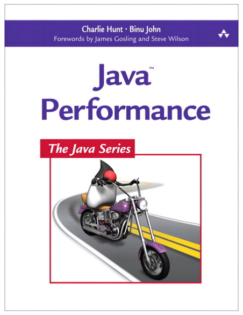
Fundamentals of GC Tuning

Charlie Hunt
JVM & Performance Junkie

Who is this guy?

Charlie Hunt

- Currently leading a variety of HotSpot JVM projects at Oracle
- Held various performance architect roles at Oracle, Salesforce.com & Sun Microsystems
- Lead author of Java Performance, published Sept 2011



What to expect

This is not a session about JVM command line options, i.e. -Xms, -Xmx, -Xmn, -XX:InsertYourFavorite

It's about understanding the basic concepts to enable you to reason about tuning a JVM's GC, and the advantages, consequences, tradeoffs of those decisions.

The Goal

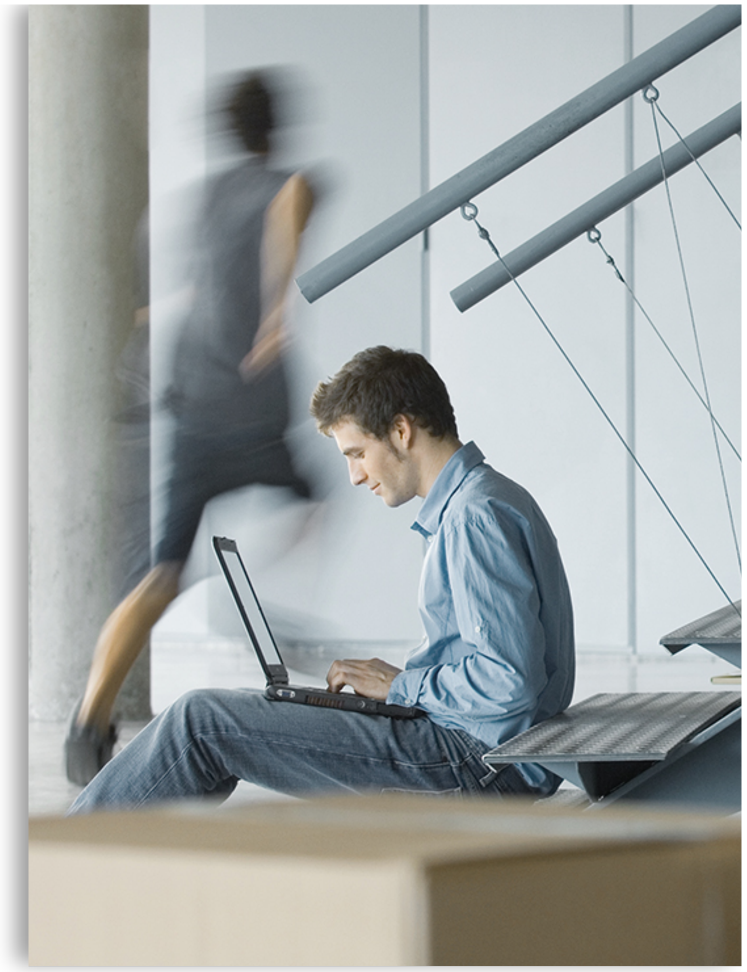
Ideally, understanding the basic concepts will enable you to tune any garbage collector.

At a minimum, make better decisions about what actions to consider taking.

Agenda

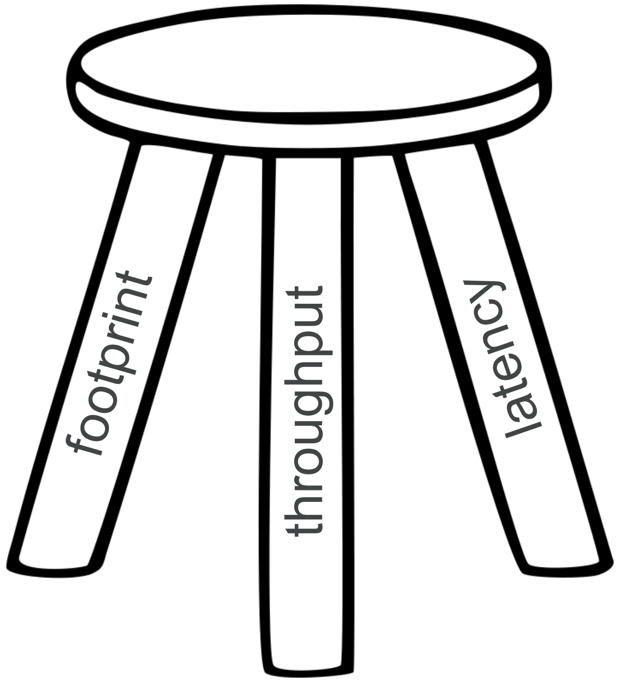
- The Key Performance Attributes
- High Level Look at Modern JVM GC Architectures
- Basic Concepts

The Performance Attributes



Three Legged Stool

- Throughput
- Latency
- (Memory) Footprint



2 of 3 Principle

Improving one or two of these performance attributes, (throughput, latency or footprint) results in sacrificing some performance in the other.

