Debugging Java performance problems

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Overview

- Tonight I am going to discuss Java performance, and how opensource tools can be used to debug performance problems on production servers
- I plan to split my 60-minutes into three parts:
  - Part 1 will provide an overview of the tools
  - Part 2 will show these tools in action
  - Part 3 will be a Q&A period
- Note: Several of the tools described in the presentation require Solaris 10 and a recent Java 6 release (Java 6 update 4 was used for testing)

Typical Performance problems

- Performance and scalability problems typically fall into three major categories:
  - Inefficient use of CPU resources
  - Inefficient use of memory resources
  - Lock contention
- The following slides will describe how to locate CPU, memory and lock contention problems in Java applications

CPU performance problems

- CPU performance problems occur when one or more threads saturate the available CPU resources, resulting in system-wide scheduling latencies
- Typical CPU problems
  – Object allocation leading to excessive garbage collection (GC)
  – Inefficient methods
  – Improper use of class libraries
  – Runaway threads

Identifying CPU problems

- If mpstat or vmstat shows high CPU utilization, the Solaris prstat utility can be run with the “-L” option to break down CPU utilization by thread:

```
$ prstat -Lam
PID     USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/LWPID
 19512   matty      50   0.0  0.1  0.0  0.0  0.0  0.0  50   0   151  0   0  java/2
```

- The output above contains the process id and process name, microstate accounting data, the thread name and the thread identifier

Identifying CPU problems (cont.)

- Once the id of a CPU bound thread is located, the jstack utility can be used to retrieve a stack trace for each thread in a process:

```
$ jstack <VMID>

 "main" prio=10 tid=0x080ce400 nid=0x2 runnable [0xfe698000..0xfe698d48] \
     java.lang.Thread.State: RUNNABLE
     at com.sun.demo.jvmti.hprof.Tracker.nativeReturnSite(Native Method)
     at com.sun.demo.jvmti.hprof.Tracker.ReturnSite(Tracker.java:74)
     at java.lang.Math.random(Math.java:695)
     at TestMain.foo(TestMain.java:15)
     at TestMain.main(TestMain.java:9)
```

- Jstack will print the name of each thread, the thread id, the full class name, the thread state and a Java stack trace
- The stack trace can be used to determine which code to analyze for potential problems, or as a starting point for further debugging

Debugging method calls with DTrace

- The Dtrace hotspot provider contains probes that fire upon method entry and exit:
  - **method-entry** - fires each time a method is entered
  - **method-return** - fires each time a method is exited
- The method probes are extremely useful for identifying which methods are consuming CPU resources on a system, and can be used to correlate system events to application events
- To use the method probes, you will first need to enable them with the jinfo utility:

```
$ jinfo -flag -XX:+DTraceMethodProbes<VMID>
```

- The probes will add additional overhead to the Java runtime, and should be disabled once profiling is complete:

```
$ jinfo -flag -XX:-DTraceMethodProbes <VMID>
```

Debugging method calls with Dtrace (cont.)

- To view the most active Java call stacks on a system, the DTrace profile provider can be used to sample the most frequently executing Java call stacks:

```
$ dtrace -o busymethod.out -n ‘profile-1001hz
 / pid == 19512 & tid == 2 /
 {
    @callstacks[jstack()] = count();
  }’
```

- After you hit cntrl+c to stop DTrace, the output file can be filtered with c++filt to demangle C++ symbols:

```
$ c++filt busymethods.out |more
```

Debugging method calls with Dtrace (cont.)

- This will produce output similar to the following (output edited for readability):

```
 Libjvm.so`long long java_lang_Thread::thread_id(oopDesc*)+0x2a
libjvm.so`long long SharedRuntime::get_java_tid(Thread*)+0x3a
libjvm.so`intSharedRuntime::dtrace_method_entry \
(JavaThread*,methodOopDesc*)+0x5c
java/util/Random.next(I)I*
TestMain.main([Ljava/lang/String;)V*
StubRoutines (1)
libjvm.so`void
libc.so.1`_thr_setup+0x52
libc.so.1`_lwp_start
24
```

Debugging method calls with Dtrace (cont.)

