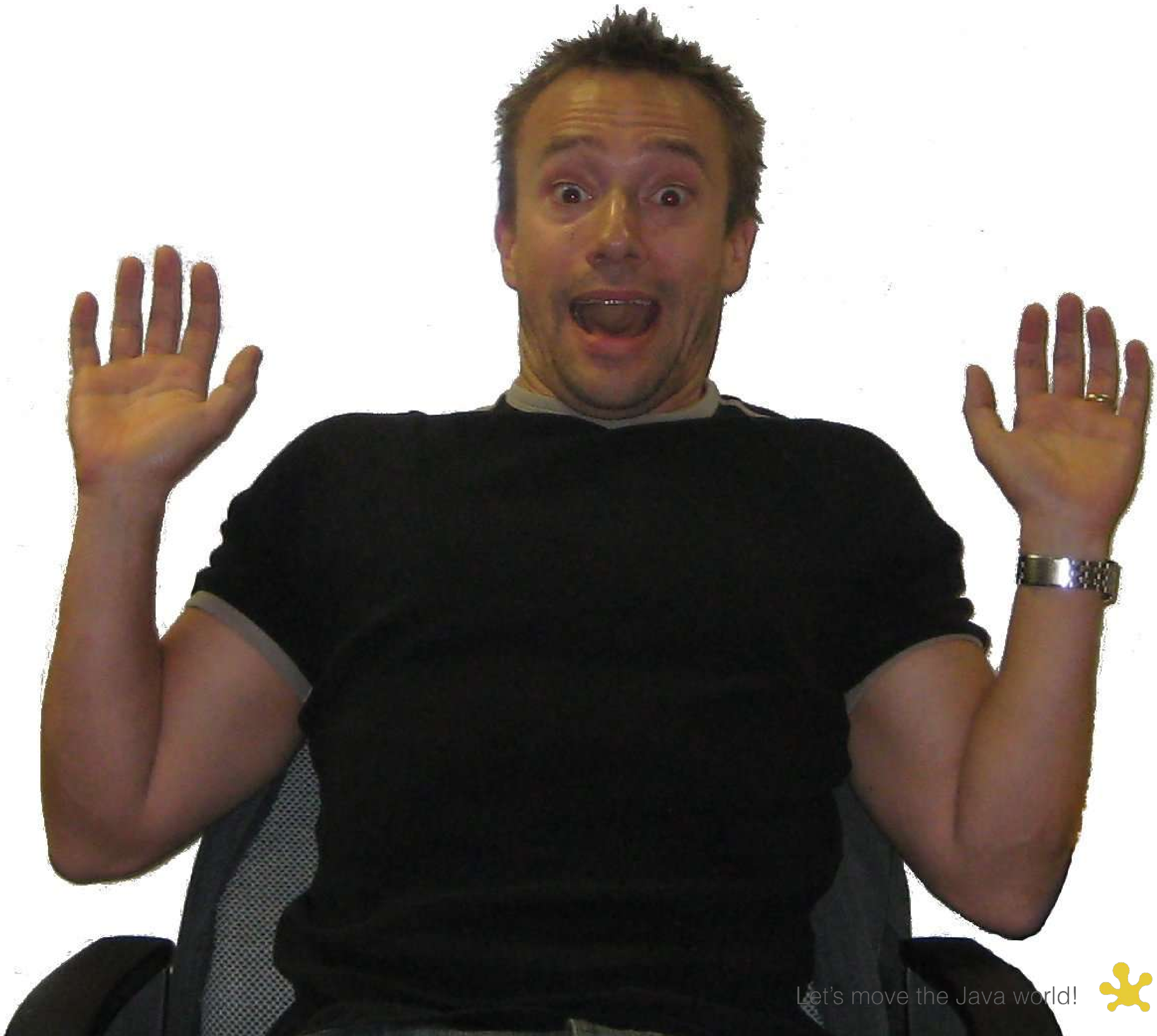
Holly Cummins
IBM Hursley Labs

Java performance - not so scary after all

So …

You have a performance problem.

What next?



Goals

After this talk you will:

- Not feel abject terror when confronted with a performance problem
- Understand when and why to use performance tools
- Have a toolkit of performance tools and techniques
- Get to know your Java application better

Speaker’s qualifications

Holly is a software developer at IBM's UK lab

- Technical lead for the Health Center
- Developed the Garbage Collection and Memory Visualizer

Holly speaks regularly on performance and garbage collection

Holly has authored several articles for developerWorks

Agenda

Performance – why it's actually cool and fun

Performance tuning techniques

Tools for identifying bottlenecks

- Memory
- CPU
- I/O
- Synchronization

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- Performance – why it's actually cool and fun
- Performance tuning techniques
- Tools for identifying bottlenecks
  - Memory
  - CPU
  - I/O
  - Synchronization

Who cares about performance?

We all do

- Sluggish web pages
- Annoying programs
- Hangs
- Crashes

Hardware and performance

Moore's law predicts exponential growth in hardware speed

- Software development corollary:
  - How to double application performance? Wait 18 months before releasing it!

Hardware and performance

- Moore's law predicts exponential growth in hardware speed
  - Software development corollary:
    - How to double application performance? Wait 18 months before releasing it!
- Clock speeds aren't going up at the same rates anymore
  - Software development corollary:
    - Uh oh.

Bad performance *costs*

"Poor application performance costs 1 in 3 enterprises over £1 million per year"

» (http://www.morse.com/press_9.htm)

Bad performance is costing *you* …

- Electricity
- Employee productivity
- Lost business
  - Example: unresponsive web pages
- Hard cash
  - Example: Arbitrage trading
    - Delays in reacting to fluctuating prices can cost millions

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- I/O
- Synchronization

Fixing performance problems

Where to start?

Let's move the Java world!


larman guthrie
Java 2 performance and idiom guide
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JAVA Performance Tuning
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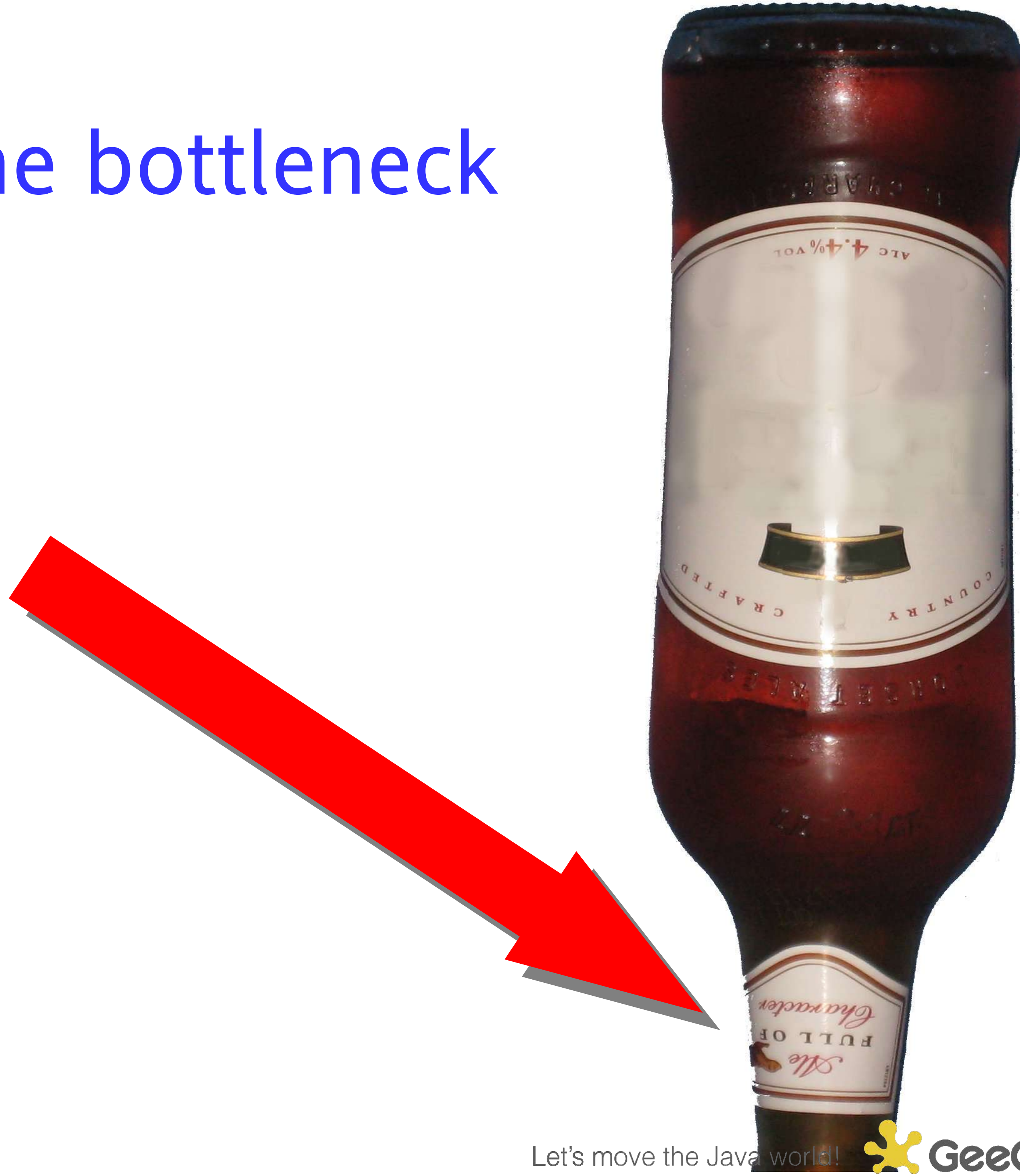
A general methodology

Performance problems are caused by limited resources

Which resource is limited?

