Java Performance Tools

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Outline

- Introduction
- Identifying performance problems
- Fixing performance problems
  - Performance tools for …
    - Space bound applications
      - IBM Monitoring and Diagnostic Tools for Java™ – GC and Memory Visualizer
      - IBM MDD4J
    - CPU bound applications
      - Method trace
    - I/O bound applications
    - Lock bound applications
      - IBM Lock Analyzer for Java

When would you use a performance tool?

- When you have a performance problem!

What's a performance problem?

- It doesn't go as fast as you think it ought to
- It doesn't go as fast as your users demand
- It starts out fine and then after some period doesn't go as fast as it used to
- It hangs
  - This is a quite severe example of a performance problem

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Assessing performance problems

- Performance must be measured before problems can be fixed
  - Otherwise you risk making things worse with a clever fix
- We don't provide a tool for this!
  - A performance tool cannot do your performance measurement for you
- Performance measurement must be based on your application and your quality of service requirements
  - Throughput
  - Response times
    - Mean response time
    - 90th percentile response time
    - Worst-case response time

The perils of benchmarks

- Sometimes measuring the performance of your own application is difficult
- Measuring the performance of a benchmark is not good enough
  - If it's your application you care about, measure your application

The perils of simulated workloads

- Generating a “real” workload can be hard in a test environment
- Tuning a system against a simulated workload can be misleading
  - Example: garbage collection can be very sensitive to the exact distribution of object sizes and the pattern of connections between objects
  - Example: Insufficient variation in data can lead to artificially warm caches and disguise I/O bottlenecks
- Care must be taken to ensure simulated workloads are sufficiently realistic

The perils of inference

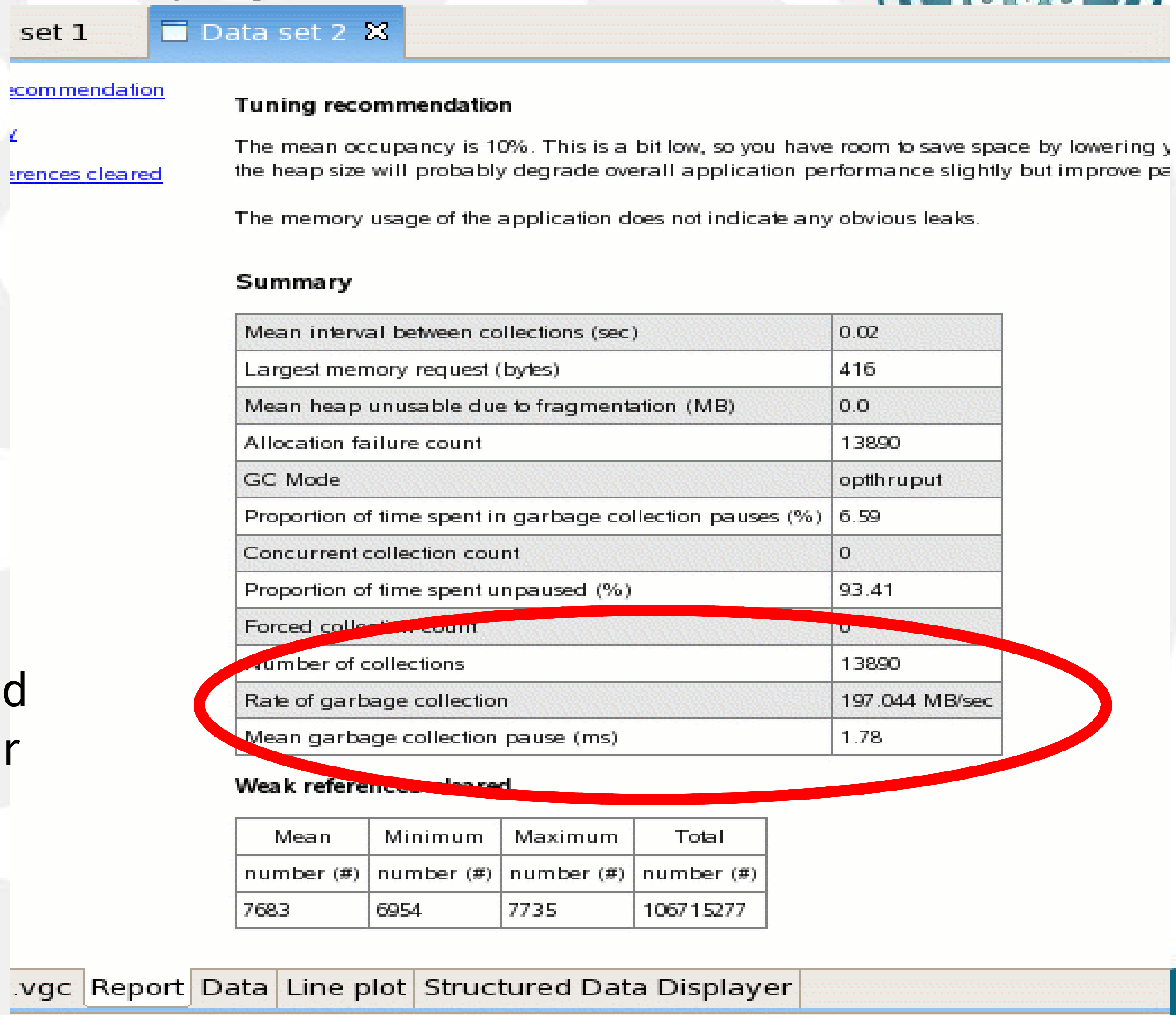
- The performance metrics from performance tools cannot tell you how well your application is performing
  - Pause times cannot tell you what your application response times are
  - Time in GC cannot tell you how fast your application is running
    - Generational garbage collectors often use more of the CPU but give better throughput, and shorter maximum response times
  - A profiler may show more time is being spent in a method, but that may be because a change prompted the JIT to inline other methods, so total time may be reduced

How well is your application performing?

- The simplest and most effective way to measure performance is to invoke System.currentTimeMillis() in a test harness to time properties of interest
- 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

Exception: Use GC to measure throughput

- Rate of garbage collection = rate of garbage generation
- If the code doesn't change, generating garbage faster is good, because garbage is a side effect of work
  - IBM Monitoring and Diagnostic Tools for Java – GC and Memory Visualizer reports the rate of garbage collection



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Fixing performance problems

- Performance problems are caused by limited resources
- Which resource is limited?
- Applications may be
  - CPU bound
  - I/O bound
  - Space bound
  - "Lock bound" (contended)

How to decide which it is?