- To list the busiest methods in an application by CPU time consumed, the DTraceToolkit j_cputime.d script can be used:

```
$ j_cputime.d 3
Top 3 counts,
PID    TYPE       NAME                                            COUNT
20221  method     java/lang/String.getChars                       76183
20221  method     java/lang/System.arraycopy                     167600
 0     total          -                                          944774

Top 3 exclusive method on-CPU times (us),
PID   TYPE       NAME                                             TOTAL
20221 method     java/util/Arrays.copyOf                         174943
20221 method     java/lang/System.arraycopy                      189579
   0  total      -                                              1346227

Top 3 inclusive method on-CPU times (us),
PID   TYPE       NAME                                             TOTAL
20221 method     java/lang/AbstractStringBuilder.expandCapacity  339847
20221 method     java/lang/AbstractStringBuilder.append          664615
20221 method     java/lang/StringBuilder.append                  772450
```

Offline CPU analysis

- The Java heap profiling agent can be used to profile Java method utilization
- There are two profiling methods:
  - **Sampling -** samples the call stacks at periodic intervals to determine the top methods
  - **Time based** - Uses byte code injection (BCI) to instrument the entry and return points in each method
- Time based profiling is much more accurate, but introduces significantly more overhead

Time based CPU profiling

- Time based CPU profiling can be enabled by loading the heap profiling agent with the cpu flag set to times:

```
$ java -agentlib:hprof=cpu=times App
```

- When the process exits or receives a control signal, the agent will write the profiling results to a file named java.hprof.txt

Time based CPU profiling (cont.)

- The profiling report will contain output similar to the following:

```
CPU TIME (ms) BEGIN (total = 1022085444) Fri Jan 25 17:21:16 2008
 rank   self     accum   count      trace    method
   1  18.65% 18.65%  252985704 301144 java.util.Random.nextDouble
   2  11.93% 30.58%  252985704 301145 java.lang.Math.random
   3  10.13% 40.72%  505971408 301142 java.util.concurrent.atomic.AtomicLong.compareAndSet
   4  10.06% 50.77%  505971409 301141 java.util.concurrent.atomic.AtomicLong.get
   5   9.39%  60.16%  126492852 301146 TestMain.foo
   6   2.58%  62.74%  126492853 301078 TestMain.<init>
```

- Trace identifiers can be used to correlate methods to stack traces:

```
TRACE 301144:
     java.util.Random.nextDouble(Random.java:Unknown line)
     java.lang.Math.random(Math.java:Unknown line)
    TestMain.foo(TestMain.java:Unknown line)
    TestMain.main(TestMain.java:Unknown line)
```

Fixing CPU performance problems

- Identifying the problem is the key to fixing issues related to CPU utilization
- Use the tools described above to collect data that you can show your developers
- If you are the developer, check the Java API reference for unintended behaviors, and write test cases to see why code is not performing as expected

Memory performance problems

- Java memory problems are probably the single biggest source of performance problems and scalability bottlenecks
- Several types of problems exist:
  - Improper allocation strategies
  - Unintentional object references
- Memory related problems typically surface in the way of OOM (out of memory) errors, long pauses due to garbage collection and heap fragmentation

Viewing memory utilization

- The Java SDK comes with the jstat utility to print utilization statistics for each Java generation:

```
 $ jstat -gc `pgrep java` 1000
  S0C      S1C      S0U  S1U      EC             EU       OC        OU      PC          PU     YGC YGCT    FGC    FGCT
GCT
 17856.0 17856.0  0.0   8004.2 357504.0 194217.5  131072.0    0.0     16384.0 6178.4     1    0.186        1
0.057    0.242
 17856.0 17856.0  0.0   8004.2 357504.0 235835.7  131072.0    0.0     16384.0 6178.4     1    0.186        1
0.057    0.242
 17856.0 17856.0  0.0   8004.2 357504.0 263580.6  131072.0    0.0     16384.0 6178.4     1    0.186        1
0.057    0.242
 17856.0 17856.0 8002.5  0.0   357504.0   0.0        131072.0    0.0    16384.0 6178.4     2   0.381        1
0.057    0.437
```

- There are also options to print class load activity, hotspot compiler statistics, new and old generation memory usage, and the reason why a GC event occurred

Debugging memory problems with DTrace

- The DTrace hotspot provider contains object allocation and garbage collection (GC) probes that can be used to observe object allocation, and collections that result from these allocations:
  - **gc-begin** - fires when a collection is about to occur
  - **gc-end** - fires when a collection finishes
  - **mem-pool-gc-begin** - fires when an individual memory pool is about to be collected
  - **mem-pool-gc-end** - fires when an individual memory pool collection finishes
  - **object-alloc** - fires when an object is allocated

Debugging memory problems with DTrace (cont.)

