Garbage Collector Magic Tuning Explained

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About me

- Simone Bordet (sbordet@intalio.com)
- Senior Java Engineer @ Intalio/Webtide
  - Previously freelance, SimulaLabs, HP
- Active in Open Source and Java communities
  - Jetty, CometD, MX4J, Foxtrot, LiveTribe, etc.
  - Co-Leader of the Java User Group Torino
- Currently working on:
  - Comet client-side and server-side applications
    - Client for browsers, J2ME and Android
  - Server-side asynchronous I/O and protocols

Do you need to tune the GC ?

GC Tuning Needed ?

- Make your application right
- Make it even righter
- Make it fast
  - Use profilers and similar tools
- At the end, when all the rest is done, and your application has been live for a while, then you can look at the Garbage Collector
  - Rarely makes any sense doing it before

GC Tuning Needed ?

- It is very difficult to replicate real load in a test environment
- To tune the Garbage Collector, you need information taken from the live system
- It will take a while to gather information
  - Allocate time in the order of weeks to this activity

- But sometimes, it really makes the difference

Do I need to tune the GC ?

A) No, but let's have some fun

B) Yes, my application needs it

Agenda

- JVM Memory Layout, Allocation and Collection
- Garbage Collector Algorithms
- Monitoring the Garbage Collector
- Tuning the Garbage Collector

