1. “I don’t have to worry about Garbage collection” – Is it true?

I have heard a few of my developer friends say: **“Garbage Collection is automatic. So, I do not have to worry about it.“** The first part is true, i.e., “Garbage Collection is automatic” on all modern platforms – Java, .NET, Golang, Python… But the second part i.e., “I don’t have to worry about it.” – may not be true. It is arguable, questionable. Here is my case to showcase the importance of Garbage Collection:

1. Unpleasant customer experience

When a garbage collector runs, it pauses the entire application to mark the objects that are in use and sweep away the objects that don’t have active references. During this pause period, all customer transactions which are in motion will be stalled (i.e., frozen). Depending on the type of GC algorithm and memory settings that you configure, pause times can run anywhere from a few milliseconds to a few minutes. Frequent pauses in the application can cause stuttering, juddering, or halting effects to your customers. It will leave an unpleasant experience for your customers.

2. Millions of dollars wasted

Here is a white paper we published, explaining factually how enterprises are wasting millions of dollars due to garbage collection. Basically, in a nutshell, modern applications are creating thousands/millions of objects. These objects must be continuously investigated to determine whether they have active references or are they ready for garbage collection. Once objects are garbage collected, the memory becomes fragmented. Fragmented memory must be compacted. All these activities consume ***enormous compute cycles***. These compute cycles translate to millions of dollars in spending. If Garbage collection performance can be optimized, it can result in several millions of dollars in cost savings.

3. Low risk, high impact performance improvements

By virtue of optimizing Garbage collection performance, you are not only improving the Garbage collection pause time, but you are improving the overall application's response time. We recently helped to tune the garbage collection performance of one of the world's largest automobile companies. Just by modifying the garbage collection settings **without refactoring a single line** of code, we improved their overall application's response time significantly. The below table summarizes the overall response time improvement we achieved with each Garbage Collection setting change we made:

	Avg Response Time (secs)	Transactions > 25 sec (%)
Baseline	1.88	16
GC settings iteration #2	4GB	8
GC settings iteration #3	4GB	8
GC settings iteration #4	4GB	8
GC settings iteration #5	4GB	8
GC settings iteration #6	4GB	8
GC settings iteration #7	4GB	8
GC settings iteration #8	4GB	8

When we started the GC tuning exercise, this automobile application's overall response time was 1.88 seconds. As we optimized Garbage Collection performance with different settings, on iteration #8, we were able to improve the overall response time to 0.95 seconds. i.e., **49.46%** improvement in the response time. Similarly, percentages of transactions taking more than 25 seconds dropped from 0.7% to 0.31%, i.e., 55% improvement. This is a significant improvement to achieve without modifying a single line of code.

All other forms of response time improvement will require infrastructure change or architectural change, or code-level changes. All of them are expensive changes. Even if you embark on making those costly changes, there is no guarantee of the application's

response time improvement.

4. Predictive Monitoring

Garbage Collection logs expose vital predictive micrometrics. These metrics can be used for forecasting application's availability and performance characteristics. One of the micrometrics exposed in Garbage Collection is 'GC Throughput' (to read more about other micrometrics, refer to this article). What is GC Throughput? If your application's GC throughput is 98%, it means your application is spending 98% of its time processing customer activity and the remaining 2% of the time in GC activity. When the application suffers from a memory problem, several minutes before GC throughput will start to degrade. Troubleshooting tools like yCrash monitors 'GC throughput' to predict and forecast the memory problems before they surface in the production environment.

5. Capacity Planning

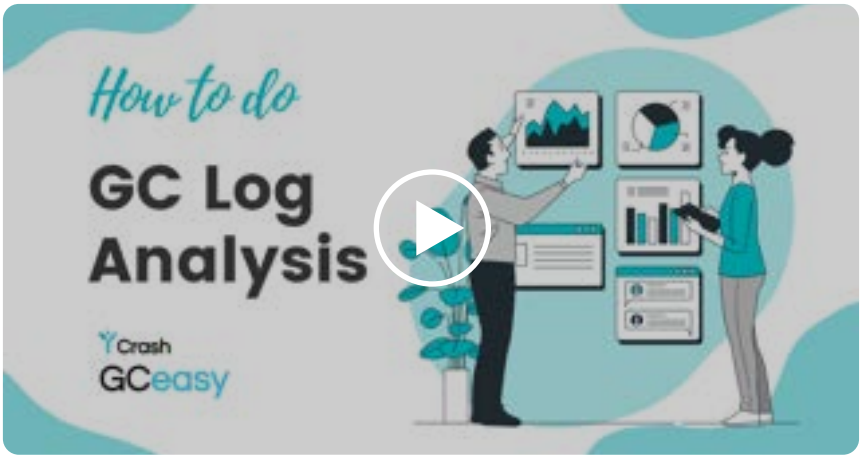
When you are doing capacity planning for your application, you need to understand your application's demand for memory, CPU, Network and storage. One of the best ways to study the demand for memory is by analyzing garbage collection behaviour. When you analyze garbage collection behaviour, you would be able to determine average object creation rate (example: 150 MB/sec), average object reclamation rate. Using these sort of micrometrics you can do effective capacity planning for your application.

Conclusion

Friends, in this post, I have made my best efforts to justify the importance of garbage collection analysis. I wish you and your team the best to benefit from the highly insightful garbage collection metrics.

2. How to do GC Log analysis?

Analyzing garbage collection log provides several advantages like: Reduces GC pause time, reduces cloud computing cost, predicts outages, provides effective metrics for capacity planning. To learn about the profound advantages of GC log analysis, please refer to this post. In this post let's learn how to analyze GC logs?



Watch video

https://www.youtube.com/watch?v=dZbmlMLCfZY

Here is an interesting video clip which walks through the best practices, KPIs, tips & tricks to effectively optimize Garbage collection performance.

Basically, there are 3 essential steps when it comes to GC log analysis:

Let's discuss these 3 steps now.

1. Enable GC Logs

Even though certain monitoring tools provide Garbage Collection graphs/metrics at real time , they don't provide a complete set of details to study the GC behavior. GC logs are the best source of information, to study the Garbage Collection behavior. You can enable GC logs, by specifying below JVM arguments in your application:

Java 8 & below versions:

If your application is running on Java 8 & below versions, then pass below arguments:

```
-XX:+PrintGCDetails -Xloggc:<gc-log-file-path>
Example:
-XX:+PrintGCDetails -Xloggc:/opt/tmp/myapp-gc.log
```

Java 8 & below versions:

If your application is running on Java 8 & below versions, then pass below arguments:

```
-XX:+PrintGCDetails -Xloggc:<gc-log-file-path>
Example:
-XX:+PrintGCDetails -Xloggc:/opt/tmp/myapp-gc.log
```

2. Measurement Duration & environment

It's always best practice to study the GC log for a 24-hour period during a weekday, so that application would have seen both high volume and low volume traffic tide.

It's best practice to collect the GC logs from the production environment, because garbage collection behavior is heavily influenced by the traffic patterns. It's hard to simulate production traffic in a test environment. Also overhead added by GC log in production servers is negligible, in fact it's not even measurable. To learn about overhead added by enabling GC logs, you can refer here.

3. Tools to analyze

Once you have captured GC logs, you can use one of the following free tools to analyze the GC logs:

1. GCeasy
2. IBM GC & Memory visualizer
3. HP Jmeter
4. Garbage Cat

3. Garbage collection patterns to predict outages

As the author of GCeasy – Garbage collection log analysis tool, I get to see few interesting Garbage Collection Patterns again & again. Based on the Garbage collection pattern, you can detect the health and performance characteristics of the application instantly. In this video and the post, let me share few interesting Garbage collection patterns that have intrigued me.

Watch video

https://www.youtube.com/watch?v=4jlfd3XCeTM

1. Healthy saw-tooth pattern

You will see a beautiful saw-tooth GC pattern when an application is healthy, as shown in the above graph. Heap usage will keep rising; once a 'Full GC' event is triggered, heap usage will drop all the way to the bottom.

In Fig 1, You can notice that when the heap usage reaches ~5.8GB, 'Full GC' event (red

triangle) gets triggered. When the 'Full GC' event runs, memory utilization drops all the way to the bottom i.e., ~200MB. Please see the dotted black arrow line in the graph. It indicates that the application is in a healthy state & not suffering from any sort of memory problems.

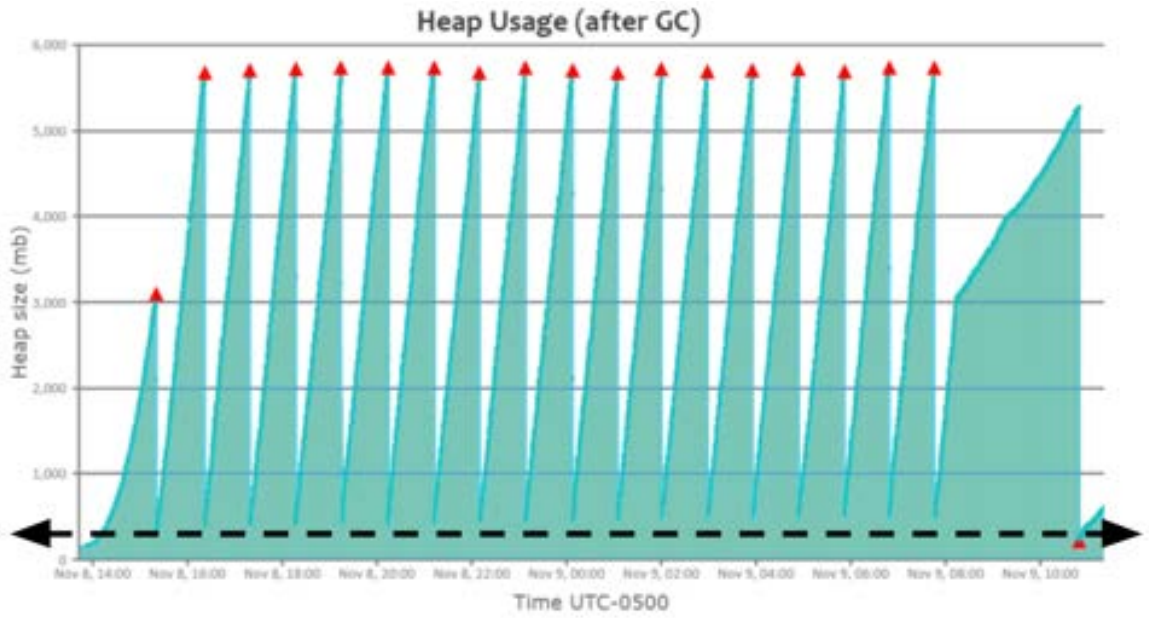


Fig 1: Healthy saw-tooth GC pattern

2. Heavy caching pattern

When an application is caching many objects in memory, 'GC' events wouldn't be able to drop the heap usage all the way to the bottom of the graph (like you saw in the earlier 'Healthy saw-tooth' pattern).

In Fig 2, you can notice that heap usage keeps growing. When it reaches around ~60GB, GC event (depicted as a small green square in the graph) gets triggered. However, these GC events aren't able to drop the heap usage below ~38GB. Please refer to the dotted black arrow line in the graph. In contrast, in the earlier 'Healthy saw-tooth pattern', you can see that heap usage dropping all the way to the bottom ~200MB. When you see this sort of pattern (i.e., heap usage not dropping till all the way to the bottom), it indicates that the application is caching a lot of objects in memory.

When you see this sort of pattern, you may want to investigate your application's heap using heap dump analysis tools like yCrash, HeapHero, Eclipse MAT and figure out whether you need to cache these many objects in memory. Several times, you might uncover unnecessary objects to be cached in the memory.

Here is the real-world GC log analysis report, which depicts this 'Heavy caching' pattern.