- The newobjects.d, objectsize.d and whoallocatebybytes.d DTrace scripts utilize these probes to measure the number the objects allocated, the size of allocations and the Java call stacks responsible for the allocations
- Prior to using the object allocation probes, the probes need to be enabled with jinfo:

  $ **jinfo -flag -XX:+DTraceAllocProbes<VMID>**
- The probes will add additional overhead to the Java runtime, and should be disabled once profiling is complete:

  $ **jinfo -flag -XX:-DTraceAllocProbes<VMID>**

Viewing object allocations

- The newobjects.d script will print the number of objects created and the total number of bytes allocated for each type of object:

```
$ newobjects.d
Class                          Objects created  Bytes Allocated
[I                             112              16064
Wasteful                       17943            287088
java/lang/StringBuilder        17943            287088
java/lang/String               17943            430632
[C                             107658           52393560
```

Viewing object sizes

- The objectsize.d script will print a distribution of object sizes:

```
$ objectsize.d
value  ------------- Distribution ------------- count
       8 |                                        0
      16 |@@@@@@@@@@@@@@@@                        95897
      32 |@@@@                                    31965
      64 |                                        1
     128 |@@@@                                    32157
     256 |@@@@                                    31965
     512 |@@@@@@@@@@@                             63932
    1024 |@@@@                                    31967
    2048 |                                        0
```

Identifying object allocation points

- The whoallocatebybytes.d script can be used to correlate Java call stacks to the number of bytes they allocated:

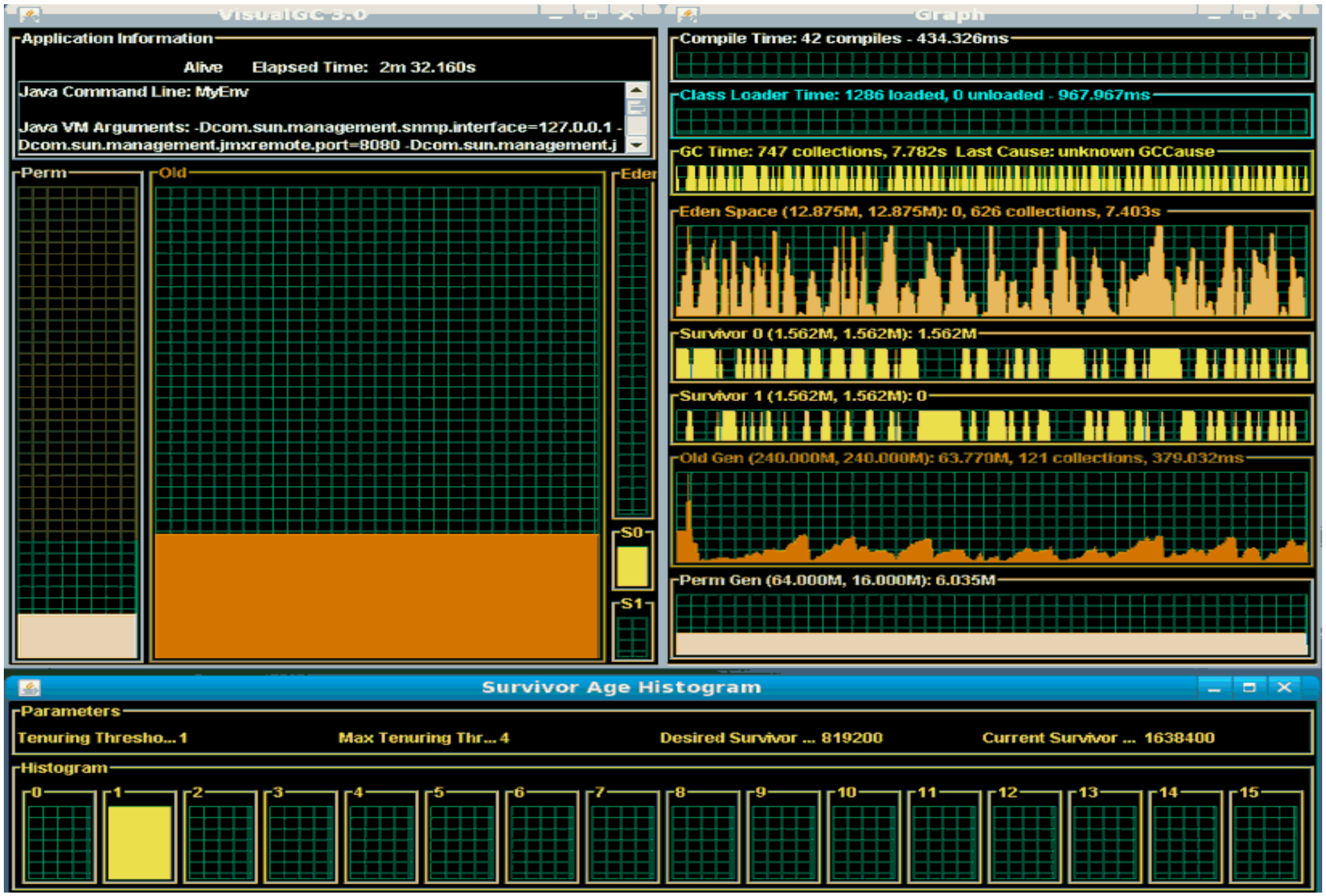
```
$ whoallocatebytes.d
 Wasteful.main([Ljava/lang/String;)V
 StubRoutines (1)
 libjvm.so`_pnGThread__v_+0×1a3
 libjvm.so`jni_CallStaticVoidMethod+0×15d
 java`JavaMain+0xd30
 libc.so.1`_thr_setup+0×52
 libc.so.1`_lwp_start
    817632
```

Monitoring memory usage with visualgc

- The visualgc utility is a freely downloadable tool from Sun, which can be used to graphically monitor the following Java runtime subsystems:
  - Classloader activity
  - Garbage collection activity
  - Hotspot compiler activity
- To use visualgc, you can run visualgc with the process id of the Java process to monitor:

```
$ visualgc <VMID>
```

VisualGC output



VisualGC 3.0

Application Information

Alive Elapsed Time: 2m 32.160s

Java Command Line: MyEnv

Java VM Arguments: -Dcom.sun.management.snmp.interface=127.0.0.1 -Dcom.sun.management.jmxremote.port=8080 -Dcom.sun.management.j

Graph

Compile Time: 42 compiles - 434.326ms

Class Loader Time: 1286 loaded, 0 unloaded - 967.967ms

GC Time: 747 collections, 7.782s Last Cause: unknown GCCause

Eden Space (12.875M, 12.875M): 0, 626 collections, 7.403s

Survivor 0 (1.562M, 1.562M): 1.562M

Survivor 1 (1.562M, 1.562M): 0

Old Gen (240.000M, 240.000M): 63.770M, 121 collections, 379.032ms

Perm Gen (64.000M, 16.000M): 6.035M

Survivor Age Histogram

Parameters

Tenuring Thresho... 1 Max Tenuring Thr... 4 Desired Survivor ... 819200 Current Survivor ... 1638400

Histogram

Offline memory analysis

- The Java heap profiling agent can be used to profile Java object allocations
- Heap profiling can be enabled by loading the heap profiling agent with the heap flag set to sites:

```
$ java -agentlib:hprof=heap=sites App
```

- When the process exits or receives a control signal, the agent will write the profiling results to a file named java.hprof.txt

Offline memory analysis (cont.)