Finding the bottleneck

Finding the bottleneck



Resources to consider

Applications may be

- CPU bound
- I/O bound
- Space bound
- “Lock bound” (contended)

Which resource is limited?

CPU bound:

- CPU utilisation consistently high

I/O bound

- CPU utilisation not consistently high

Lock bound

- CPU utilisation not consistently high

Space bound

- Any of the above!

These heuristics aren't precise enough

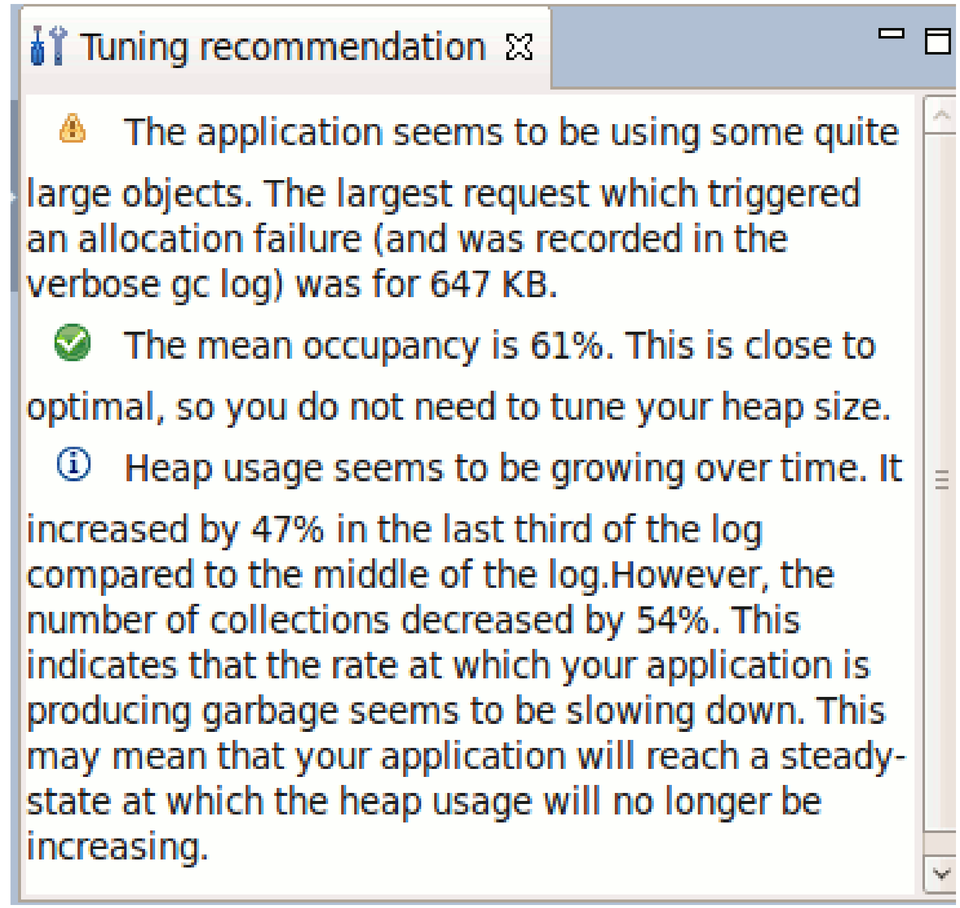
What is the JVM doing?

Tools can help

Even better … tools with recommendations

Recommendations provide

- Visual indicator of status
- Explanation of problems and solutions
- Suggested command line



A word of caution

- Performance must be measured before problems can be fixed
  - Otherwise you risk making things worse with a clever fix
- Performance measurement must be based on your application and your quality of service requirements
- Measurements must be made in a system as similar as possible to the production one

How well is your application performing?

The simplest way to measure performance is System.currentTimeMillis() in a test harness

Performance can be very variable, so measurements must be repeated

Allow unmeasured warm-up period

- (If that's how the application will run)
- Allows caches to be populated and methods to be compiled

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Tools for identifying bottlenecks

- Memory
- CPU
- I/O
- Synchronization

IBM Performance Tools

IBM provides a number of tools to identify and fix performance bottlenecks

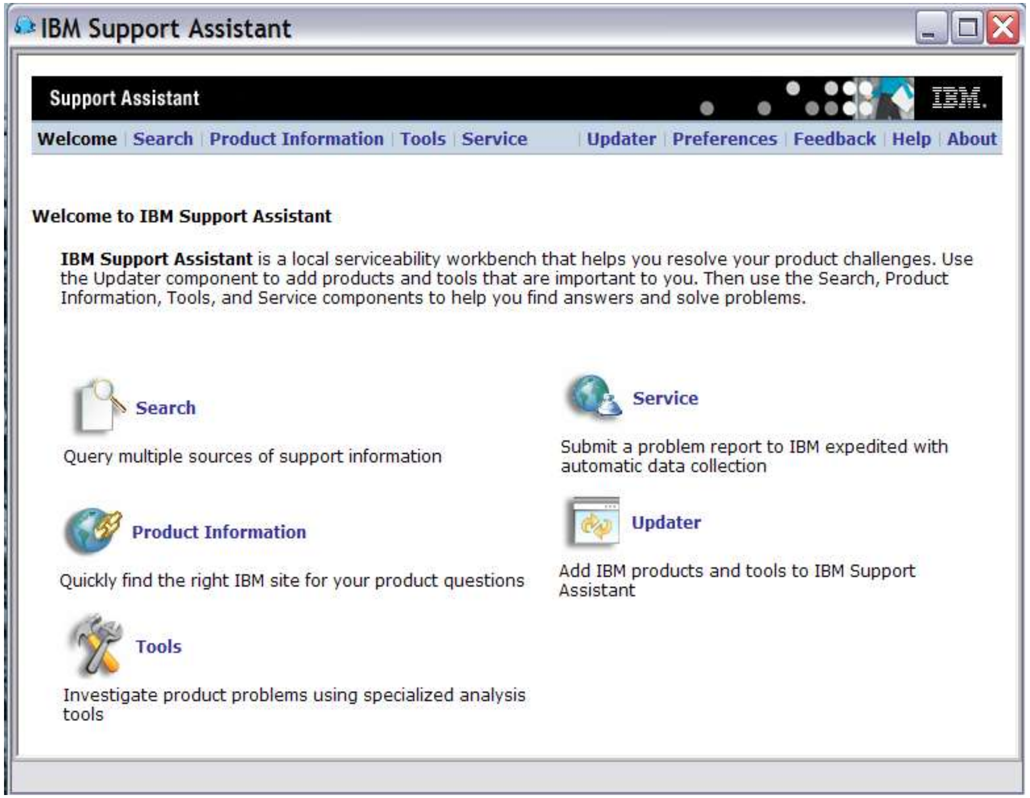
The tools are all free

Most – but not all – are for IBM JVMs only

Tools available from IBM Support Assistant

IBM Support Assistant (ISA)

- Hosting for Serviceability Tools across product families
- Automatic problem determination data gathering
- Assist with opening PMR’s and working with IBM Support
- Documentation:
  - Aggregated search across sources
  - Regular updates to Diagnostics Guide



http://www.ibm.com/software/support/isa

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Space-bound applications

Memory is a crucial resource

Excessive memory usage can cause:

- Poor throughput
- Unresponsive applications
- Unpredictable program behavior
- Crashes in the application

Diagnosing space-bound applications

Space bound can be disguised as CPU bound

- Java has garbage collection
- If the GC is running excessively it will hog the CPU

Space-bound can also be disguised as I/O bound

- Excessive “in use” footprint can cause
  - Paging
  - Cache misses

Checking memory usage in Java

Two approaches

- Verbose GC
  - On IBM platforms, use -Xverbose:gc or -Xverbosegclog:$file to write directly to a file
  - Logs may be analyzed with a verbose gc analysis tool
- Live memory monitoring
  - Requires specialized tools

