IBM Java: JVM Tuning

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Session 16761
Tues, March 3, 2015: 1:45 PM-2:45 PM
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Java Road Map

**Language Updates**

Java 5.0
- New Language features:
  - Autoboxing
  - Enumerated types
  - Generics
  - Metadata

Java 6.0
- Performance Improvements
- Client WebServices Support

Java 7.0
- Support for dynamic languages
- Improve ease of use for SWING
- New IO APIs (NIO2)
- Java persistence API
- JMX 2.x and WS connection for JMX agents
- Language Changes

Java 8.0**
- Language improvements
- Closures for simplified fork/join

**IBM Java Runtimes**

IBM Java 5.0 (J9 R23)
- Improved performance
  - Generational Garbage Collector
  - Shared classes support
  - New J9 Virtual Machine
  - New Testarossa JIT technology
- First Failure Data Capture
- Common runtime technology
  - ME, SE, EE

IBM Java 6.0 (J9 R24)
- Improvements in
  - Performance
  - Serviceability tooling
  - Class Sharing
- XML parser improvements
  - z10™ Exploitation
  - DFP exploitation for BigDecimal
  - Large Pages
  - New ISA features

IBM Java 6.0.1/Java 7 (J9 R26)
- Improvements in
  - Performance
  - GC Technology
  - z196™ Exploitation
  - OOO Pipeline
  - 70+ New Instructions
  - JZOS/Security Enhanc

IBM Java 7 (J9 R26 SR3)
- Improvements in
  - Performance
  - zEC12™ Exploitation
  - Transactional Exec
  - Flash 1Meg LPs
  - 2G large pages
  - Hints/traps

IBM Java 8 (J9 R28)
- Improvements in
  - Performance
  - RAS
  - Monitoring
  - z13™ Exploitation
  - SIMD
  - SMT
  - Crypto acceleration

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**Timelines and deliveries are subject to change.**

• **New Java8 Language Features**
  – Lambdas, virtual extension methods
• **IBM z13 exploitation**
  – Vector exploitation and other new instructions
  – Instruction scheduling
• **General throughput improvements**
  – Up-to 17% better application throughput
  – Significant improvements to ORB
• **Improved crypto performance for IBMJCE**
  – Block ciphering, secure hashing and public key
    • Up-to 4x improvement to Public Key using ECC
    • CPACF instructions: AES, 3DES, SHA1, SHA2, etc
• **Significantly improved application ramp-up**
  – Up-to 50% less CPU to ramp-up to steady-state
  – Improved perf of ahead-of-time compiled code
• **Improved Monitoring**
  – JMX beans for precise CPU-time monitoring
• **Enhancements to JZOS Toolkit for Java batch**

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IBM z13 – Taking Java Performance to the Next Level

Continued aggressive investment in Java on Z

Significant set of new hardware features tailored and co-designed with Java

Simultaneous Multi-Threading (SMT)
- 2x hardware threads/core for improved throughput
- Available on zIIPs and IFLs

Single Instruction Multiple Data (SIMD)
- Vector processing unit
- Accelerates loops and string operations

Cryptographic Function (CPACF)
- Improved performance of crypto co-processors

New Instructions
- Packed Decimal ↔ Decimal Floating Point
- Load Immediate on Condition
- Load Logical and Zero Rightmost Byte

Up to 50% improvement in throughput for generic applications
Up to 2X improvement in throughput per core for security enabled applications

New 5.0 GHz 8-Core Processor Chip
480Mb L4 cache to optimize for data serving

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WebSphere Application Server for Linux on z

- Aggregate HW, SDK and WAS Improvement: WAS 6.1 (IBM Java 5) on z9 to WAS 8.5 (IBM Java 7) on zEC12

~4.5x aggregate hardware and software improvement comparing WAS 6.1 IBM Java5 on z9 to WAS 8.5 IBM Java7 on zEC12

(Controlled measurement environment, results may vary)
Application Serving – SSL-Enabled DayTrader3.0

Secure Application Server with SSL (clear key)
1 CP and 4 zIIPs

2.6x improvement in throughput with IBM Java 8 and IBM z13

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(Controlled measurement environment, results may vary)
Java Tuning: Agenda