- The profiling report will contain data similar to the following:

```
SITES BEGIN (ordered by live bytes) Fri Jan 25 22:18:51 2008
          percent          live          alloc'ed  stack class
rank self       accum     bytes       objs     bytes          objs        trace     name
 1   84.58%  84.58%  11088704  15751  37680192   53523    300295   char[]
 2   7.76%    92.34%   1017784   1876    137723136  254136  300042   char[]
 3   2.86%    95.20%    374928   15622  1284552      53523    300294   java.lang.String
 4   0.53%    97.63%     68992       98    7040000     10000     300268   char[]
```

- Trace identifiers can be used to correlate object allocations to the Java stack that is responsible for allocating the objects:

```
TRACE 300295:
        java.util.Arrays.copyOfRange(Arrays.java:3209)
        java.lang.String.<init>(String.java:216)
        java.lang.StringBuilder.toString(StringBuilder.java:430)
        Objects.allocateObjects(Objects.java:49)
```

Is memory allocation impacting performance?

- This depends on the nature of the application, the workload being performed, the type of client accessing the application, and the impact of latency on service delivery
- You can measure application pauses due to GC (and the objects that resulted in the collection being performed) by adding the "-XX:+PrintGCApplicationStoppedTime" and "-Xloggc:gc.log" options to the java command line
- This will produce log entries similar to the following:

```
Total time for which application threads were stopped: 0.0068135
seconds
105.616: [GC 61914K->50759K(129472K), 0.0067066 secs]
Total time for which application threads were stopped: 0.0070856
```

Fixing memory allocation problems

- Detecting the type of allocation issue and the problem site is the key to fixing memory related problems
- The Dtrace hotspot provider can be used to identify problems in production, and the Java heap profiling agent and jhat utility can be used to identify problems offline

Lock contention problems

- Lock contention issues occur when two or more threads need access to a specific resource to perform a unit of work, and are required to wait for a period of time to acquire the resource because another thread has control of the resource
- Locking issues can be split into three categories
  - Native lock contention (e.g., acquiring a mutex lock)
  - Java lock contention (e.g., acquiring a monitor)

Detecting native lock contention

- Solaris 10 ships with the plockstat utility, which provides an easy way to measure locks in native code:

```
$ plockstat -A -p <PID>
Mutex hold

Count     nsec  Lock                          Caller
---------------------------------------------------------------------------
78       36496  libc.so.1`libc_malloc_lock   libjava.so`getString8859_1Chars+0x72
184       9848  libc.so.1`libc_malloc_lock   libjvm.so`__1cCosGmalloc6FI_pv_+0x2b
Mutex spin

Count     nsec Lock                          Caller
---------------------------------------------------------------------------
    1     7075 libc.so.1`libc_malloc_lock   libzip.so`Java_java_util_zip_Inflater_i
    2     5383 libc.so.1`libc_malloc_lock   libjvm.so`__1cCosEfree6Fpv_v_+0x1b
```

Debugging JVM lock contention with DTrace

- The Dtrace hotspot provider provides a large set of probes that can be used to measure lock contention:
  - **monitor-contended-enter** - fires when a thread attempts to enter a contended monitor
  - **monitor-contended-entered** - fires when a thread successfully enters a contended monitor
  - **monitor-contended-exit** - fires when a thread leaves a monitor that other threads are waiting to enter
  - **monitor-wait** - fires when a thread begins waiting on a monitor via a call to Object.wait()
  - **monitor-waited** - fires when a thread completes an Object.wait()
  - **monitor-notify** - fires when a thread calls Object.notify to notify threads that are waiting on a condition
  - **monitor-notifyAll** - fires when a thread calls Object.notifyAll to notify threads that are waiting on a monitor

Debugging JVM lock contention with DTrace (cont.)

- The jlockstat.d and jlockpath.d DTrace scripts can be used to measure how much time threads spend waiting for monitors, and which code paths are involved
- Prior to using the scripts, jinfo needs be run to enable the Dtrace monitor probes:

```
$ jinfo -flag -XX:+DTraceMonitorProbes <VMID>
```

- The probes will add additional overhead to the Java runtime, and should be disabled once profiling is complete:

```
$ jinfo -flag -XX:-DTraceMonitorProbes <VMID>
```