IBM Monitoring and Diagnostic tools for Java – GC and Memory Visualizer

Handles verbose GC from all versions of IBM JVMs

- 1.4.2 through 1.6.0
- zSeries
- iSeries
- WebSphere real time

… and Solaris platforms

… and HP-UX platforms

GC and Memory Visualizer capabilities

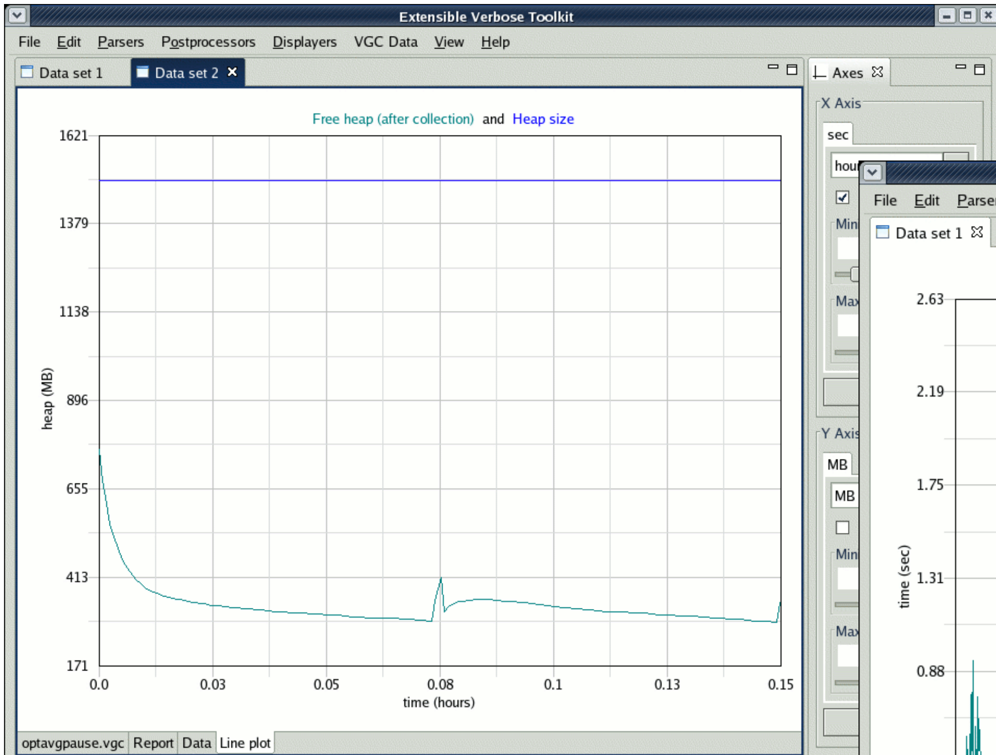
Analyses

- heap usage
- heap size
- pause times
- many other properties

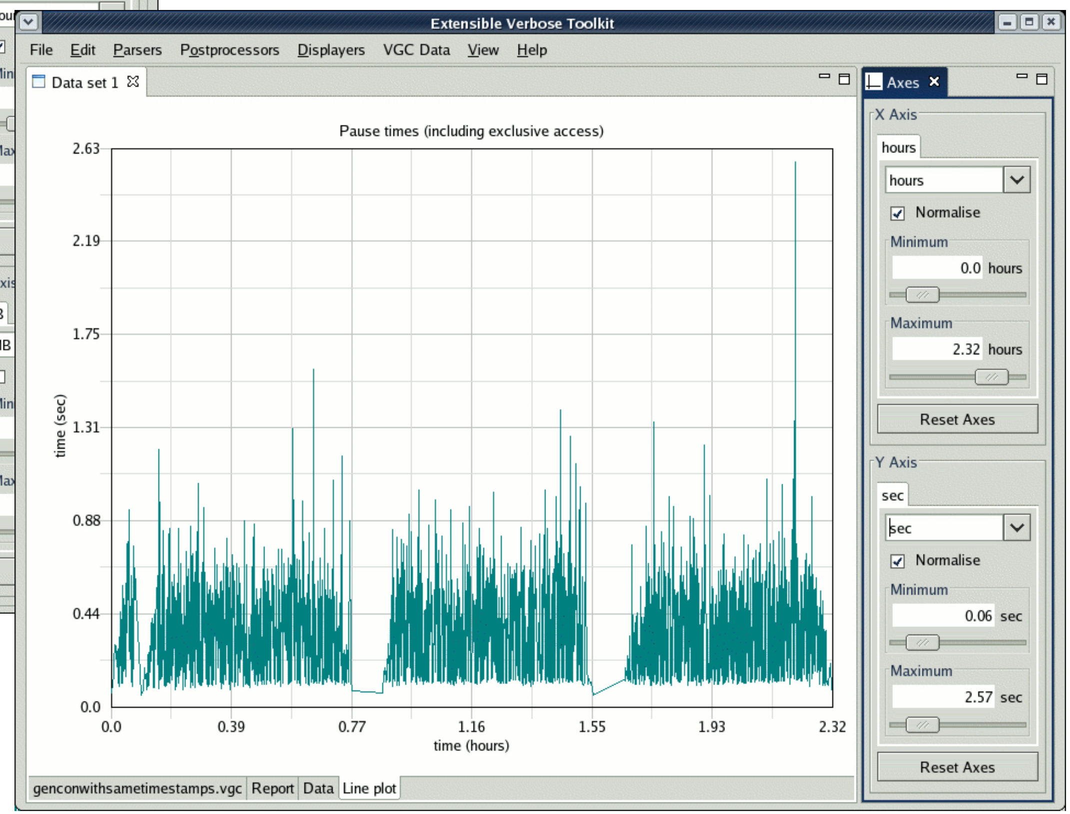
Provides tuning recommendations

Compares multiple logs in the same reports

The GC and Memory Visualizer
Heap Visualization



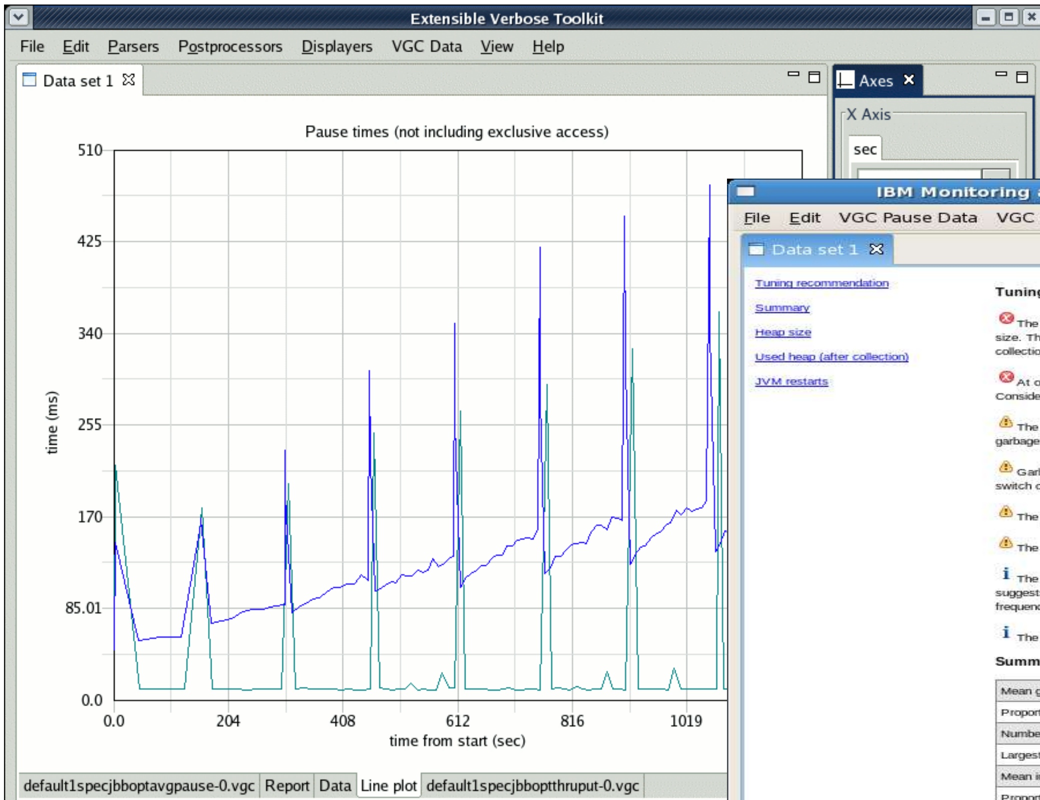
Heap occupancy

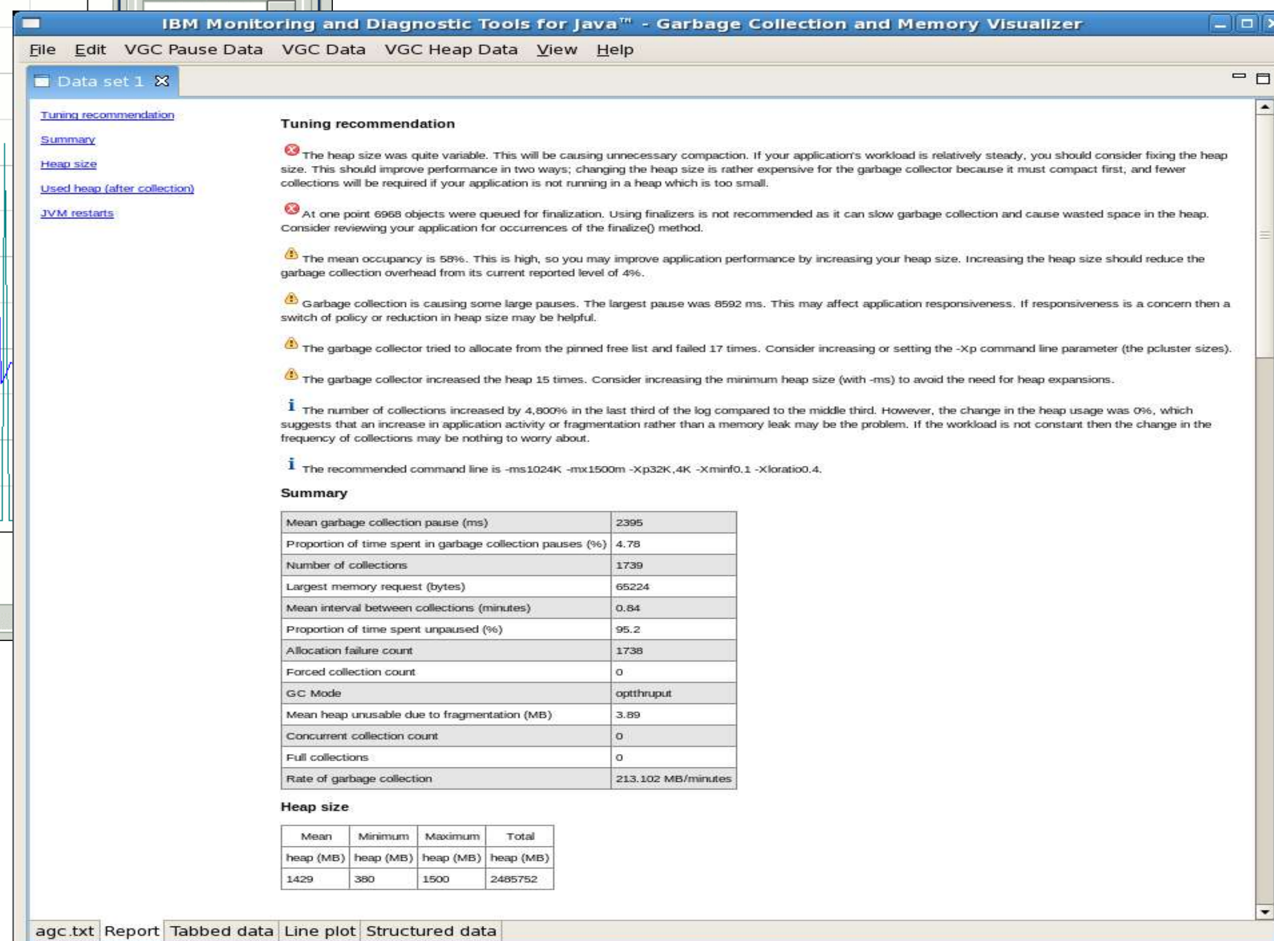


Pause times

The GC and Memory Visualizer - Comparison & Advice

Performance advisor…





Compare runs…

What does GC tell you?

High heap occupancy indicates an application is likely space bound

- Increase heap size or lower application footprint

If GC is using more than 10% or 20% of the CPU action may be required

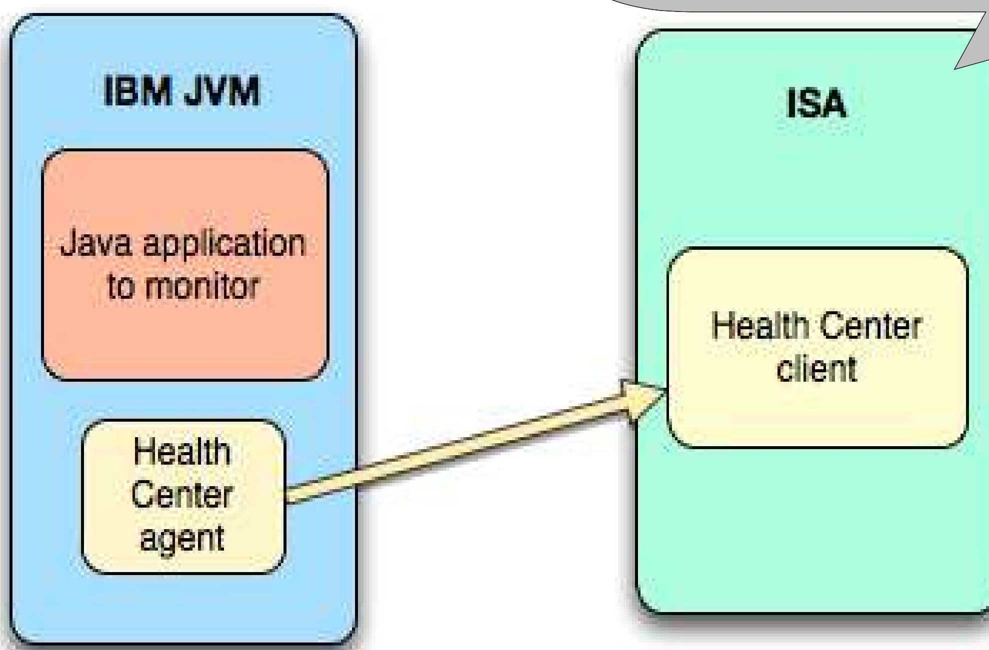
- Alternate choice of policy
- GC tuning

IBM Monitoring and Diagnostic Tools for Java - Health Center

