Java Performance Tuning

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- ❑ Specification
- ❑ Framework
- ❑ Pattern

Specification

Provides API , standards, recommended practices, codes
And technical publications, reports and studies.

JCP - Java Community Process
JSR - Java Specification Request

JSRs directly relate to one or more of the Java platforms.

There are 3 collections of standards that comprise the three Java editions:

Standard, Enterprise and Micro

Java EE (47 JSRs)
The Java Enterprise Edition offers APIs and tools for developing multitier enterprise applications.

Java SE (48 JSRs)
The Java Standard Edition offers APIs and tools for developing desktop and server-side enterprise applications.

Java ME (85 JSRs)
Java ME technology, Java Micro Edition, designed for embedded systems (mobile devices)

JSR 168,286,301 - Portlet Applications

JSR 127,254,314 - JSF

JSR 220 - Ejb3.0 & Jpa   JSR 318 – EJB 3.1

JSR 340: Java Servlet 3.1 Specification

JSR 250 - Common Annotations for java

JSR 303 - Java Bean Validations

JSR 224- Jax-ws

JSR 311,370 - Jax-RS

JSR 299 - Context & DI

JSR 330 – DI

JSR-303 - Bean Validations

JSR208,312 – JBI (Java Business Integration)

A **framework** is a body of pre-written code that acts as a template or skeleton, which a developer can then use to create an application by filling in their own code as needed to get the app to work as they intend it to.

A framework is created to be used over and over so that developers can program their application without the manual overhead of creating every line of code from scratch.

Java frameworks are bodies of prewritten code used by developers to create apps using the Java programming language.

A Java framework is a type of framework specific to the Java programming language, used as a platform for developing software applications and Java programs.