- IBM JVM(J9) Garbage Collector (GC)
  - Overview
  - Policies
- IBM Monitoring and Diagnostic Tools
- Dynamic Compilations
  - Shared Classes + Ahead Of Time compilations
  - Runtime Instrumentation
- JNI Best Practices
Garbage Collector: Overview
Java Memory Usage

- Java is an Operating System (OS) process. Some memory is used by the OS and C-language runtime.
- Area left over is termed the “User Space” and is divided into:
  - Java Virtual Machine (JVM) runtime
  - Java Heap(s)
  - Native heap
Garbage Collector: Overview

- The GC works on the Java Heap memory
- Responsible for allocation and freeing of:
  - Java objects, arrays and classes
- Allocates objects using a contiguous section of Java heap
- Ensures the object remains as long as it is in use ("live")
- Determines "live-ness" based on a reference from another "live" object or from a known root
- Reclaims objects that are no longer referenced
- Ensures that any finalize method is run before the object is reclaimed
Garbage Collector: Overview

Two main GC technologies:

1. Mark Sweep Collector
   - Mark: Find all live objects
   - Sweep: Reclaim unused heap memory
   - Compact: Reduce fragmentation (optional)

2. Copy Collector
Garbage Collector: Overview

GC occurs under two scenarios:

1. An allocation failure:
   - Not enough contiguous memory available

2. A programmatically requested GC cycle:
   - Call to System.GC();
GC: Performance Effect

- GC affects application's performance:
  - Pause times (responsiveness/Consistency)
  - Throughput
  - Footprint
- Typical tradeoffs:
  - Pause time vs. Throughput
    - Tradeoff frequency and length of pauses vs. throughput
- Footprint vs. Frequency
  - Tradeoff smaller footprint vs. frequency of GC pauses/events
IBM J9 Garbage Collector Family

Why have many policies? Why not just the best?

- Cannot always dynamically determine what tradeoffs the user/application are willing to make
- Definition of a performance problem is user centric

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<thead>
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IBM J9 Garbage Collector: optthruput

- Global Mark and Sweep Garbage Collection
- Uses “flat” heap
- Single stop-the-world (STW) phase
  - Application “pauses” while GC is done
- Parallel GC via use of “GC Helper Threads”
  - “Parked” set of threads that wake to share GC work
  - Configurable using -Xgcthreads

**Time**

<table>
<thead>
<tr>
<th>Thread 1</th>
<th>Thread 2</th>
<th>Thread 3</th>
<th>Thread n</th>
</tr>
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Application GC

*Picture is only illustrative and doesn’t reflect any particular real-life application. The purpose is to show theoretical differences in pause times between GC policies.*
IBM J9 Garbage Collector: **optthruput**

Recommended Deployment Scenarios

- **Best when:**
  - Application is optimized for throughput rather than short GC pauses
  - Pause time problems are not evident
  - “Batch” type applications

- **Was default in Java 5 and Java 6, but not in Java 7 and Java 8.**
Tuning: Fixed vs. Variable Heap Size

- Should the heap size be “fixed”? … depends on application

- Fixed heap size
  - Minimum heap size (-Xms) = Maximum heap size (-Xmx)
  - Best when memory usage is fairly constant and known

- Variable heap size
  - Set only -Xmx
  - GC adapts heap size
  - Best when memory usage varies over time or unknown
  - Provides flexibility and avoids OutOfMemoryErrors
  - Allows fine tuning of the heap usage

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IBM J9 Garbage Collector: optavgpause

- Reduces pause time spent inside STW GC vs optthruput
- Results in more consistent pauses
- Slight overhead on application's throughput performance
- Uses **Concurrent** Marking and Sweeping
  - Carries out some STW work while application is running
- Policy focuses on responsiveness criteria

![Diagram showing the comparison between optthruput and optavgpause]
IBM J9 Garbage Collector: gencon

- Best of both worlds: Throughput and Small Pause Times
- Default policy in Java 6.0.1, Java 7 and Java 8
- Heap is split into two areas:
  - Objects created in the nursery
  - Objects that survive enough collections are promoted to tenured area
- Why a generational + concurrent solution?
  - For most workloads objects die young
    - Generational allows a better return on investment (less effort, better reward)
  - Reduce large pause times
    - Mitigates cost of object movement, and cache misses
IBM J9 Garbage Collector: gencon

Motivation

• Most objects die young - focus on recently created objects

• Example: String concatenation

3 objects created!