- Live monitoring tool with very low overhead for IBM® Java™ 5.0 and 6.0
  - 2.6% overhead against WebSphere benchmark (full set of data being collected)
- Gives insight into how your application is behaving
- Delivers set-up and tuning recommendations to help avoid application problems

How the Health Center works

Client (installed in the IBM Support Assistant) makes a network connection to the agent



Agent must be installed into your JVM and enabled with a command-line option

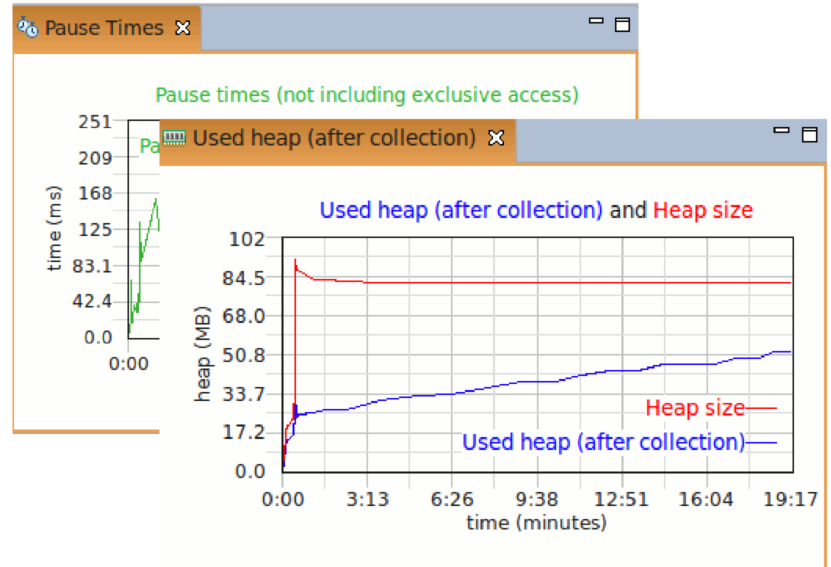
Health Center GC monitoring

- Visualises heap usage and garbage collection pause times over time.
- Identifies memory leaks
- Suggests command-lines and tuning parameters
- Same recommendation logic as GCMV

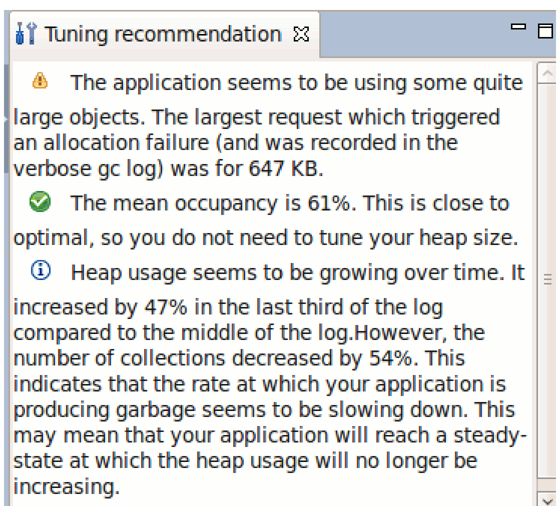
DEMO

Using the Health Center to check memory usage

Garbage Collection



Visualize garbage collection (GC) to spot trends and catch problems before they occur



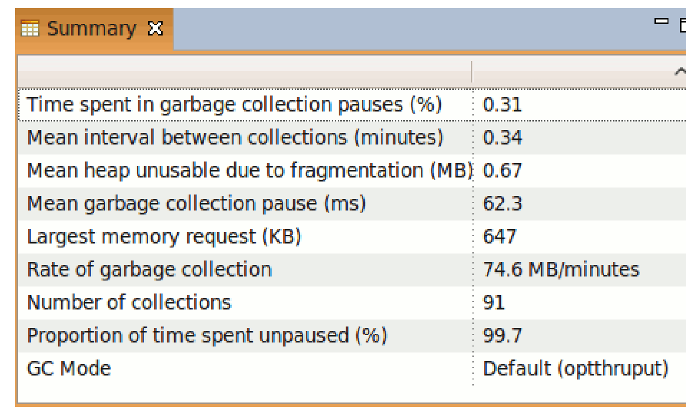
Tuning recommendation

The application seems to be using some quite large objects. The largest request which triggered an allocation failure (and was recorded in the verbose gc log) was for 647 KB.