Ex: Spring, Hibernate, Spring Boot etc.,

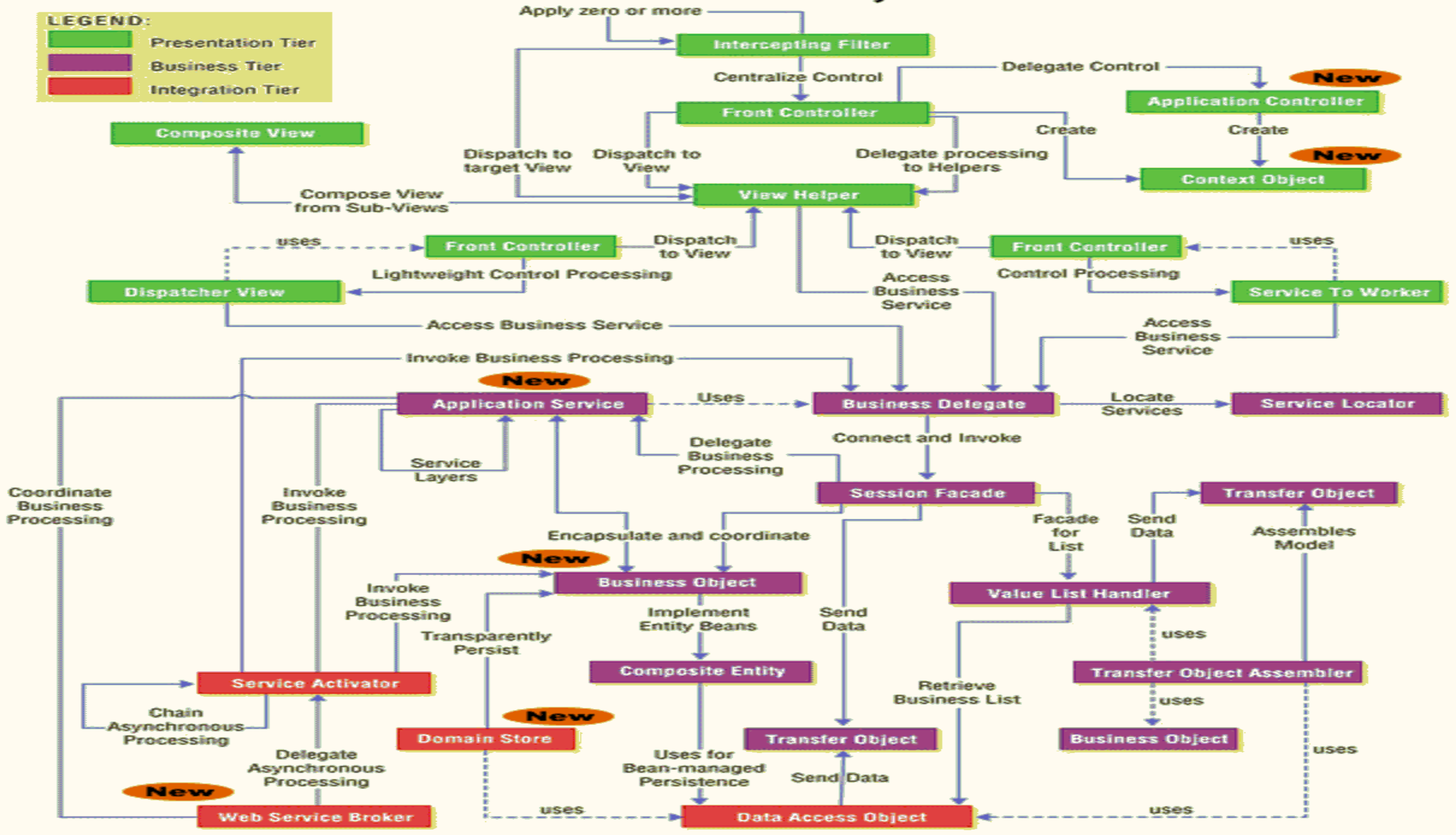
Design Pattern

In software engineering, a software design pattern is a general, reusable solution to a commonly occurring problem within a given context in software design

GOF Design Patterns

		Purpose		
		Creational	Structural	Behavioral
SCOPE	Class	Factory Method	Class Adapter	Interpreter Template Method
	OBJECT	Abstract Factory Builder Prototype Singleton	Bridge Composite Decorator Façade Flyweight Object Adapter Proxy	Chain of Responsibility Command Iterator Mediator Memento Observer State Strategy Visitor

Core J2EE Patterns, 2nd Edition



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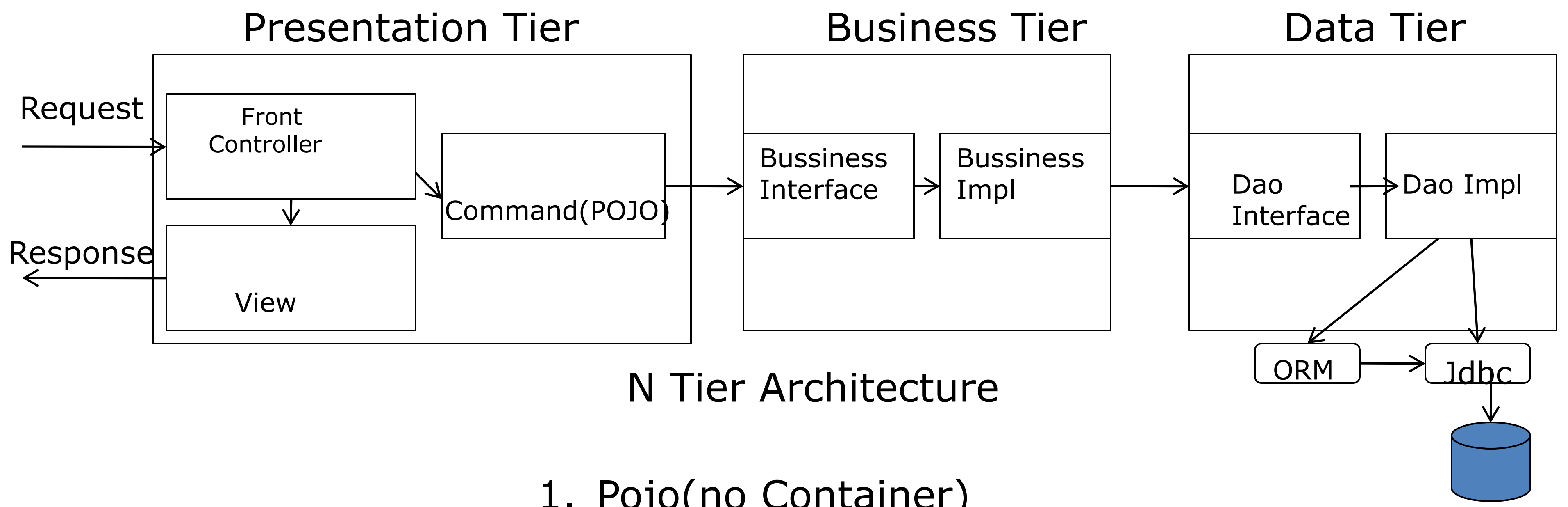
RESTful API Patterns

- ❑ Statelessness
- ❑ Content Negotiation
- ❑ URI Templates
- ❑ Pagination
- ❑ Versioning
- ❑ Authorization
- ❑ API facade
- ❑ Discoverability
- ❑ Idempotent
- ❑ Circuit breaker

