Extreme Performance with Java

QCon NYC - June 2012

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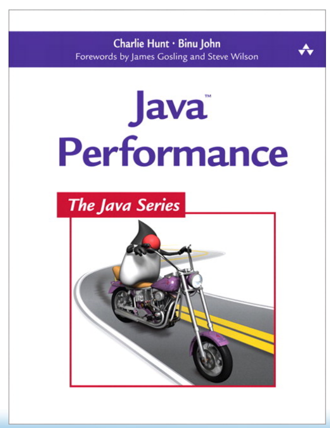
In a Nutshell

What you need to know about a modern JVM in order to be effective at writing a low latency Java application.

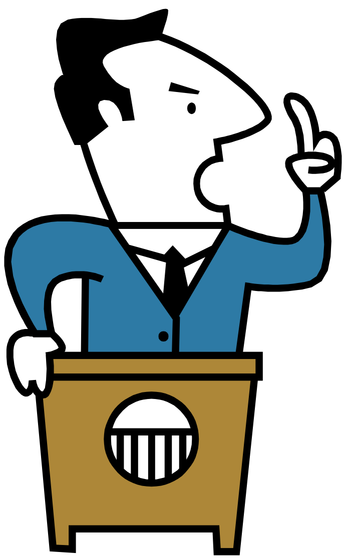
Who is this guy?

- Charlie Hunt
    - Architect of Performance Engineering at Salesforce.com
    - Former Java HotSpot VM Performance Architect at Oracle
    - 20+ years of (general) performance experience
    - 12+ years of Java performance experience
    - Lead author of ***Java Performance*** published Sept. 2011



Agenda

- What you need to know about GC
- What you need to know about JIT compilation
- Tools to help you



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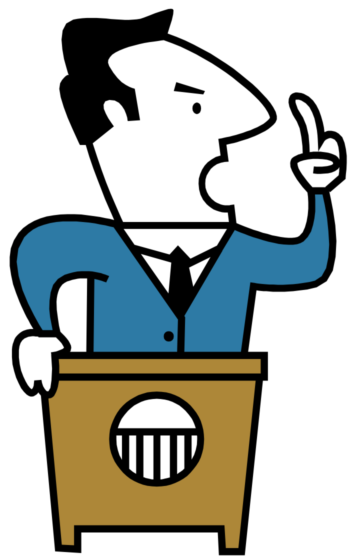
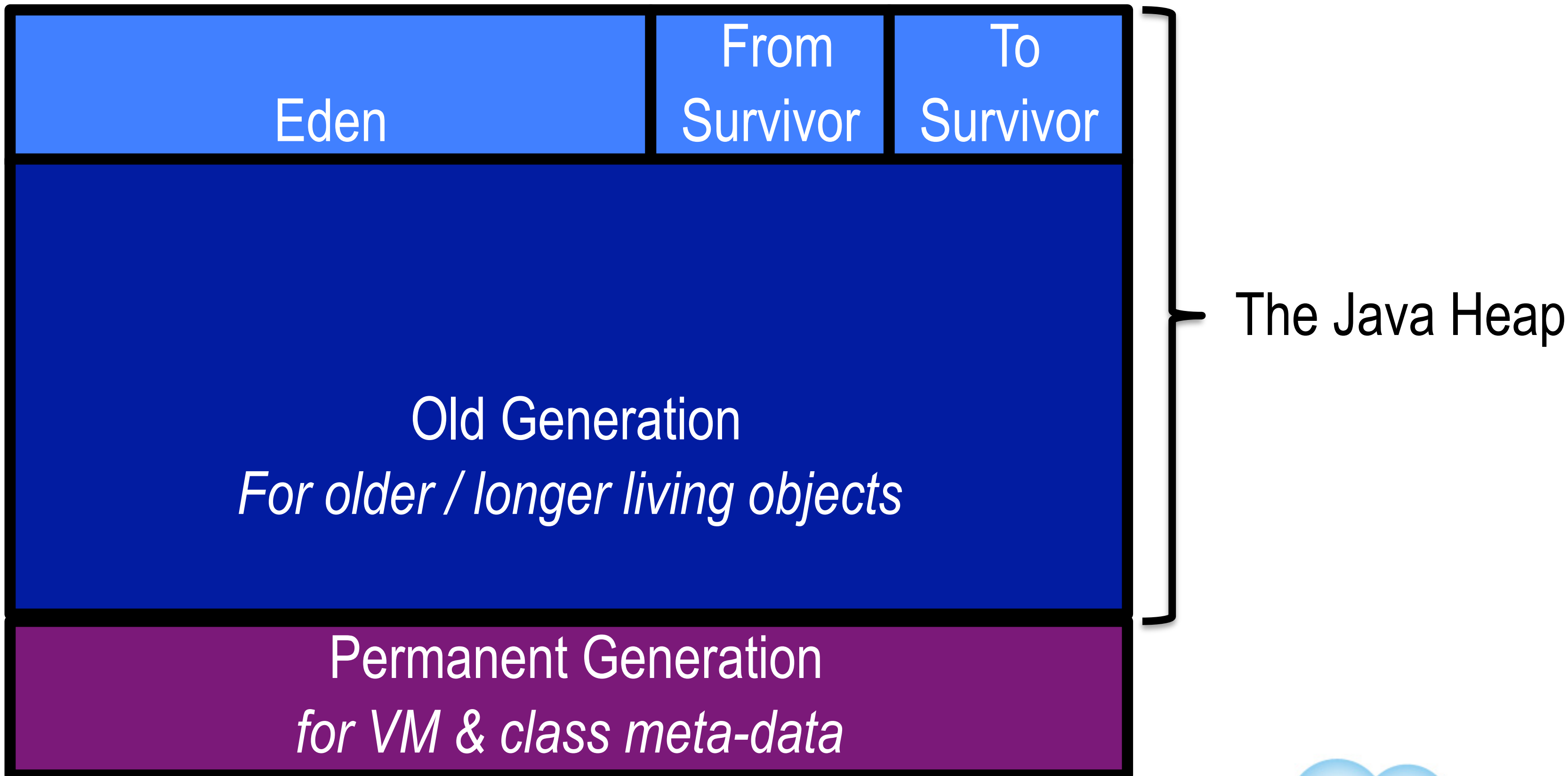