JVM Memory Layout, Allocation and Collection

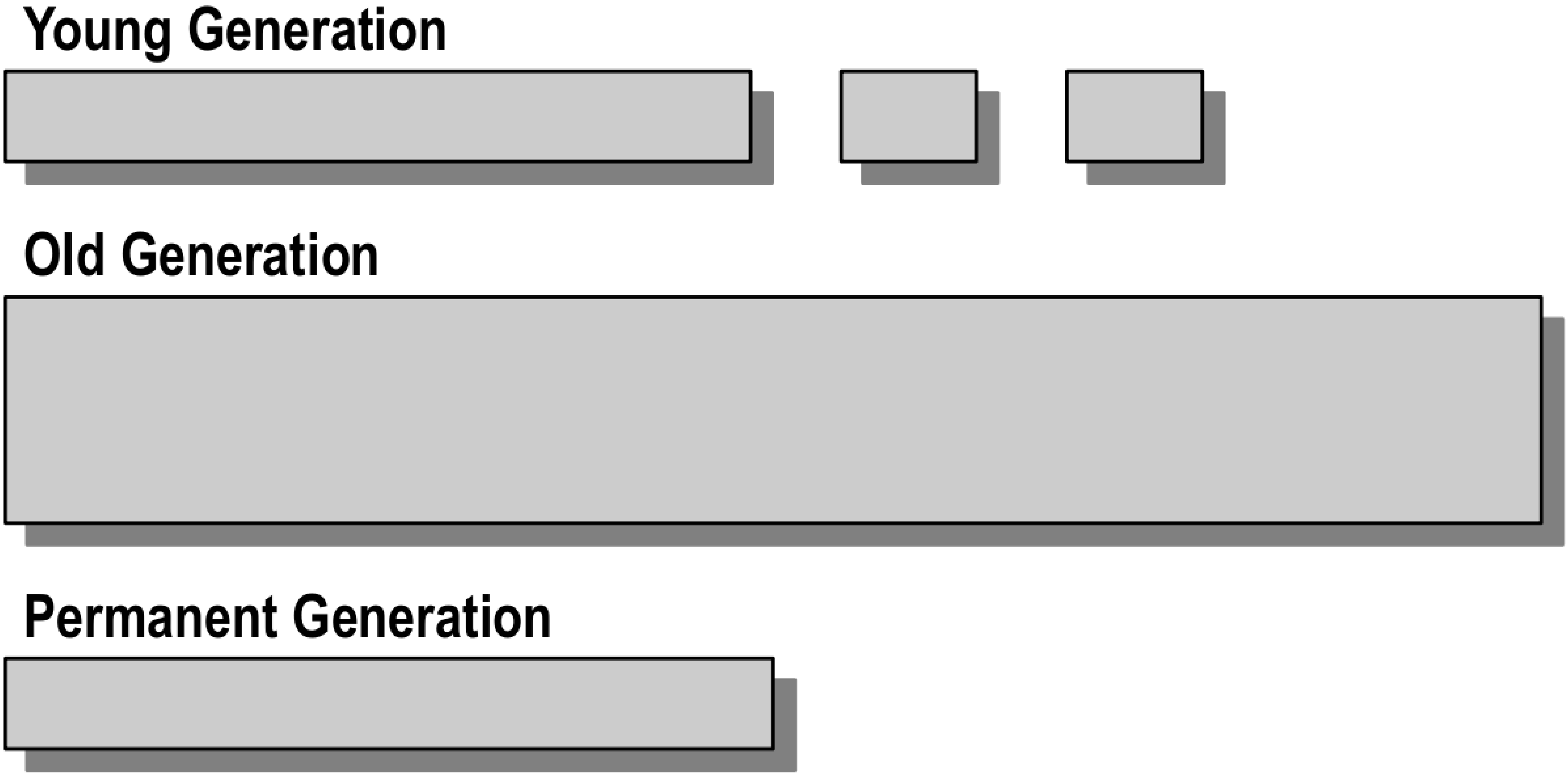
JVM Memory Layout

- The JVM divides the memory it manages in 3 major “generations”:
  - Young Generation (or “New”)
  - Old Generation (or “Tenured”)
  - Permanent Generation
- Young + Old = Total Heap
- -Xmx<size> sizes the total heap
  - Default Young:Old ratio on 64-bit server JVM is 1:2

JVM Memory Layout

- The Young Generation is again divided in 3 “spaces”:
  - Eden Space
  - Survivor Space 0
  - Survivor Space 1
- -Xmn<size> sizes the Young Generation
  - There are other flags to fine tune it, but this works well