Microservice Patterns:

- ❑ API gateway
- ❑ Service registry
- ❑ Circuit breaker
- ❑ Messaging
- ❑ Database per Service
- ❑ Access Token
- ❑ Saga
- ❑ Event Sourcing & CQRS



N Tier Architecture

1. Servlet/jsp
2. MVC
   Struts
   JSF
   Flex
   Gwt
   Spring MVC
   ...

1. Pojo(no Container)
2. Ejb 2.x(HW Container)
   -Session Bean
   -Mdb
3. Pojo + LW Container
   - Spring
   - Microcontainer
   - Xwork
4. Ejb3.0

1. Jdbc(pojo)
2. Ejb 2.x – Entity Bean
3. Jdo
4. ORM
   - Hibernate
   - Kodo
   - Toplink
   - MyBatis
5. JPA

+ Spring Templates

Performance - Tuning

Define the requirements

- ❑ Target a specific area for improvement.
- ❑ Quantify or at least suggest an indicator of progress.
- ❑ The goal must be realistic, feasible

Measure don’t guess

Need a tool to measure and optimize your code?

Some of the good tools are :

- ➢Jstat
- ➢JMC
- ➢Jvisualvm
- ➢Jconsole
- ➢Jprofiler
- ➢Dynatrace , AppDynamics, Your Kit Java Profiler
- ➢Spring Boot Actuator

One thing at a time

Don’t think that having lots of developers optimize code will lead to better performance.

Wrong! Changing lot of things in parallel can have strange results.

Developer **A** could have done a good optimization but at the same time developer **B** deploys code that makes things worst

– so nobody will see the optimization of developer **A**.

Automate

Most of the times, developers have no time for performance testing and analysis in most cases. Especially because every change can lead to a decrease of performance.

Therefore It is recommend to automate the process of analyzing performance.

What you need is a Continuous Delivery Pipeline which includes profiling and performance analysis of acceptance and load tests and a performance report for each build/release – including comparison of performance metrics for two builds.

.

Only optimize if needed

When is tuning needed?

The answer is: When the requirements are not met. What this tip means is that we should stop tuning if the requirements are met.

In many cases there is a rule that the more you optimize your application, the harder it is and the more you have to change your code.

In many cases “better performance” therefore also is in conflict with “better maintainability”. So stop tuning when the requirements are met – even if you have the ambition to optimize the application to the limit.

Learn to parallelize

With more CPUs on the boards that have more and more Cores we have to develop applications that are able to utilize these architecture.

Knowledge of Threads, Concurrency, Locking etc. will get most performance and throughput out of a system.

Sometimes it can also be interesting to look at specialized programming languages like Scala for better built-in concurrency support.

Learn to scale

Vertical scalability (or **scale up**) is maybe the easiest way to scale a system – you just put more hardware into one box. But this approach is limited, as normally you cannot put unlimited CPUs and RAM into one box. In many cases (like mainframes) this is also a very expensive approach.

Horizontal scalability (or **scale out**) means to run the application on more than one box. This approach is more scalable and cheaper but also more complex from an application point of view: We have to deal with clustering, replication of data and new approaches to store and scale data.

✓ **Virtualization or Cloud** infrastructure can be even more complicated because the scale out process is automated and bidirectional – which means that hardware is not only added on demand but also removed if not needed.