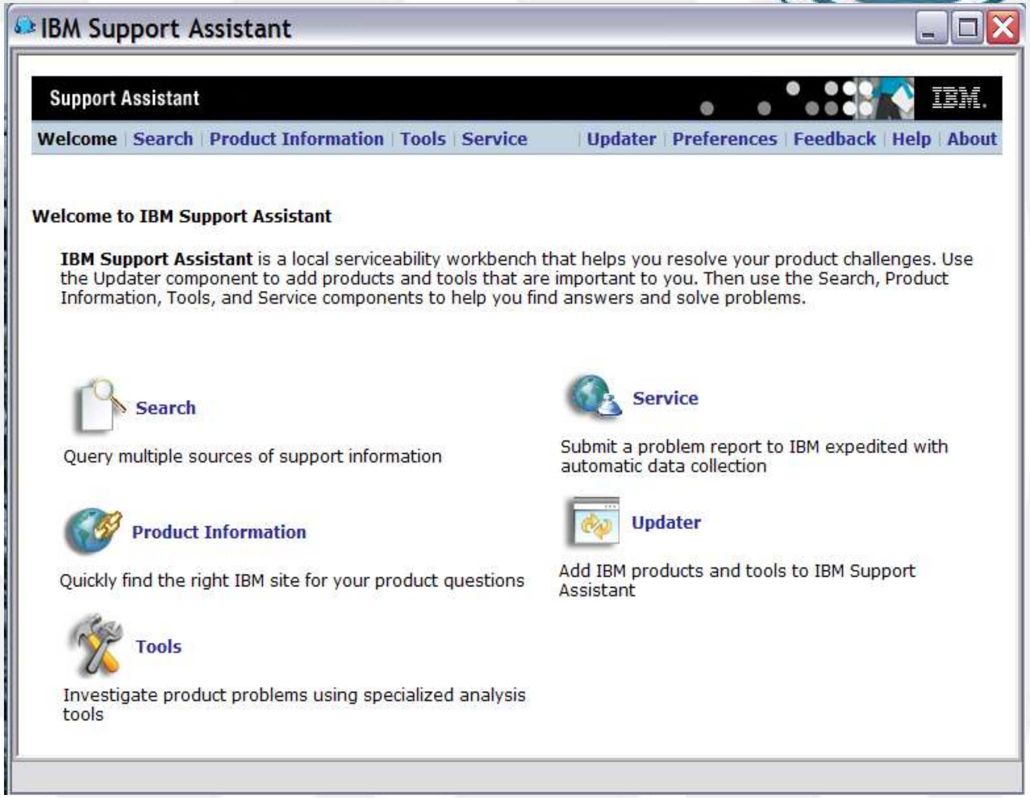
- CPU bound
  - CPU utilisation consistently high
- I/O bound
  - CPU utilisation not consistently high
- Lock bound
  - CPU utilisation not consistently high
- Space bound
  - Any of the above!
- These heuristics aren't precise enough, so tools are required to guide diagnosis

IBM Performance Tools

- IBM provides a number of tools to identify and fix performance bottlenecks
- The tools are all freely available
- Most – but not all – are targeted for IBM JVMs only
- Tools available from
  - alphaWorks (alpha tools)
  - IBM Support Assistant (fully supported tools)

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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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
- Enabling verbose garbage collection can quickly identify or rule out space issues
  - 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

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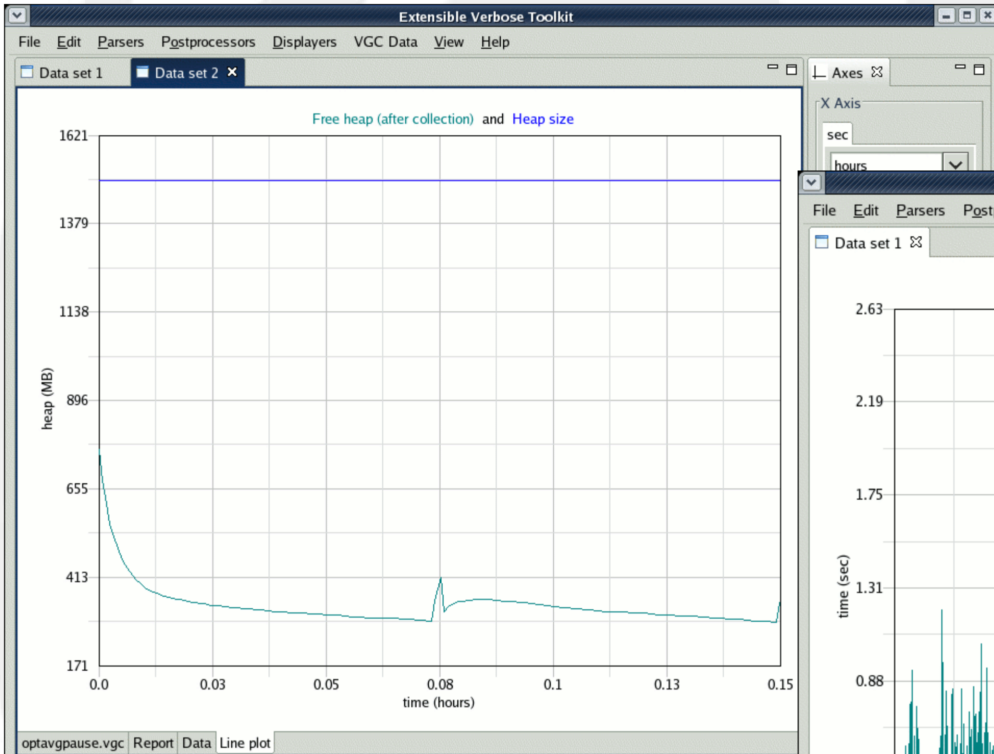
The GC and Memory Visualizer

- IBM Monitoring and Diagnostic Tools for Java – GC and Memory Visualizer (formerly known as EVTK) is a verbose GC analysis tool
- Handles verbose GC from all versions of IBM JVMs
  - 1.4.2 and lower
  - 5.0 and higher
  - zSeries
  - iSeries
  - WebSphere real time
- … and Solaris platforms
- … and HP-UX platforms