The mean occupancy is 61%. This is close to optimal, so you do not need to tune your heap size.

Heap usage seems to be growing over time. It increased by 47% in the last third of the log compared to the middle of the log.However, the number of collections decreased by 54%. This indicates that the rate at which your application is producing garbage seems to be slowing down. This may mean that your application will reach a steady-state at which the heap usage will no longer be increasing.

Get recommendations about GC policies and heap sizes



Summary

Time spent in garbage collection pauses (%)	0.31
Mean interval between collections (minutes)	0.34
Mean heap unusable due to fragmentation (MB)	0.67
Mean garbage collection pause (ms)	62.3
Largest memory request (KB)	647
Rate of garbage collection	74.6 MB/minutes
Number of collections	91
Proportion of time spent unpaused (%)	99.7
GC Mode	Default (optthruput)

Check GC rate and time statistics

Check GC performance

What's the problem? Application throughput, or responsiveness?

Low mean pause time – GC probably not the cause of any unresponsiveness

Summary

Mean garbage collection pause (ms)	10.7
Largest memory request (KB)	128
Rate of garbage collection	15646 MB/minutes
Number of collections	3866
Mean interval between collections (minutes)	0.00045
Mean heap unusable due to fragmentation (MB)	1.37
Time spent in garbage collection pauses (%)	40.1
Proportion of time spent unpaused (%)	59.9
GC Mode	Default (optthruput)

High percentage of time spent paused – 40%...

...but also a high rate of garbage collection. Do I expect to be generating this much garbage?

Assessing Footprint

Is the footprint too big?

Assessing Footprint

Is the footprint too big?

Is the footprint growing?

- Bad bad news

Assessing Footprint

Is the footprint too big?

Is the footprint growing?

- Bad bad news

If left unchecked, a memory leak will eventually cause a crash

Memory leaks in Java?

Memory leaks happen when objects which are no longer required still use up memory

Two kinds of memory leak:

- Losing a reference to an object which is no longer in use
- Holding on to a reference for an object which is no longer in use

Garbage collection eliminates the first kind, but not the second

Diagnosing footprint issues

You need to know what objects are on the heap

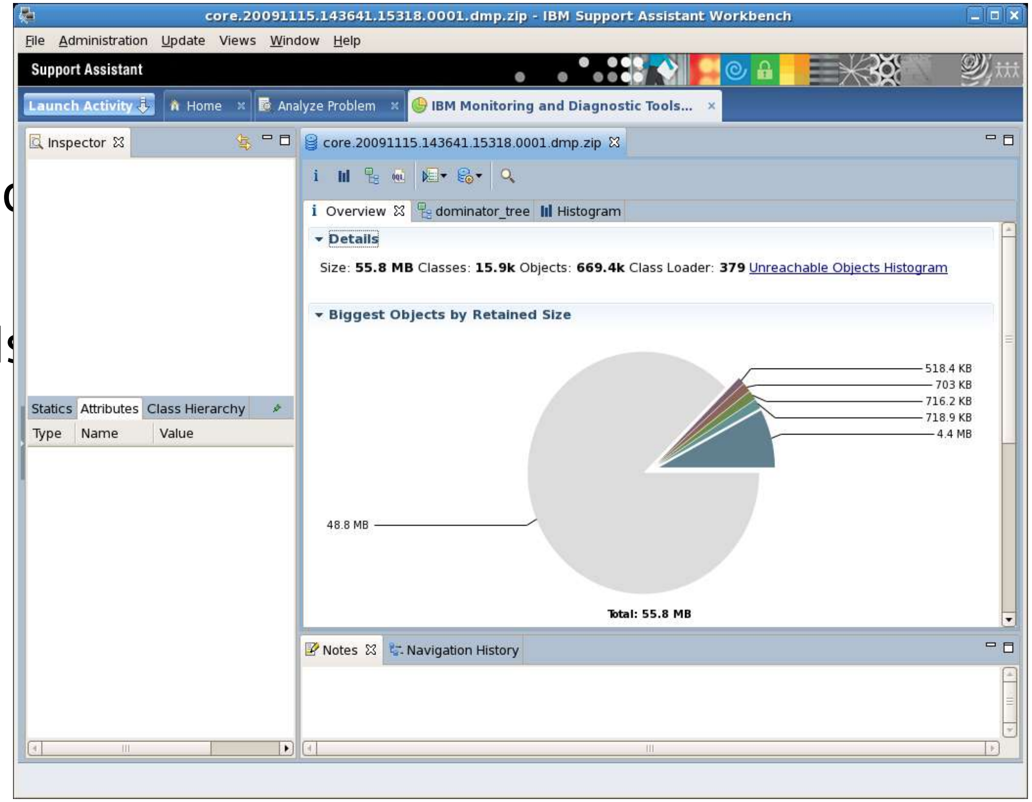
Heap dumps are a record of every object on the heap

- Automatically produced on OutOfMemoryErrors
- Can be triggered programatically

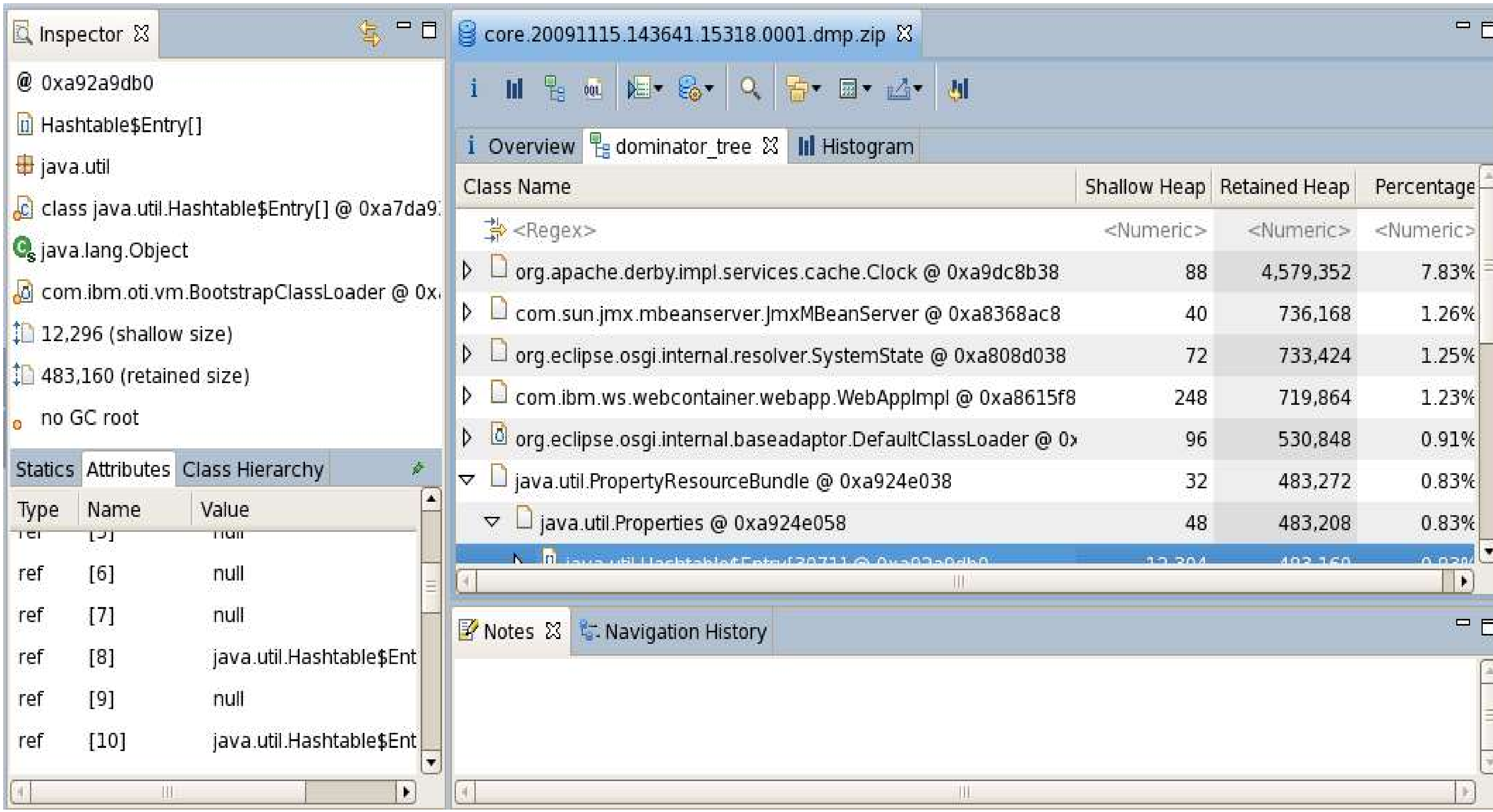
Extremely useful for problem solving, but tooling support is essential

Memory Analyzer

- Open source heap dump analysis tool
- Wide platform coverage
  - HPROF dumps from HotSpot based JVMs
  - DTFJ system dumps from IBM JVMs
  - Portable Heap Dumps (PHD) file from IBM JVMs
- Available from
  - www.eclipse.org
  - IBM Support Assistant



Detailed view of heap contents



DEMO

Using the Memory Analyzer to identify memory consumers

Optimizing footprint

Inspect the set of retained objects

- Use dominator tree
- Use histogram

Search for inefficiently used data structures

Look for redundant data

- Use "Group by Value"

Don't forget native memory

Java applications use – and may leak - native memory

Low occupancy is no guarantee an application is not space bound.

