycle
- Memory leaks from unclosed threads

3. ExecutorService Architecture

ExecutorService provides a **thread pool** that:

- **Reuses threads** instead of creating new ones
- **Queues tasks** when all threads are busy
- **Controls concurrency** with configurable pool sizes
- **Handles exceptions** gracefully
- **Manages lifecycle** (shutdown, termination)

4. Core ExecutorService Types

4.1 Fixed Thread Pool

```
// Creates pool with fixed number of threads
ExecutorService executor = Executors.newFixedThreadPool(4);
// Submit tasks
for (int i = 0; i < 10; i++) {
    final int taskId = i;
    executor.submit(() -> {
        System.out.println("Task " + taskId +
                " running on " + Thread.currentThread().getName());
        // Simulate work
        Thread.sleep(2000);
    });
}

// Always shutdown!
executor.shutdown();
```

4.2 Cached Thread Pool

```
// Creates threads on demand, reuses idle threads
ExecutorService executor = Executors.newCachedThreadPool();

// Good for short-lived tasks
executor.submit(() -> quickTask());
executor.submit(() -> anotherQuickTask());

executor.shutdown();
```

4.3 Single Thread Executor

```
// Guarantees sequential execution
ExecutorService executor = Executors.newSingleThreadExecutor();

executor.submit(() -> System.out.println("Task 1"));
executor.submit(() -> System.out.println("Task 2"));
executor.submit(() -> System.out.println("Task 3"));
// Output: Task 1, Task 2, Task 3 (in order)

executor.shutdown();
```

4.4 Scheduled Thread Pool

```
ScheduledExecutorService scheduler =
Executors.newScheduledThreadPool(2);

// Run after delay
scheduler.schedule(() -> {
    System.out.println("Delayed task executed!");
}, 5, TimeUnit.SECONDS);

// Run repeatedly
scheduler.scheduleAtFixedRate(() -> {
    System.out.println("Periodic task: " + new Date());
}, 0, 3, TimeUnit.SECONDS);

scheduler.shutdown();
```

5. Task Submission Methods

submit() vs execute()

```
ExecutorService executor = Executors.newFixedThreadPool(2);

// execute() - Fire and forget (void)
executor.execute(() -> {
    System.out.println("Fire and forget task");
});

// submit() - Returns Future for result tracking
Future<String> future = executor.submit(() -> {
    Thread.sleep(1000);
    return "Task completed!";
});

try {
// Get result (blocks until complete)
    String result = future.get();
    System.out.println(result);

// Get result with timeout
    String result2 = future.get(2, TimeUnit.SECONDS);
} catch (Exception e) {
    System.err.println("Task failed: " + e.getMessage());
}

executor.shutdown();
```

6. Proper Shutdown Patterns

6.1 Graceful Shutdown

```
ExecutorService executor = Executors.newFixedThreadPool(4);

// Submit tasks...
executor.submit(() -> longRunningTask());

// Graceful shutdown
executor.shutdown(); // No new tasks accepted

try {
    // Wait for existing tasks to complete
    if (!executor.awaitTermination(60, TimeUnit.SECONDS)) {
        // Force shutdown if tasks don't complete
        executor.shutdownNow();

        // Wait a bit more
        if (!executor.awaitTermination(60, TimeUnit.SECONDS)) {
            System.err.println("Executor did not terminate");
        }
    }
} catch (InterruptedException e) {
    executor.shutdownNow();
    Thread.currentThread().interrupt();
}
```

6.2 Try-with-resources (Java 19+)

```
try (ExecutorService executor = Executors.newVirtualThreadPerTaskExecutor()) {
// Submit tasks...
    executor.submit(() -> processData());

// Automatic shutdown when leaving try block
}
// executor.close() called automatically
```