- String object, containing “String”
- StringBuffer object, containing “String”, then appended with “Concatenated!”
- String object, containing the result: “String Concatenated!”

String str = new String ("String ");
str += "Concatenated!";

• Two of those three objects are no longer required!

• Other examples: transactions in banking /commerce, DB, web page request, GUI functions
IBM J9 Garbage Collector: gencon
Nursery Space Implementation

Nursery uses Copying GC:

- Nursery is split into two spaces:
  - Allocate space: used for new allocations and objects that survived previous collections
  - Survivor space: used for objects surviving this collection

- Collection causes live objects to be:
  - copied from Allocate space to survivor space
  - copied to the Tenured space if they have survived sufficient collections

✓ Small but frequently collected area
✓ Reduces fragmentation
✓ Improves data locality
✓ Speeds up future allocations

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IBM J9 Garbage Collector: gencon

Tenure Space Implementation

- Tenure space uses Concurrent Mark and Sweep GC (same as optavgpause)
- Less frequently collected

Picture is only illustrative and doesn’t reflect any particular real-life application. The purpose is to show theoretical differences in pause times between GC policies.
IBM J9 Garbage Collector: gencon
Recommended Deployment Scenarios

Best when:
- Application allocates many short-lived objects
- Application is transaction-based
- The heap space is fragmented
IBM J9 Garbage Collector: balanced

Goal: Improve responsiveness
- Reduced max pause times to achieve more consistent behaviour
- Incremental collection targets best ROI areas of the heap

Expands platform exploitation possibilities
- Virtualization: group heap data by frequency of access, direct OS paging decisions
- Dynamic reorganization of data structures to improve memory hierarchy utilization (performance)

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IBM J9 Garbage Collector: balanced
Recommended Deployment Scenarios

Best when:

- Large (>4GB) heaps – to reduce long GC pause
- Frequent global garbage collections
- Excessive time spent in global compaction
Choosing the right GC policy

• Typical configuration
  – Pick a policy based on desired application behaviour
  – Tune heap sizes (use tooling)
  – Helper threads (-Xgcthreads)
  – Lots of other tuning knobs, suggest try hard to ignore, to avoid over-tuning
  – Monitor and re-tune if needed

• Rule of thumb:
  – If GC overhead is > 10%, you’ve most likely chosen the wrong policy

• Best practice:
  – Don’t use System.gc()
  – Avoid finalizers
  – Memory leaks are possible even with a garbage collector
# IBM J9 Garbage Collector Family

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Java Tuning: Agenda

- IBM JVM(J9) Garbage Collector (GC)
  - Overview
  - Policies
  - Choosing the right policy
- IBM Monitoring and Diagnostic Tools
- Dynamic Compilations
  - Shared Classes + Ahead Of Time compilations
  - Runtime Instrumentation
- JNI Best Practices
Garbage Collection
IBM Monitoring and Diagnostic Tools for Java

Health Center

• Motivating questions:
  – What is my JVM doing? Is everything ok?
  – Why is my application running slowly?
  – Why is it not scaling?
  – Am I using the right options?

• Overview
  – Lightweight live monitoring tool with very low overhead
  – Understand how your application is behaving, diagnose potential problems with recommendations
  – Visualize garbage collection, method profiling, class loading, lock analysis, file I/O and native memory usage
  – Suitable for all Java applications running on IBM’s JVM

Complete your session evaluations online at www.SHARE.org/Seattle-Eval
Garbage Collection
IBM Monitoring and Diagnostic Tools for Java

GC and Memory Visualizer (GCMV)

• **Motivating questions:**
  - How is the GC behaving? Can I do better?
  - How much time is GC taking?
  - How much free memory does my JVM have?

• **Overview**
  - Analyze Java verbose GC logs, providing insight into application behaviour
  - Visualize a wide range of GC data and Java heap statistics over time
  - Provides the ability to detect memory leaks and optimize GC
  - Recommends tuning options to improve performance

Complete your session evaluations online at www.SHARE.org/Seattle-Eval
Memory Analyzer

• Motivation questions:
  – Why did I run out of Java memory?
  – What’s in my Java heap? How can I explore it and get new insights?