Hunt, John. Java Performance. Upper Saddle River, NJ, Addison-Wesley, 2011

2 of 3 Principle (updated)

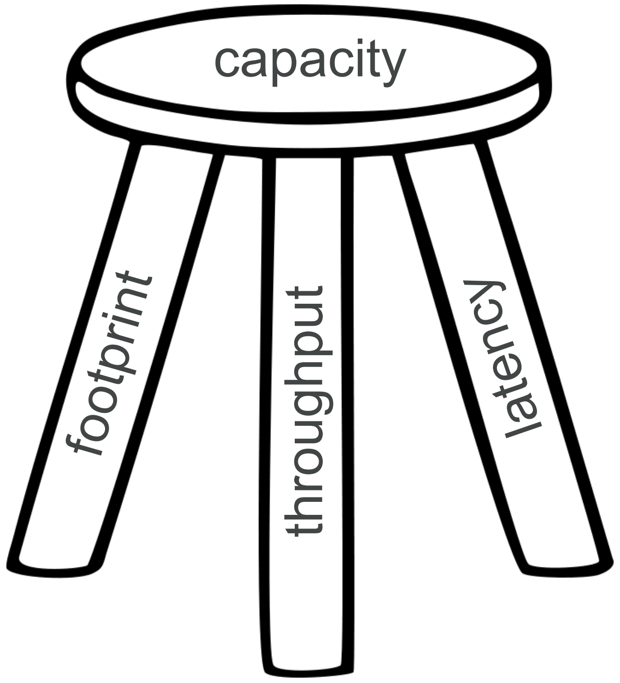
Improving all three performance attributes [usually] requires a lot of non-trivial [development] work.

Another Principle - (yet to be named)

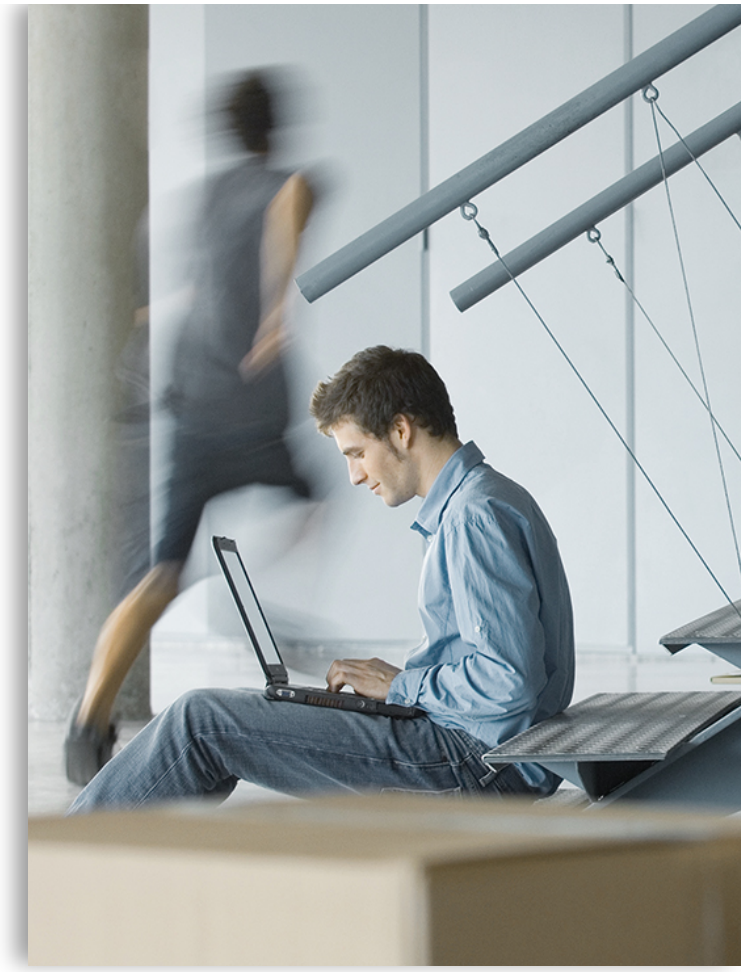
An improvement in throughput and/or latency may reduce or lower the amount of available CPU to the application, or other applications executing on the same system. Thus impacting the capacity of the system.

Perhaps an Enhanced Three Legged Stool ?