Native memory use is not logged in verbose GC

OutOfMemory errors may occur even though there is lots of room in the heap

Tracking native memory usage

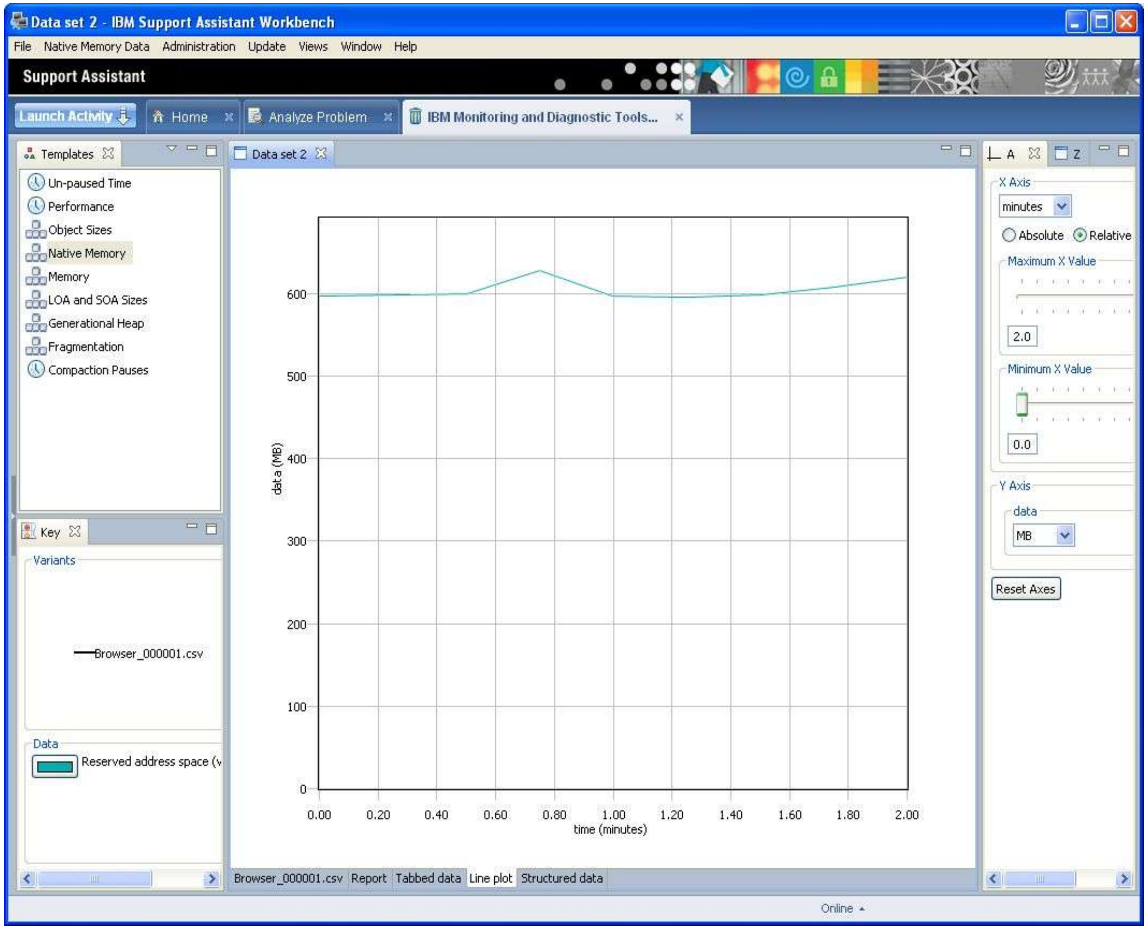
Use platform-specific tools

- Windows perfmon tool
- Linux ps
- AIX vmstat

GCMV and native memory

GCMV can visualize native memory

Provides recommendations



Identifying native memory contents

- What is in the non-heap memory?
  - Internal JVM data
  - Interned Strings (for some JVMs)
  - Classes (for some JVMs)
  - NIO direct byte buffers
  - Thread data
- Difficult to analyze native memory directly
  - But … some of these have wrapper objects in the Java heap

Using Memory Analyzer

Heap dump analysis can be used to identify some native memory issues

- Are there a lot of Thread objects?
- Are there a lot of NIO direct byte buffers?

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CPU bound applications

Code is being invoked more than it needs to be

- Easily done with event-driven models

An algorithm is not the most efficient

- Easily done without algorithms research!

Diagnosing CPU bound applications

Fixing CPU bound applications requires knowledge of what code is being run

- Identify methods which are suitable for optimisation
  - Optimising methods which the application doesn't spend time in is a waste of your time
- Identify methods where more time is being spent than you expect
  - “Why is so much of my profile in calls to this trivial little method?”

Method trace and profiling

There are two ways to work out what code your application is doing

- Trace
- Sampling profiling

Method trace

Tracing

- Does not require specialist tools (but is better with them)
- Records every invocation of a subset of methods
- Gives insight into sequence of events
- In the simplest case, System.out.println
- Usually focussed on targeted packages or methods

Method profiling

Profiling

- Requires specialist tools
- Samples all methods and provides statistics
- Can give a broad picture of application activity

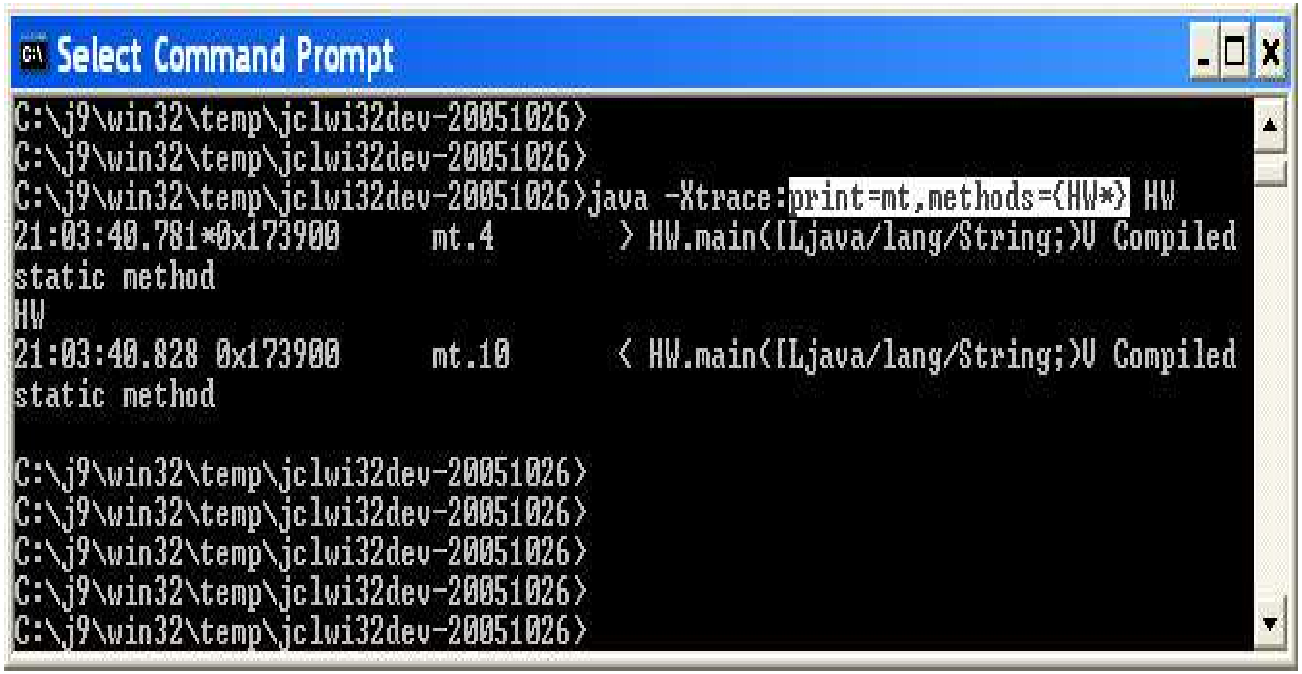
IBM Java method trace

Entry and exit trace for any Java methods

Instrumentation-free, and no extra code required

No fancy GUI, but very very powerful

Not overhead-free, but lower overhead than equivalent function implemented in Java



Controlling what is traced

Can select on package, class or method name:

- Package: methods={java/lang/*}
- Class: methods={java/lang/String.*}
- Method: methods={HelloWorld.main}

Also ! operator and combination allowed:

- methods={java/lang/*,!java/lang/String*}

Possible to create huge volume of output, so use sensible method specifications!