Java HotSpot VM Heap Layout



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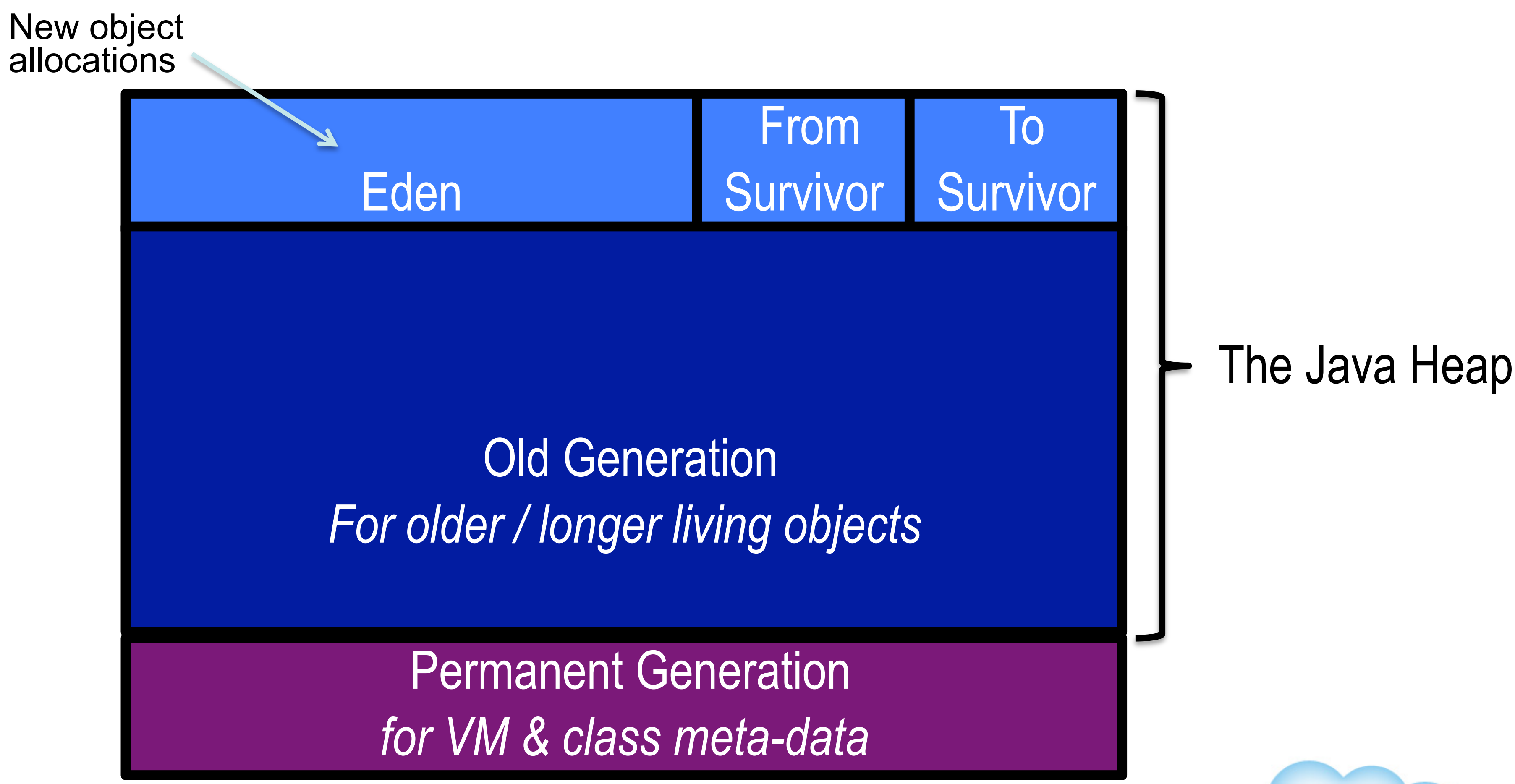

