Faster Java™ Applications: How To Tune The HotSpot™ Virtual Machine

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Sun™ Tech Days
Agenda

- Profile of JVM workload
- HotSpot™ VM internal architecture
- Garbage collection
- General HotSpot™ performance tuning
- Tuning HotSpot™ for application servers
- Further Information
JVM Workload

Server-side applications
- Bytecode Execution
- Memory Mgmt.
- Other
- Thread Synchronization

Client-side applications
- Waiting for Native Windowing Code
- Bytecode Execution
- Memory Mgmt.
- Other
HotSpot™ Major Features

- Fast thread synchronization
- Adaptive compilation
- Generational garbage collector
Memory Model

- Handleless objects
- Two-word object headers
- Reflective data as objects
- Native thread support
Adaptive Compilation

- Program Source
- JavaC
- Byte codes
- Dynamic Compiler
- Native Machine Code
- Virtual Machine
- Profiler
- Control
- HotSpot™

Class File Identical For All VMs

Compiled Machine Code Changes During Lifetime of Application

Aggressive Inlining Loop unrolling
Objects Need Storage Space

- Age old problems
  - How to allocate space efficiently
  - How to reclaim unused space (garbage) efficiently and reliably
- C (malloc and free)
- C++ (new and delete)
- Java™ (new and Garbage Collection)
GC Responsibilities

- Garbage detection
  - Distinguish live objects from garbage
  - Reference counting
  - Cyclic reference problem

- Garbage reclamation
  - Make space available to the running program again
Most objects are very short lived

- 80-98% of all newly allocated objects die within a few million instructions
- 80-98% of all newly allocated objects die before another megabyte has been allocated

This impacts heavily on choices for GC algorithms
Collector Algorithms

- Copying
- Mark - Sweep
- Mark - Compact
- Incremental
- Generational
- Parallel Copy
- Concurrent
- Parallel Scavenge
Copying GC

From space

Root Set

To space

Before

From space

To space

After
Copying GC

- Stop-the-world collector
- Very Efficient
  - Traverses object list and copies objects in a single cycle
  - Simultaneous detection and reclamation
- GC pause is directly proportional to total size of live objects
  - Bigger semi-spaces improve efficiency
  - Less frequent GC, more dead objects
Mark – Sweep GC

- Stop-the-world collector
- Distinguish live objects from garbage
  - Traverse graph of pointer relationships
  - Mark objects that can be reached
- Reclaim the space
  - Heap space is “swept” for marked areas
  - Free space is added to a free list, ready for use
Mark – Sweep Problems

- Different-sized objects cause fragmentation
  - Multiple free lists for different-sized blocks
- Cost of collection proportional to size of heap
  - Not just live objects
- Locality of reference
  - New objects get interleaved with old objects
  - Bad for VM-based operating systems
Mark – Compact GC

Before

After
Mark – Compact GC

- Eliminates fragmentation issue of Mark-Sweep
- Allocation becomes stack-based
- Order of objects maintained
  - Locality of reference
- Requires multiple passes to complete
  - Mark live objects
  - Compute new location
  - Update pointers
Incremental GC

- Stop-the-world impacts performance
  - Big heap, big pauses (00's – 000's ms)
- Interleave units of GC work with application work
- Problem is that references change while GC runs
  - Get floating garbage
Old objects tend to live for a long time
- GC can spend lots of time analysing and copying the same objects

Generational GC divides heap into multiple areas (generations)
- Objects segregated by age
- New objects die more quickly, GC more frequent
- Older generations collected less frequently
- Different generations use different algorithms
HotSpot™ VM Heap Layout

- Eden Space
- From Space
- To Space
- Survivor Ratio
- Young Generation
- Tenured Space
- Old Generation
- Permanent Space
- Permanent Generation

- (2Mb default)
- (64Kb default)
- (5Mb min, 44Mb max default)
- (4Mb default)
Young Generation Heap Size

Eden = NewSize –

\(((\text{NewSize} / (\text{SurvivorRatio} + 2)) \times 2)\)

From Space = (NewSize – Eden / 2)

To Space = (NewSize – Eden) / 2)

- \(\text{-XX:NewSize}\)
- \(\text{-XX:MaxNewSize}\)
- \(\text{-XX:NewRatio}\)
- \(\text{-XX:SurvivorRatio}\)
Old Generation Heap Size

- Tenured generation
  - Objects with long lifetime

- -Xms
- -Xmx
- -XX:MinHeapFreeRatio
- -XX:MaxHeapFreeRatio
Permanent Heap Size

- Used to hold class files
- Default size is 4Mb

-XX:PermSize
-XX:MaxPermSize
-Xnoclassgc
Parallel Copy GC

- Similar to copy-collector
  - Still stop-the-world
- Allocates as many threads as CPUs
  - Algorithm optimized to minimize contention
- Maximize work throughput
  - Work stealing
Parallel Copy GC

Single Threaded Stop-the-world collector

Application Threads

GC Thread(s)

Parallel, multi-threaded Stop-the-world young generation collector
Parallel Copy Collector

- **-XX:+UseParNewGC**
  - Default copy collector will be used on single CPU machines

- **-XX:ParallelGCThreads=<num>**
  - Default is number of CPUs
  - Can be used to force the parallel copy collector to be used on single a CPU machine
Concurrent GC