JVM Memory Layout



Young Generation

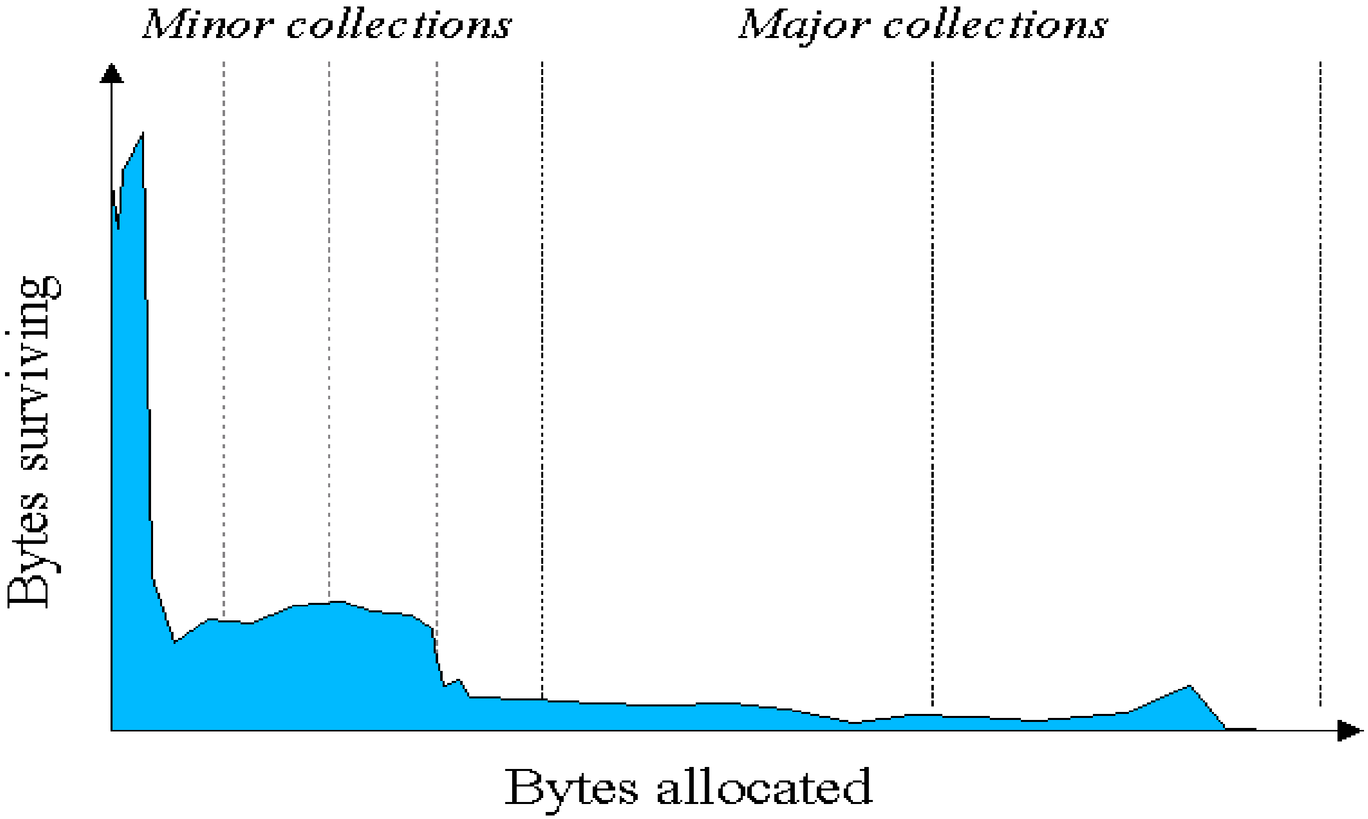
Old Generation

Permanent Generation

JVM Memory Layout

- Why does the JVM have “generations” ?
- Careful analysis of Java applications showed that there are 2 types of garbage:
  - “short-term” garbage, whose life is very short (few seconds or less)
  - “long-term” garbage, whose life is longer (few minutes to application lifetime)
- “Short-term” garbage is often responsible of most of the garbage generated
  - An efficient GC for “short-term” garbage can free up most of the heap

JVM Memory Layout



JVM Allocation Strategies

- What happens when the JVM needs to allocate memory ?
- It tries to allocate it in Young Generation, in the Eden space
- If that fails (not enough space left), then:
  - It triggers a Young Generation collection; or
  - It allocates it in the Old Generation directly (rare and possibly try to avoid it)

JVM Young Generation Collection

- When the Eden Space is full, a so called “minor collection” is triggered
  - Eden Space is emptied
  - Survivor objects are copied into Survivor Space 0
  - Survivor Space 1 is copied into Survivor Space 0
    - The Survivor Age is increased
    - Default Survivor Age on 64-bit server JVM is 4
  - Older survivors overflow to the Old Generation

- If not enough room in Survivor Space ?
  - Overflow to Old Generation

JVM Old Generation Collection

- When the Old Generation is full, a so called “full collection” is triggered
- Exact behavior depends on the GC algorithm
- When the GC cannot free memory in the Old Generation, an OutOfMemoryError occurs