Triggering events

Can request certain actions occur when chosen methods are entered or exited

Actions such as coredump, javadump, etc.

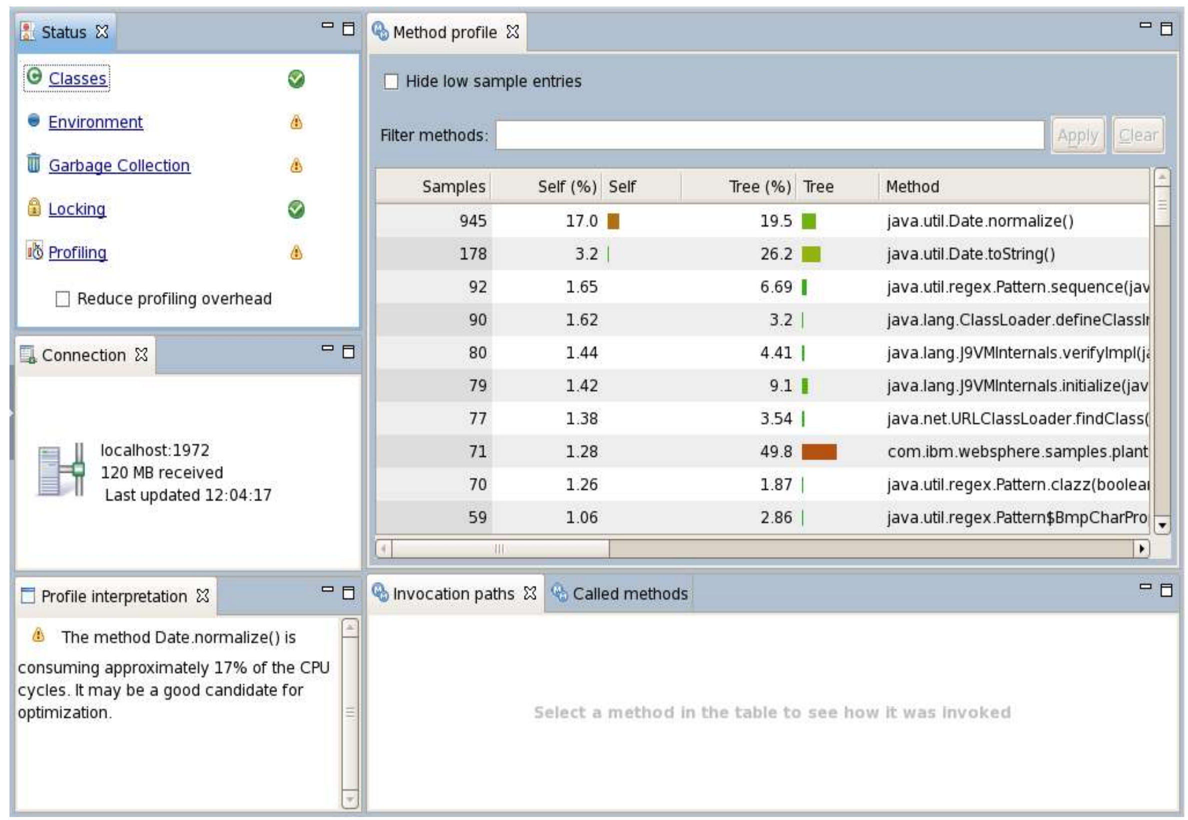
Actions such as enabling more method trace!

Can cause action to occur on n'th instance of trigger condition

Can specify how many times the action occurs

Method profiling with Health Center

- Always-on profiling offers insight into application activity
- Identifies the hottest methods in an application
- Full call stacks to identify where methods are being called from and what methods they call
- No bytecode instrumentation, no recompiling



DEMO

Using the Health Center
to optimise a code path

Profiling

Self: time spent in this method

Tree: time spent in this method and methods it called

Samples	Self (%)	Self	Tree (%)	Tree	Method
638	46.8		52.5		testApplicationSink.put(I)
439	32.2		35.4		testApplicationSink.get()
106	7.77		7.77		testApplicationSink.createLargeObje
27	1.98		1.98		java.lang.Thread.sleep(JI)
23	1.69		1.69		java.lang.String.lastIndexOf(II)

Low-overhead sampling profiler shows which Java code is hottest

Dig deeper into the data to see why a method is being caled

Invocation paths | Called methods

Methods that call testApplicationSink.put()

- testApplicationSink.put
  - testApplicationFill.run (99.6%)
  - testApplicationSink.put (0.41%)

Invocation paths | Called methods

Methods called by testApplicationSink.put()

- testApplicationSink.put
  - testApplicationSink.createLargeObjects (9.46%)
  - Thread.sleep (1.39%)
    - Thread.sleep (100%)
  - testApplicationSink.put (0.42%)

See which code branches are run most often

Identify a problem method

Do any methods stand out as particularly hot?

Samples	Self (%)	Self	Tree (%)	Tree	Method
633	21.2		60.6		java.util.regex.Pattern.compile()
290	9.73		13.2		java.io.BufferedReader.readLine(Z)
233	7.82		16.8		java.util.regex.Pattern.atom()
231	7.75		7.75		java.util.regex.Pattern.newSlice([IIZ)
223	7.49		28.1		java.util.regex.Pattern.sequence(Ljava.util.r
218	7.32		8.76		java.util.regex.Pattern$Node.study(Ljava.uti
124	4.16		5.54		java.util.regex.Matcher.<init>(Ljava.util.reg
115	3.86		5.14		java.util.regex.Pattern$Curly.match0(Ljava.u

Do I expect my application to be primarily doing regex pattern compilation?

Need to either make Pattern.compile() more efficient or call it less

Methods that call java.util.regex.Pattern.compile()

- Pattern.compile
  - Pattern.<init> (50.2%)
    - FollowerCount.findScreenName (55.0%)
    - Pattern.compile (45.0%)
  - Pattern.compile (49.8%)
    - FollowerCount.findScreenName (100%)
      - FollowerCount.getFollowers (100%)

Which methods are calling Pattern.compile? Could I optimize to call Pattern.compile less?

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Diagnosing I/O-bound applications

A number of tools may be required to isolate the causes of I/O delays

Use the GC and Memory Visualizer to check sweep times

- Sweep times should be very short
- Long sweep times indicate access to memory is slow (paging)

Use method trace to trace calls to network and disk I/O

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Concurrency and performance

- Hardware speed is being achieved by scaling out instead of up
- Getting performance gains from multicore systems is *hard*
- Concurrency is next great challenge in software engineering
  - Designing for concurrency is hard
  - Threads need to synchronize with each other to have a chance of application correctness

Concurrency and performance (ii)

Synchronization has a performance cost

- Effectively makes execution single-core

This cost goes up with the number of cores

- Synchronization needs to be a lot smarter on huge systems
- At some point synchronization becomes the main performance bottleneck