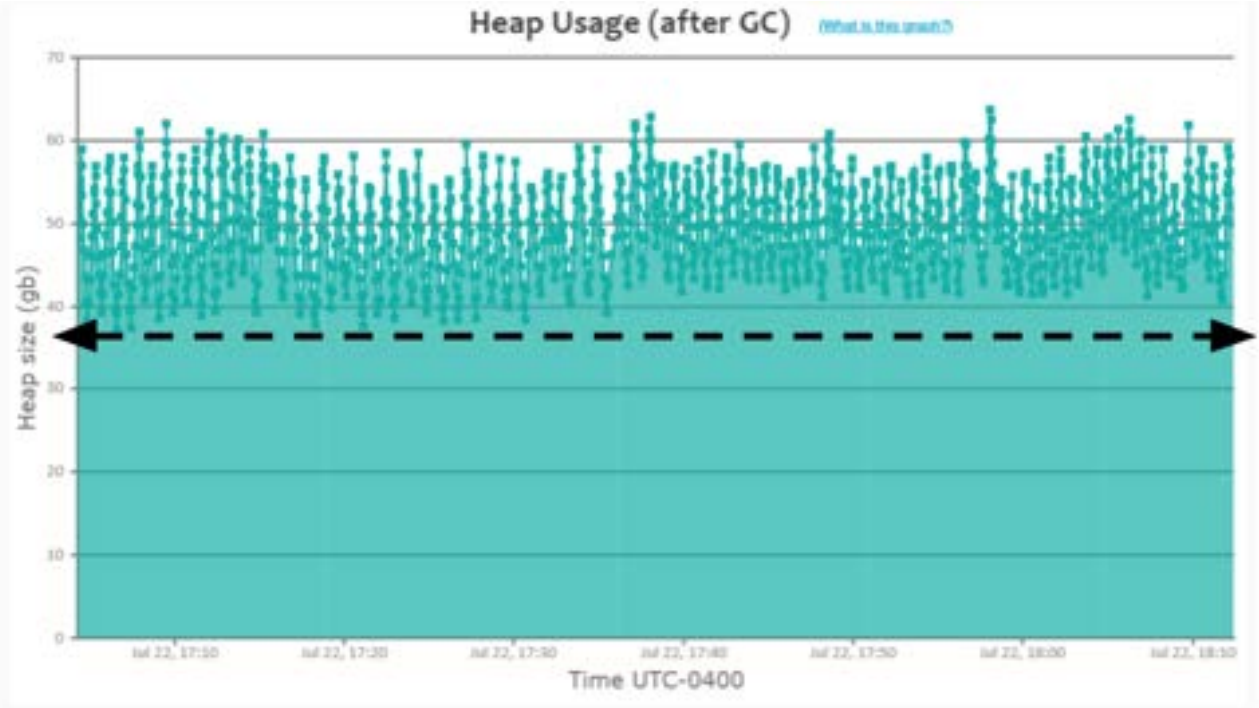


Fig 2: Healthy caching GC pattern

3. Acute memory leak pattern

Several applications suffer from this 'Acute memory leak pattern'. When an application suffers from this pattern, heap usage will climb up slowly, eventually resulting in OutOfMemoryError.

In Fig 3, you can notice that 'Full GC' (red triangle) event gets triggered when heap usage reaches around ~43GB. In the graph, you can also observe that amount of heap that full GC events could recover starts to decline over a period of time, i.e., you can notice that

a. When the first Full GC event ran, heap usage dropped to 22GB

b. When the second Full GC event ran, heap usage dropped only to 25GB

c. When the third Full GC event ran, heap usage dropped only to 26GB

d. When the final full GC event ran heap usage dropped only to 31GB

Please see the dotted black arrow line in the graph. You can notice the heap usage gradually climbing up. If this application runs for a prolonged period (days/weeks), it will experience OutOfMemoryError (please refer to Section #5 – 'Memory Leak Pattern').

Here is the real-world GC log analysis report, which depicts this 'Acute memory leak'

pattern.

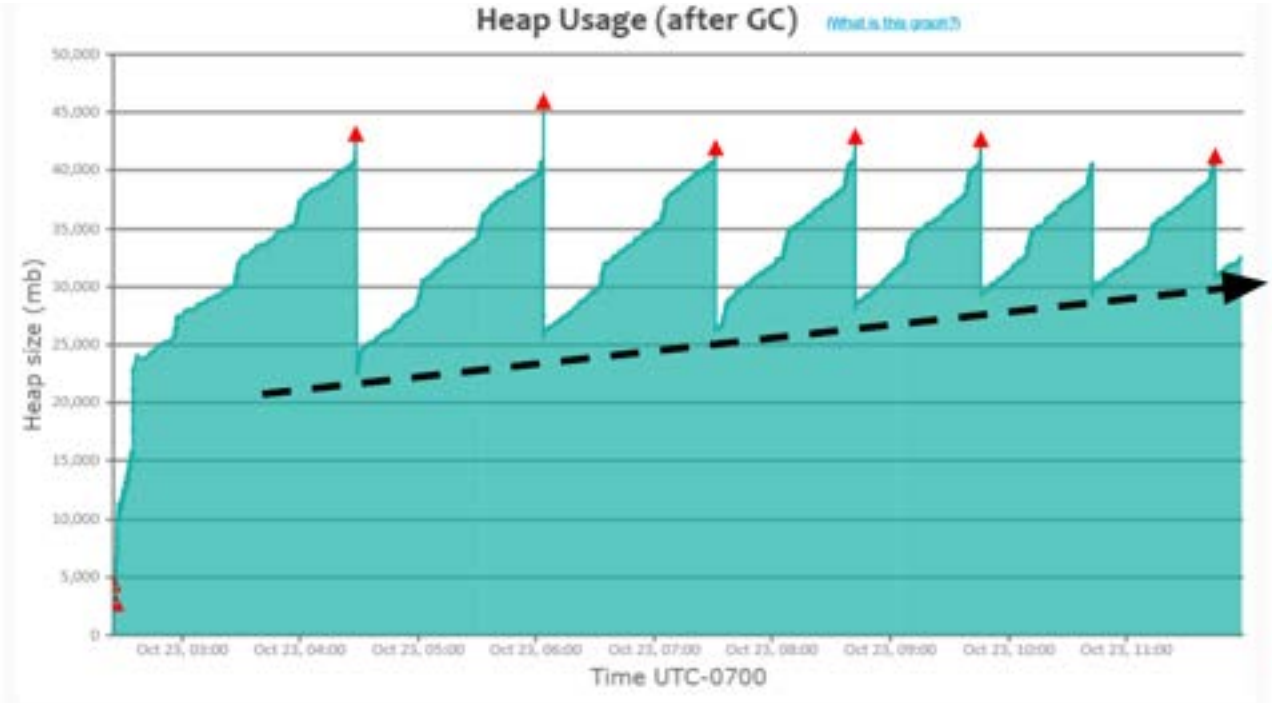


Fig 3: Acute memory leak pattern

4. Consecutive Full GC pattern

When the application's traffic volume increases more than JVM can handle, this Consecutive full GC pattern will become pervasive.

In Fig 4, please refer to the black arrow mark in the graph. From 12:02pm to 12:30 pm on Oct' 06, Full GCs (i.e., 'red triangle') are consecutively running; however, heap usage isn't dropping during that time frame. It indicates that traffic volume spiked up in the application during that time frame, thus the application started to generate more objects, and Garbage Collection couldn't keep up with the object creation rate. Thus, GC events started to run consecutively. Please note that when a GC event runs, it has two side effects:

a. CPU consumption will go high (as GC does an enormous amount of computation).

b. Entire application will be paused; no customers will get response.

Thus, during this time frame, 12:02pm to 12:30pm on Oct' 06, since GC events are consecutively running, application's CPU consumption would have been skyrocketing and customers wouldn't be getting back any response. When this kind of pattern surfaces, you can resolve it using one of the solutions outlined **in this post**.

Here is the real-world GC log analysis report, which depicts this 'Consecutive Full GC' pattern.

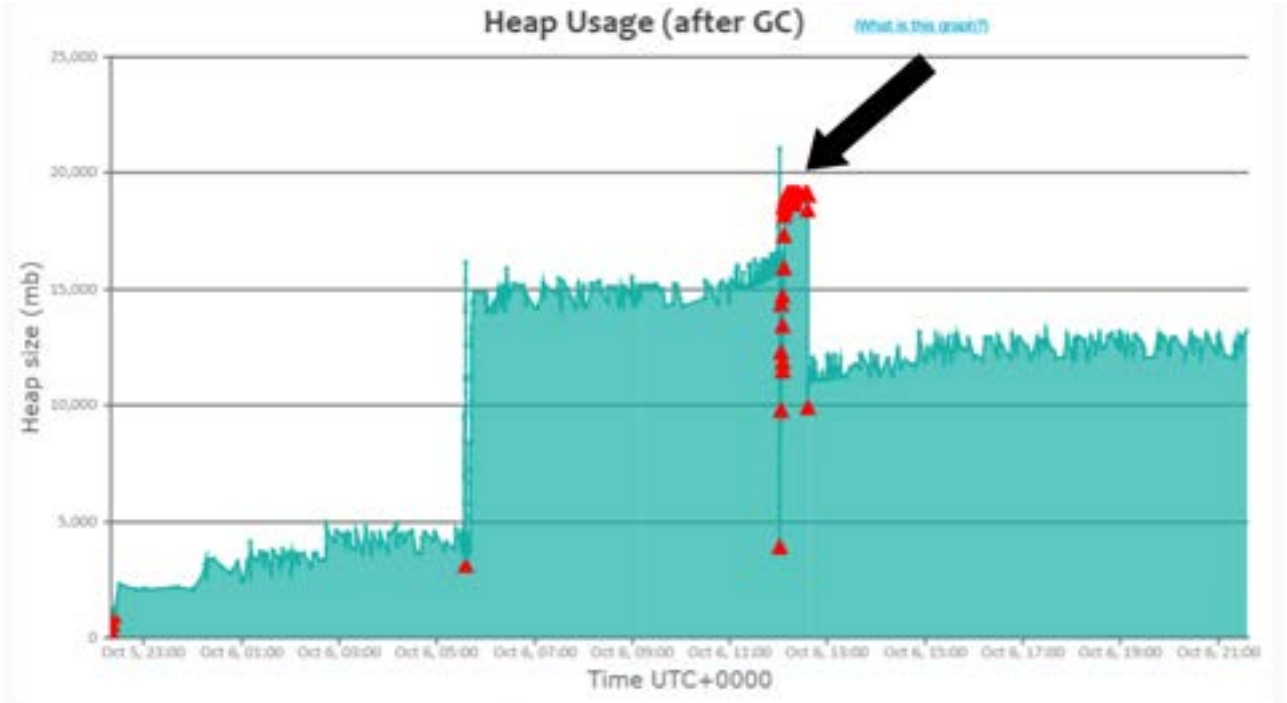


Fig 4: Consecutive full GC pattern

5. Memory Leak Pattern

This is a 'classic pattern' that you will see whenever the application suffers from memory problems. In Fig 5, please observe the black arrow mark in the graph. You can notice that Full GC (i.e., 'red triangle') events are continuously running. This pattern is similar to the previous 'Consecutive Full GC' pattern, with one sharp difference. In the 'Consecutive Full GC' pattern, application would recover from repeated Full GC runs and return back to normal functioning state, once traffic volume dies down. However, if the application runs into a memory leak, it wouldn't recover, even if traffic dies. The only way to recover the application is to restart the application. If the application is in this state, you can use tools like yCrash, HeapHero, Eclipse MAT to diagnose memory leak. Here is a more detailed post on how to diagnose Memory leak.

Here is the real-world GC log analysis report, which depicts this 'Memory Leak' pattern.