- Throughput
- Latency
- (Memory) Footprint
- Capacity



High Level Look at Modern JVM GC Architectures



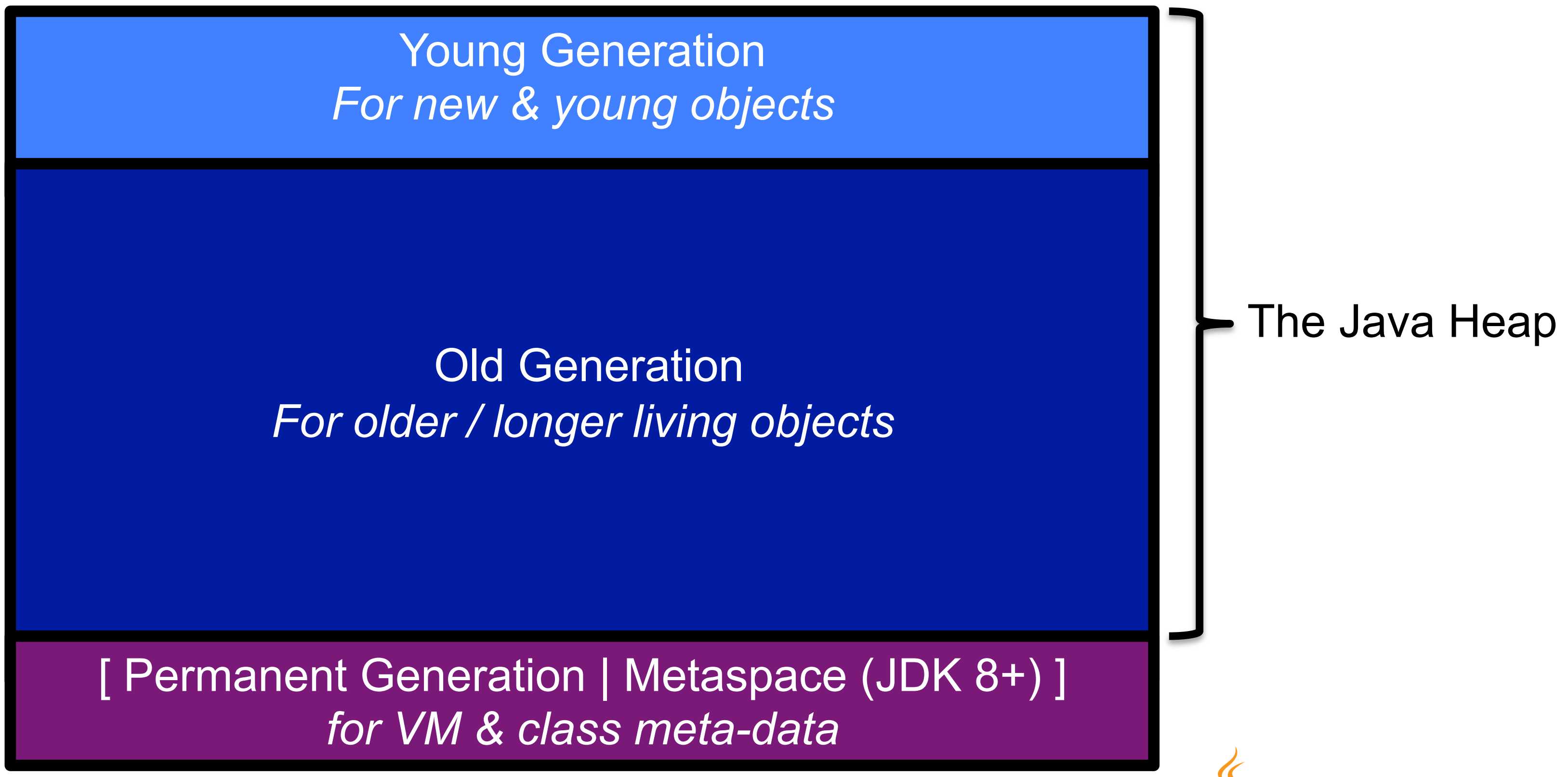
Generational GC

- [Almost] all modern JVMs use a generational GC
  - Segregate objects by age into different spaces, and bias collection of younger objects
  - Typically two generations; young & old
- JVMs with generational GCs
  - HotSpot – all GCs supported by Oracle
  - JRockit – all, except JRockit Real-Time
  - Zing – C4 GC
  - J9 – all AFAIK … admit I'm not familiar with J9's GCs

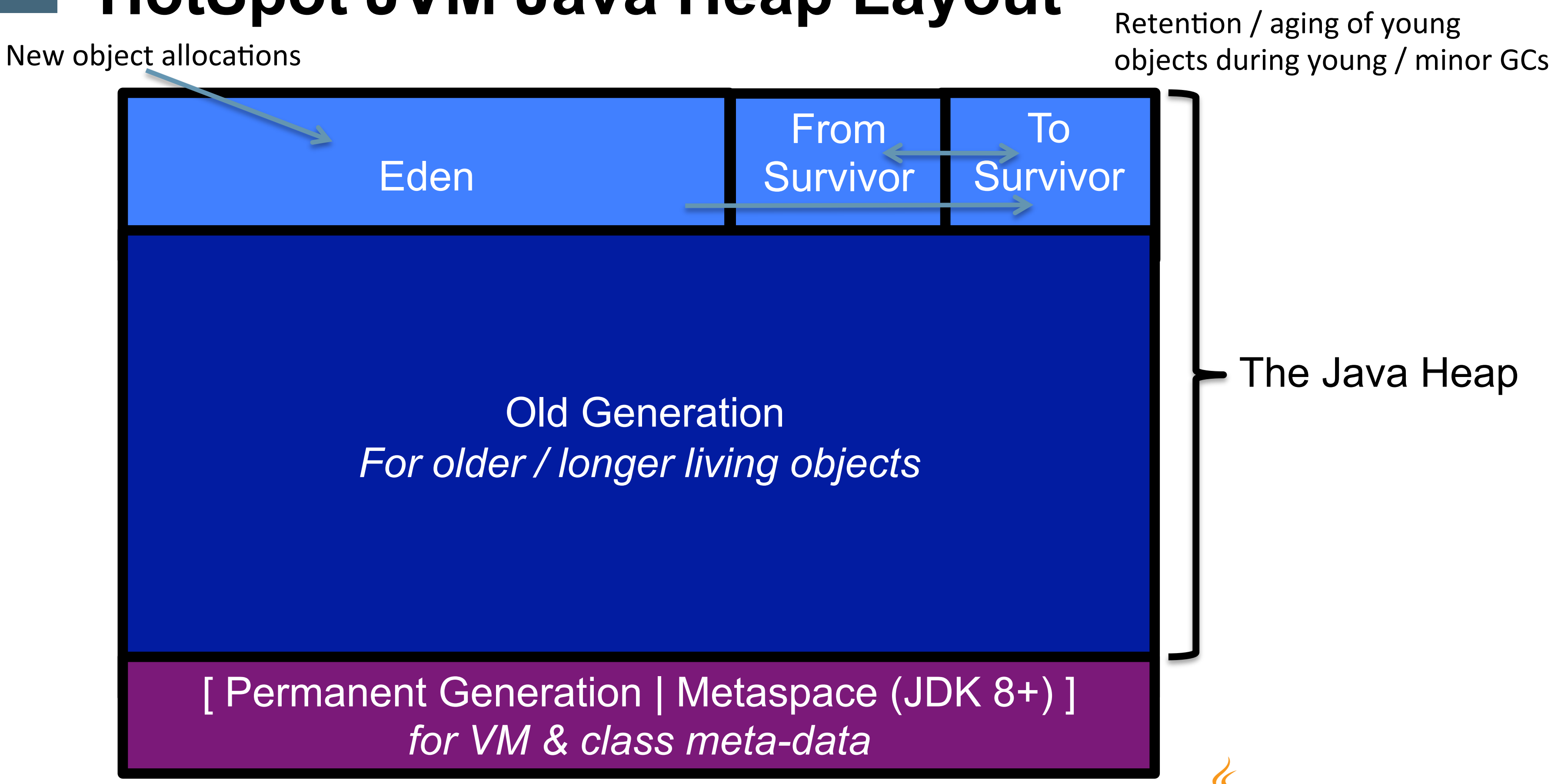
Why Generational GC ?