Even on two-core systems, locking can be a big performance cost

Diagnosing lock bound applications

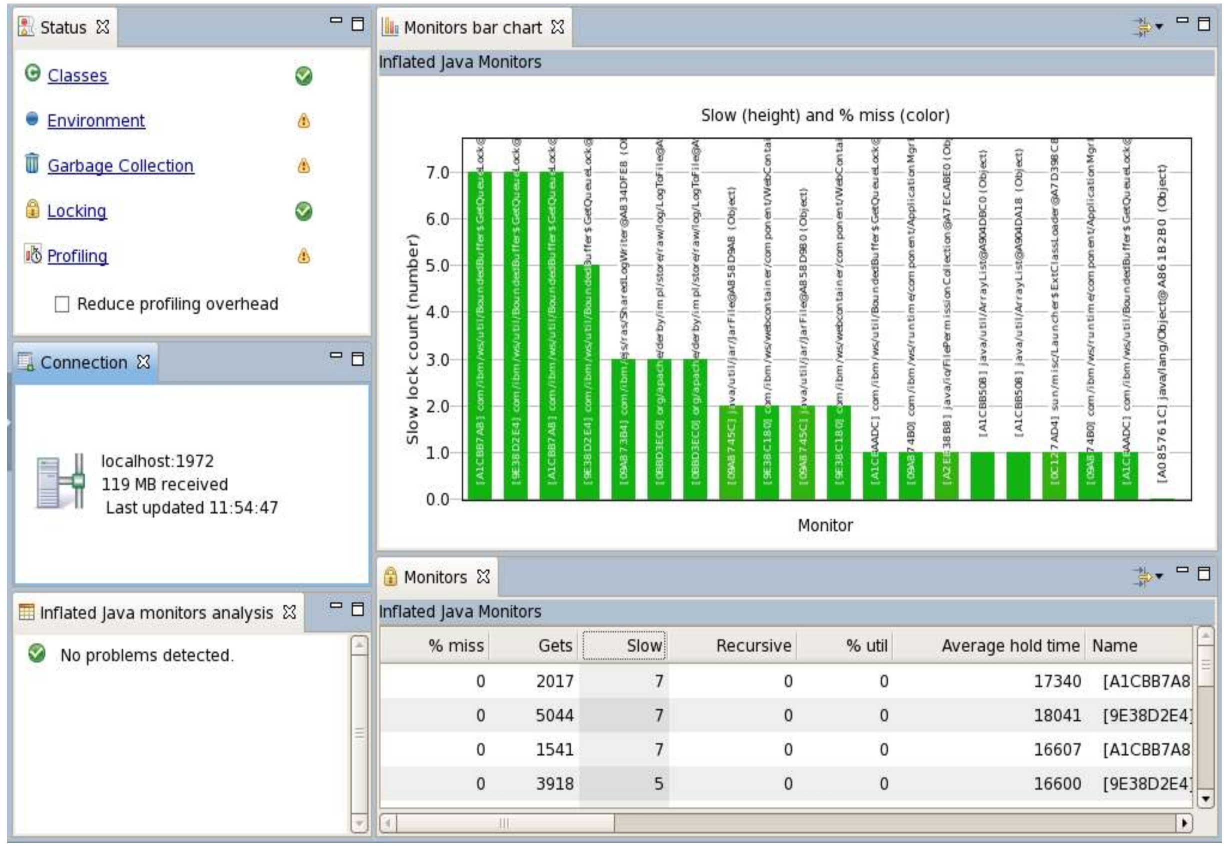
Poor synchronization can cause significant application delays

IBM provides tooling to quickly diagnose and identify contended locks

- Health Center provides information on locks used in Java applications and the JVM

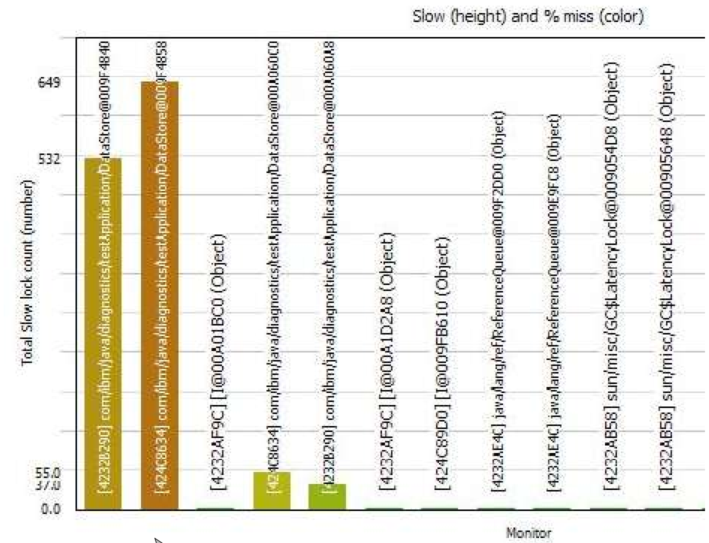
Lock analysis

- Always-on lock monitoring
- Quickly allows the usage of all of locks to be profiled
- Identifies locks which might be preventing the application from scaling



Identify lock contention

Orange or red colour indicates most of the attempts to synchronize were blocked



High average hold time indicates we're holding the lock a long time – doing too much work in it?

Tall bar indicates a large number of requests were blocked

Inflated Java Monitors

% miss	Gets	Slow	Recursive	% util	Average hold time	Name
58	918	532	0	40	122769063	[4232B290] com/ibm/java/diagnostics/testApplication/DataStore@009F4840 (Object)
73	894	649	0	46	143574982	[424C8634] com/ibm/java/diagnostics/testApplication/DataStore@009F4858 (Object)
0	364	0	0	0	423770	[4232AF9C] [I@00A01BC0 (Object)
46	119	55	0	15	27489641	[424C8634] com/ibm/java/diagnostics/testApplication/DataStore@00A060C0 (Object)
39	95	37	0	6	14664944	[4232B290] com/ibm/java/diagnostics/testApplication/DataStore@00A060A8 (Object)
0	42	0	0	0	53090	[4232AF9C] [I@00A1D2A8 (Object)

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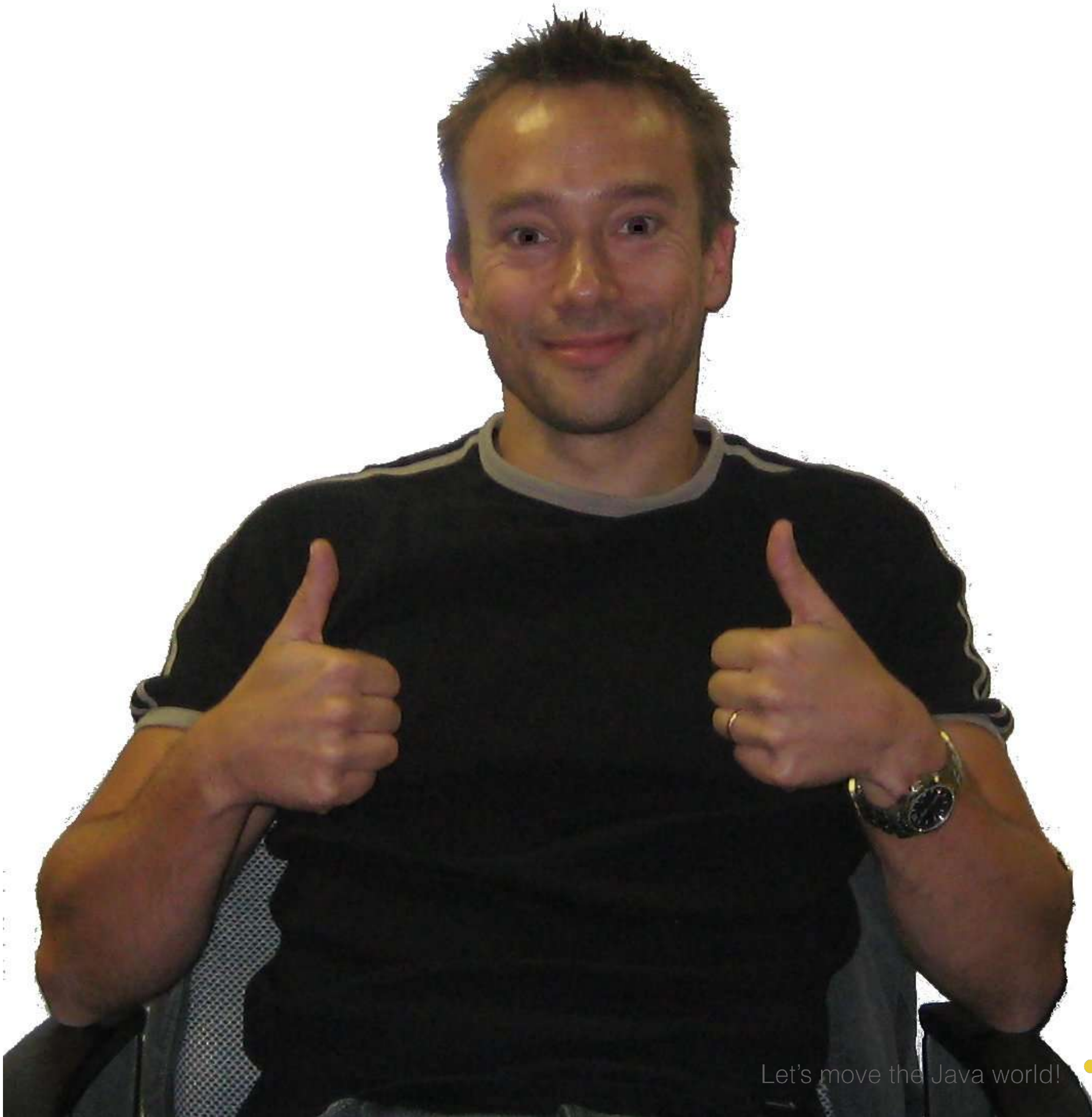
So …

You have a performance problem …

You diagnose and fix it.



Conclusions

Improving application performance starts with identifying limited resources

Tools can help fix performance bottlenecks

- Space bound
  - GC and Memory Visualizer/Health Center
  - Memory Analyzer
- CPU bound
  - Health Center
- Lock bound
  - Health Center

Where to find more information

- IBM Support Assistant
  - http://www-01.ibm.com/software/support/isa/
- IBM Monitoring and Diagnostic Tools for Java
  - www.ibm.com/developerworks/java/jdk/tools/
- Health Center YouTube videos
  - http://www.youtube.com/watch?v=5Tcktcl0qxs (overview)
  - http://www.youtube.com/watch?v=6WjE9U0jvEk (client install)
  - http://www.youtube.com/watch?v=Hdp0mJ13NLQ (agent install)

Health Center Forum

- http://www.ibm.com/developerworks/forums/forum.jspa?forumID=1461

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