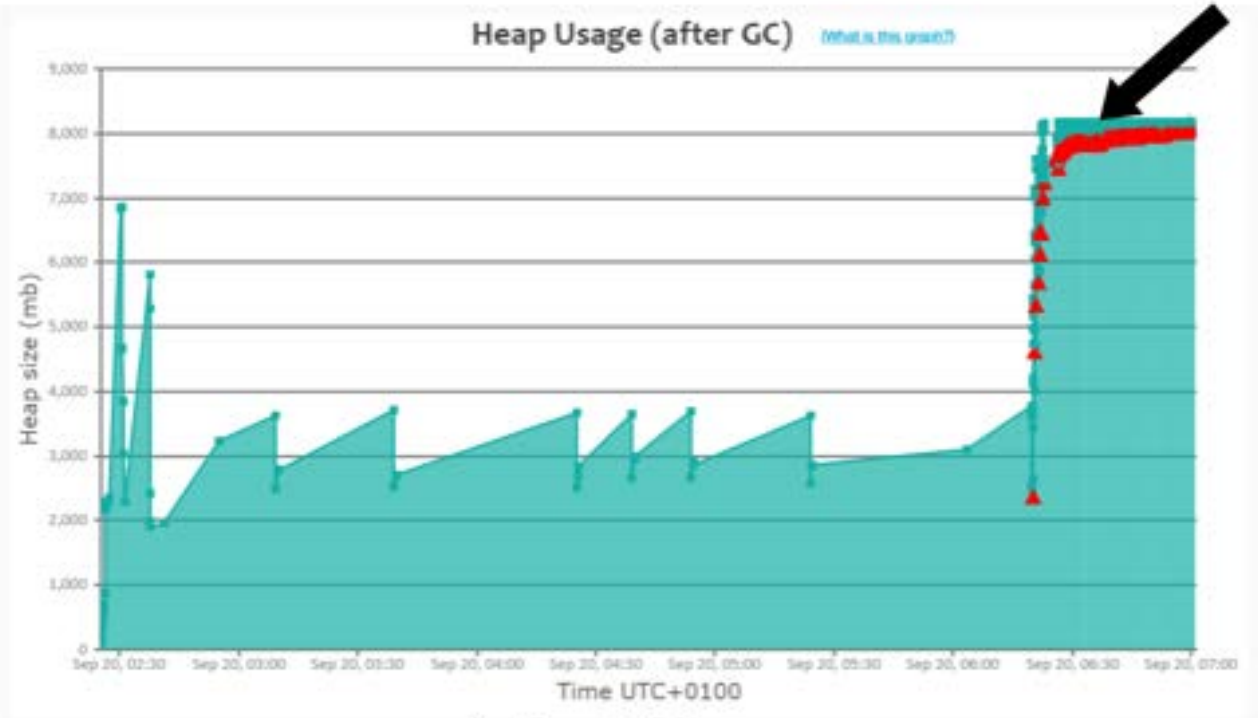


Fig 5: Memory leak GC pattern

6. Metaspace Memory problem Pattern

If you notice in this graph pattern, Full Garbage Collection events are consecutively triggered after 12:30am even though only 10% of maximum heap size is reached. Maximum available heap size for this application is 2.5GB, whereas Full GC events are triggered even memory is reaching 250MB (i.e., 10% of the maximum size). Typically, consecutive full GCs are triggered only when maximum heap size is reached. When you see this sort of pattern it's indicative that Metaspace region is reaching its maximum size. This can happen when

a. Metaspace region size is under allocated

b. Memory leak in the Metaspace region.

You can increase Metaspace region size by passing this JVM argument (-XX:MaxMetaspaceSize). You can refer to this post to see how to troubleshoot Metaspace memory problem.

Here is the real-world GC log analysis report, which depicts this 'Metaspace Memory problem' Pattern.

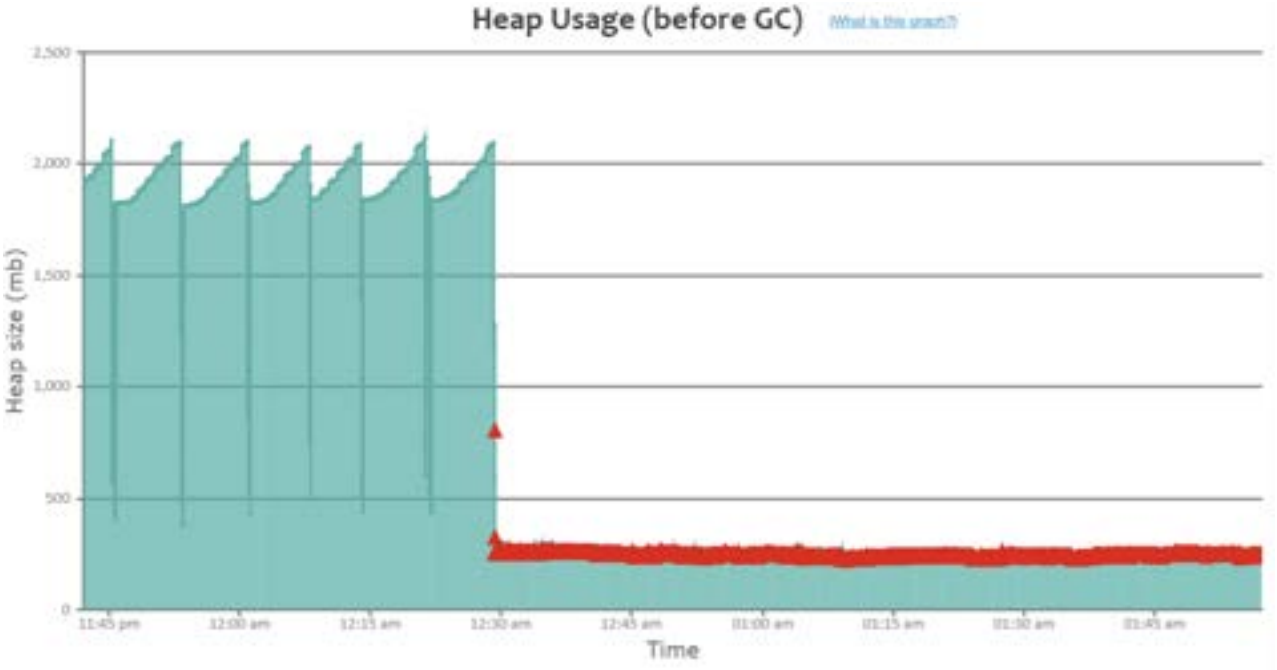


Fig 6: Metaspace memory problem pattern

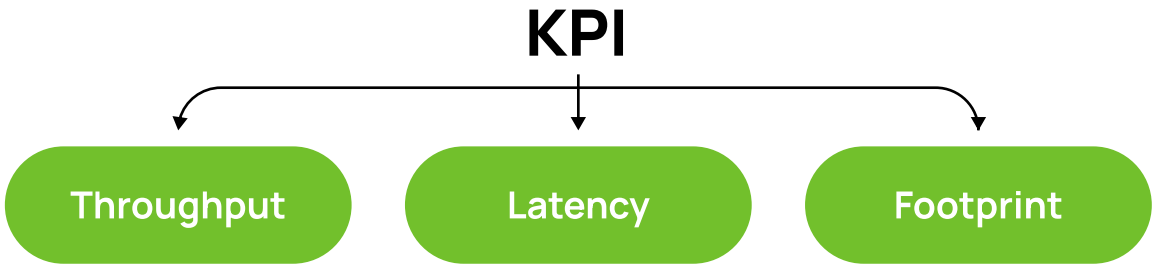
Conclusion

You can also consider enabling your application's Garbage collection log (as it doesn't add any measurable overhead to your application) and study the garbage collection behavior. It may reveal insightful views/perspectives about your application that you weren't aware of before.

4. Memory tuning: Key Performance Indicators

When you are tuning the application's memory & Garbage Collection settings, you should take well-informed decisions based on the key performance indicators. But there are overwhelming amount of metrics reported; which one to choose and which one to leave? This article intends to explain the right KPIs and right tools to source them.

What are the right KPIs?



Throughput

Throughput is the amount of productive work done by your application in a given time period. This brings the question what is productive work? what is non-productive work?

Productive Work: This is basically the amount of time your application spends in processing your customer's transactions.

Non-Productive Work: This is basically the amount of time your application spend in house-keeping work, primarily Garbage collection.

Let's say your application runs for 60 minutes. In this 60 minutes let's say 2 minutes is spent on GC activities.

It means application has spent 3.33% on GC activities (i.e. 2 / 60 * 100)

It means application throughput is 96.67% (i.e. 100 – 3.33).

Now the question is: What is the acceptable throughput %? It depends on the applicationand business demands. Typically one should target for more than 95% throughput.

Latency

This is the amount of time taken by one single Garbage collection event to run. This indicator should be studied from 3 fronts.

a. **Average GC Time:** What is the average amount of time spent on GC?

b. **Maximum GC time:** What is the maximum amount of time spent on a single GC event? Your application may have service level agreements such as "no transaction can run beyond 10 seconds". In such cases, your maximum GC pause time can't be running for 10 seconds. Because during GC pauses, entire JVM freezes – no customer transactions will be processed. So it's important to understand the maximum GC pause time.

c. **GC Time Distribution:**You should also understand how many GC events are completing with in what time range (i.e. within 0 – 1 second, 200 GC events are completed, between 1 – 2 second 10 GC events are completed …)

Footprint

Footprint is basically the amount CPU consumed. Based on your GC algorithm, based on your memory settings, CPU consumption will vary. Some GC algorithms will consume more CPU (like Parallel, CMS), whereas other algorithms such as Serial will consume less CPU.

According to memory tuning Gurus, you can pick only 2 of them at a time.

- If you want good throughput and latency, then footprint will degrade.
- If you want good throughput and footprint, then latency will degrade.
- If you want good latency and footprint, then throughput will degrade.

Right Tools

Throughput and Latency can be obtained from analyzing Garbage collection Logs.

Upload your application's Garbage Collection log file in **http://gceasy.io/** tool. This tool can parse Garbage Collection logs and generates Throughput and Latency indicators for you. Below is the screen shot from the **http://gceasy.io/** tool showing the throughput and latency:

Fig 1: KPI section from GCeasy.io report

Footprint (i.e. CPU consumption) can be obtained from the monitoring tools – Nagios, NewRelic, AppDynamics,…

5. Tips to reduce Long GC Pauses

Long GC Pauses are undesirable for applications. It affects your SLAs; it results in poor customer experiences, and it causes severe damages to mission critical applications. Thus in this article, I have laid out key reasons that can cause long GC pauses and potential solutions to solve them.

1. High Object Creation Rate

If your application's object creation rate is very high, then to keep with it, garbage collection rate will also be very high. High garbage collection rate will increase the GC pause time as well. Thus, optimizing the application to create less number of objects is THE EFFECTIVE strategy to reduce long GC pauses. This might be a time-consuming exercise, but it is 100% worth doing. In order to optimize object creation rate in the application, you can consider using java profilers like JProfiler, YourKit, JVisualVM….). These profilers will report

- What are the objects that created?
- What is the rate at which these objects are created?
- What is the amount of space they are occupying in memory?
- Who is creating them?

Always try to optimize the objects which occupy the most amount of memory. Go after big fish in the pond.

Tit-bit: How to figure out object creation rate?
Upload your GC log to the Universal Garbage Collection log analyzer tool **GCeasy.** This tool will report the object creation rate. There will be field by name 'Avg creation rate' in the section 'Object Stats.' This field will report the object creation rate. Strive to keep

this value lower always. See the image (which is an excerpt from the GCeasy generated report), showing the 'Avg creation rate' to be 8.83 mb.sec.

Object Stats

These are good metrics to compare with previous baseline

Total created bytes	3.82 tb
Total promoted bytes	16.48 tb
Avg creation rate	8.83 mb/sec
Avg promotion rate	38 kb/sec

2. Undersized Young Generation

When young Generation is undersized, objects will be prematurely promoted to Old Generation. Collecting garbage from old generation takes more time than collecting it from young Generation. Thus increasing young generation size has a potential to reduce the long GC pauses. Young Generation can be increased setting either one of the two JVM arguments

-Xmn: specifies the size of the young generation

-XX:NewRatio: Specifies ratio between the old and young generation. For example, setting -XX:NewRatio=3 means that the ratio between the old and young generation is 3:1. i.e. young generation will be fourth of the overall heap. i.e. if heap size is 2 GB, then young generation size would be 0.5 GB.

3. Choice of GC Algorithm

Choice of GC algorithm has a major influence on the GC pause time. Unless you are a GC expert or intend to become one or someone in your team is a GC expert – you can tune GC settings to obtain optimal GC pause time. Assume if you don't have GC expertise, then I would recommend using G1 GC algorithm, because of it's auto-tuning capability. In G1 GC, you can set the GC pause time goal using the system property '-XX:MaxGCPauseMillis.' Example:

```
-XX:MaxGCPauseMillis=20
```

As per the above example, Maximum GC Pause time is set to 200 milliseconds. This is a soft goal, which JVM will try it's best to meet it. If you are already using G1 GC algorithm

and still continuing to experience high pause time, then refer to this article.

4. Process Swapping

Sometimes due to lack of memory (RAM), Operating system could be swapping your application from memory. Swapping is very expensive as it requires disk accesses which is much slower as compared to the physical memory access. In my humble opinion – no serious application in a production environment should be swapping. When process swaps, GC will take a long time to complete.

Below is the script obtained from StackOverflow (thanks to the author) – which when executed will show all the process that are being swapped. Please make sure your process is not getting swapped.

```
#!/bin/bash
# Get current swap usage for all running processes
# Erik Ljungstrom 27/05/2011
# Modified by Mikko Rantalainen 2012-08-09
# Pipe the output to "sort -nk3" to get sorted output
# Modified by Marc Methot 2014-09-18
# removed the need for sudo

SUM=0
OVERALL=0
for DIR in `find /proc/ -maxdepth 1 -type d -regex "^/proc/[0-9]+"`
do
  PID=`echo $DIR | cut -d / -f 3`
  PROGNAME=`ps -p $PID -o comm –no-headers`
  for SWAP in `grep VmSwap $DIR/status 2>/dev/null | awk '{ print $2 }'`
  do
    let SUM=$SUM+$SWAP
  done
  if (( $SUM > 0 )); then
    echo "PID=$PID swapped $SUM KB ($PROGNAME)"
  fi
  let OVERALL=$OVERALL+$SUM
  SUM=0
done
echo "Overall swap used: $OVERALL KB"
```

If you find your process to be swapping then do one of the following:

a. Allocate more RAM to the server
b. Reduce the number of processes that running on the server, so that it can free up the memory (RAM).

c. Reduce the heap size of your application (which I wouldn't recommend, as it can cause other side effects).