-XX:+UseConcMarkSweepGC

ApplicationThreads

Stop-the-world initial mark phase

Concurrent mark phase

Stop-the-world re-mark phase

Concurrent sweep phase
Parallel Scavenge GC

- Stop-the-world
- Similar to parallel-copy collector
- Aimed at large young spaces (12-80Gb)
- Scales well with more CPUs
- Adaptive tuning policy
  - Survivor ratio
- Promotion undo to prevent out of memory
Parallel Scavenge Collector

-XX:+UseParallelGC
-XX:ParallelGCThreads=<num>
  - Control number of threads
-XX:+UseAdaptiveSizePolicy
  - Automatically sizes the young generation and selects optimum survivor ratio
Factors Affecting GC

- Rate of object creation
- Object life spans
  - Temporary, intermediate, long
- Types of object
  - Size, complexity
- Relationships between objects
  - Difficulty of determining and tracking object references
Profile, profile, profile!
Use profile data to determine factors affecting performance
Modify parameters to optimize performance
Repeat
Profiling GC

- Simplest approach
  - -verbose:gc
  - -Xrunhprof
  - -XX:+PrintGCDetails
  - -XX:+PrintGCTimeStamps
  - -XX:+PrintHeapAtGC
    - Warning: very verbose
Quick Performance Fix

- Always upgrade to the latest version of the JDK/JRE
  - Sun is always working to improve performance
  - Sun is always working to reduce the number of 'undocumented features'
Performance Example

SPECjbb2000 Performance Improvement

Normalized to 1.4.1 Performance

- Sun™ Tech Days
- Sun Microsystems

Changed implementation of **AggressiveHeap** option
Object Lifetimes

- Temporary
  - Die before encountering a young GC
- Intermediate
  - Die before being tenured to old space
- Long
  - Get promoted to old heap space
- Ratio of these has big impact on heap layout
Reducing Object Lifetimes

- Code inspection
  - Remove references when not required
  - Can do this explicitly with
    ```
    objectRef = null;
    ```
- Avoid creating objects
  - Intermediate objects silently created when immutable object values change
Object Pooling

- Can be good for heavy weight objects
  - Database connections/threads
  - Reduce frequency of young GC

- Can also be bad
  - Pooling can be more expensive than creation/collection
  - Can violate good OO design principles
Disabling Tenuring

- Promote all live objects
  - No tenuring of objects in survivor spaces
  - Good for apps with few intermediate objects

- `-XX:MaxTenuringThreshold=0`
  - Number of times an object is copied in the survivor spaces

- `-XX:SurvivorRatio=100`
  - Ensures all of young generation is allocated to the eden space
Helping The GC

- Reduce state
  - Objects die before leaving eden
- Avoid references that span heaps
  - More work required to trace links between young and old spaces
- Flatten objects
  - Complex structures require additional work to determine live objects
Heap Sizing

- Extremely important to GC performance
- Factors to consider
  - Young GC frequency/collection time
  - Ratio and number of short, intermediate and long life objects
  - Promotion size
  - Old GC frequency/collection times
  - Old heap fragmentation/locality problems
Sizing The Young Heap

- Fragmentation is not an issue
  - Locality of reference could be
- Maximize collection of temporary objects
  - Reduces promotion & tenuring
- Minimize frequency of GC
- Rule of thumb: make it as large as possible
  - Given acceptable collection times
Sizing the Old Heap

- Ensure heap fits in physical memory
  - Paging and locality of reference issues
- Larger young heap, smaller old heap
- Oversized heap increases collection times
  - Locality of reference problems
  - Use ISM and Variable page sizes to alleviate
Intimate Shared Memory

- Designed for use on big memory Solaris machines
  - Don't use if memory requirements will cause paging
  - JDK1.3.1 introduced support for heaps > 2Gb
  - ISM uses larger page sizes (4Mb rather than 8Kb)
  - Locks pages into memory (no paging to disk)
  - `-XX:+UseISM` (Solaris Only)
  - `-XX:+UsePermISM` (Solaris Only)
  - `-XX:+UseMPSS` (Solaris 9 Only)
  - Need to change shm parameters in `/etc/system`
-XX:+UseAggressiveHeap

- Must have min of 256MB RAM
- Overall heap will be around 3850Mb
- Thread allocation area 256MB
- GC deferred as long as possible
- Do not use -Xms or -Xmx with this
- May cause stack space to run out
  - Use -Xss to compensate
- Not suited to multi-app servers
HotSpot™ Thread Options

- `-XboundThreads` *
- `-XX:+UseThreadPriorities`
- `-XX:+UseLWPSynchronisation` **
- `-XX:+AdjustConcurrency` *

* Solaris Only
** SPARC Only
General Tuning Advice

- Allocate more memory to the JVM
  - 64Mb default is often too small
- Set -Xms and -Xmx to be the same
  - Increases predictability, improves startup time
- Set Eden/Tenured space ratio
  - Eden >50% is bad
  - Eden = 33%, Tenured = 66% seems to be good
Understanding the virtual machine will help you tune performance

Use profiling tools to find bottlenecks

Adapt HotSpot™ parameters to your application

Always use the latest JRE

Sun is always improving Java™ performance
Further Information

- java.sun.com/blueprints/performance
- java.sun.com/products/hotspot
- research.sun.com/projects/jfluid
- developers.sun.com/dev/coolstuff/jvmstat
- Developer.java.sun.com/developer/technicalArticles/Programming/GCPortal
Q&A