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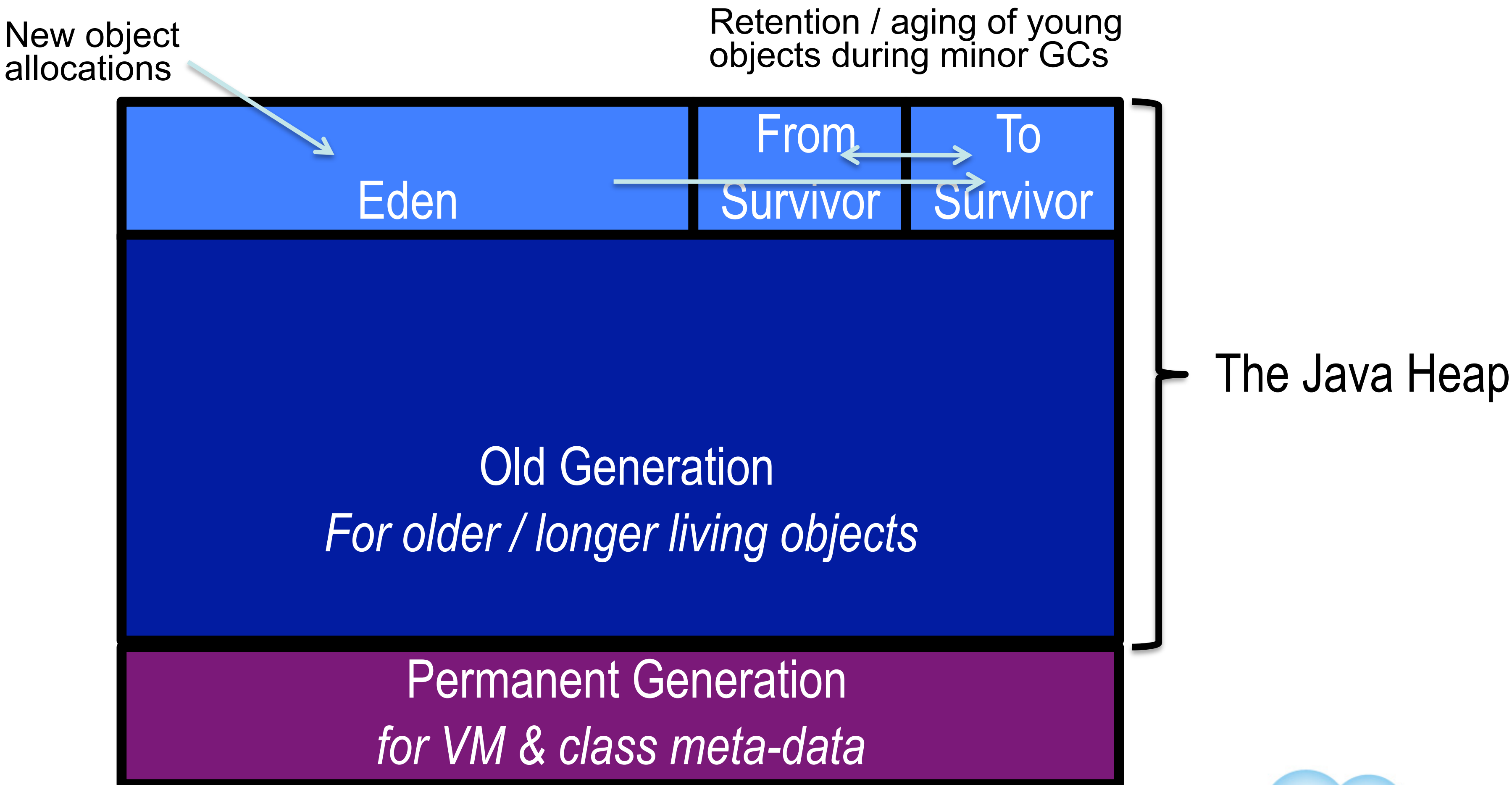