5. Less GC Threads

For every GC event reported in the GC log, user, sys and real time are printed. Example:

```
[Times: user=25.56 sys=0.35, real=20.48 secs]
```

To know the difference between each of these times, please read the article. (I highly encourage you to read the article, before continuing this section). If in the GC events you consistently notice that 'real' time isn't significantly lesser than the 'user' time – then it might be indicating that there aren't enough GC threads. Consider increasing the GC thread count. Say suppose 'user' time 25 seconds, and you have configured GC thread count to be 5, then real time should be close to 5 seconds (because 25 seconds / 5 threads = 5 seconds).

WARNING: Adding too many GC threads will consume a lot of CPU and takes away a resource from your application. Thus you need to conduct thorough testing before increasing the GC thread count.

6. Background IO Traffic

If there is a heavy file system I/O activity (i.e. lot of reads and writes are happening) it can also cause long GC pauses. This heavy file system I/O activity may not be caused by your application. Maybe it is caused by another process that is running on the same server, still, can cause your application to suffer from long GC pauses. Here is a brilliant article from LinkedIn Engineers, which walks through this problem in detail.

When there is a heavy I/O activity, you will notice the 'real' time to be significantly more than 'user' time. Example:

```
[Times: user=0.20 sys=0.01, real=18.45 secs]
```

When this pattern happens, here are the potential solutions to solve it:
a. If high I/O activity is caused by your application, then optimize it.
b. Eliminate the processes which are causing high I/O activity on the server
c. Move your application to a different server where I/O activity is less

Tit-bit: How to monitor I/O activity?

You can monitor I/O activity, using the sar (System Activity Report), in Unix. Example:

```
sar -d -p 1
```

Above commands reports the reads/sec and writes/sec made to the device every 1 second. For more details on 'sar' command refer to this tutorial.

7. System.gc() calls

When System.gc() or Runtime.getRuntime().gc() method calls are invoked it will cause stop-the-world Full GCs. During stop-the-world full GCs, entire JVM is freezed (i.e. No user activities will be performed during period). System.gc() calls are made from one of the following sources:

1. Your own application developers might be explicitly calling System.gc() method.
2. It could be 3rd party libraries, frameworks, sometimes even application servers that you use could be invoking System.gc() method.
3. It could be triggered from external tools (like VisualVM) through use of JMX
4. If your application is using RMI, then RMI invokes System.gc() on a periodic interval. This interval can be configured using the following system properties:

– Dsun.rmi.dgc.server.gcInterval=n

– Dsun.rmi.dgc.client.gcInterval=n

Evaluate whether it's absolutely necessary to explicitly invoke System.gc(). If there is no need to then, please remove it. On the other hand, you can forcefully disable the System.gc() calls by passing the JVM argument: '-XX:+DisableExplicitGC'. For complete details on System.gc() problems & solution refer to this article.

Tit-bit: How to know whether System.gc() calls are explicitly called?

Upload your GC log to the Universal Garbage Collection log analyzer tool GCeasy. This tool has a section called 'GC Causes.' If GC activity is triggered because of 'System.gc()' calls then it will be reported in this section. See the image (which is an excerpt from the GCeasy generated report), showing that System.gc() was made 4 times during the lifetime of this application.

Object Stats

These are good metrics to compare with previous baseline

Cause	Count
Allocation Failure	242
System.gc() calls	4
Promotion Failure	1
GCLocker Initiated GC	2

8. Large Heap size

Large heap size (-Xmx) can also cause long GC pauses. If heap size is quite high, then more garbage will be get accumulated in the heap. When Full GC is triggered to evict the all the accumulated garbage in the heap, it will take long time to complete. Logic is simple: If you have small can full of trash, it's going to be quick and easy to dispose them. On the other hand if you have truck load of trash, it's going to take more time to dispose them.

Suppose your JVMs heap size is 18GB, then consider having three 6 GB JVM instances, instead of one 18GB JVM. Small heap size has great potential to bring down the long GC pauses.

CAUTION: All of the above mentioned strategies should be rolled to production only after thorough testing & analysis. All strategies may not apply to your application. Improper usage of these strategies can result in negative results.

9. Workload distribution

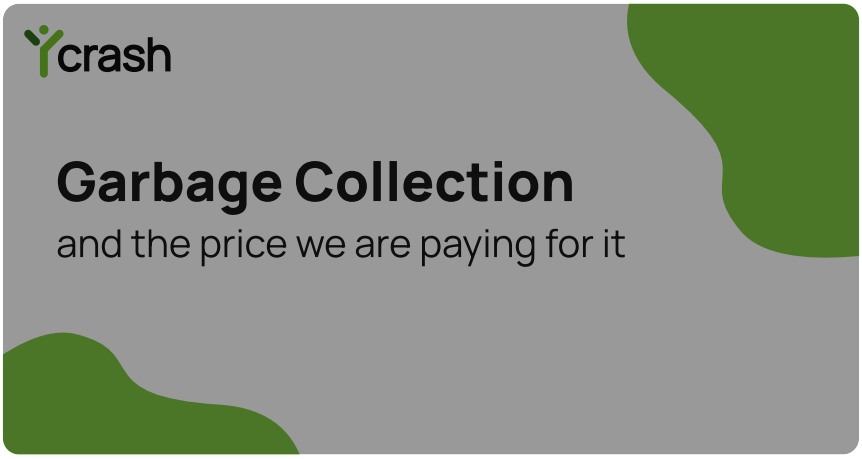
Eventhough there are multiple GC threads, sometimes work load is evenly distributed between GC worker Threads. There are multiple reasons why GC workloads may not be evenly broken up amoing GC threads. For example:

a. Scanning of large linear data structures currently can not be parallelized.b. Some times of events only triggers single thread collector (example when there is 'concurrent mode failure' in CMS collection)

If you happen to use CMS (Concurrent Mark & Sweep algorithm), you can consider passing -**XX:+CMSScavengeBeforeRemark** argument. This can create more balanced workloads among GC worker threads.

6. How many millions of dollars enterprises waste due to Garbage collection?

We truly believe enterprises are wasting millions of dollars in garbage collection. We equally believe enterprises are wasting these many millions of dollars even without knowing they are wasting. Intent of this post is to bring visibility on how several millions of dollars are wasted due to garbage collection.



Watch video

https://www.youtube.com/watch?v=N1_ScYlSlGs&t=7s

What is Garbage?

All applications have a finite amount of memory. When a new request comes, the application creates objects to service the request. Once a request is processed, all the objects created to service that request are no longer needed. In other terms those

objects become garbage. They have to be evicted/removed from the memory so that room is created to service new incoming requests.

Garbage collection evolution: Manual → Automatic

3 – 4 decades back, C, C++ programming languages were popularly used by the development community. In those-programming languages garbage collection needs to be done by the developers. i.e., application developers need to write code to dispose of unreferenced objects from the memory. If developers forget (or miss) to write that logic in their program, then the application will suffer from memory leak. Memory leaks will cause applications to crash. Thus, memory leaks were claimed to be quite pervasive back in those days.

In the mid-1990s when the Java programming language was introduced, it provided automatic garbage collection i.e., developers no longer have to write logic to dispose of unreferenced objects. Java Virtual machine will itself automatically remove unreferenced objects from memory. Definitely it was a great productivity improvement, developers enjoyed this feature. On top of it, a number of memory leak related crashes also came down. Sounds great so far, right? But there was one catch to this automatic garbage collection.

To do this automatic garbage collection, JVM has to pause the application to identify unreferenced objects and dispose them. This pausing can take anywhere from a few milliseconds to few minutes, depending on the application, workload & JVM settings. When an application is paused to do garbage collection, no customer transactions will be processed. Any customer transactions that are in the middle of processing will be halted. It will result in poor response time to the customers. So, this was the trade-off, i.e., for developer productivity and minimizing memory leak related crashes, application pause times got introduced in automatic garbage collection. By doing effective tuning we can bring down the pause time, but it cannot be eliminated.

This might sound like a minor performance hit to the customer's response time. But it does not stop there, today enterprises are losing millions of dollars because of this automatic garbage collection. Below are the interesting facts/details.

Garbage collection Throughput

'GC Throughput' is one of the key metrics that is studied when it comes to Garbage collection tuning. This metric is cleverly reported in percentage. What is 'GC Throughput %?'. It is basically the amount of time application spends in processing the customer transactions vs amount of time application spends in processing Garbage collection activities. Say suppose application has 98% as it's GC Throughput, it means application is spending 98% of its time in processing customer transactions and remaining 2% of time in processing Garbage collection activities.

Does 98% GC throughput sound good to you? Since human minds are trained to read 98% as A grade score, definitely 98% GC throughput should sound good. But in reality, it is not the case. Let us look at the below calculations.

In 1 day, there are **1440 minutes** (i.e. 24 hours x 60 minutes).

98% GC throughput means application is spending **28.8 minutes/day** in garbage collection. (i.e., the application is spending 2% of time in processing GC activities. 2% of 1440 minutes is 28.8 minutes).

What is this telling us? Even if your GC throughput is 98%, your application is spending 28.8 minutes/day (i.e., almost 30 minutes) in Garbage collection. For that 28.8 minutes period your application is pausing. **It's not doing anything for your customer.**

One way to visualize this problem is: Say you have bought a brand-new expensive car and you want to drive this car for a couple of hours. How will you feel if the car runs only for 1 hour and 50 minutes, but stops intermittently in the middle of the road for 10 minutes, and still ends up consuming gasoline? This is what is happening exactly in automatic garbage collection. JVM keeps pausing intermittently, while application is still processing customer transactions.

Dollars wasted

Even healthy application's GC throughput ranges from 99% to 95%. Sometimes it could go even below than that. In the below table I have summarized how many dollars mid-size(1K instances/year), large-size(10K instances/year) and very large(100K instances/year) enterprises would be wasting based on their application's GC throughput percentage.

GC Throughput %	99%	98%	97%	96%	95%
Minutes wasted by 1 instance per day	14.4 min	28.8 min	43.2 min	57.6 min	72 min
Hours wasted by 1 instance per year	87.6 hrs	175.2 hrs	262.8 hrs	350.4 hrs	438 hrs
Dollars wasted by mid-size company (1K Instances per year)	$50.07K	$100.14K	$150.21K	$200.28K	$250.36K
Dollars wasted by large size company (10K Instances per year)	$500.77K	$1.00M	$1.50M	$2.00M	$2.50M
Dollars wasted by X-Large size company (100K Instances per year)	$5.00M	$10.01M	$15.02M	$20.02M	$25.03M

Here are the assumptions I have used for our calculation:

1. Midsize enterprise would have their application running on 1000 EC2 instances. Large size enterprises would have their application running on 10,000 EC2 instances. Very large enterprises would have their application running on 100,000 EC2 instances.
2. For our calculation, I assume these enterprises are running on t2.2x.large 32G RHEL on-demand instances in US West (North California) EC2 instances. Cost of this type of EC2 instance is $ 0.5716/hour.