Measuring Java monitor contention

- The jlockstat.d script measures the time spent waiting on contended monitors:

```
$ jlockstat.d
Monitor events (Cntrl+C to display events)
Classname             JVM pid     Count       Time (ms)
-------------------   ----------  ----------  ----------
ContentionObject1     739         748
181069190
ContentionObject2     739         532         98765
ContentionObject3     739         12          654
```

Correlating monitor contention to Java stacks

- The jlockpath.d script will collect a Java stack trace each time a monitor is contended, and display the stack traces along with the time they waited for a monitor when the script exits:

```
$ jlockpath.d > lockstat.out
$ cat lockstat.out | egrep -v '(libjvm|libc)'
monitorenter_nofpu Runtime1 stub
ContentionObject.update(I)V*
ThreadObject.run()V
StubRoutines (1)
748
```

Detecting deadlocks

- Deadlocks occur when two or more threads are waiting for a synchronization primitive that is owned by the other thread
- The jstack utility will print deadlocks if they exist:

  $ **jstack -l <VMID>**

Offline lock analysis

- The Java heap profiling agent can be used to analyze an application for threads that are waiting to enter a monitor
- Monitor profiling can be enabled by loading the heap profiler agent with the monitor flag set to y:

```
$ java -agentlib:hprof=monitor=y App
```

- When the process exits or receives a control signal, the agent will write the profiling results to a file named java.hprof.txt

Offline lock analysis (cont.)

```
MONITOR LContentionObject;
    owner: thread 200005, entry count: 1
     waiting to enter: thread 200028, thread 200027, thread 200026, thread
200025,
     thread 200024, thread 200023, thread 200022, thread 200021, thread
200020,
     thread 200019, thread 200018, thread 200017, thread 200016, thread
200015,
     thread 200014, thread 200013, thread 200012, thread 200011, thread
200010,
     thread 200009, thread 200008, thread 200007, thread 200006, thread
200004
     waiting to be notified:
 MONITOR Ljava/lang/Shutdown$Lock;
     owner: thread 200030, entry count: 1
     waiting to enter:
     waiting to be notified:
```