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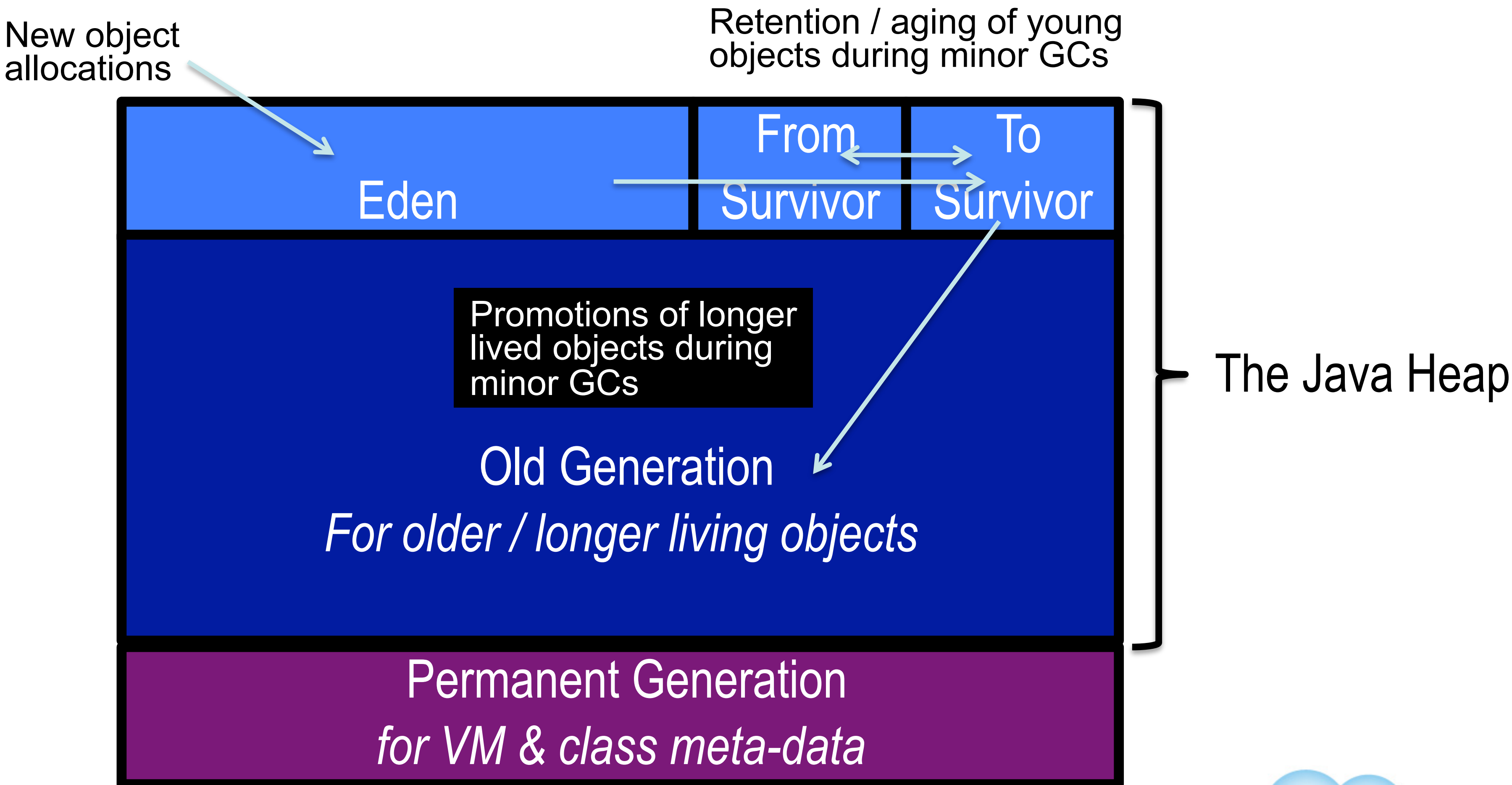