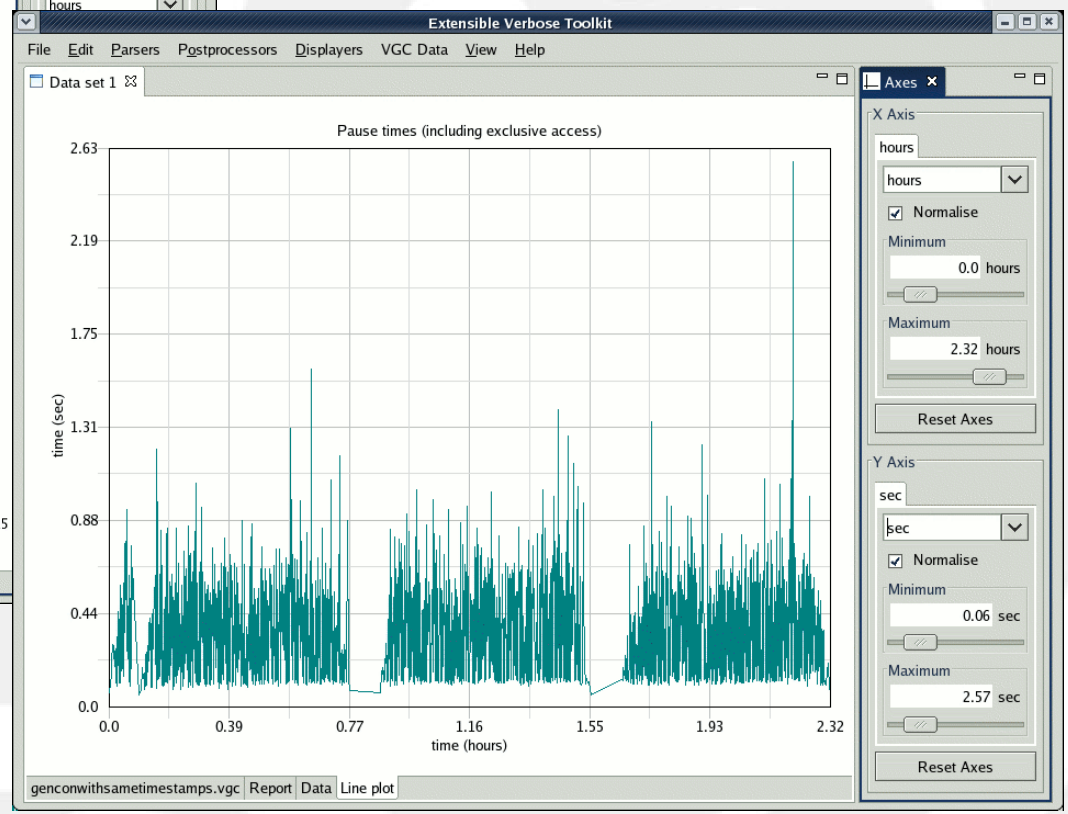
GC and Memory Visualizer capabilities

- Analyses heap usage, heap size, pause times, and many other properties
- Provides tuning recommendations
- Compares multiple logs in the same plots and reports
- Many views on data
  - Reports
  - Graphs
  - Tables
- Can save data to
  - HTML reports
  - JPEG pictures
  - CSV files

The GC and Memory Visualizer
Heap Visualization



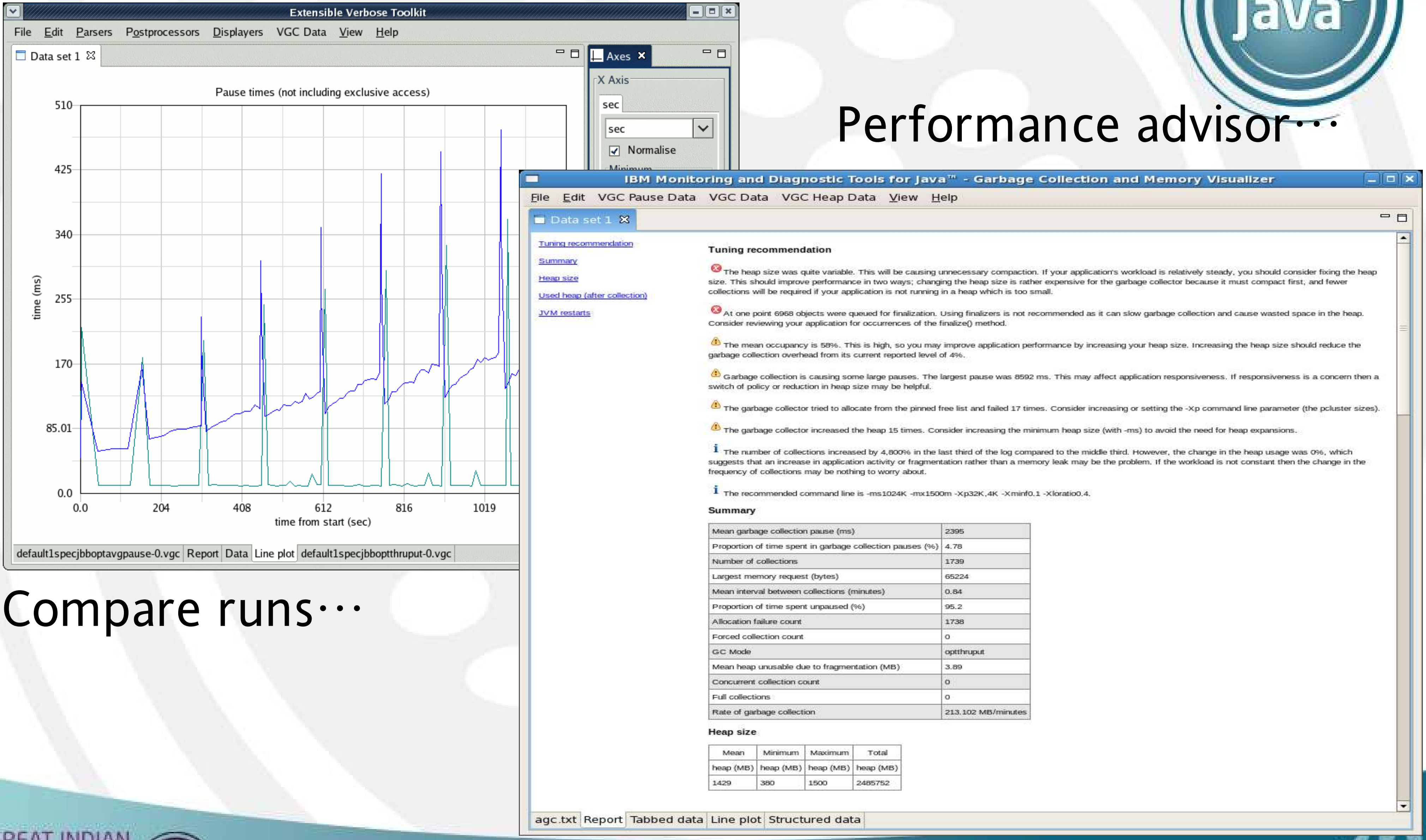
Heap occupancy



Pause times

The GC and Memory Visualizer - Comparison &

Performance advisor…



Compare runs…

What does garbage collection tell you?