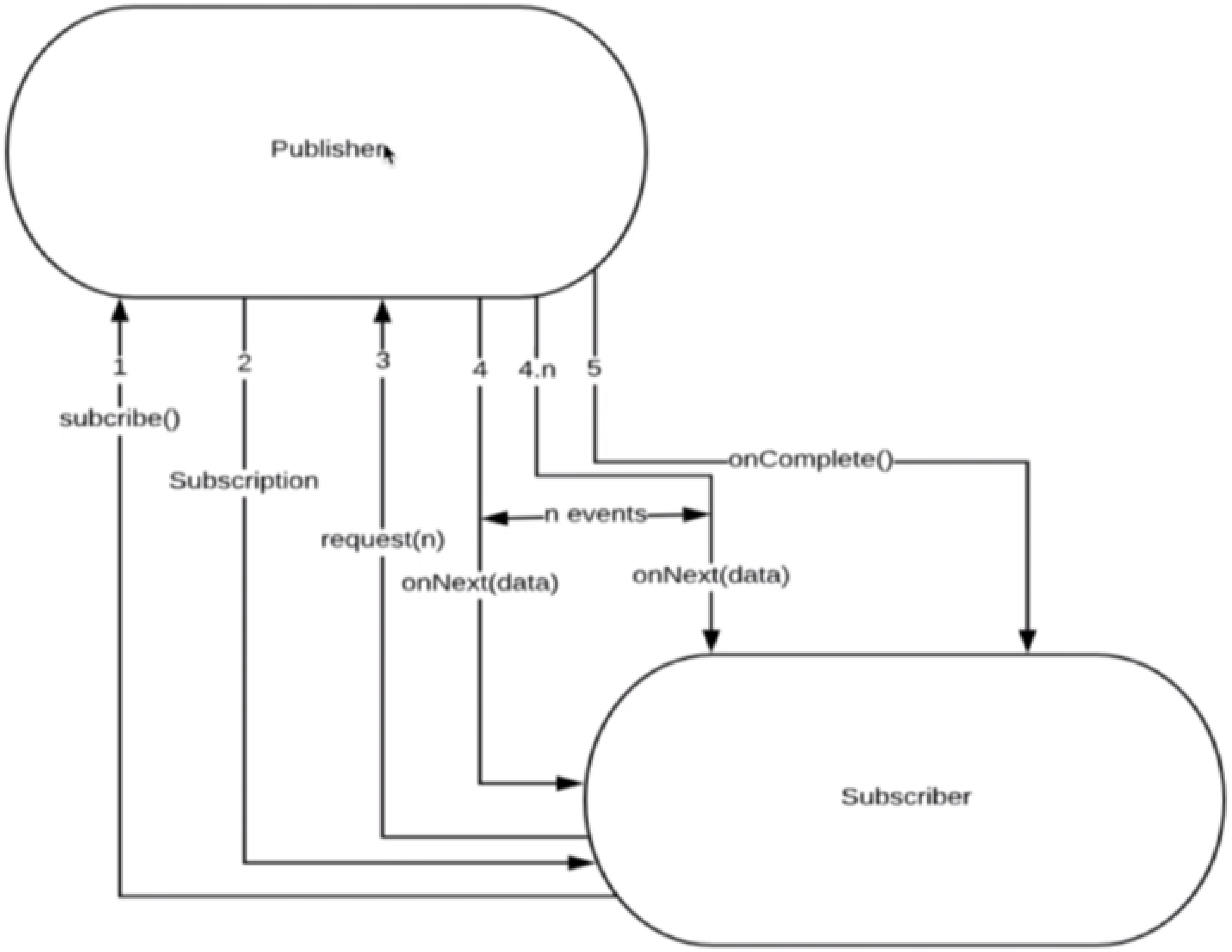
✓ **Map/Reduce frameworks** like Hadoop are kind of a mixture of parallelism and scalability for an application, because you split your application logic into pieces that can be run in parallel on many nodes. This can also help to improve performance and scalability of some problem domains.

✓ **Reactive Programming**

The term, “reactive,” refers to programming models that are built around reacting to changes.

It is a new programming paradigm, built around publisher-subscriber pattern (observer pattern), asynchronous and Non Blocking, where the Data flows as an Event/Message Driven stream, Functional Style code (not Imperative) and Back Pressure on Data Streams.