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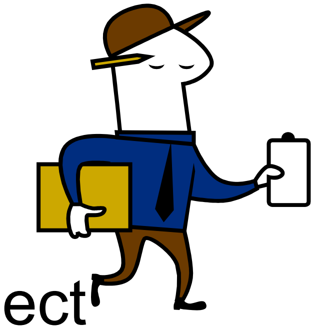
- Frequency of object promotion into old generation is dictated by
  - Frequency of minor GCs (how quickly objects age)
  - Size of the survivor spaces (large enough to age effectively)
    - Ideally promote as little as possible (more on this coming)

Important Concepts (2 of 4)



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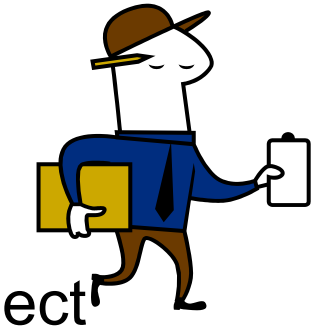

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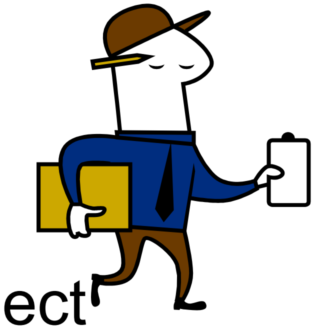

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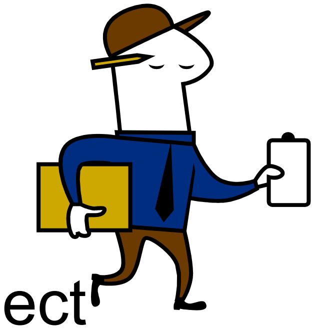
    - May get promoted to old generation sooner than desired
    - May cause other retained objects to get promoted earlier



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  - GC only visits live objects
  - GC duration is a function of the number of live objects and object graph complexity

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- Don’t be afraid to allocate short lived objects
  - … especially for immediate results
- GCs love small immutable objects and short-lived objects
  - … especially those that seldom survive a minor GC

Important Concepts (4 of 4)

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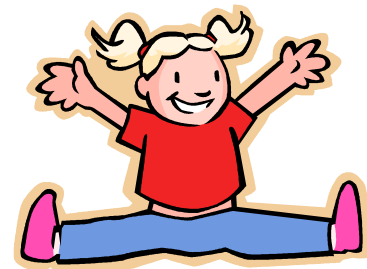
  - … more frequent needs for possibly either; concurrent old generation collection, or old generation compaction (i.e. full GC) … or some kind of disruptive GC activity
- It is better to use short-lived immutable objects than long-lived mutable objects

Ideal Situation



- After application initialization phase, only experience minor GCs and old generation growth is negligible
  - Ideally, never experience need for old generation collection
  - Minor GCs are (generally) the fastest GC