- Weak generational hypothesis
  - Most objects die young
- #1 reason for generational GCs
  - Improved throughput

HotSpot JVM Java Heap Layout



HotSpot JVM Java Heap Layout


New object allocations
Retention / aging of young objects during young / minor GCs
Eden
From Survivor
To Survivor
Old Generation
For older / longer living objects
The Java Heap
[Permanent Generation | Metaspace (JDK 8+)]
for VM & class meta-data

When tuning GC

General Approach

- Think in terms of
  - Frequency
    - How frequent can I live with GC events occurring?
  - Duration
    - For STW GC, how long of a GC pause can I tolerate?
    - For concurrent GC, how much capacity (CPU consumption), throughput and additional memory am I willing to sacrifice?
- Note: answers to these will differ depending on the application
  - And, they can also differ between application stakeholders

First Important Concept

Important Concept #1

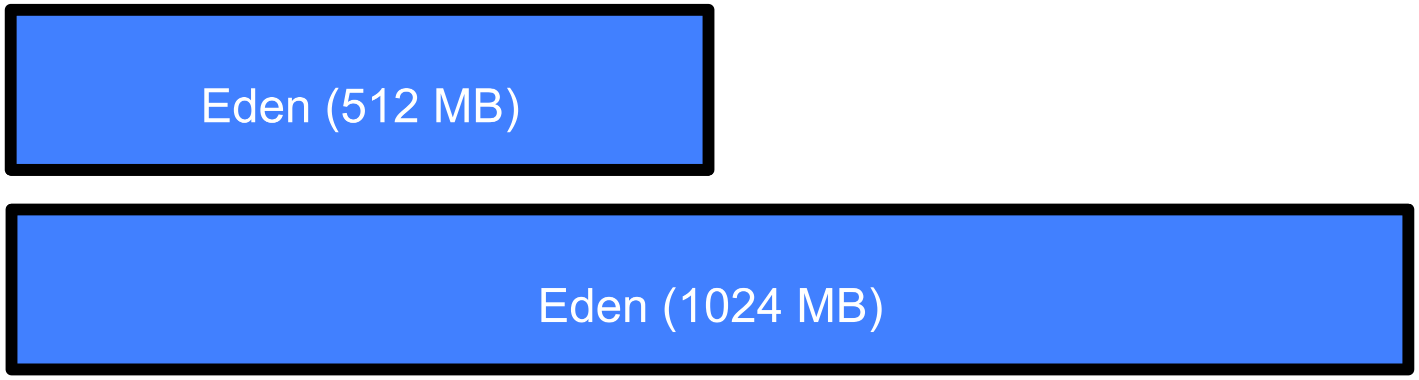
Frequency of Minor / Young GCs

- Frequency of a minor GC event is dictated by
  - Application object allocation rate – how fast it's allocating objects
  - Size of Eden space
    - This applies to the HotSpot JVM
    - For other generational JVMs it will be the size of the space where new objects are allocated.
    - For STW collectors, once that space is exhausted, a GC event occurs.
    - For concurrent collectors, there's usually an occupancy threshold that once it's surpassed, a concurrent GC event commences.