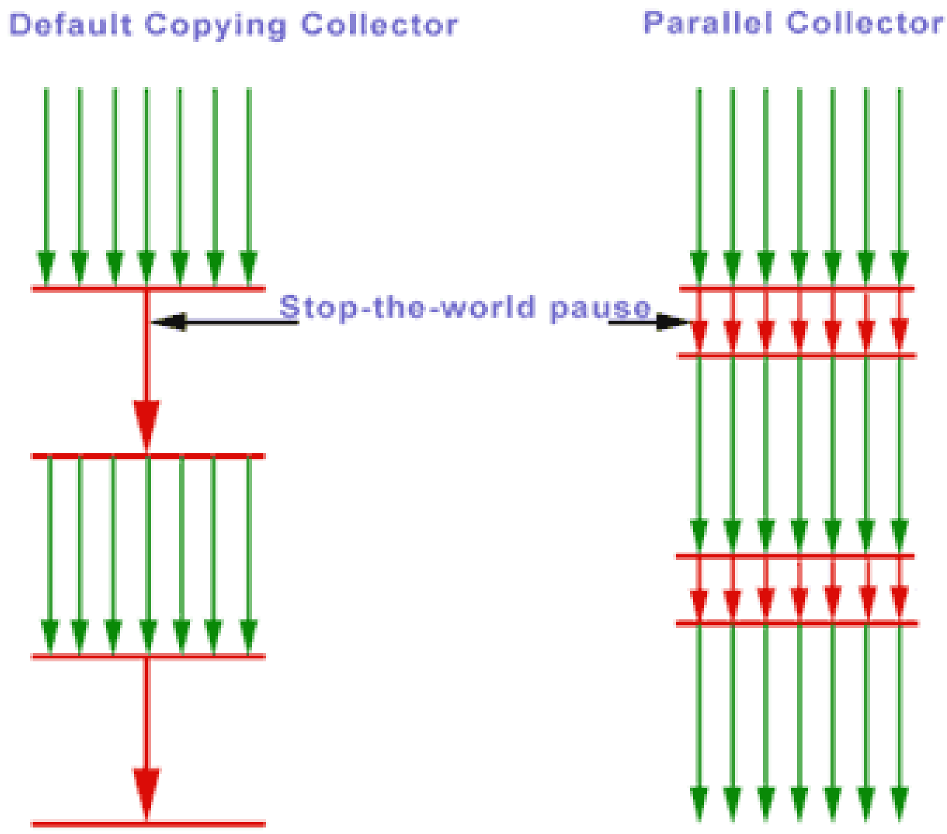
Garbage Collector Algorithms

Garbage Collector Algorithms

- JDK 6 has 5 Garbage Collector Algorithms:
- Parallel (PS – Parallel Scavenge)
  - Two available for the Young Generation
    - -XX:+UseParallelGC, cannot be used with CMS
    - -XX:+UseParNewGC, for use with CMS
  - One available for the Old Generation
    - XX:+UseParallelOldGC
- Concurrent (CMS – Concurrent Mark Sweep)
  - Only for the Old Generation
    - -XX:+UseConcMarkSweepGC
- Serial
  - Only for the Old Generation

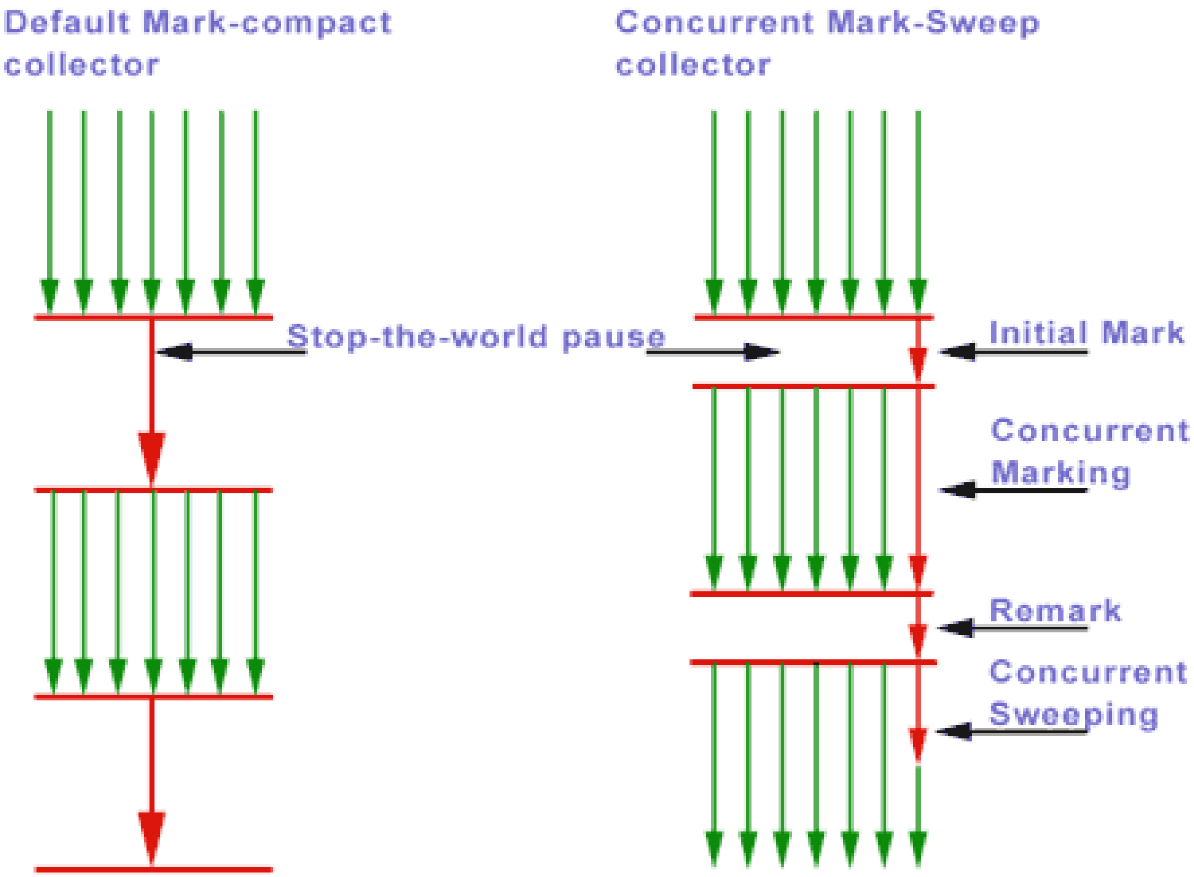
Garbage Collector Algorithms

- Parallel == <u>full</u> stop-the-world, multi-threaded



Garbage Collector Algorithms

- CMS == partial stop-the-world, multi threaded



Parallel Algorithms

- Parallel Algorithms
  - Grow and Shrink the Generation they work on
  - Compact the space
- Young Generation Algorithms
  - Collection time depends on number of live objects
  - Not on the Generation size, not on the amount of garbage