Advice on choosing a GC

- Start with Parallel GC (-XX:+UseParallel[Old]GC)
  - Parallel GC offers the fastest minor GC times
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- Move to CMS or G1 if needed (for old gen collections)
  - CMS minor GC times are slower due to promotion into free lists
  - CMS full GC avoided via old generation concurrent collection
  - G1 minor GC times are slower due to remembered set overhead
  - G1 full GC avoided via concurrent collection and fragmentation avoided by "partial" old generation collection

GC Friendly Programming (1 of 3)

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- Advice,
  - Avoid large object allocations if you can
    - Especially frequent large object allocations during application "steady state"

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- Data Structure Re-sizing
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- Object pooling potential issues
  - Contributes to number of live objects visited during a GC
    - Remember GC duration is a function of live objects
  - Access to the pool requires some kind of locking
    - Frequent pool access may become a scalability issue

GC Friendly Programming (3 of 3)

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- Finalizers
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  - Requires at least 2 GCs cycles and GC cycles are slower
  - If possible, add a method to explicitly free resources when done with an object
    - Can't explicitly free resources?
    - Use Reference Objects as an alternative (see DirectByteBuffer.java)

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- Referent is cleared by GC
  - JVM GC’s implementation determines how aggressive they are cleared
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    - Remember the relationship between object retention
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- IMO, SoftReferences == bad idea!

Subtle Object Retention (1 of 2)