• Overview
  – Tool for analyzing heap dumps and identifying memory leaks from JVMs
  – Works with IBM system dumps, heapdumps and Sun HPROF binary dumps
  – Provides memory leak detection, footprint analysis and insight into wasted space
  – Provides SQL like object query language (OQL)
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Dynamic Runtime

• Java Runtime Environment **dynamically** loads Java classes at runtime

• The Java Virtual Machine (JVM) can:
  – Interpret Java methods’ bytecodes.
  – Compile Java methods’ bytecodes into assembly instructions.

• Compilations
  – Pros:
    • Compiles only the methods that matter
    • Profiles your application characteristics for better optimizations
    • Optimize for your exact hardware
  – Cons:
    • Compilation ➔ runtime overhead
Sharing across JVMs!

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Shared Classes

- Store classes into a cache that is shared by multiple JVMs
- Read-only portions of the class
- Memory footprint reduction
- Startup time improvements (class initialization)
- Cache memory page protection (read-only caches)
Ahead of Time Compilations

• Compiled code generated “ahead-of-time” (AOT)
• Subsequent JVMs can simply load this AOT code
• Startup time improvements
• CPU utilization reduction
• Persisted into the same shared cache
Why not AOT everything?

- Dynamic class loading is a fundamental feature of Java
  - JVM must support dynamic class loading to pass Java certification
  - Classes may not even be stored on disk: Built on-the-fly from raw bytes
    - e.g. Java serialization and reflection services
  - Classes can be transformed on loading to insert new code or adjust existing code

- Dynamic class loading means constraints on compilation change
  - Re-use of a compilation requires verification that same conditions exists in new instance
AOT/JIT Best Practices

- JIT modes:
  - Default: balanced throughput, startup, rampup (server-side)
  - -Xquickstart: faster startup, reduced throughput (client-side)
  - -Xtune:virtualized: reduced compilation overhead, reduced throughput

- Many diagnostic knobs, **not** for performance tuning
  - Impose a new compilation count
  - Impose optimization level
  - Limit compilation to a specific set of methods

- Tuning the shared classes cache size (-Xscmx)


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Runtime Instrumentation

- Hardware profiling infrastructure added in zEC12
- Low overhead, highly granular data
- Designed and built for dynamic runtimes like Java!

- How is the JIT using Runtime Instrumentation (RI)?
  - Software-based sampling is challenged in detecting ‘hot’ methods in large, flat Java applications
    - Tens of thousands of compilations → overhead
    - RI provides more granular data
      - JIT initially compiles using cheaper optimizations.
      - RI data to identify ‘important’ methods to recompile
DayTrader Ramp-up

DayTrader 3 Rampup

zOS 64-bit, 4 zEC12 cores, Liberty 8.5.5.5

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(Controed measurement environment, results may vary)
JNI Best Practices: Performance Pitfalls

• See http://www.ibm.com/developerworks/java/library/j-jni
• Common performance pitfalls
  – Not caching method IDs, field IDs, and classes
    • Avoid redundant calls to FindClass(), GetFieldID(), GetMethodId(), and GetStaticMethodID()
  – Triggering array copies
    • Assume arrays are buffered, hence be precise about which elements you really need to avoid needless copying
  – Reaching back instead of passing parameters
    • When possible, flatten object fields into parameters of call. Avoid using JNI services to get to object fields
  – Choosing the wrong boundary between native and Java code
    • Assume Native <-> Java call overhead 10x slower than Native <-> Native or Java <-> Java
• Run –Xcheck:jni!
Thank You!

- Please complete your session evaluations!

Session 16761:
IBM Java: JVM Tuning

- [www.share.org/Seattle-Eval](http://www.share.org/Seattle-Eval)

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Summary of Links

• Documentation
  • http://www.ibm.com/developerworks/java/jdk/docs.html

• zOS SDK
  • http://www.ibm.com/servers/eserver/zseries/software/java

• System z Linux SDK
  • http://www.ibm.com/developerworks/java/jdk/linux/download.html

• GC Tuning documentation
  • http://www.ibm.com/developerworks/views/java/libraryview.jsp?search_by=java+technology+ibm+style:
  • http://www-01.ibm.com/support/docview.wss?uid=swg27013824&aid=1
  • http://www.ibm.com/developerworks/websphere/techjournal/1106_bailey/1106_bailey.html#sec-ng

• IBM Support Assistant
  • http://www.ibm.com/software/support/isa/