7. Real-World Example: Parallel File Processing

```
public class FileProcessor {
    private final ExecutorService executor;

    public FileProcessor(int threadCount) {
        this.executor = Executors.newFixedThreadPool(threadCount);
    }

    public List<String> processFiles(List<Path> files) {
        List<Future<String>> futures = files.stream()
                .map(file -> executor.submit(() -> processFile(file)))
                .collect(Collectors.toList());

        // Collect results
        return futures.stream().map(future -> {
            try {
                return future.get(30, TimeUnit.SECONDS);
            } catch (Exception e) {
                return "Error processing file: " + e.getMessage();
            }
        }).collect(Collectors.toList());
    }

    private String processFile(Path file) throws IOException {
        // Simulate heavy file processing
        String content = Files.readString(file);
        Thread.sleep(1000); // Simulate processing time
        return "Processed: " + file.getFileName() + " (" + content.length() + " characters)";
    }

    public void shutdown() {
        executor.shutdown();
        try {
            if (!executor.awaitTermination(60, TimeUnit.SECONDS)) {
                executor.shutdownNow();
            }
        } catch (InterruptedException e) {
            executor.shutdownNow();
            Thread.currentThread().interrupt();
        }
    }
}
```

8. Best Practices & Common Pitfalls

8.1 What NOT to Do

❌ Common Mistakes

```
// Memory leak - never shutdown!
ExecutorService executor = Executors.newFixedThreadPool(10);
executor.submit(() -> doWork());
// Missing shutdown!

// Ignoring exceptions
executor.submit(() -> {
    throw new RuntimeException("Oops!");
}); // Exception swallowed silently!

// Wrong pool size
ExecutorService tiny = Executors.newFixedThreadPool(1);
// Submitting 1000 CPU-intensive tasks - bottleneck!
```

8.2 Best Practices

✅ Recommended Approaches

```
// 1. Always shutdown executors
try (var executor = Executors.newFixedThreadPool(4)) {
// Use executor
}

// 2. Handle exceptions properly
Future<?> future = executor.submit(() -> riskyOperation());
try {
    future.get();
} catch (ExecutionException e) {
    Throwable cause = e.getCause();
    log.error("Task failed", cause);
}

// 3. Choose appropriate pool size
int cores = Runtime.getRuntime().availableProcessors();
// CPU-intensive: cores or cores + 1
// I/O-intensive: cores * 2 or higher
ExecutorService executor = Executors.newFixedThreadPool(cores);
```

9. Performance Guidelines

9.1 Pool Sizing Guidelines

Workload Type	Recommended Pool Size	Reasoning
CPU-bound tasks	Number of cores	Avoid context switching overhead
I/O-bound tasks	Cores × 2 to Cores × 4	Threads wait for I/O, can handle more
Mixed workload	Cores × 1.5	Start conservative, tune based on metrics

9.2 Monitoring

```
ThreadPoolExecutor tpe = (ThreadPoolExecutor) executor;
System.out.println("Active threads: " + tpe.getActiveCount());
System.out.println("Completed tasks: " + tpe.getCompletedTaskCount());
System.out.println("Queue size: " + tpe.getQueue().size());
```

10. Modern Alternatives (Java 19+)

Virtual Threads

```
// Virtual threads - lightweight, perfect for I/O
try (var executor = Executors.newVirtualThreadPerTaskExecutor()) {
    // Can handle millions of virtual threads!
    for (int i = 0; i < 1_000_000; i++) {
        executor.submit(() -> {
            // I/O operation
            callWebService();
        });
    }
}
```

💡 Virtual Threads Benefits

- Extremely lightweight (thousands of bytes vs MB for platform threads)
- Perfect for I/O-bound workloads
- Can create millions without performance degradation
- Automatic scaling based on workload

11. Quick Reference Guide

When to Use Each Type

Scenario	Best Choice	Why
Web server request handling	FixedThreadPool	Predictable resource usage
Background tasks	CachedThreadPool	Adapts to workload
Sequential processing	SingleThreadExecutor	Guarantees order
Scheduled jobs	ScheduledThreadPool	Built-in timing
High I/O operations	VirtualThreads	Extremely lightweight

Essential Shutdown Pattern

```
executor.shutdown();
try {
    if (!executor.awaitTermination(60, TimeUnit.SECONDS)) {
        executor.shutdownNow();
        if (!executor.awaitTermination(60, TimeUnit.SECONDS)) {
            System.err.println("Executor did not terminate");
        }
    }
} catch (InterruptedException e) {
    executor.shutdownNow();
    Thread.currentThread().interrupt();
}
```

Java ExecutorService Complete Guide
A comprehensive reference for concurrent programming in Java

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