Concurrent Algorithm

- CMS Algorithm
  - Does not compact (its worst “defect”)
  - Hence it is subject to space fragmentation
- What happens when the space is too fragmented and allocation fails ?
  - CMS falls back to the Serial algorithm
  - Very long stop-the-world pause
- Try to never reach that point with CMS

How many GC ?

- There always are 2 collectors running in the JVM
  - One for the Young Generation
  - One for the Old Generation
- You can tune both independently, but they are related
  - This is what makes tuning difficult

Monitoring the Garbage Collector

Monitoring the collector

- -XX:+PrintCommandLineFlags
  - Reprints all implied options
- -XX:+PrintGCDateStamps
- -XX:+PrintGCTimeStamps
  - GC time information
- -XX:+PrintGCDetails
  - GC activity information
- -XX:+DisableExplicitGC
  - Avoids RMI's System.gc()
- -Xloggc:<file>
  - Outputs to a file

Monitoring the collector

- Analyze the GC log file to understand:
  - GC overhead
    - time spent in GC / time spent in application
  - Max stop-the-world pause
  - Allocation rate and promotion rate
- Use jstat to gather further information
  - jstat -gcutil <pid>
- GC overhead vs Max stop-the-world pause
  - Overhead can be really low, but pauses really long

Tuning the Garbage Collector

Tuning the Garbage Collector

- You need to choose/tune 2 things:
  - Generation Sizes
  - GC algorithm
- Advice #1:
  - Make your heap BIG
- Big heaps reduce the frequency of collections
  - And increase the chance that objects do not survive
- Use -Xms<size> == -Xmx<size>
  - Saves grow/shrink time

Tuning the Garbage Collector

- Young Generation sizing: make it BIG
  - Can go up to same size as Old Generation
  - Remember: collection time does not depend on size
- Advice #2:
  - Maximize garbage in Young Generation
- Collection in Young Generation is cheap
- Usually not much tuning needed
  - The GC algorithm will be Parallel

Tuning the Garbage Collector

- Output example (collection frequency: ~35 s)
  - -XX:+UseParNewGC -XX:+PrintTenuringDistribution

```
2010-06-02T06:43:08.589-0700: 940.165: [GC 940.165: [ParNew
Desired survivor size 104857600 bytes, new threshold 4 (max 4)
- age   1:   43824512 bytes,   43824512 total
- age   2:   17958408 bytes,   61782920 total
- age   3:   20590872 bytes,   82373792 total
- age   4:   14776712 bytes,   97150504 total
: 1793581K->132958K(1843200K), 0.1019750 secs] 2003784K->357779K(5939200K), 0.1021550 secs] [Times: user=0.60 sys=0.04, real=0.10 secs]
```

  - Total Heap: 2003784 – 357779 = 1646005 collected (in Young)
  - Young Generation: 1793581 – 132958 = 1660623
  - Promoted: 1660623 – 1646005 = 14618
  - Times: user/real = 6 (6x parallelism)
  - Ages: ~44 MB age 1; ~18 MB age 2; ~21 MB age 3; ~15 MB age 4

Tuning the Garbage Collector

- Old Generation sizing: make it BIG
  - Bigger than or equal to Young Generation
  - Remember: collection time does depend on size

- Advice #3:
  - Try to avoid full collections

- Collection in Old Generation is expensive

Tuning the Garbage Collector

- Parallel Old Generation Collector
- Has auto-tuning features (“ergonomics”)
  - Not sure how good / reliable they are
- Not much tuning needed anyway
- Explicit tuning gives full control

Tuning the Garbage Collector

- Compact Mark Sweep (CMS) Old Generation Collector, or “low-pause” collector

- Advice #4
  - Try to avoid promotions

- CMS does not compact space
  - Need to avoid fragmentation
- But you can schedule a compacting full GC
  - For example, at night