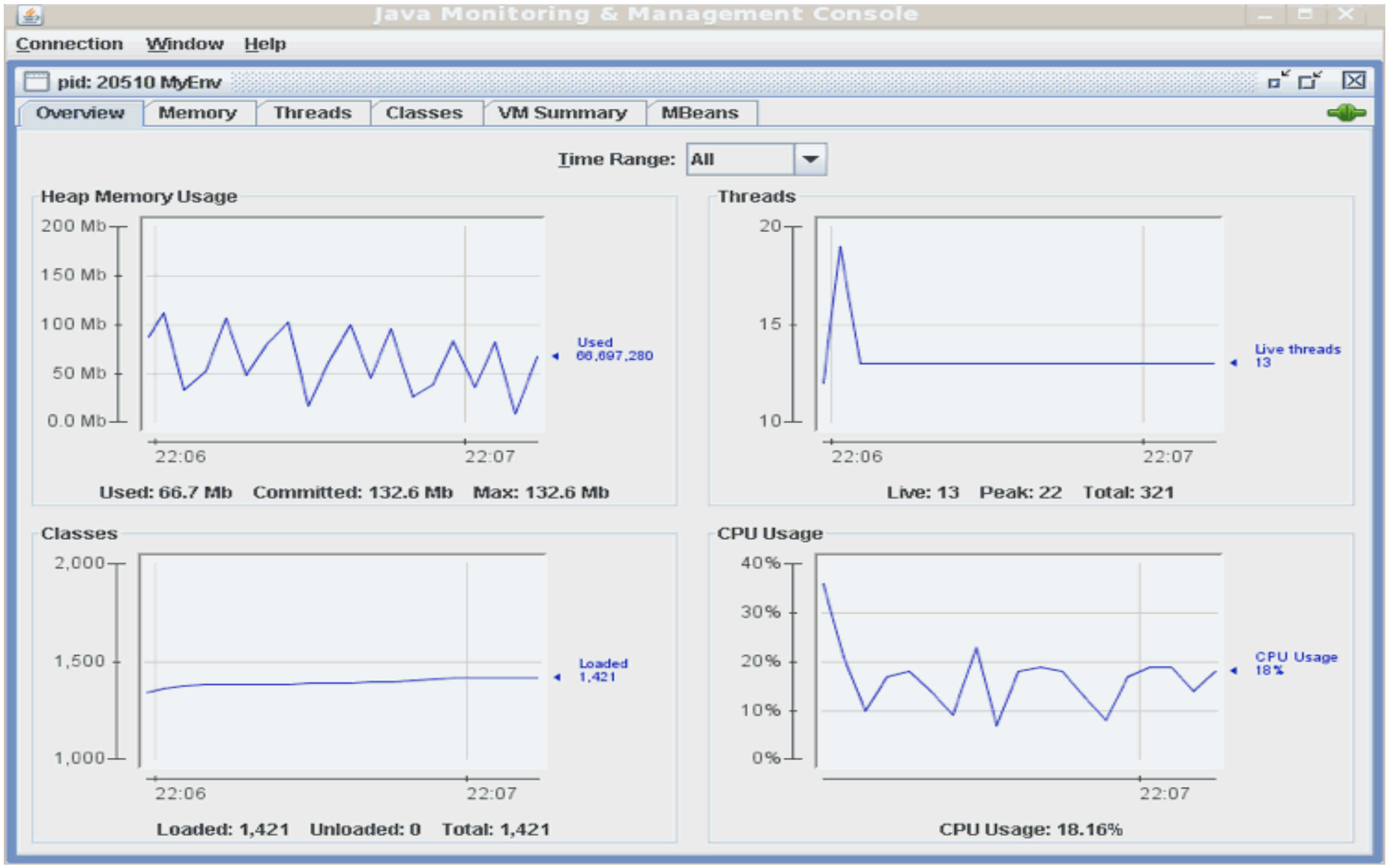
Fixing lock contention issues

- Detecting the type of lock contention issue (native lock acquisition vs. Java monitor acquisition) and the problem site is the key to fixing lock contention problems
- Plockstat will show problematic code paths in native code, and the jlockpath.d Dtrace script will show problematic code paths in Java code
- Fixing lock contention issues often involves changes to the way an application is architected, since lock-free architectures and fine grained locking typically require

Summarizing JVM utilization with jconsole

- The jconsole utility can be used to summarize heap utilization, system utilization, class loader activity and much much more
- Also allows you to enable and disable options on a live JVM, which can be useful for setting profiling flags after startup (jinfo provides similar capabilities from the command line)

Jconsole output



Time Range: All

Used: 66.7 Mb Committed: 132.6 Mb Max: 132.6 Mb

Live: 13 Peak: 22 Total: 321

Loaded: 1,421 Unloaded: 0 Total: 1,421

CPU Usage: 18.16%

Trending Java performance

- System utilization can be trended with a number of opensource packages:
  – MRTG
  – Orca
  – Cacti
- Java virtual machine performance can be trended using either JMX or the Java SNMP agent
- A script (jvmstat.pl) to trend JVM utilization is available on the prefetch.net website

Conclusion

- Java code can perform extremely well, and the tools described in this presentation should help you get to the bottom of any performance problems that may be occurring in your environment
- Solaris 10 and opensolaris are ideal platforms for debugging java performance problems
- Even if you don’t run Solaris in production, you can use Solaris and Dtrace to debug performance problems, and then transfer those performance wins back to your preferred operating system

References

- **DTrace users guide**
  http://docs.sun.com/app/docs/doc/817-6223/
- **DTrace hotspot probes**
  http://blogs.sun.com/kamg/#Dtrace_Probes_in_Mustang_Hotspot
- **DTraceToolkit**
  http://opensolaris.org/os/community/dtrace/dtracetoolkit/
- **Garbage collection tuning**
  http://java.sun.com/docs/hotspot/gc5.0/gc_tuning_5.html
- **Java troubleshooting Guide:**
  http://java.sun.com/javase/6/webnotes/trouble/
- **Lock profiling scripts**
  http://prefetch.net/blog/index.php/2008/02/03/using-the-dtrace-hotspot-provider-to-observe-java-monitor-contention
- **Object allocation scripts:**
  http://prefetch.net/blog/index.php/2007/10/31/using-the-dtrace-hotspot-provider-to-observe-java-object-allocations/

Questions?