Important Concept #1

Changing the frequency of a minor GC event

- Less frequent GC
  - Make Eden size bigger (assuming same object allocation rate)



- Same allocation rate, 2x increase in Eden space, time between GC increases 2x, i.e. minor GC frequency cut in ½

Important Concept #1

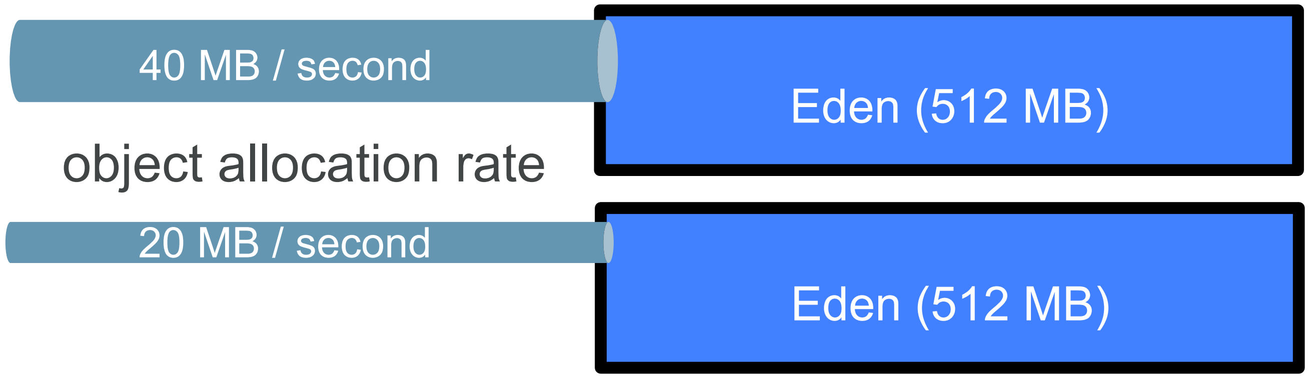
Choices for making Eden size larger

- HotSpot JVM's CMS GC, Parallel GC and Serial GC
  - Increase -Xmn, -XX:NewSize / -XX:MaxNewSize
  - -XX:SurvivorRatio if you want preserve young gen size but change Eden and Survivor sizes
- HotSpot JVM's G1 GC
  - Increase -XX:MaxGCPauseMillis
    - G1's heuristics generally assume greater pause time implies larger Eden space

Important Concept #1

How to change the frequency of a minor GC event

- Reduce object allocation rate
  - Eden space fills more slowly with reduced object allocation rate



- Obvious, right? 2x drop in allocation rate, time to fill Eden space increases 2x, i.e. time between GC increases 2x

Important Concept #1

Strategies for reducing object allocation rate

- Profile application and reduce object allocations
  - Focus on unnecessary object allocations!
- Throttle application
  - Reduce the injection rate or load on the application

Second Important Concept

Important Concept #2

Minor GC Duration (pause time)

- Number of live objects has strongest influence of minor GC duration
  - GC only visit (i.e. marks) and evacuates live objects
- There are other things that can influence minor GC duration
  - Overuse (or abuse) of Reference objects; Weak, Soft, Phantom and Final
  - Memory locality of the marked objects, and evacuation location
  - Young generation object kept live by an old generation reference
  - There can be other reasons
- In short, ideally minor GC duration should be dominated by marking and evacuation time

Important Concept #2

Choices for reducing minor GC pause time

- Faster memory and CPU (in general a faster system)
- Faster STW GC algorithm
- Concurrent GC
  - May introduce more CPU consumption which can reduce available capacity
  - May require more memory (footprint) to handle floating garbage
- Fewer live objects

Important Concept #2

Options for realizing fewer live objects

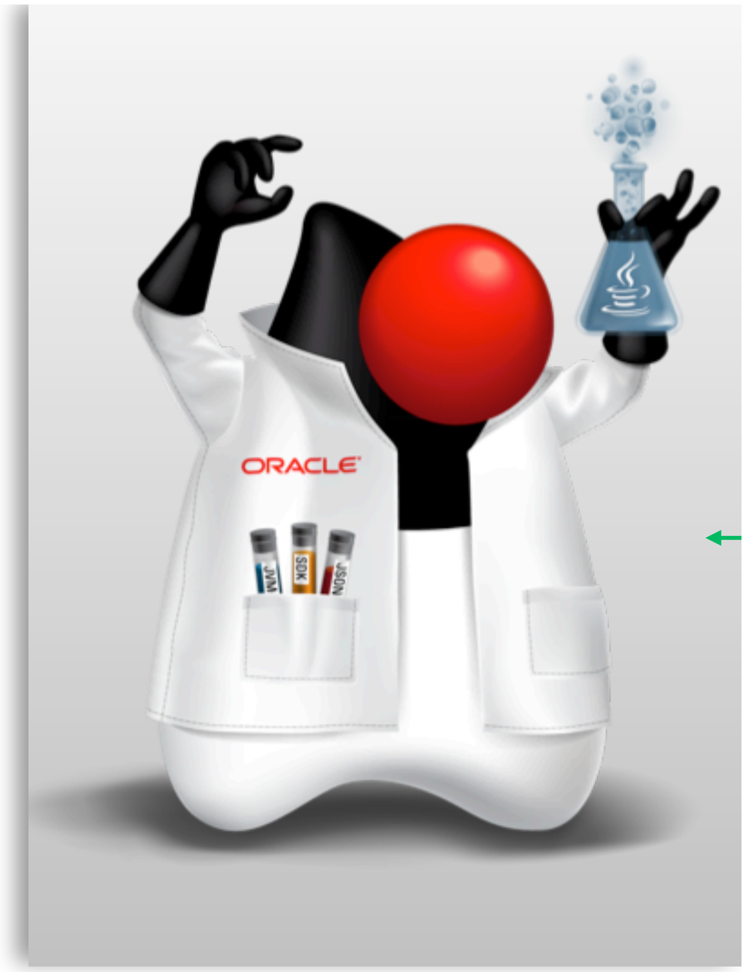
- Strategies for achieving fewer live objects per minor GC
  - Smaller Eden space
    - Fewer objects in general implies fewer live objects
      - But may not always hold … smaller Eden space implies Eden space fills faster … implies more frequent minor GCs … less time for an object to die … higher live objects to objects allocated ratio
    - Common approach with a concurrent collector in old generation
      - Push “collection work” off til later
        - » Leads to more frequent old generation [concurrent] collections, higher CPU consumption … can impact capacity