- Consider the following:

```
class MyImpl extends ClassWithFinalizer {
    private byte[] buffer = new byte[1024 * 1024 * 2];
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- What's the object retention consequences if ClassWithFinalizer has a finalizer?

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- What about inner classes?
  - Remember that inner classes have an implicit reference to the outer instance
- Potentially can increase object retention
- Again, increased object retention … more live objects at GC time … increased GC duration

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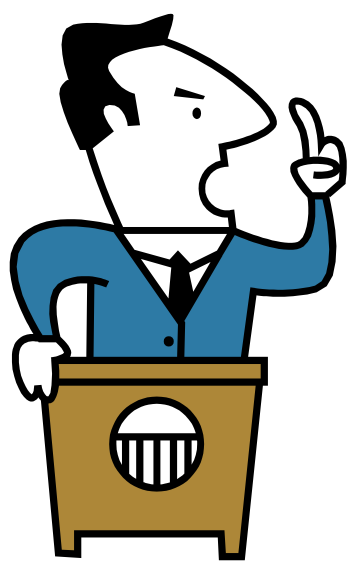

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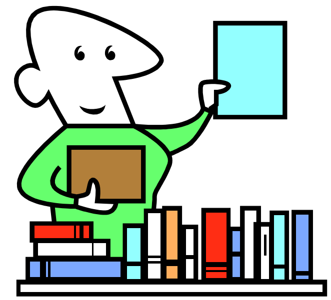

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  - Assumptions may turn out (later) to be wrong … it must keep information around to “recover” which (may) limit type(s) of optimization(s)
  - New classloading or code path … possible de-opt/re-opt

Inlining and Virtualization, Completing Forces

- Greatest optimization impact realized from “method inlining”
  - Virtualized methods are the biggest barrier to inlining
    - Good news … JIT compiler can de-virtualize methods if it only sees 1 implementation of a virtualized method … effectively makes it a mono-morphic call

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    - Good news … JIT compiler can de-virtualize methods if it only sees 1 implementation of a virtualized method … effectively makes it a mono-morphic call
    - Bad news … if JIT compiler later discovers an additional implementation it must de-optimize, re-optimize for 2nd implementation … now we have a bi-morphic call
    - This type of de-opt & re-opt will likely lead to lesser peak performance, especially true when / if you get to the 3rd implementation because now its a mega-morphic call

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- How 'bout writing "JIT Compiler Friendly Code" ?
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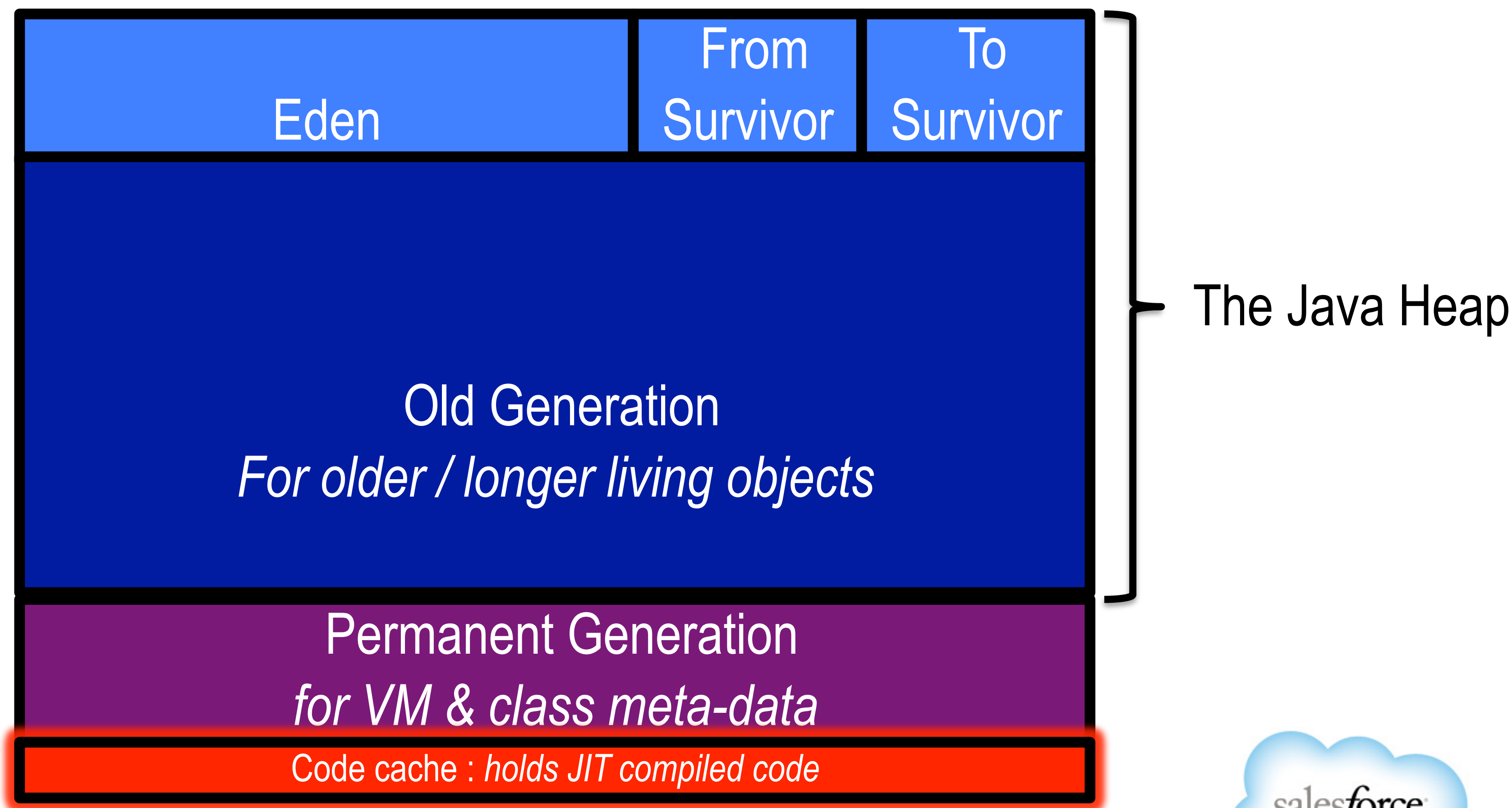
- Advice?
  - Write code in its most natural form, let the JIT compiler figure out how to best optimize it
  - Use tools to identify the problem areas and make code changes as necessary

Code cache, the “hidden space”



Code cache

- Default size is 48 megabytes for HotSpot Server JVM
  - 32 megabytes for HotSpot Client JVM
- If you run out of code cache space
  - JVM prints a warning message:
    - “CodeCache is full. Compiler has been disabled.”
    - “Try increasing the code cache size using -XX:ReservedCodeCacheSize=“
- Common symptom … application mysteriously slows down after its been running for a lengthy period of time
  - Generally, more likely to see on enterprise class apps

Code cache

- How to monitor code cache space
  - Can’t merely periodically look at code cache space occupancy in JConsole
  - JIT compiler will throw out code that’s no longer valid, but will not re-initiate new compilations, i.e. -XX:+PrintCompilation shows “made not entrant” and “made zombie”, but not new activations