From all the below graphs you can notice the amount of money midsize, large size and very large size enterprise would be wasting due to garbage collection:

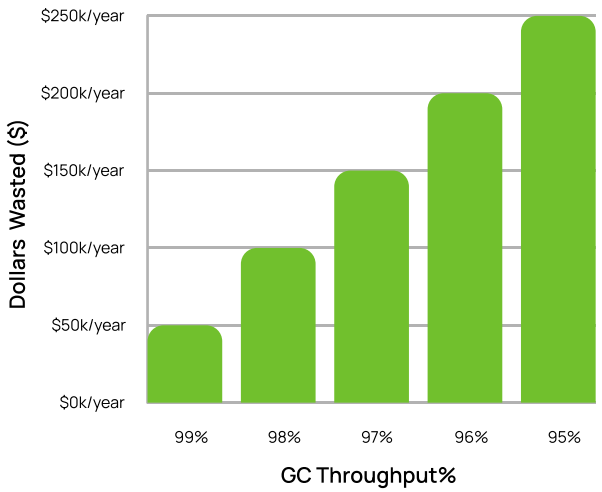


Fig 1: Money wasted by midsize enterprise due to Garbage Collection

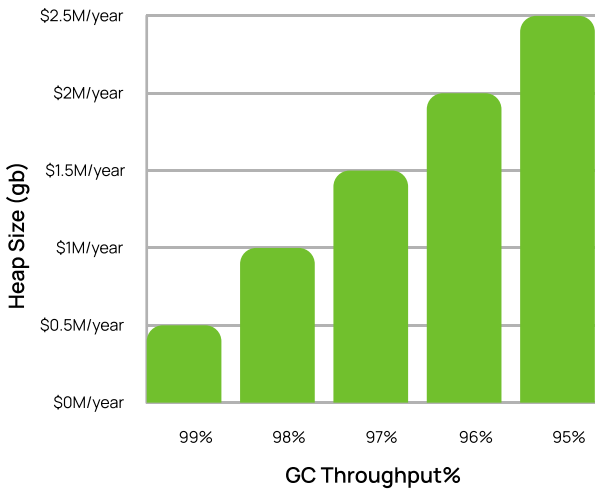


Fig 1.1: Money wasted by large size enterprise due to Garbage Collection

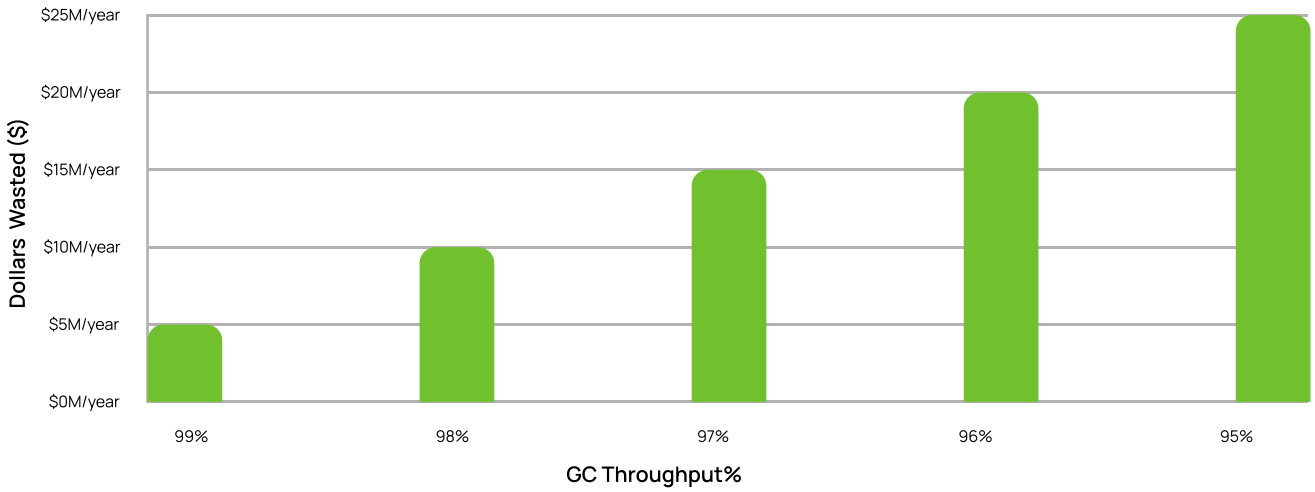


Fig 1.2: Money wasted by very large size enterprise due to Garbage Collection

Note 1: Here I have made calculations with assumptions GC throughput ranges only from 99% to 95%, several applications tend to have much poorer throughput. In such circumstances the amount of dollars wasted will be a lot more.

Note 2: I have used t2.2x.large 32G RHEL instance for calculation. Several enterprises tend to use machines with much larger capacity. In such circumstances, the amount of dollars wasted will be a lot more.

Counter arguments

Following are the counter arguments that can be placed against this study:

1. For my study I have used AWS EC2 on-demand instances, rather I could have taken dedicated instances for my calculations. Difference between on-demand and dedicated instances is only approximately 30%. So, the price point can fluctuate only by 30%. Still 70% of the above cost is outrageous.
2. Another argument can be AWS cloud is costly, I could have used some other cloud provider or bare metal machines or serverless architecture. Yes, these all are valid counter arguments, but they will shift the calculation only by a few percentages. But the case that garbage collection is wasting resources cannot be disputed.

You are open to articulate any other counter arguments in the comments section. I will try to respond to it.

Conclusion

In this post I have presented the case on how an exorbitant amount of money is wasted due to garbage collection. Unfortunate thing is: money is wasted even without our awareness. As applications developers/managers/executives we can do the following:

1. We should try to tune garbage collection performance , so that our applications starts to spend very less time on Garbage collection.
2. Modern applications tend to create tons of objects even to service simple requests. Here is our case study which shows the amount of memory wasted by the well celebrated spring boot framework. We can try to write efficient code, so that our applications tend to create very less number of objects to service the incoming requests. If our applications create a smaller number of objects, then very less garbage needs to be evicted from memory. If garbage is less, the pause time will also come down.

7. Simple & effective G1 GC tuning tips

G1 GC is an adaptive garbage collection algorithm that has become the default GC algorithm since Java 9. We would like to share a few tips to tune G1 Garbage collector to obtain optimal performance.

1. Maximum GC Pause time

Consider passing '-XX:MaxGCPauseMillis' argument with your preferred pause time goal. This argument sets a target value for maximum pause time. G1 GC algorithm tries it's best to reach this goal.

2. Avoid setting young gen size

Avoid setting the young generation size to a particular size (by passing '-Xmn, -XX:NewRatio' arguments). **G1 GC algorithm** modifies young generation size at runtime to meet its pause-time goals. If the young generation size is explicitly configured, then pause time goals will not be achieved.

3. Remove old arguments

When you are moving from other GC algorithms (CMS, Parallel, ...) to G1 GC algorithm, remove all the JVM arguments related to the old GC algorithm. Typically passing old GC algorithms arguments to G1 will have no effect, or it can even respond in a negative way.

4. Eliminating String duplicates

Because of inefficient programming practices, modern applications waste a lot of memory. Here is a case study showing memory wasted by the Spring Boot framework. One of the primary reasons for memory wastage is the duplication of string. A recent

study indicates that 13.5% of application's memory contains duplicate strings. G1 GC provides an option to eliminate duplicate strings when you pass the '-XX: +UseStringDeduplication' argument. You may consider passing this argument to your application if you are running on Java 8 update 20 and above. It has the potential to improve the overall application's performance. You can learn more about this property in this article.

5. Understand default settings

For tuning purposes, in the below table, we have summarized important G1 GC algorithm arguments and their default values:

G1 GC argument	Description
-XX:MaxGCPauseMillis=200	Sets a maximum pause time value. The default value is 200 milliseconds.
-XX:G1HeapRegionSize=n	Sets the size of a G1 region. The value has to be power of two i.e. 256, 512, 1024,.... It can range from 1MB to 32MB.
-XX:GCTimeRatio=12	Sets the total target time that should be spent on GC vs total time to be spent on processing customer transactions. The actual formula for determining the target GC time is [1 / (1 + GCTimeRatio)]. Default value 12 indicates target GC time to be [1 / (1 + 12)] i.e. 7.69%. It means JVM can spend 7.69% of its time in GC activity and remaining 92.3% should be spent in processing customer activity.
-XX:ParallelGCThreads=n	Sets the number of the Stop-the-world worker threads. If there are less than or equal to 8 logical processors then sets the value of n to the number of logical processors. Say if your server 5 logical processors then sets n to 5.If there are more than eight logical processors, set the value of n to approximately 5/8 of the logical processors. This works in most cases except for larger SPARC systems where the value of n can be approximately 5/16 of the logical processors.
-XX:GCTimeRatio=12	Sets the number of parallel marking threads. Sets n to approximately 1/4 of the number of parallel garbage collection threads (ParallelGCThreads).
-XX:InitiatingHeap OccupancyPercent=45	GC marking cycles are triggered when heap's usage goes beyond this percentage. The default value is 45%.

-XX:G1NewSizePercent=5	Sets the percentage of the heap to use as the minimum for the young generation size. The default value is 5 percent of your Java heap.
-XX:G1MaxNewSize Percent=60	Sets the percentage of the heap size to use as the maximum for young generation size. The default value is 60 percent of your Java heap.
-XX:G1OldCSetRegion ThresholdPercent=10	Sets an upper limit on the number of old regions to be collected during a mixed garbage collection cycle. The default is 10 percent of the Java heap.
-XX:G1ReservePercent=10	Sets the percentage of reserve memory to keep free. The default is 10 percent. G1 Garbage collectors will try to keep 10% of the heap to be free always.

6. Study GC Causes

One of the effective ways to optimize G1 GC performance is to study the causes triggering the GC and provide solutions to reduce them. Here are the steps to study the GC causes.

1. Enable GC log in your application. It can be enabled by passing following JVM arguments to your application during startup time:

Up to Java 8:

```
-XX:+PrintGCDetails -XX:+PrintGCDateStamps -Xloggc:{file-path}
```

From Java 9 and above:

```
-Xlog:gc*:file={file-path}
```

{file-path}: is the location where GC log file will be written

2. You can analyze the GC log file using free tools like GCeasy, Garbage Cat, HP Jmeter. These tools report the reasons that are triggering the GC activity. Below is the GC Causes table generated by GCeasy tool when G1 GC Log file was uploaded. Full analysis report can be **found here**.

Fig 1: G1 GC causes (except from GCeasy report)

Below are the solutions to address each of them.

6.1. Full GC – Allocation Failure

Full GC – Allocation failures happen for two reasons:

- Application is creating too many objects that can't be reclaimed quickly enough.
- When heap is fragmented, direct allocations in the Old generation may fail even when there is a lot of free space

Here are the potential solutions to address this problem:

1. Increase the number of concurrent marking threads by setting '-XX:ConcGCThreads' value. Increasing the concurrent marking threads will make garbage collection run fast.
2. Force G1 to start marking phase earlier. This can be achieved by lowering '-XX:InitiatingHeapOccupancyPercent' value. Default value is 45. It means the G1 GC marking phase will begin only when heap usage reaches 45%. By lowering the value, the G1 GC marking phase will get triggered earlier so that Full GC can be avoided.
3. Even though there is enough space in a heap, a Full GC can also occur due to lack of a contiguous set of space. This can happen because of a lot of humongous objects present in the memory (refer to section '6.3. G1 Humongous Allocation' in this article). A potential solution to solve this problem is to increase the heap region size by using the option '-XX:G1HeapRegionSize' to decrease the amount of memory wasted by humongous objects.

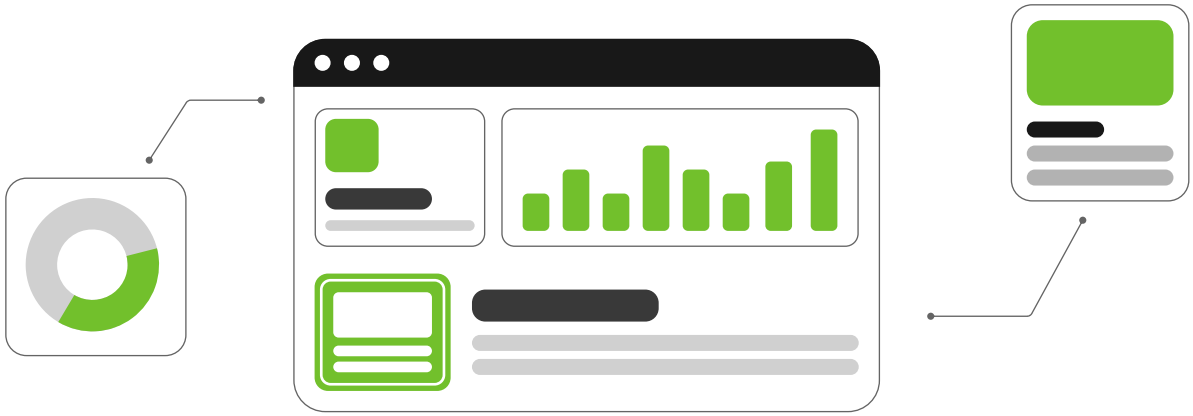
6.2. G1 Evacuation Pause or Evacuation Failure

When you see G1 Evacuation pause, then G1 GC does not have enough memory for either survivor or promoted objects or both. The Java heap cannot expand since it is already at its max. Below are the potential solutions to fix this problem:

1. Increase the value of the '-XX:G1ReservePercent' argument. Default value is 10%. It means the G1 garbage collector will try to keep 10% of memory free always. When you try to increase this value, GC will be triggered earlier, preventing the Evacuation pauses.
2. Start the marking cycle earlier by reducing the '-XX:InitiatingHeapOccupancyPercent'. The default value is 45. Reducing the value will start the marking cycle earlier. GC marking cycles are triggered when heap's usage goes beyond 45%. On the other hand, if the marking cycle is starting early and not reclaiming, increase the '-XX:InitiatingHeapOccupancyPercent' threshold above the default value.
3. You can also increase the value of the '-XX:ConcGCThreads' argument to increase the number of parallel marking threads. Increasing the concurrent marking threads will make garbage collection run fast.
4. If the problem persists you may consider increasing JVM heap size (i.e. -Xmx)

6.3. G1 Humongous Allocation

Any object that is more than half a region size is considered a "Humongous object". If the regions contain humongous objects, space between the last humongous object in the region and the end of the region will be unused. If there are multiple such humongous objects, this unused space can cause the heap to become fragmented. Heap fragmentation is detrimental to application performance. If you see several Humongous allocations, please increase your '-XX:G1HeapRegionSize'. The value will be a power of 2 and can range from 1MB to 32MB.