- High heap occupancy indicates an application is likely space bound
  - Increasing heap size or lowering application footprint should improve performance

- If GC is using more than 10% or 20% of the CPU action may be required
  - Alternate choice of policy
  - GC tuning

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
- Memory pressure and even OutOfMemory errors may occur even though there is lots of room in the heap
- Use platform-specific tools
  - Windows perfmon tool
  - Linux ps
  - AIX vmstat

When should you size the heap?

- If performance is important
  - Fixing the heap size prevents the JVM shrinking the heap when the memory usage drops and then having to re-grow when it increases again
  - Try -Xmaxf=100 option to allow growth but prevent shrinking
- If the application uses a lot of memory
  - Most JVMs will avoid using all the memory on a box!
  - The IBM JVM has an upper limit of half the physical memory
  - If the application needs more than this intervention is required

Demonstration: Using the GC and Memory Visualizer to size the heap.

- Sample application allocates many objects, keeps some, and regularly throws some away

Allocator.java

```java
package com.ibm.sample;
import java.util.Random;

/**
 * A class which holds objects in a hashmap
 * without ever removing them and
 * therefore leaks memory.
 */
public class Allocator
{
    private static final int K = 1024;
    private Object[] things = new Object[1000];

    public static void main(String[] args) {
        new Allocator().allocate();
    }

    public void allocate() {
        int allocated = 0;
        while (allocated < 100*K*K) {
            final int[] thing = new int[new Random().nextInt(50*K)];
            int index = new Random().nextInt(things.length);
            things[index] = thing;
            allocated += things.length;
        }
    }
```

Try out various heap sizes

- Some will be obviously bad
- Most will seem fine

cumminsh@grizzly:~/projects/garbagecollection/javazone-workspace/allocat

File Edit View Terminal Tabs Help

```
[cumminsh@grizzly allocator]$ heap=100
[cumminsh@grizzly allocator]$ java -Xverbosegclog:allocator${heap}.vgc -Xms${hea
p}m -Xmx${heap}m -cp bin com.ibm.sample.Allocator
JVMDUMP006I Processing Dump Event "uncaught", detail "java/lang/OutOfMemoryError
" - Please Wait.
JVMDUMP007I JVM Requesting Snap Dump using '/home/cumminsh/projects/garbagecolle
ction/javazone-workspace/allocator/Snap0001.20070817.153626.20793.trc'
JVMDUMP010I Snap Dump written to /home/cumminsh/projects/garbagecollection/javaz
one-workspace/allocator/Snap0001.20070817.153626.20793.trc
JVMDUMP007I JVM Requesting Heap Dump using '/home/cumminsh/projects/garbagecolle
ction/javazone-workspace/allocator/heapdump.20070817.153626.20793.phd'
JVMDUMP010I Heap Dump written to /home/cumminsh/projects/garbagecollection/javaz
one-workspace/allocator/heapdump.20070817.153626.20793.phd
JVMDUMP007I JVM Requesting Java Dump using '/home/cumminsh/projects/garbagecolle
ction/javazone-workspace/allocator/javacore.20070817.153626.20793.txt'
JVMDUMP012E Error in Java Dump: /home/cumminsh/projects/garbagecollection/javazo
ne-workspace/allocator/javacore.20070817.153626.20793.txt
JVMDUMP013I Processed Dump Event "uncaught", detail "java/lang/OutOfMemoryError"
.
Exception in thread "main" java.lang.OutOfMemoryError
        at com.ibm.sample.Allocator.allocate(Allocator.java:21)
        at com.ibm.sample.Allocator.main(Allocator.java:15)
[cumminsh@grizzly allocator]$
```

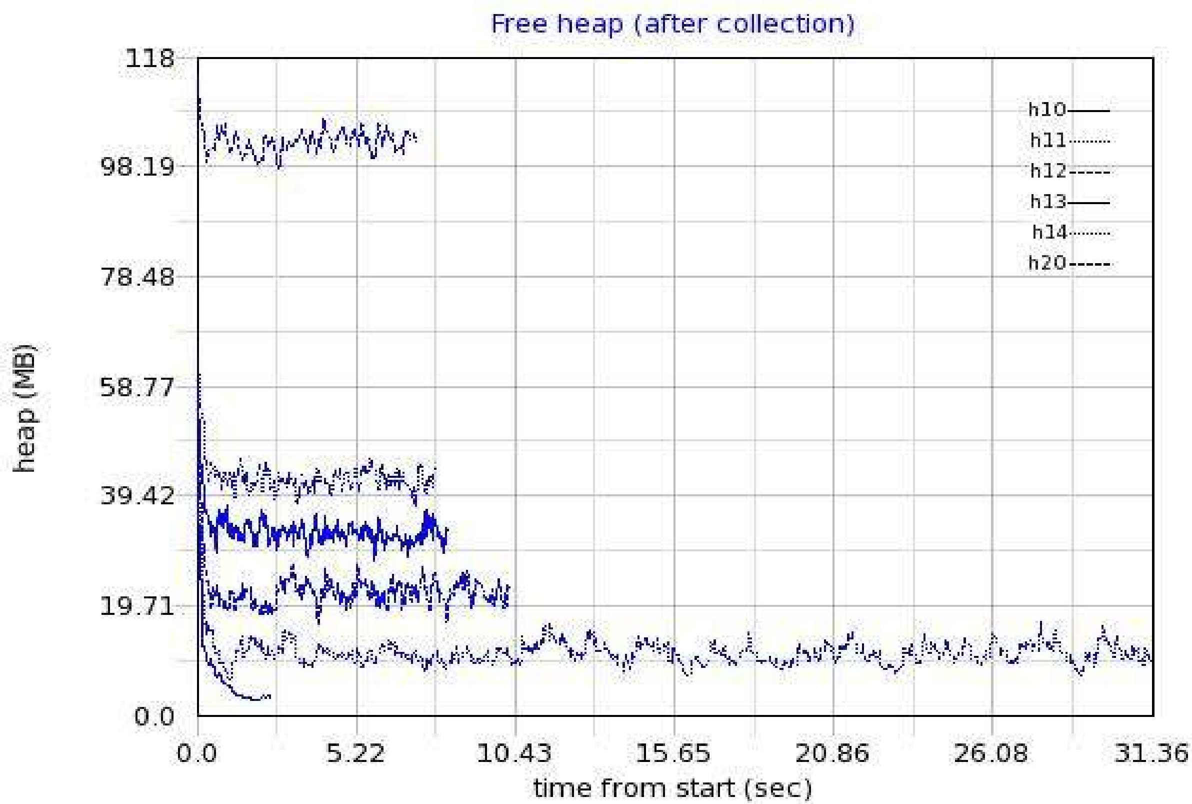
cumminsh@grizzly:~/projects/ga

File Edit View Terminal Tabs Help

```
[cumminsh@grizzly allocator]$ heap=200
[cumminsh@grizzly allocator]$ java -Xverbosegclog:allocator${heap}.vgc -Xms${hea
p}m -Xmx${heap}m -cp bin com.ibm.sample.Allocator
[cumminsh@grizzly allocator]$
```