Publisher/Subscriber Event Flow

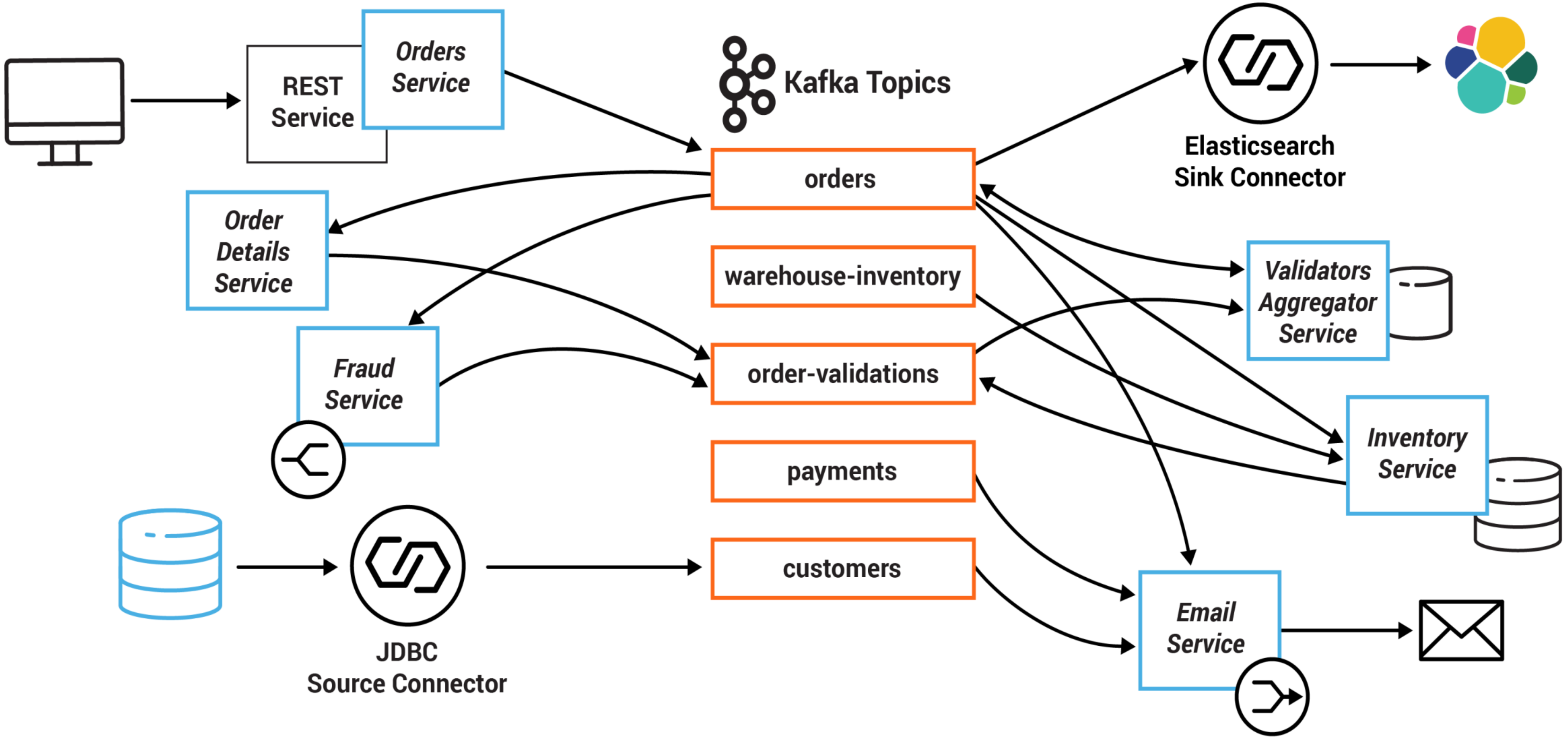


Streaming platform

Stream is an unbounded, continuous real-time flow of records.

It has three key capabilities:

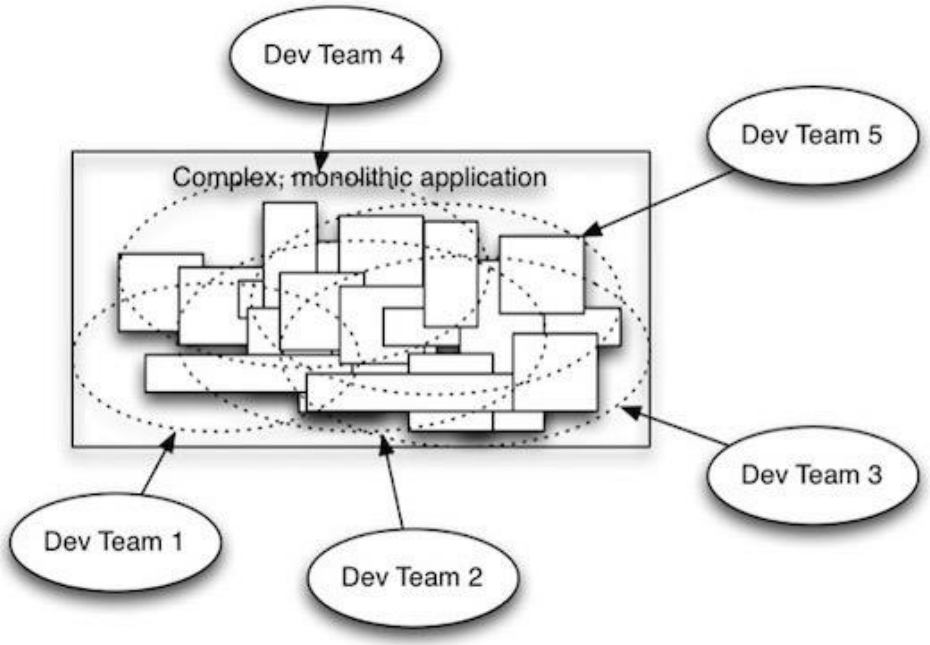
- Streams of records are stored in a fault-tolerant durable way.
- Process streams of records as they occur, almost real-time with low latency.
- Publish and subscribe to streams of records, similar to a message queue or enterprise messaging system.