Important Concept #2

Options for realizing fewer live objects

- Strategies for achieving fewer live objects per minor GC
  - Remove unnecessary object retention
    - Not to be confused with unnecessary object allocation
  - Profile the application
    - Look for potential assignment between two objects that spans multiple generations
      - Objects in young gen may be presumed alive
      - Look at java.util.LinkedList.clear() as an example

Third Important Concept

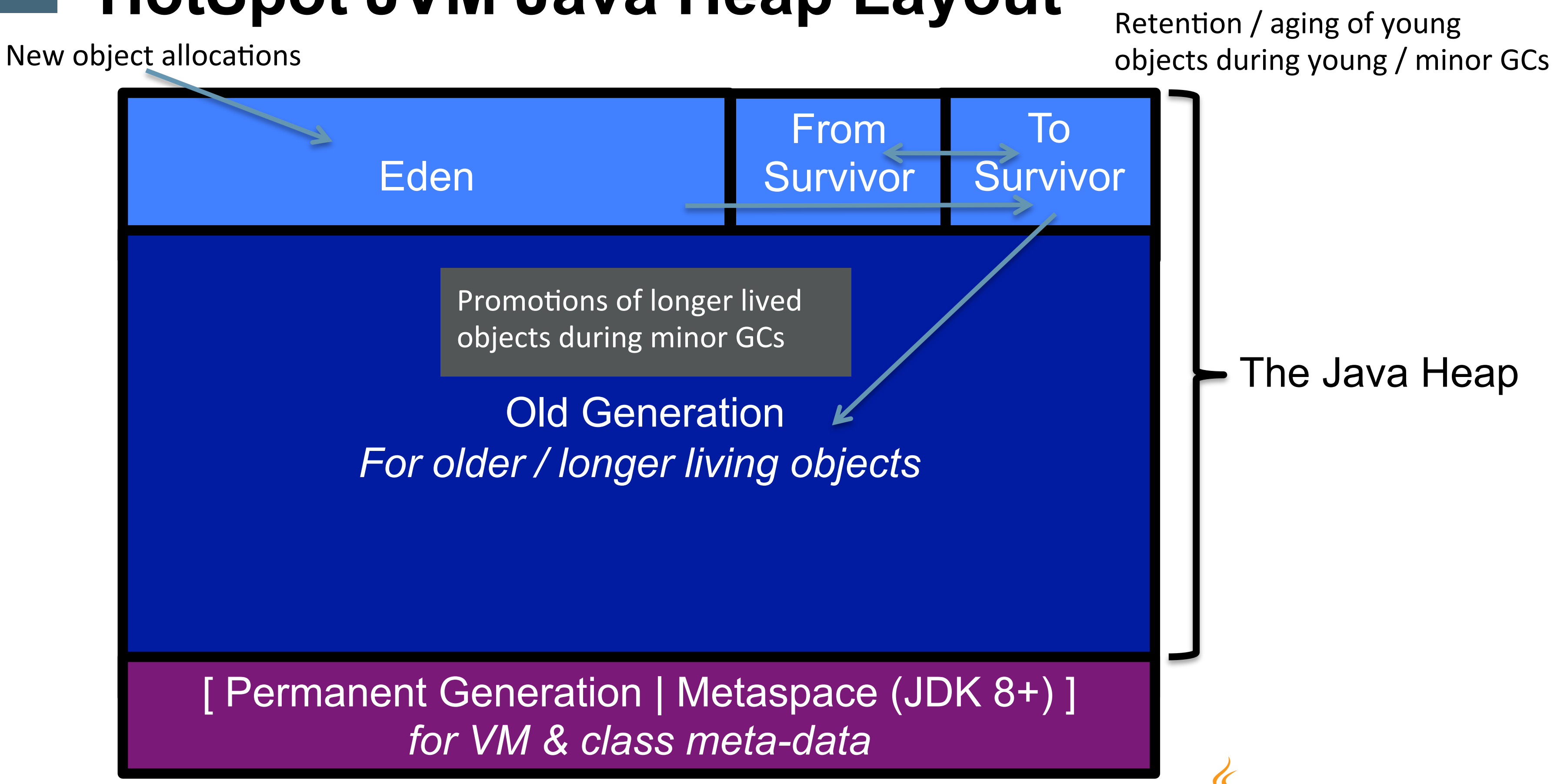


Important Concept #3

Old Generation Collection Frequency

- First some background info
  - Lots of variation with Old Generation collectors, STW & concurrent
    - HotSpot’s Parallel GC, ParallelOld GC and Serial GC are STW
    - HotSpot’s CMS GC and G1 GC are mostly concurrent
    - JRockit has both STW and mostly concurrent GCs
    - Zing C4 is a concurrent GC
    - J9 (AFAIK) has both STW and mostly concurrent

HotSpot JVM Java Heap Layout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Promotions of longer lived objects during minor GCs
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Important Concept #3