Use the GC and Memory Visualizer to decide

- Consider summary data and plotted data



Summary

Variant	h10	h1				
Mean interval between collections (sec)	0.04	0.01				
Largest memory request (bytes)	204392	204816				
Mean heap unusable due to fragmentation (MB)	3.36	6.59				
Allocation failure count	64	2126				
GC Mode	optthruput	optthruput	optthruput	optthruput	optthruput	optthruput
Proportion of time spent in garbage collection pauses (%)	91.36	78.0	35.02	19.4	14.62	8.94
Concurrent collection count	0	0	0	0	0	0
Proportion of time spent unpaused (%)	8.64	22.0	64.98	80.6	85.38	91.06
Forced collection count	0	0	0	0	0	0
Number of collections	64	2126	724	397	286	112
Rate of garbage collection	123.117 MB/sec	313.827 MB/sec	978.698 MB/sec	1,215.701 MB/sec	1,294.461 MB/sec	1,416.56 MB/sec
Mean garbage collection pause (ms)	36.09	11.9	5.47	4.66	4.61	6.27

The trade-off between heap and performance

Heap size	Occupancy	GC overhead	Time taken
100 MB	Out Of Memory crash		
110 MB	89%	77%	30s
120 MB	82%	37%	9s
130 MB	75%	20%	9s
140 MB	69%	14%	8s
200 MB	49%	9%	7s
400 MB	24%	4%	7s
800 MB	12%	4%	7s

What's the right heap size?

- It depends!
- What other demands are there for heap on the system?
- Larger heaps generally give better performance
  - But …
    - Very large heaps give diminishing returns
    - Pause times will generally be longer with larger heaps and may be very long with enormous heaps
    - Some policies are more sensitive than others to heap size
- As a rule of thumb, aim for no more than 70% used heap (occupancy)
- 50% used heap is a good balance between improving performance and avoiding waste

Assessing Footprint

- After you've sized the heap, is the footprint what you expect?
- If not, why not?
  - Excessive caching
  - Excessive cloning
  - Bloated object structures
- Solution may be to reduce application's memory usage rather than increase the heap size
- Sometimes the solution may be to increase application's memory usage if it's using less than expected
  - “If my footprint's that small then I can cache all that stuff and speed up my application”

Diagnosing footprint issues

- Understanding leaks and excessive footprint needs an understanding of what objects are on the heap
  - Take a heap or system dump
  - Heap dumps are triggered automatically on OutOfMemoryErrors
  - Dumps may be triggered with ctrl-break (windows) or kill -3 (unix)
  - Dumps may also be triggered on method entry and other events
  - Dumps may also be triggered programmatically
- Once you have a dump, the dump can be analysed to discover what's holding onto memory

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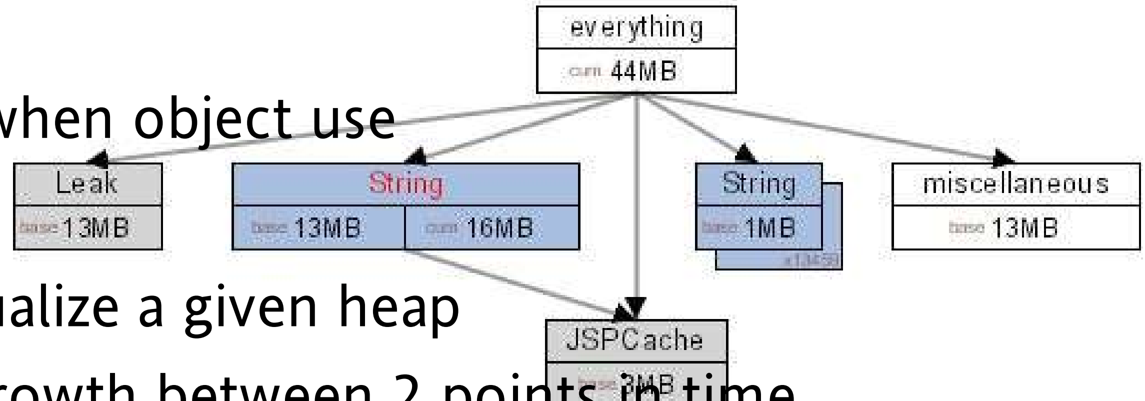
MDD4J

- Java Memory Analysis tool
  - Help explain / track down OutOfMemoryError
  - Footprint analysis
  - Performance problems when object use
- 2 modes of use
  - Single snapshot – to visualize a given heap
  - Delta mode – to track growth between 2 points in time
- Input data types supported
  - IBM Portable Heap Dump (heapdump.phd)
  - IBM Text heap dump (heapdump.txt)
  - HPROF heap dump format (hprof.txt)
- Available through IBM Support Assistant



Memory Dump Diagnostic for Java (MDD4J) v2.0.0 Beta - IBM Support Assistant

Support Assistant

Memory Dump Diagnostic for Java

Analysis Summary | Suspects | Explore Context and Contents | Browse

Data structures with large drops in reach size

#	Object type of suspected container	Reach size of the container object	Drop in reach size
0	**java/util/Hashtable$Entry[]**	**3MB**	**3MB**