Tuning the Garbage Collector

```
2010-06-02T10:25:06.432-0700: 14258.007: [GC [1 CMS-initial-mark:
3304088K(4096000K)] 3427806K(5939200K), 0.0678380 secs] [Times: user=0.06
sys=0.00, real=0.07 secs]


2010-06-02T10:25:06.500-0700: 14258.075: [CMS-concurrent-mark-start]
2010-06-02T10:25:07.401-0700: 14258.976: [CMS-concurrent-mark: 0.897/0.901 secs]
[Times: user=2.42 sys=0.13, real=0.90 secs]


2010-06-02T10:25:07.401-0700: 14258.976: [CMS-concurrent-preclean-start]
2010-06-02T10:25:07.492-0700: 14259.067: [CMS-concurrent-preclean: 0.076/0.091
secs] [Times: user=0.15 sys=0.01, real=0.09 secs]
2010-06-02T10:25:07.492-0700: 14259.067: [CMS-concurrent-abortable-preclean-start]


 CMS: abort preclean due to time 2010-06-02T10:25:12.589-0700: 14264.164: [CMS-
concurrent-abortable-preclean: 4.970/5.097 secs] [Times: user=7.17 sys=0.41,
real=5.10 secs]
```

Tuning the Garbage Collector

```
2010-06-02T10:25:12.592-0700: 14264.167: [GC[YG occupancy: 593314 K
(1843200 K)]14264.168: [Rescan (parallel) , 0.0766200 secs]14264.244:
[weak refs processing, 0.1023280 secs]14264.347: [class unloading,
0.0059520 secs]14264.353: [scrub symbol & string tables, 0.0026240
secs] [1 CMS-remark: 3304088K(4096000K)] 3897403K(5939200K),
0.1925890 secs] [Times: user=0.70 sys=0.01, real=0.20 secs]
```

```
2010-06-02T10:25:12.785-0700: 14264.361: [CMS-concurrent-sweep-start]
2010-06-02T10:25:15.655-0700: 14267.231: [CMS-concurrent-sweep:
2.860/2.860 secs] [Times: user=4.37 sys=0.28, real=2.86 secs]
```

```
2010-06-02T10:25:15.655-0700: 14267.231: [CMS-concurrent-reset-start]
2010-06-02T10:25:15.688-0700: 14267.264: [CMS-concurrent-reset:
0.033/0.033 secs] [Times: user=0.06 sys=0.01, real=0.04 secs]
```

Tuning the Garbage Collector

- CMS-initial-mark is the first stop-the-world phase
- Followed by a concurrent mark phase
- Then a concurrent preclean, that is meant to be interrupted
  - In this case by a 5 second timeout
- CMS-remark is the second stop-the-world phase
- Followed by a concurrent sweep phase
- Then a final reset phase
- The whole CMS cycle took 9.257 s (with a 5 s timeout)

Tuning the Garbage Collector

- It is possible to make CMS parallel
  - -XX:ParallelCMSThreads=<number>
- Trade off between CMS cycle time and overhead during concurrent phases
  - More threads will benefit the application during parallel phases, but hurt during concurrent phases
- CMS big risk: the collection cannot complete, so a compacting full collection is triggered
  - Which implies BIG pauses

Tuning the Garbage Collector

- CMS triggers by default when Old Generation is 92% full
    - Do not trust online sources that say 68%, try yourself
- Threshold at 92% could be too high
    - Leaves little space for big allocations
        - Remember, it's fragmented
    - A promotion from Young Generation may not find enough space
        - And a compacting full collection will trigger: big pause
    - A CMS collection does not finish before the Old Generation is full
        - “Concurrent mode failure”

Tuning the Garbage Collector

- The most important tuning parameter for CMS:
  - -XX:CMSInitiatingOccupancyFraction
- Tells at what percentage trigger the CMS collection
  - You need trials and errors to tune it
- Trade off between collection frequency, collection overhead and risk of big pauses

Questions
&
Answers

References

- JDK 6 GC Reference:
  - http://java.sun.com/javase/technologies/hotspot/gc/gc_tuning_6.html
- JDK 6 JVM Options:
  - http://java.sun.com/javase/technologies/hotspot/vmoptions.jsp
- Jon the Collector's blog:
  - http://blogs.sun.com/jonthecollector
- GC mailing lists archives:
  - http://mail.openjdk.java.net/mailman/listinfo/hotspot-gc-use
  - http://mail.openjdk.java.net/mailman/listinfo/hotspot-gc-dev