REST Service
Orders Service
Kafka Topics
orders
warehouse-inventory
order-validations
payments
customers
Elasticsearch Sink Connector
Order Details Service
Fraud Service
Validators Aggregator Service
Inventory Service
Email Service
JDBC Source Connector

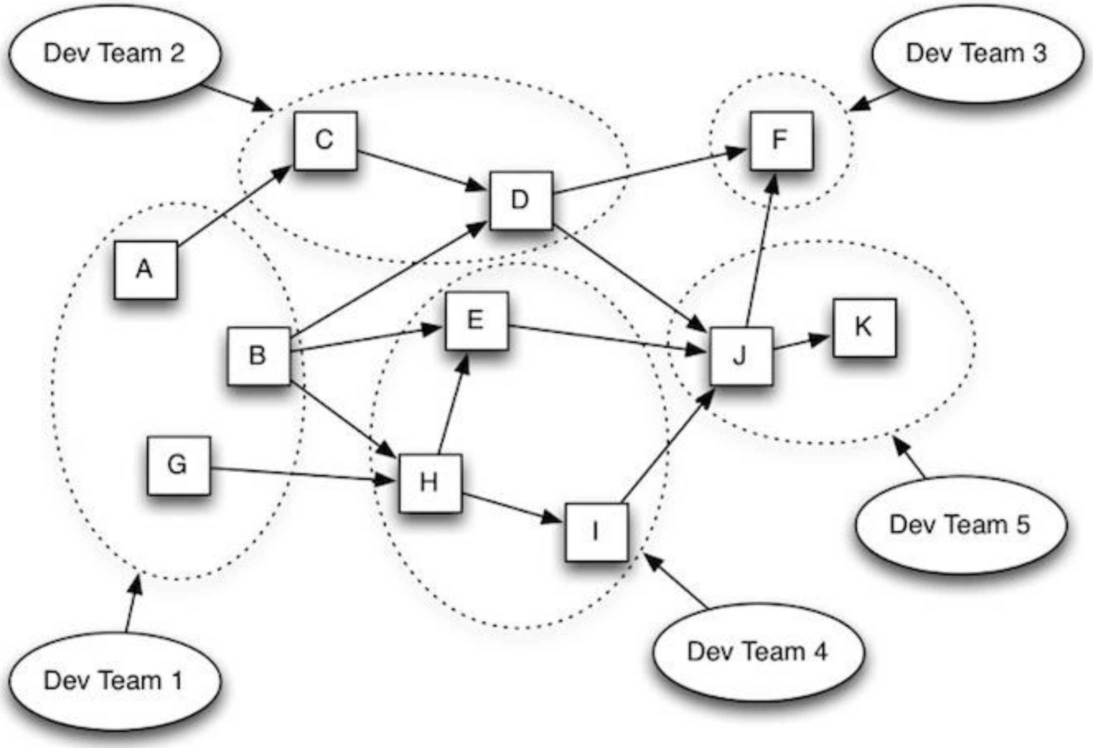
✓**Microservices** :

Microservice architecture is a method of developing software applications as a suite of independently deployable, small, modular services in which each service runs a unique process and communicates through a well-defined, lightweight mechanism to serve a business goal.

Cloud Native Application, The Twelve-Factor App



Monolithic Application



Microservices Architecture

Cache it

Memory is cheap these days and retrieving data from disks or via network (distributed systems) is still expensive. So caching is one of the things you have to keep in mind when you want to get performance.