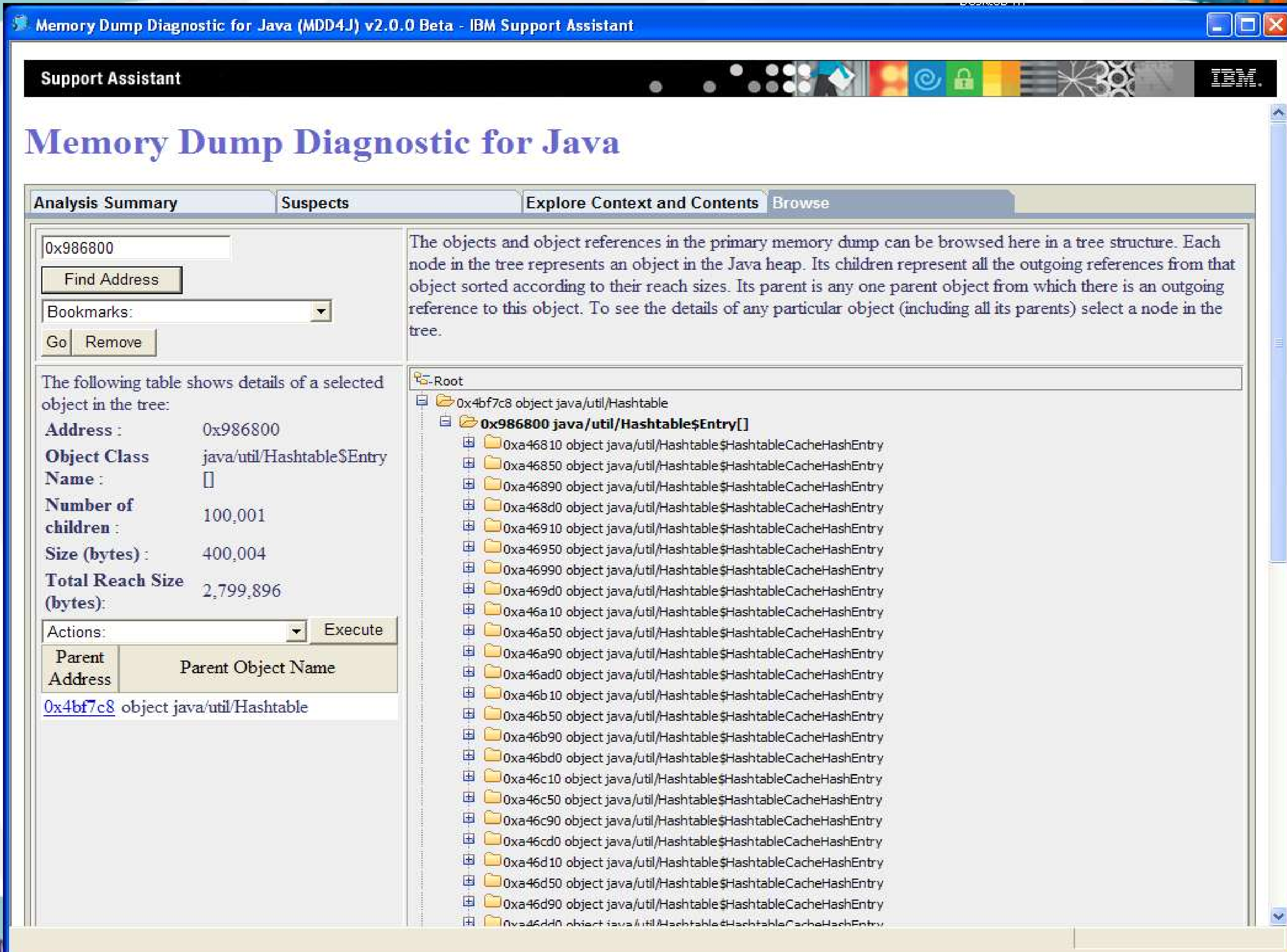
Object Types that contribute most to growth in heap size

#	Suspected Object Type	Growth in number of instances	Growth in Bytes
0	java/lang/Integer	200,032	3,200,512
1	java/util/Hashtable$HashtableCacheHashEntry	100,036	2,801,008
2	java/lang/String	1,858	52,024
3	char[]	1,658	163,666
4	java/util/HashMap$Entry	457	12,796

Packages that contribute most to growth in heap size

#	Suspected Package	Growth in number of instances
0	java/lang	202,115
1	**java/util**	**100,692**
2	java/io	88
3	sun/misc	48
4	java/net	40

The following suspects are related to the selected suspect:1



Memory Dump Diagnostic for Java (MDD4J) v2.0.0 Beta - IBM Support Assistant
Support Assistant
IBM.
Memory Dump Diagnostic for Java
Analysis Summary
Suspects
Explore Context and Contents
Browse
0x986800
Find Address
Bookmarks:
Go
Remove
The objects and object references in the primary memory dump can be browsed here in a tree structure. Each node in the tree represents an object in the Java heap. Its children represent all the outgoing references from that object sorted according to their reach sizes. Its parent is any one parent object from which there is an outgoing reference to this object. To see the details of any particular object (including all its parents) select a node in the tree.
The following table shows details of a selected object in the tree:
Address : 0x986800
Object Class Name : java/util/Hashtable$Entry[]
Number of children : 100,001
Size (bytes) : 400,004
Total Reach Size (bytes): 2,799,896
Actions:
Execute
Parent Address
Parent Object Name
0x4bf7c8 object java/util/Hashtable
Root
0x4bf7c8 object java/util/Hashtable
0x986800 java/util/Hashtable$Entry[]
0xa46810 object java/util/Hashtable$HashtableCacheHashEntry
0xa46850 object java/util/Hashtable$HashtableCacheHashEntry
0xa46890 object java/util/Hashtable$HashtableCacheHashEntry
0xa468d0 object java/util/Hashtable$HashtableCacheHashEntry
0xa46910 object java/util/Hashtable$HashtableCacheHashEntry
0xa46950 object java/util/Hashtable$HashtableCacheHashEntry
0xa46990 object java/util/Hashtable$HashtableCacheHashEntry
0xa469d0 object java/util/Hashtable$HashtableCacheHashEntry
0xa46a10 object java/util/Hashtable$HashtableCacheHashEntry
0xa46a50 object java/util/Hashtable$HashtableCacheHashEntry
0xa46a90 object java/util/Hashtable$HashtableCacheHashEntry
0xa46ad0 object java/util/Hashtable$HashtableCacheHashEntry
0xa46b10 object java/util/Hashtable$HashtableCacheHashEntry
0xa46b50 object java/util/Hashtable$HashtableCacheHashEntry
0xa46b90 object java/util/Hashtable$HashtableCacheHashEntry
0xa46bd0 object java/util/Hashtable$HashtableCacheHashEntry
0xa46c10 object java/util/Hashtable$HashtableCacheHashEntry
0xa46c50 object java/util/Hashtable$HashtableCacheHashEntry
0xa46c90 object java/util/Hashtable$HashtableCacheHashEntry
0xa46cd0 object java/util/Hashtable$HashtableCacheHashEntry
0xa46d10 object java/util/Hashtable$HashtableCacheHashEntry
0xa46d50 object java/util/Hashtable$HashtableCacheHashEntry
0xa46d90 object java/util/Hashtable$HashtableCacheHashEntry

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Diagnosing 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!