6.4. System.gc()

When 'System.gc()' or 'Runtime.getRuntime().gc()' API calls are invoked from your application, stop-the-world Full GC events will be triggered. You can fix this problem through following solutions:

a. **Search & Replace**
This might be a traditional method :-), but it works. Search in your application code base for 'System.gc()' and 'Runtime.getRuntime().gc()'. If you see a match, then remove it. This solution will work if 'System.gc()' is invoked from your application source code. If 'System.gc()' is going to be invoked from your 3rd party libraries, frameworks, or through external sources then this solution will not work. In such circumstance, you can consider using the option outlined in #b and #c.

b. **-XX:+DisableExplicitGC**
You can forcefully disable System.gc() calls by passing the JVM argument –'XX:+DisableExplicitGC' when you launch the application. This option will silence all the 'System.gc()' calls that are invoked from your application stack.

c. **-XX:+ExplicitGCInvokesConcurrentAndUnloadsClasses**
You can pass '-XX:+ExplicitGCInvokesConcurrent' JVM argument. When this argument is passed, GC collections run concurrently along with application threads to reduce the lengthy pause time.

c. **RMI**
If your application is using RMI, you can control the frequency in which 'System.gc()' calls are made. This frequency can be configured using the following JVM arguments when you launch the application:

```
-Dsun.rmi.dgc.server.gcInterval=n
-Dsun.rmi.dgc.client.gcInterval=n
```

The default value for these properties in

JDK 1.4.2 and 5.0 is 60000 milliseconds (i.e. 60 seconds)

JDK 6 and later release is 3600000 milliseconds (i.e. 60 minutes)

You might want to set these properties to a very high value so that it can minimize the impact.

For more details about 'System.gc()' calls, and it's GC impact you can refer **to this article.**

6.5 Heap Dump Initiated GC

'Heap dump Initiated GC' indicates that heap dump was captured from the application using tools like jcmd, jmap, profilers,... Before capturing the heap dump, these tools typically trigger full GC, which will cause long pauses.. We shouldn't be capturing heap dumps unless there is absolute necessity.

Conclusion

We hope you find this article useful. Best wishes to tune your application to get optimal performance.

8. CMS deprecated – next steps?

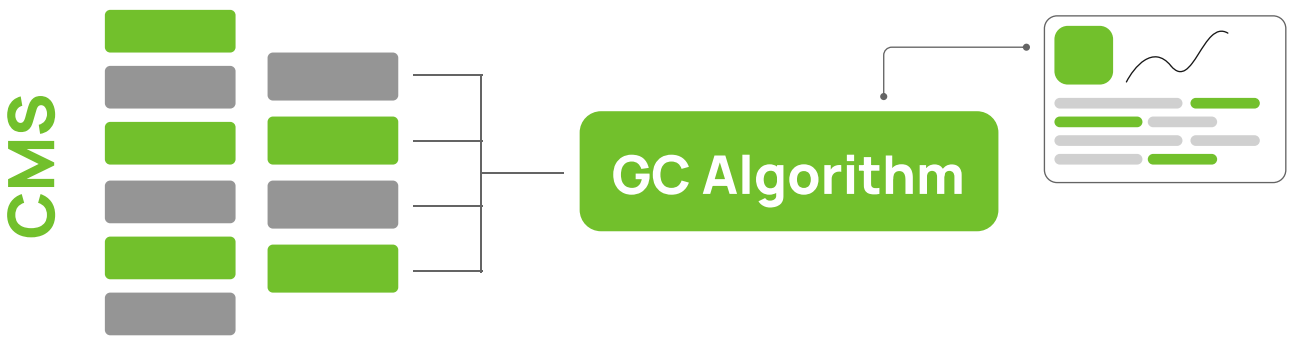
Popular Concurrent Mark Sweep (CMS) GC algorithm is deprecated in JDK 9. According to JEP-291, this decision has been made to reduce the maintenance burden of GC code base and accelerate new development.

Thus from Java 9, if you launch the application with -XX:+UseConcMarkSweepGC (argument which will activate CMS GC algorithm), you are going to see below WARNING message:

```
Java HotSpot(TM) 64-Bit Server VM warning: Option UseConcMarkSweepGC was deprecated in version 9.0 and will likely be removed in a future release.
```

Why CMS is deprecated?

If there are lot of baggage to carry, it's hard to move forward quickly. This is what happening in CMS case as well. CMS is highly configurable, sophisticated algorithm and thereby inherits a lot of complexities into GC code base in JDK. Only if JDK development team can simplify the GC code base, they can accelerate and innovate in GC arena. Below table summarizes the number of JVM arguments that can be passed to each GC algorithm.



GC Algorithm	JVM arguments (approximately)
Common to all	50
Parallel	6
CMS	72
G1	26
G1	8

There are around 50 GC related arguments can be passed to JVM, which are common to all GC algorithms. On top of these 50 arguments, just for CMS alone, you can pass 72 additional arguments. Way greater number of arguments than any other GC algorithms as summarized in the above table. Thus, you can see the coding complexity required by JDK team to support all these arguments.

What are the next steps if you are using CMS?

As I am writing this blog on Feb' 2019, I can see 3 different choices in front of us:

1. Switch to G1 GC algorithm
2. Switch to Z GC algorithm (Early access in JDK 11, 12)
3. Continue with CMS

Let's explore each option in this section.

1. **Switch to G1 GC algorithm**
   G1 GC has become default GC algorithm since java 9. So, you may consider moving your application to this algorithm. It may provide better performance characteristics than CMS GC algorithm. It's much easier to tune as there are comparatively a smaller number of arguments. Also, it provides options to eliminate duplicate strings from memory. If you can eliminate duplicate strings, it may help you to bringing down overall memory footprint.

2. **Switch to Z GC algorithm**
   Z GC is a scalable low-latency garbage collector. Its goal is to keep GC pause times less than 10ms. Early access of Z GC algorithm is available in java 11, 12. So if your application is running on java 11, 12. You may consider upgrading to Z GC algorithm. Our preliminary analysis of Z GC is showing excellent results.

3. **Continue with CMS**
   For certain applications, we have seen CMS to delivery spectacular results which aren't matched by G1 GC even after lot of tuning. So, if you have explored other two options and convinced CMS algorithm is the marriage made for your application in heaven :-), you can consider running with CMS algorithm itself. There are even arguments continuing to keep CMS alive in this OpenJDK JDK9-dev mailing list. On my personal experience, I am seeing the features and APIs which are deprecated in Java 1.1, are continuing to exist even in Java 12 (even after 20 years). It seems all deprecated APIs and features seems to survive (& never die). Thus, continuing to run on CMS is also an option. Of course, it's your call and your application stakeholders call.

Conclusion

Note that each application is unique and different. So, don't get carried away by the journals, literatures you find on the internet that talks about GC tuning/tweaking (including this article). When you instrument new GC setting, do thorough testing, benchmark performance characteristics, study these KPIs and then make a conscious decision.

9. Rotating GC Log Files

Garbage Collection logs are essential artifacts to optimize application's performance and trouble shoot memory problems. Garbage Collection logs can be generated in a particular file path by passing the "-Xloggc" JVM argument.

```
Example: -Xloggc:/home/GCEASY/gc.log
```

But the challenge to this approach is: whenever the application is restarted, old GC log file will be over-ridden by the new GC log file as the file path is same (i.e. /home/GCEASY/gc.log).

Thus you wouldn't be able to analyze the old GC logs that existed before restarting the application. Especially if the application has crashed or had certain performance problems then, you need old GC Logs for analysis.

Because of the heat of the production problem, most of the time, IT/DevOps team forgets to back up the old GC log file; A classic problem that happens again & again, that we all are familiar :-). Most human errors can be mitigated through automation and this problem is no exception to it.

A simple strategy to mitigate this challenge is to write new GC log contents in a different file location. In this article 2 different strategies to do that are shared with you:

1. Suffix timestamp to GC Log file

If you can suffix the GC log file with the time stamp at which the JVM was restarted then, GC Log file locations will become unique. Then new GC logs will not over-ride the old GC logs. It can be achieved as shown below:

```
"-XX:+PrintGCDetails -XX:+PrintGCDateStamps -Xloggc:/home/GCEASY/gc-%t.log"
```

'%t' suffixes timestamp to the gc log file in the format: 'YYYY-MM-DD_HH-MM-SS'. So generated GC log file name will start to look like: 'gc-2019-01-29_20-41-47.log'

This strategy has one minor drawback:

a. **Growing file size**
   Suppose if you don't restart your JVMs, then GC log file size can be growing to huge size. Because in this strategy new GC log files are created only when you restart the JVM. But this is not a major concern in my opinion, because one GC event only occupies few bytes. So GC log file size will not grow beyond a manageable point for most applications.

2. Use -XX:+UseGCLogFileRotation

Another approach is to use the JVM system properties:

```
"-XX:+PrintGCDetails -XX:+PrintGCDateStamps -Xloggc:/home/GCEASY/gc.log -XX:+UseGCLogFileRotation -
XX:NumberOfGCLogFiles=5 -XX:GCLogFileSize=2M"
```

When '-XX:-UseGCLogFileRotation' is passed GC log rotation is enabled by the JVM itself.

'-XX:NumberOfGClogFiles' sets the number of files to use when rotating logs, must be >= 1. The rotated log files will use the following naming scheme, <filename>.0, <filename>.1, …, <filename>.n-1.

'-XX:GCLogFileSize' defines the size of the log file at which point the log will be rotated, must be >= 8K

But this strategy has few challenges:

a. **Losing old GC Logs**
   Suppose if you had configured -XX:NumberOfGCLogFiles=5 then, over a period of time, 5 GC log files will be created:

   gc.log.0 — oldest GC Log content
   gc.log.1
   gc.log.2
   gc.log.3
   gc.log.4 — latest GC Log content

   Most recent GC log contents will be written to 'gc.log.4' and old GC log content

will be present in 'gc.log.0'.

When the application starts to generate more GC logs than the configured '-XX:NumberOfGCLogFiles' in this case 5, then old GC log contents in gc.log.0 will be deleted. New GC events will be written to gc.log.0. It means you will end up not having all the generated GC logs. You will loose the visibility of all events.

b. **Mixed-up GC Logs**
Suppose application has created 5 gc log files i.e.

gc.log.0
gc.log.1
gc.log.2
gc.log.3
gc.log.4

then, let's say you are restarting the application. Now new GC logs will be written to gc.log.0 file and old GC log content will be present in gc.log.1, gc.log.2, gc.log.3, gc.log.4 i.e.

gc.log.0 — GC log file content after restart
gc.log.1 — GC log file content before restart
gc.log.2 — GC log file content before restart
gc.log.3 — GC log file content before restart
gc.log.4 — GC log file content before restart

So your new GC log contents get mixed up with old GC logs. Thus to mitigate this problem you might have to move all the old GC logs to a different folder before you restart the application.

c. **Forwarding GC logs to central location**
In this approach, current active file to which GC logs are written is marked with extension ".current". Example, if GC events are currently written to file 'gc.log.3' it would be named as: 'gc.log.3.current'.
If you want to forward GC logs from each server to a central location, then most DevOps engineers uses 'rsyslog'. However this file naming convention poses significant challenge to use 'rsyslog', as described in this blog.

c. **Tooling**
   Now to analyze the GC log file using the GC tools such as (gceasy.io, GCViewer….), you will have to upload multiple GC log files instead of just one single GC Log file.

Conclusion

You can debate on which approach you want to take for rotating GC log files, but don't debate on whether to rotate the GC log files or not. It will come very handy when need comes. You never know when need comes.