Ex : Hibernate L1 & L2 Caches, WebServer Cache

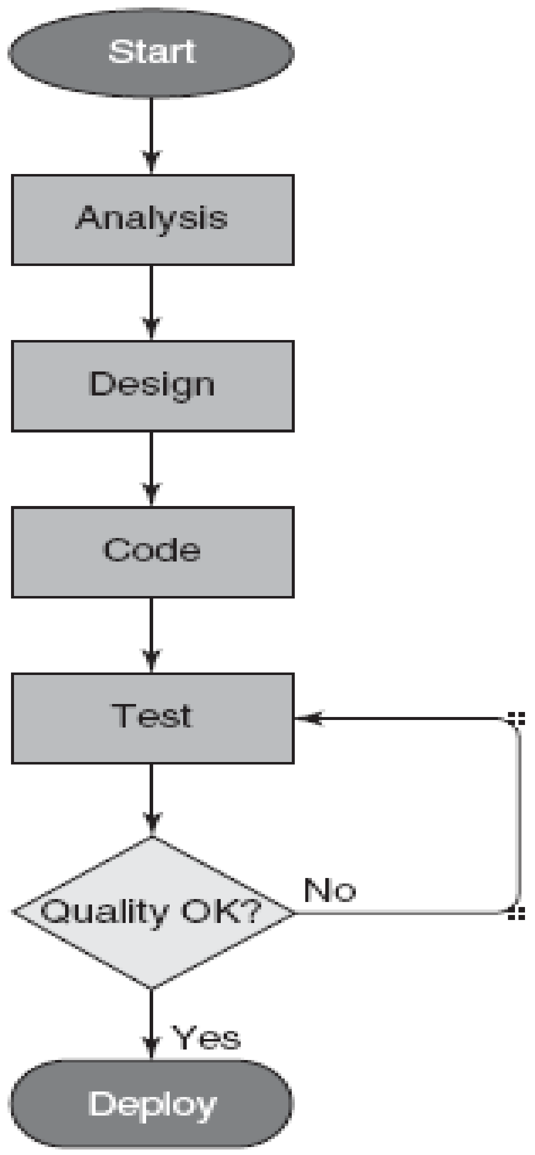
Right Abstraction

This is also a simple rule: Don’t be too abstract in your application design.

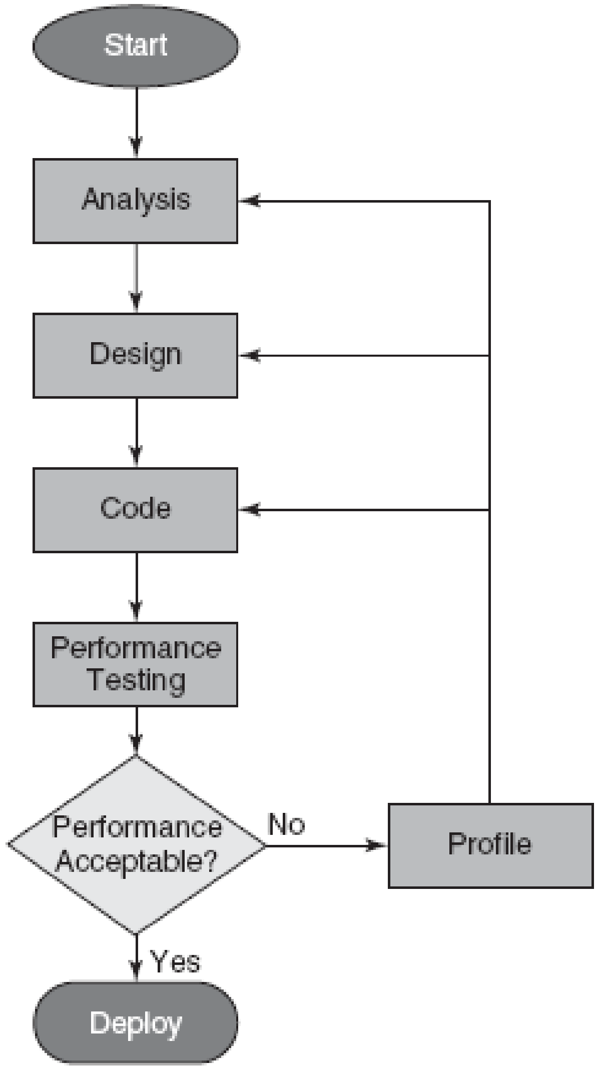
E.g. don’t create a layer above your database that abstracts away all special features of Oracle/DB2/MSSQL/……this will make your application slow.