- 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
  - Profiling
- Trace
  - 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
- Profiling
  - Requires specialist tools
  - Samples all methods and provides statistics

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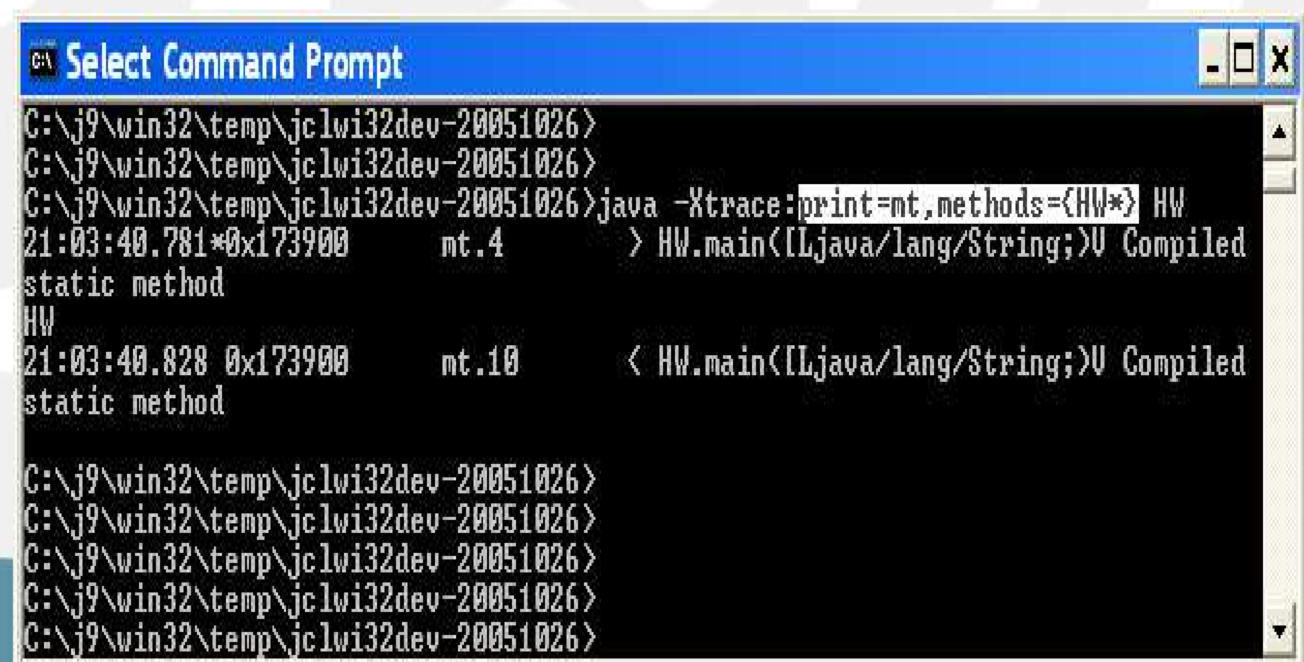
IBM Java method trace

- Traces any Java methods
- Instrumentation-free, and no extra code required
- No fancy GUI, but very very powerful
- Detailed information:
  - Entry and Exit points, with thread information and microsecond time stamps

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



Controlling what is traced

- Can select methods 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 trace!
- Can cause action to occur on n’th instance of trigger condition
- Can specify how many times the action occurs
- Multiple trigger types and actions can be specified

Using triggering to trace only some of the time

- Can start trace suspended, and resume / suspend it on matching method conditions
- E.g. use start up option –Xtrace:resumecount=1 to start trace suspended.
- Trigger={method{HelloWorld.main*,resumethis,suspendthis}}
- This will cause the requested tracing to take effect only inside HelloWorld.main method
- Less work than stepping through in a debugger and creates a permanent record

Suspend / resume in action

Command Prompt

```
C:\j9\win32\temp\jclwi32dev-20051026>
C:\j9\win32\temp\jclwi32dev-20051026>java -Xtrace:print=mt,methods={HW*,com/ibm/
jvm/io/*},trigger={method{HW.main,resumethis,suspendthis}},resumecount=1 HW
21:31:24.703*0x414c8a00      mt.4         > HW.main([Ljava/lang/String;)V Compile
d static method
21:31:24.703 0x414c8a00      mt.1         > com/ibm/jvm/io/ConsolePrintStream.pri
ntln(Ljava/lang/String;)V Compiled method, This = 414467a0
21:31:24.703 0x414c8a00      mt.1         > com/ibm/jvm/io/ConsolePrintStream.get
NewlinedString(Ljava/lang/Object;)Ljava/lang/String; Compiled method, This = 414
46788
21:31:24.703 0x414c8a00      mt.1         > com/ibm/jvm/io/ConsolePrintStream.get
NewlinedString(Ljava/lang/Object;Z)Ljava/lang/String; Compiled method, This = 41
446774
21:31:24.703 0x414c8a00      mt.7         < com/ibm/jvm/io/ConsolePrintStream.get
NewlinedString(Ljava/lang/Object;Z)Ljava/lang/String; Compiled method
21:31:24.703 0x414c8a00      mt.7         < com/ibm/jvm/io/ConsolePrintStream.get
NewlinedString(Ljava/lang/Object;)Ljava/lang/String; Compiled method
HW
21:31:24.703 0x414c8a00      mt.7         < com/ibm/jvm/io/ConsolePrintStream.pri
ntln(Ljava/lang/String;)V Compiled method
21:31:24.718 0x414c8a00      mt.10        < HW.main([Ljava/lang/String;)V Compile
d static method

C:\j9\win32\temp\jclwi32dev-20051026>
```

GREAT INDIAN DEVELOPER SUMMIT

Triggering and Method Trace in Action

- -Xtrace:print=mt,methods={myapp/MyTime*},resumecount=1,trigger=method{myapp/MyTime.main,resume,suspend}

```
21:05:47.992*0x806cb00      mt.3         > myapp/MyTime.main([Ljava/lang/String;)V
   Bytecode static method
21:05:47.994 0x806cb00      mt.19          - Static method arguments: ([L@55D8CB98)
21:05:47.994 0x806cb00      mt.0           > myapp/MyTime.<init>()V Bytecode method, This
   = 809baec
21:05:47.994 0x806cb00      mt.18            - Instance method receiver: myapp/
   MyTime@55D8CBA8 arguments: ()
21:05:47.994 0x806cb00      mt.6           < myapp/MyTime.<init>()V Bytecode method
21:05:47.994 0x806cb00      mt.0           > myapp/MyTime.test()V Bytecode method, This =
   809baf0
21:05:47.994 0x806cb00      mt.18            - Instance method receiver: myapp/
   MyTime@55D8CBA8 arguments: ()
21:05:48.079 0x806cb00      mt.6           < myapp/MyTime.test()V Bytecode method
21:05:48.079 0x806cb00      mt.9         < myapp/MyTime.main([Ljava/lang/String;)V
   Bytecode static method
```

- Only real time (79ms) is in the call to MyTime.test()
- Could now drill down into MyTime.test()