Old Generation Collection Frequency

- Old generation collection frequency is dictated by
  - the rate at which objects are promoted from young generation to old generation
    - HotSpot promotes objects based on an age tenuring threshold
      - Age is # of minor GCs an object survives
      - Age tenuring threshold computed at each minor GC
  - Size of the old generation space
    - STW GCs collect when space is exhausted, concurrent GCs use an occupancy threshold to initiate concurrent collection cycle

Important Concept #3

How to reduce Old Generation collection frequency

- Strategies for reducing the promotion rate
  - More effective object aging
    - In HotSpot, tune survivor space sizes using -XX:SurvivorRatio – strive to promote objects at max tenuring threshold
    - Increase Eden space size using -Xmn, -XX:[Max]NewSize
      - Minor GCs occur less frequently, object age increments slower
    - Reduce object allocation rate
      - Minor GCs occur less frequently, object age increments slower

Important Concept #3

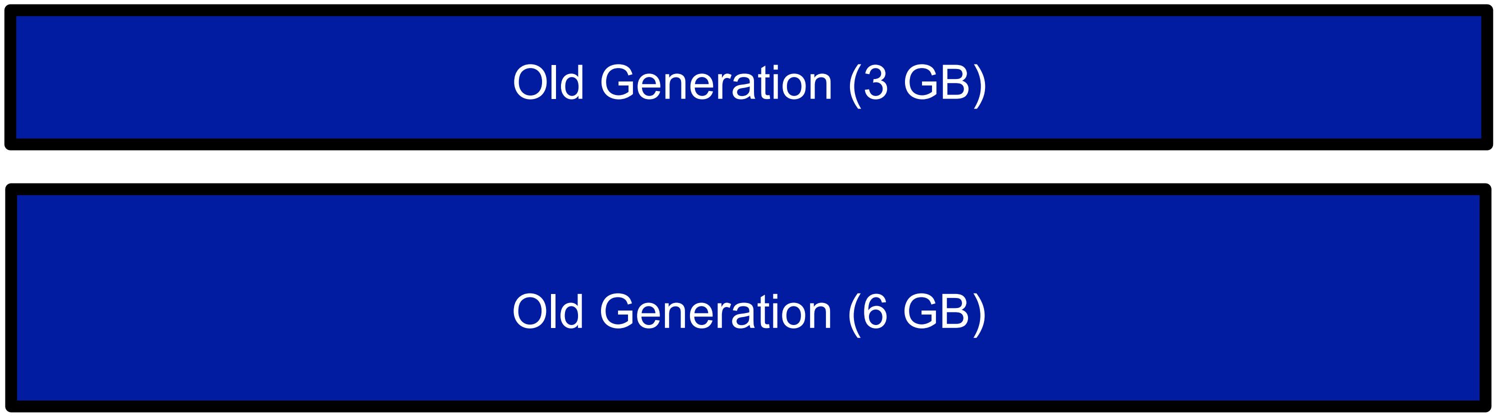
How to reduce Old Generation collection frequency continued …

- Strategies for reducing the promotion rate
  - Reduce object retention
    - Fewer objects to promote per minor GC
    - Also reduces the required survivor space size to avoid early promotion
    - May also reduce the frequency of minor GCs which allows objects to age longer in young generation survivor spaces

Important Concept #3

How to reduce Old Generation collection frequency continued …

- Make old generation size bigger (assuming same promotion rate)



- Same promotion rate, 2x increase in old gen space, time between old generation collection increases 2x

Important Concept #3

Choices for increasing the size of old generation

- For the HotSpot JVM
  - For Parallel GC, CMS GC and Serial GC
    - Increase -Xms and -Xmx, and keep young generation sizing the same i.e. -Xmn, -XX:[Max]NewSize, -XX:SurvivorRatio
  - For G1 GC
    - May require an increase in both -Xms / -Xmx and

      -XX:InitiatingHeapOccupancyPercent

Important Concept #3

How to reduce Old Generation collection frequency continued …

- Lower old generation occupancy after collection
  - A form of lowering object retention
  - More available space to fill in old generation after collection
- Approach similar as described earlier for reducing object retention
  - Profile the application and look for objects unnecessarily kept live longer than need be

Important Concept #3

What about frequency of concurrent collection cycles?

- Reducing frequency of concurrent collection cycles in old generation
  - Increase heap occupancy threshold that initiates a concurrent cycle
    - Reduces total CPU cycles used for GC over life of application execution
    - But, higher risk of running out of available old generation space
      - Don't want to "lose the race"
    - In HotSpot CMS GC, -XX:CMSInitiatingHeapOccupancyFraction
      - Also suggest -XX:+UseCMSInitiatingOccupancyOnly
    - In HotSpot G1 GC, -XX:InitiatingHeapOccupancyPercent

Forth Important Concept

Important Concept #4

Duration of old generation collection

- I'm making a distinction between a Full GC, and an old generation collection
  - Full GC may involve collecting and compacting both young generation and old generation – (this is the default behavior for the HotSpot JVM)
  - Collecting old generation means the collecting of old generation only, not necessarily compacting old generation, and (obviously) not collecting young generation

Important Concept #4

- Duration of old generation collection
  - Similar to minor GC, number of live objects has strongest influence of old generation collection duration
  - Other things that can influence old generation collection duration
    - Overuse (or abuse) of Reference objects; Weak, Soft, Phantom and Final
      - Note: SoftReferences can also influence old generation collection frequency
    - Memory locality, etc.