    - So, code cache could look like it has available space when it has been exhausted previously – can be very misleading!

Code cache

- Advice
  - Profile app with profiler that also profiles the JVM
    - Look for high JVM Interpreter CPU time
  - Check log files for log message saying code cache is full
  - Use -XX:+UseCodeCacheFlushing on recent Java 6 and Java 7 Update releases
    - Will evict least recently used code from code cache
    - Possible for compiler thread to cycle (optimize, throw away, optimize, throw away), but that’s better than disabled compilation
  - Best option, increase -XX:ReservedCodeCacheSize, or do both +UseCodeCacheFlusing & increase ReservedCodeCacheSize

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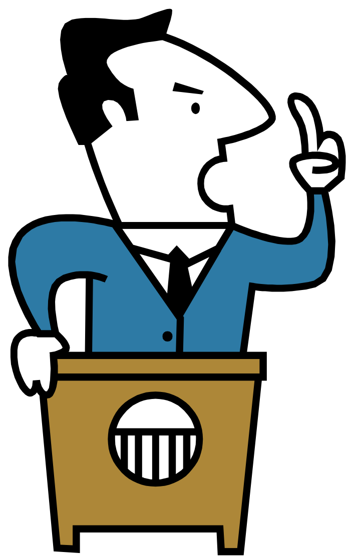

GC Analysis Tools

- Offline mode, after the fact
  - GCHisto or GCViewer (search for “GCHisto” or “chewiebug GCViewer”) – both are GC log visualizers
  - Recommend -XX:+PrintGCDetails, -XX:+PrintGCTimeStamps or -XX:+PrintGCDateStamps
- Online mode, while application is running
  - VisualGC plug-in for VisualVM (found in JDK’s bin directory, launched as 'jvisualvm')
- VisualVM or Eclipse MAT for unnecessary object allocation and object retention

JIT Compilation Analysis Tools

- Command line tools
  - -XX:+PrintOptoAssembly
    - Requires “debug JVM”, can be built from OpenJDK sources
    - Offers the ability to see generated assembly code with Java code
    - Lots of output to digest
  - -XX:+LogCompilation
    - Must add -XX:+UnlockDiagnosticVMOptions, but “debug JVM” not required
    - Produces XML file that shows the path of JIT compiler optimizations
    - Very, very difficult to read and understand
    - Search for “HotSpot JVM LogCompilation” for more details

JIT Compilation Analysis Tools

- GUI Tools
  - Oracle Solaris Studio Performance Analyzer (my favorite)
    - Works with both Solaris and Linux (x86/x64 & SPARC)
    - Better experience on Solaris (more mature, port to Linux fairly recent, some issues observed on Linux x64)
    - See generated JIT compiler code embedded with Java source
    - Free download (search for "Studio Performance Analyzer")
    - Also a method profiler, lock profiler and profile by CPU hardware counter
  - Similar tools
    - Intel VTune
    - AMD CodeAnalyst

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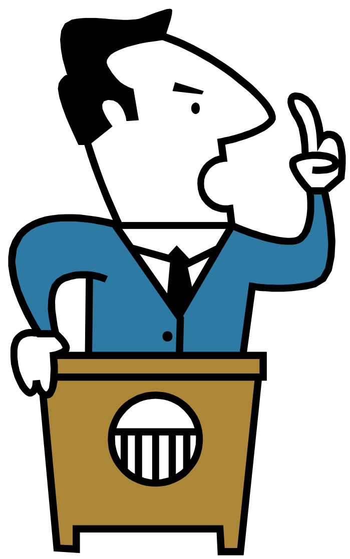

Acknowledgments

- Special thanks to Tony Printezis and John Coomes. Much of the GC related material, especially the “GC friendly”, is material originally drafted by Tony and John
- And thanks to Tom Rodriguez and Vladimir Kozlov for sharing their HotSpot JIT compiler expertise and advice

Additional Reading Material

- *Java Performance*. Hunt, John. 2012
  - High level overview of how the Java HotSpot VM works including both JIT compiler and GC along with many other “goodies”
- *The Garbage Collection Handbook*. Jones, Hosking, Moss. 2012
  - Just about anything and everything you’d ever want to know about GCs, (used in any programming language)

Thank you!

ADM

Adaptive Delivery Methodology