10. Sys time greater than User time Pattern

Time taken by every single GC event is reported in the GC log. In every GC event, there are 'user', 'sys', and 'real' time. What does these time mean? What is the difference between them?

- 'real' time is the total elapsed time of the GC event. This is basically the time that you see on the clock.
- 'user' time is the **CPU time spent in user-mode code** (outside the kernel)
- 'Sys' time is the amount of **CPU time spent in the kernel**. This means executing CPU time spent in system calls within the kernel, as opposed to library code, which is still running in user-space.

To learn more about these times, please refer to this article.

In normal (all most all) GC events, user time will be greater than sys time. It's because, in a GC event, most of the time is spent within the JVM code and only very less time is spent in the kernel. But in certain circumstances, you might see sys time to be greater than user time.

Example

```
[Times: user=0.04 sys=0.35, real=0.42 secs]
```

Here you can notice the sys time to be 0.35 seconds which is considerably higher than user time 0.04 seconds.

If you observe multiple occurrences of this scenario in your GC log then it might be indicative of one of the following problems:

1. Operating System problem

Operating System exceptions such as page faults, misaligned memory references, and floating-point exceptions consume large amount of system time. Make sure your OS is running with proper patches, upgrades, and sufficient CPU/memory/disk space.

2. VM related Problem

If your application is running in a virtualized environment, may be because of nature of the emulation sys time can be higher than user time. Make sure virtualized environment is NOT OVERLOADED with too many environments and also ensure that there are adequate resources available in the Virtual Machine for your application to run

3. Memory constraint

In Linux operating system, JVM and OS will request large pages (like in the magnitued of 2mb size/page). If Operatin system can not find contiguous free space to allocate 2mb page, then operating system will stop all stop all the process that is running and starts moving around the data to find contiguous free space. If OS does this then 'sys' will be typically higher than real time.

If this turns out to be case either allocate sufficient memory on the machine or reduce number of processes running on the machine.

4. Disk I/O Pressure

JVM creates and writes statistics about safepoints and garbage collection events in the /tmp/hsperfdata_(username) file. This file gets updated when GC events run. Occasionally linux kernel threads blocks the GC threads from updating this file when there is heavy disk I/O. Thus very heavy disk I/O activity can increase GC pause time. When this problem happen either real time will be much greater than user + Sys time or sys time will be higher than user time.

If this turns out to be case, try to reduce disk I/O activity. You can measure disk I/O activity using **lsof**.

11. Real time greater than User and Sys time Pattern

Time taken by every single GC event is reported in the GC log. In every GC event, there are 'user', 'sys', and 'real' time. What does these time mean? What is the difference between them?

- 'real' time is the total elapsed time of the GC event. This is basically the time that you see in the clock.
- 'user' time is the **CPU time spent in user-mode code** (outside the kernel).
- 'Sys' time is the amount of **CPU time spent in the kernel**. This means executing CPU time spent in system calls within the kernel, as opposed to library code, which is still running in user-space.

To learn more about these times, please refer to this article.

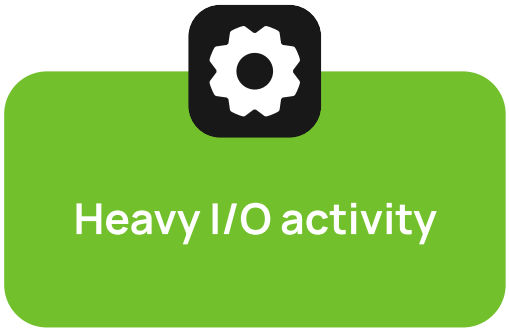
In normal (all most all) GC events, real time will be less than user + sys time. It's because of multiple GC threads work concurrently to share the work load, thus real time will be less than user + sys time. Say user + sys time is 2 seconds. If 5 GC threads are concurrently working then real time should be some where in the neighbourhood of 400 milliseconds (2 seconds / 5 GC threads).

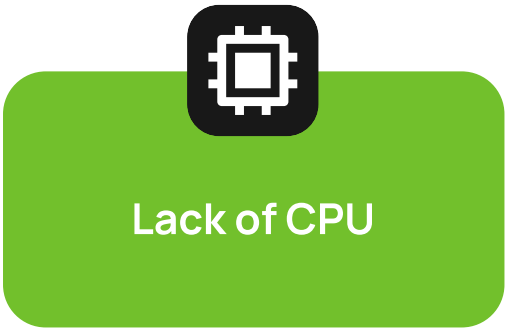
But in certain circumstances you might see real time to be greater than user + sys time.

Example

```
[Times: user=0.20 sys=0.01, real=18.45 secs]
```

If you notice multiple occurrences of this scenario in your GC log then it might be indicative of one of the following problems:





1. Heavy I/O activity

When there is heavy I/O activity (i.e. networking/disk access/user interaction) on the server then real time tend to spike up to a great extent. As part of GC logging, your application makes a disk access. If there is a heavy I/O activity on the server then GC event might be stranded, causing spiked up real time.

Note: Even if your application is not causing the heavy I/O activity, the other process on the server may cause the heavy I/O activity leading to the high real time. Here is a brilliant article from LinkedIn engineers, explaining the GC problem they experienced because of high I/O activity.

You can monitor I/O activity on your server, using the sar (System Activity Report), in Unix.

Example

```
sar -d -p 1
```

Above commands reports the reads/sec and writes/sec made to the device every 1 second. For more details on 'sar' command refer to this tutorial.

If you notice high I/O activity on your server then you can do one of the following to fix the problem:

a. If high I/O activity is caused by your application, then optimize your application's I/O activity.b. Eliminate the processes which are causing high I/O activity on the serverc. Move your application to a different server where I/O activity is less

2. Lack of CPU

If multiple processes are running on your server and if your application doesn't get enough CPU cycles to run, it will start to wait. When the application starts to wait then real time will be considerably higher than user + sys time.

You can use the commands like 'top' or monitoring tools (nagios, newRelic, AppDynamics…) to observe the CPU utilization on the server. If you notice CPU utilization to be very high and your process doesn't get enough cycles to run then you can do one of the following to fix the problem:

a. Reduce the number of processes that is running on the server, so that your application gets fair chance to runb. Increase the CPU capacity – if you are in AWS cloud (or equivalent), move to a bigger instance type which has more CPU cores

c. Move your application to a new server where there is adequate CPU capacity

12. How to take Thread dumps? – 8 options

Thread dumps are vital artifacts to diagnose CPU spikes, deadlocks, poor response times, memory problems, unresponsive applications, and other system problems. There are great online thread dump analysis tools such as http://fastthread.io/, which can analyse and spot problems. But to those tools you need provide proper thread dumps as input. Thus in this article, I have documented 8 different options to capture thread dumps.

1. jstack

'jstack' is an effective command line tool to capture thread dumps. jstack tool is shipped in JDK_HOMEbin folder. Here is the command that you need to issue to capture thread dump:

```
jstack -l <pid> > <file-path>
```

where

pid: is the Process Id of the application, whose thread dump should be captured

file-path: is the file path where thread dump will be written in to.

Example

```
jstack -l 37320 > /opt/tmp/threadDump.txt
```

As per the example thread dump of the process would be generated in /opt/tmp/threadDump.txt file.

Jstack tool is included in JDK since Java 5. If you are running in older version of java,

consider using other options

2. Kill -3

In major enterprises for security reasons only JREs are installed on production machines. Since jstack and other tools are only part of JDK, you wouldn't be able to use jstack tool. In such circumstances 'kill -3' option can be used.

```
kill -3 <pid
```

where

pid: is the Process Id of the application, whose thread dump should be captured

Example

```
Kill -3 37320
```

When 'kill -3' option is used thread dump is sent to the standard error stream. If you are running your application in tomcat, thread dump will be sent into <TOMCAT_HOME>/logs/catalina.out file.

Note: To my knowledge this option is supported in most flavours of *nix operating systems (Unix, Linux, HP-UX operating systems). Not sure about other Operating systems.

3. JVisualVM

Java VisualVM is a graphical user interface tool that provides detailed information about the applications while they are running on a specified Java Virtual Machine (JVM). It's located in JDK_HOMEbinjvisualvm.exe. It's part of Sun's JDK distribution since JDK 6 update 7.s

Launch the jvisualvm. On the left panel, you will notice all the java applications that are running on your machine. You need to select your application from the list (see the red color highlight in the below diagram). This tool also has the capability to capture thread dumps from the java processes that are running on the remote host as well.

Fig 1: Java Visual VM

Now go to the “Threads” tab. Click on the “Thread Dump” button as shown in the below image. Now Thread dumps would be generated.

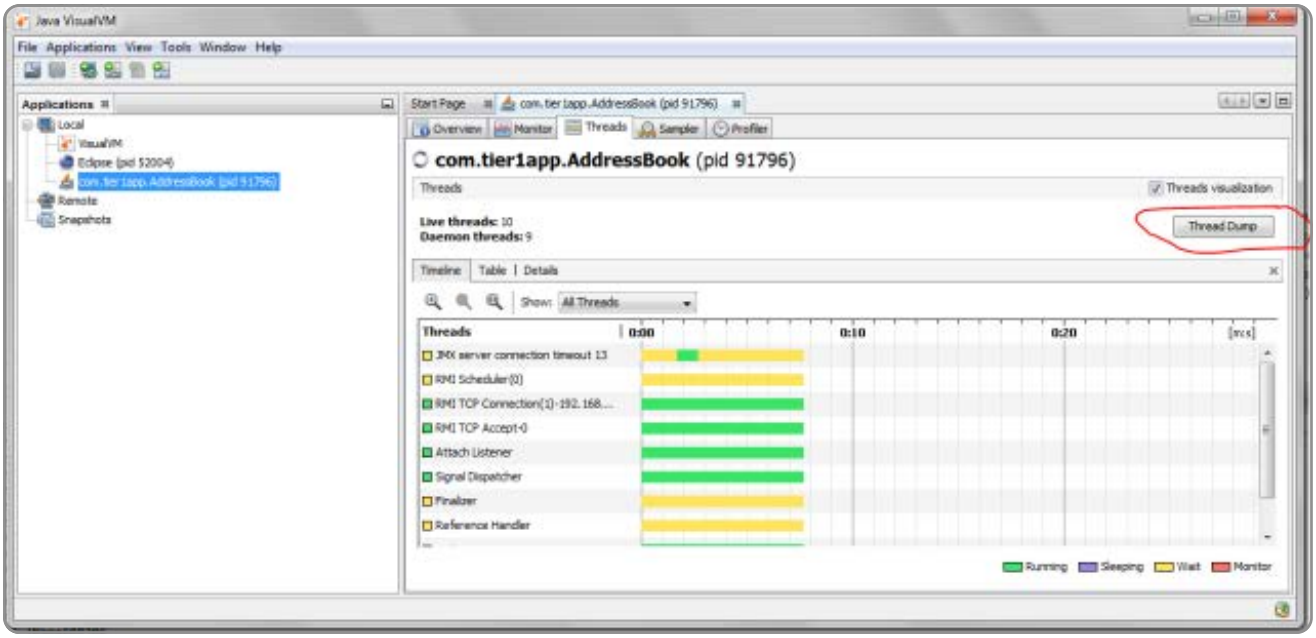


Fig 1.1: Highlighting “Thread Dump” button in the “Threads” tab

4. JMC

Java Mission Control (JMC) is a tool that collects and analyze data from Java applications running locally or deployed in production environments. This tool has been packaged into JDK since Oracle JDK 7 Update 40. This tool also provides an option to take thread dumps from the JVM. JMC tool is present in JDK_HOMEbinjmc.exe

Once you launch the tool, you will see all the Java processes that are running on your local host. Note: JMC also can connect with java processes running on the remote host. Now on the left panel click on the “Flight Recorder” option that is listed below the Java process for which you want to take thread dumps. Now you will see the “Start Flight Recording” wizard, as shown in the below figure.