Triggering and Method Trace in Action

- Drill down into MyTime.test():
- Extend scope of methods traced, and reduce scope of tracing into MyTime.test()
- `-Xtrace:print=mt,methods={myapp/*},resumecount=1,trigger=method{myapp/MyTime.test,resume,suspend}`

```
21:07:14.968*0x806cb00      mt.0         > myapp/MyTime.test()V Bytecode method, This = 809baf0
21:07:14.970 0x806cb00      mt.18         - Instance method receiver: myapp/MyTime@55D8CBA8 arguments: ()
21:07:15.067 0x806cb00      mt.3          > myapp/MyTimer.getTime()V Bytecode static method
21:07:15.067 0x806cb00      mt.19          - Static method arguments: ()
21:07:15.067 0x806cb00      mt.9          < myapp/MyTimer.getTime()V Bytecode static method
21:07:15.069 0x806cb00      mt.6         < myapp/MyTime.test()V Bytecode method
```

Other uses of trace

- Can count tracepoints using
- java -Xtrace:count={tracepoint_selection} Class
- This is almost like a sampling profiler

Outline

- Introduction
- Identifying performance problems
- Fixing performance problems
  - Performance tools for …
    - Space bound applications
      - IBM Monitoring and Diagnostic Tools for Java™ – GC and Memory Visualizer
      - IBM MDD4J
    - CPU bound applications
      - Method trace
    - I/O bound applications
    - Lock bound applications
      - IBM Lock Analyzer for Java

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
  - This indicates the application is probably paging
- Use method trace to trace calls to network and disk I/O

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Diagnosing lock bound applications

- Infelicitous synchronization can cause significant application delays
- IBM provides a tool to quickly diagnose and identify contended locks
  - A contended lock is the opposite of a contented lock!

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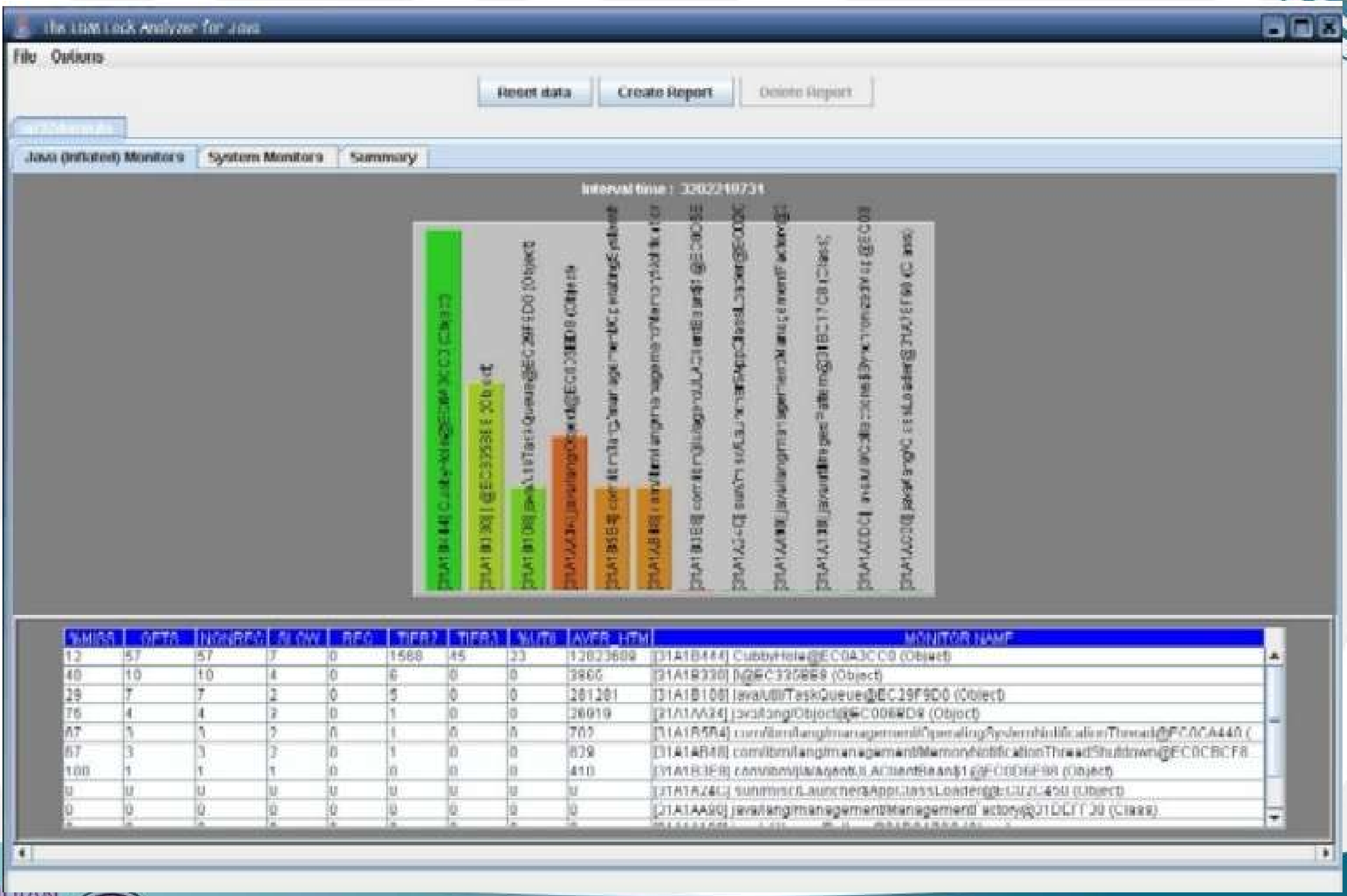
IBM Lock Analyzer for Java

- Download from http://www.alphaworks.ibm.com/tech/jla
- JLA provides profiling data on monitors used in Java applications and the JVM:
  - Counters associated with contended locks
  - Total number of successful acquires
  - Recursive acquires
  - Frequency with which a thread had to block waiting on the monitor
  - Cumulative time the monitor was held.
  - For platforms that support 3 Tier Spin Locking the following are also collected
    - Number of times the requesting thread went through the inner (spin loop) while attempting to acquire the monitor.
    - Number of times the requesting thread went through the outer (thread yield loop) while attempting to acquire the monitor.

IBM Lock Analyzer for Java



What do the bars mean?

- The Lock Analyzer provides very detailed information on locking and synchronization in the table below the chart
- In most cases the chart will be enough
- The height of the bar indicates how often threads were blocked waiting for the lock
- The colour of the bar indicates what fraction of the attempts were unsuccessful

Conclusions

- Improving application performance starts with identifying limited resources
- Tools can help fix performance bottlenecks
  - Space bound
    - GC and Memory Visualizer
    - MDD4J
  - CPU bound
    - Method tracing
  - Lock bound
    - Lock Analyzer for Java

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Any Questions?