Important Concept #4

- For old generation collection, desire duration to be dominated by time to mark live objects
  - And, if the GC also does compaction, then also live object compaction
  - HotSpot Parallel GC and Serial GC mark live objects and compacts them, aka a mark-compact collector
    - These GCs also happen to be STW collectors, both young & old generation collectors

Important Concept #4

- Note, for [mostly] concurrent old generation collection, also desire duration to be dominated by time to mark live objects
  - HotSpot CMS GC does not do compaction - it is a mark-sweep collector
    - No compaction unless promotion failure – resorts to a Full GC
  - HotSpot G1 GC achieves compaction by evacuating live objects from old generation regions to available (empty) old generation regions
    - Evacuation (copy) time is where you want G1 to spend most of its time outside of marking
    - Evacuation in G1 is a STW part of a G1 concurrent old gen collection

Important Concept #4

What can be done to reduce old generation collection pause time

- Faster memory and CPU (in general a faster system)
- Faster STW GC algorithm
- Concurrent old generation collection
  - May introduce more CPU consumption which can reduce throughput and available capacity
  - May require more memory (footprint) to handle floating garbage
- Fewer live objects in old generation

Important Concept #4

Summary of concurrent old generation collection trade-offs

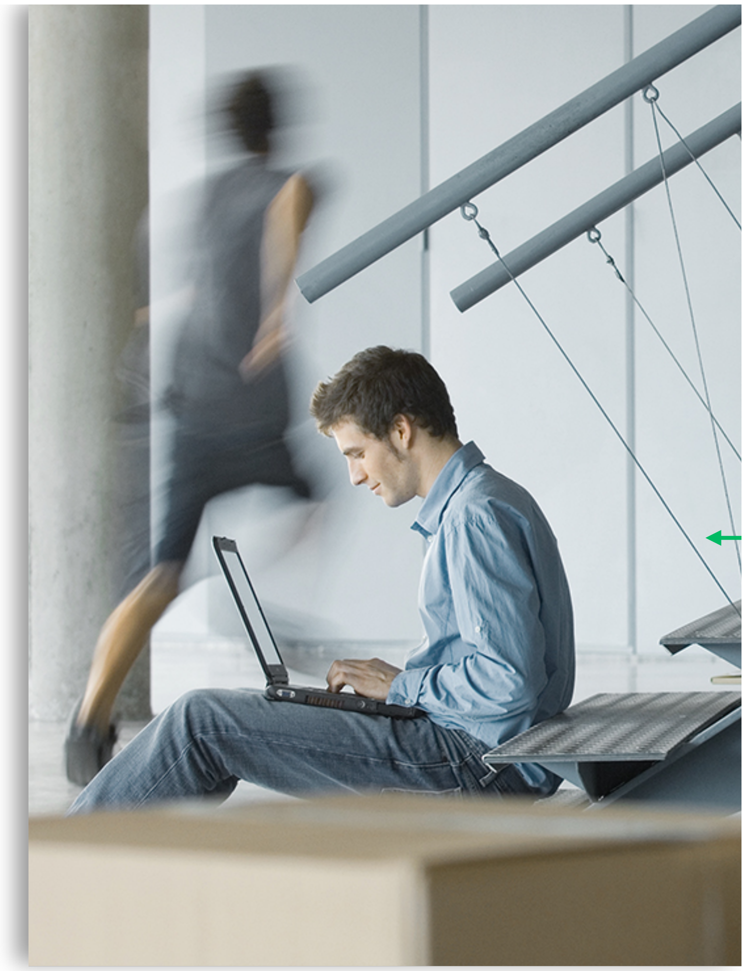
- What are you gaining with [mostly] concurrent collector
  - Lower GC pause times / improved latency
- What are you sacrificing / giving up
  - Usually more Java heap
  - More CPU consumption
- Translation, for improving latency, you’re sacrificing something in at least one, or possibly all three of
  - footprint, throughput and capacity

Important Concept #4

Strategies for Fewer Live Objects

- Achieving fewer live objects per old generation collection
  - Larger old generation space ?
    - Possibly
      - In general, if the increase is size allows more objects to die
      - Example, if the length of a typical application transaction is greater than the time between old generation collection, then increasing old generation could reduce the number of live objects marked during an old generation collection

Summary

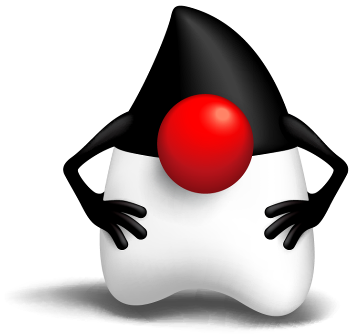


Take away

If you think about GC tuning in terms of garbage collection frequency and duration, for both young generation, and old generation collection you can reason about the action to take to meet the throughput, latency, footprint and available capacity goals for your application.

Credits

- Huge thank you to all HotSpot GC team members, past and present
- Countless others, past and present from the HotSpot JVM team



Last Slide --- I Promise!!!

Additional Reading (Books)

- Java Performance [1]
  - Discounted tomorrow (May 21st) $19.99 – http://informit.com/deals
- Java Performance: The Definitive Guide [2]
- The Garbage Collection Handbook [3]

[1] Hunt, John. Java Performance. Upper Saddle River, NJ, Addison-Wesley, 2011
[2] Oaks. Java Performance: The Definitive Guide. Sebastopol, CA, O'Reilly Media, Inc. 2014
[3] Jones, Hosking, Moss. The Garbage Collection Book. Boca Raton, FL, CRC Press 2012

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