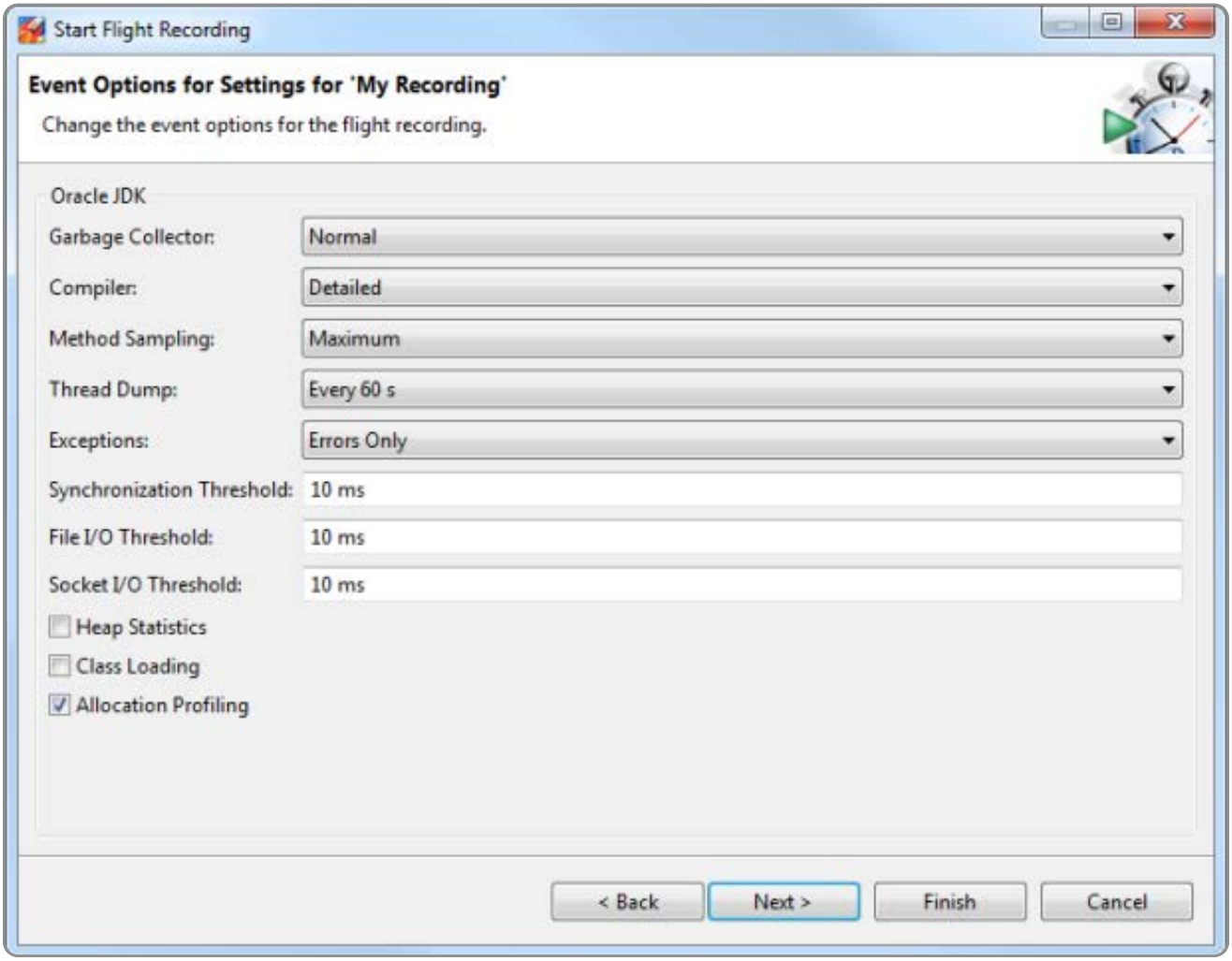


Fig 2: Flight Recorder wizard showing ‘Thread Dump’ capture option.

Here in the “Thread Dump” field, you can select the interval in which you want to capture thread dump. As per the above example, every 60 seconds thread dump will be captured. After the selection is complete start the Flight recorder. Once the recording is complete, you will see the thread dumps in the “Threads” panel, as shown in the figure below.

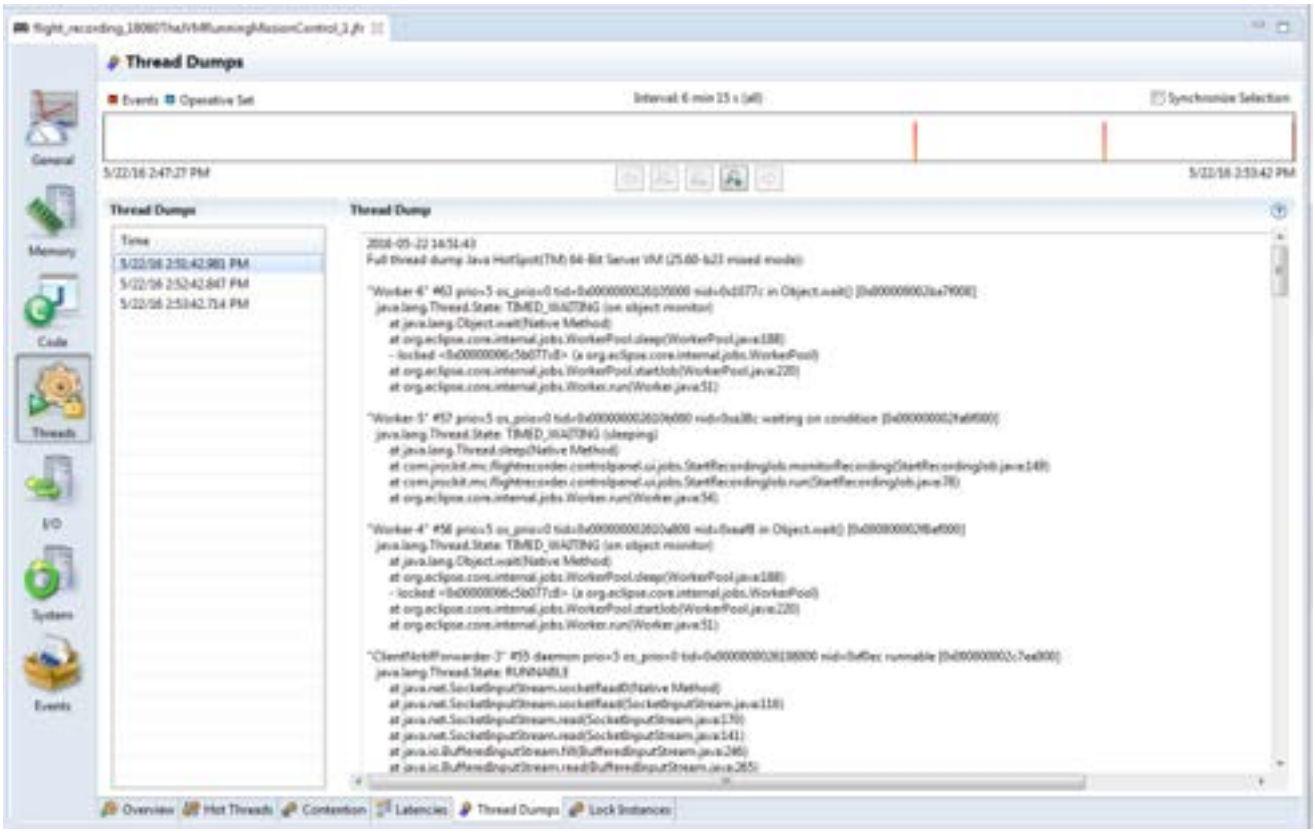


Fig 2.1: Showing captured 'Thread Dump' in JMC.

5. Windows (Ctrl + Break)

This option will work only in Windows Operating system.

- Select command line console window in which you have launched application.
- Now on the console window issue the "Ctrl + Break" command.

This will generate thread dump. A thread dump will be printed on the console window itself.

Note 1: in several laptops (like my Lenovo T series) "Break" key is removedJ. In such circumstance, you have to google to find the equivalent keys for the "Break." In my case, it turned out that "Function key + B" is the equivalent of "Break" key. Thus I had to use "Ctrl + Fn + B" to generate thread dump.s

Note 2: But one disadvantage with the approach is thread dump will be printed on the windows console itself. Without getting the thread dump in a file format, it's hard to use the thread dump analysis tools such as **http://fastthread.io**. Thus when you launch the application from the command line, redirect the output a text file i.e. Example if you are launching the application "SampleThreadProgram", you would issue the command:

```
java -classpath . SampleThreadProgram
```

instead, launch the SampleThreadProgram like this

```
java -classpath . SampleThreadProgram
```

Thus when you issue “Ctrl + Break” thread dump will be sent to **C:workspacethreadDump.txtfile.**

6. ThreadMXBean

Since JDK 1.5 ThreadMXBean has been introduced. This is the management interface for the thread system in the Java Virtual Machine. Using this interface also you can generate thread dumps. You only have to write few lines of code to generate thread dumps programmatically. Below is a skeleton implementation on ThreadMXBean implementation, which generates Thread dump from the application.

```
public void  dumpThreadDump() {
    ThreadMXBean threadMxBean = ManagementFactory.getThreadMXBean();
    for (ThreadInfo ti : threadMxBean.dumpAllThreads(true, true)) {
      System.out.print(ti.toString());
    }
  }
```

7. APM Tool – App Dynamics

Few Application Performance Monitoring tools provide options to generate thread dumps. If you are monitoring your application through App Dynamics (APM tool), below are the instructions to capture thread dump:

1. Create an action, selecting Diagnostics→Take a thread dump in the Create Action window.

2. Enter a name for the action, the number of samples to take, and the interval between the thread dumps in milliseconds.

3. If you want to require approval before the thread dump action can be started, check the Require approval before this Action checkbox and enter the email address of the individual or group that is authorized to approve the action. See Actions Requiring Approval for more information.

4. Click OK.

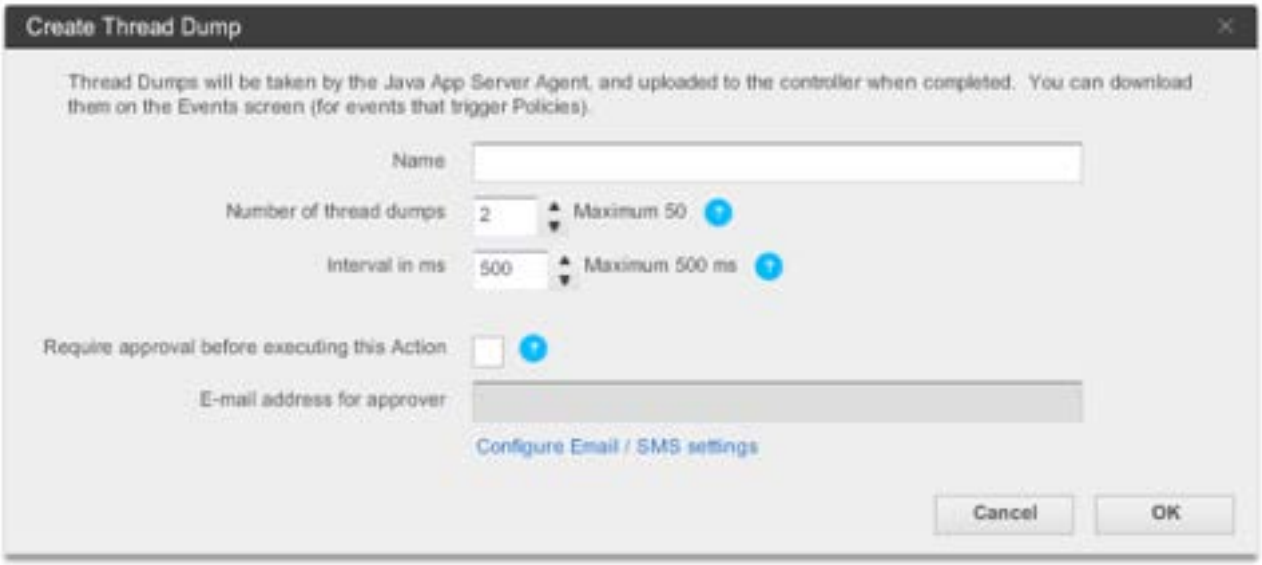


Fig 3: App dynamics thread dump capturing wizard

8. JCMD

The jcmd tool was introduced with Oracle's Java 7. It's useful in troubleshooting issues with JVM applications. It has various capabilities such as identifying java process Ids, acquiring heap dumps, acquiring thread dumps, acquiring garbage collection statistics.

Using the below JCMD command you can generate thread dump:

```
jcmd <pid> Thread.print > <file-path>
```

where

pid: is the Process Id of the application, whose thread dump should be captured

file-path: is the file path where thread dump will be written in to.

Example

```
jcmd 37320 Thread.print > /opt/tmp/threadDump.txt
```

As per the example thread dump of the process would be generated in /opt/tmp/threadDump.txt file.

Conclusion

Even though 8 different options are listed to capture thread dumps, IMHO, 1. 'jstack' and 2. 'kill -3' and 8. 'jcmd' are the best ones. Because they are:

a. Simple (straightforward, easy to implement)

b. Universal (works in most of the cases despite OS, Java Vendor, JVM version, …)