ORM, Data Repositories etc.,

Traditional Software Development Process


Start
Analysis
Design
Code
Test
Quality OK?
No
Yes
Deploy

Performance Process Software Development

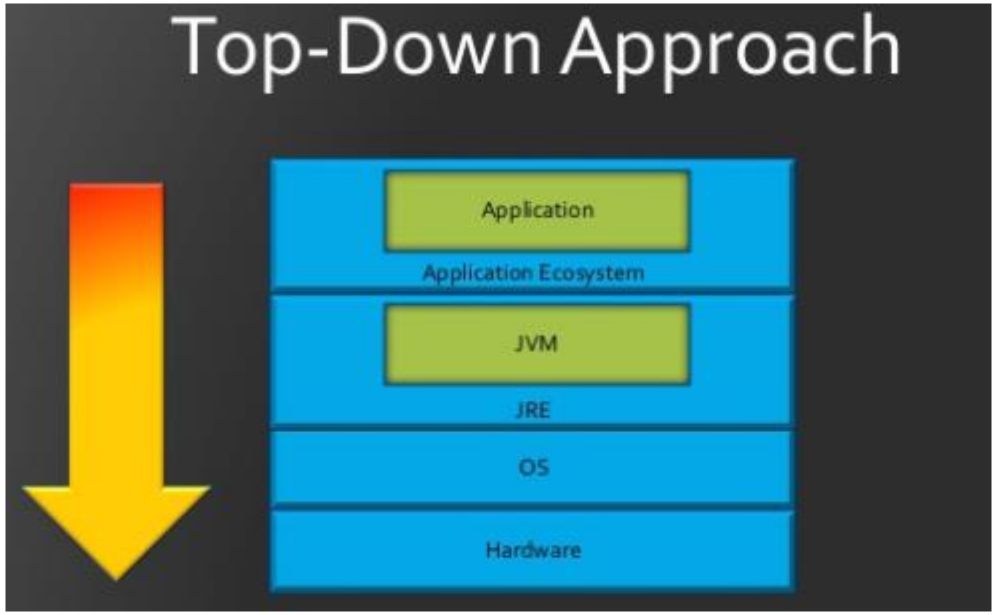

Start
Analysis
Design
Code
Performance Testing
Performance Acceptable?
No
Profile
Yes
Deploy

The following list is an example of the types of questions these requirements should answer:

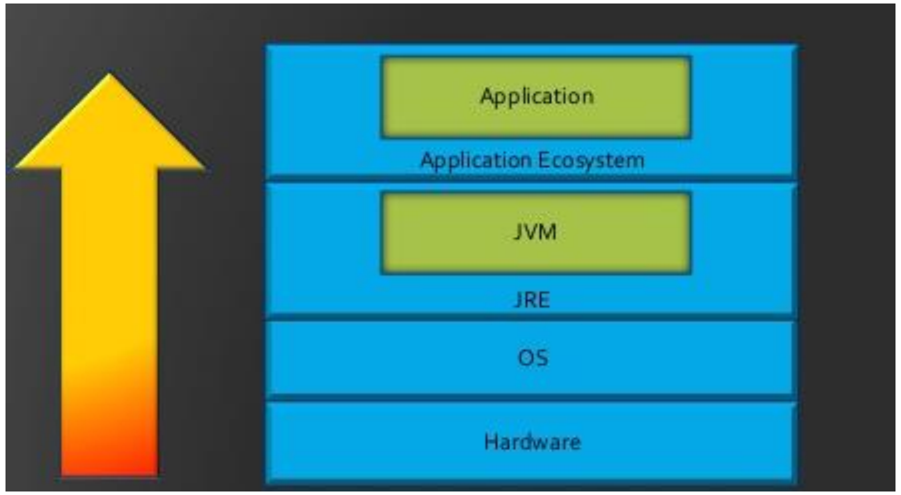
- ✓ What is the expected throughput of the application?
- ✓ What is the expected latency?
- ✓ How many concurrent users or concurrent tasks shall the application support?
- ✓ What is the accepted throughput and latency at the maximum number of concurrent users or concurrent tasks?
- ✓ What is the maximum worst case latency?
- ✓ What is the frequency of garbage collection induced latencies that will be tolerated?

Two Approaches, Top Down and Bottom Up

Top down, as the term implies, focuses at the top level of the application and drills down the software stack looking for problem areas and optimization opportunities.



Bottom up begins at the lowest level of the software stack, at the CPU level looking at statistics such as CPU cache misses, inefficient use of CPU instructions, and then working up the software stack at what constructs or idioms are used by the application.



Principles of Performance Tuning

The Principles of Java Application Performance Tuning :

To fully tune a Java application, we need at least a basic level of understanding of:

- ✓ Hardware;
- ✓ OS processes
- ✓ The JVM
- ✓ Garbage collection
- ✓ JIT compilation
- ✓ Locks
- ✓ Concurrency
- ✓ Class loading
- ✓ Object creation

One procedure for Java performance tuning is to repeatedly:

- ✓ Specify target performance
- ✓ Specify the JVM configuration(s)
- ✓ Check that OS CPU
- ✓ memory, and IO are acceptable, or tune
- ✓ Check that response times are acceptable, or tune
- ✓ Check that throughput is acceptable, or tune

After any change from tuning, start again from the beginning of this sequence.

- ✓ Throughput and response times often impact each other, tuning to optimize one frequently adversely affects the other, so we need to balance to get the overall best performance.

- ✓ Currently the G1 is the best collector for low pause times

What is application throughput?

- ✓ Throughput is the way of quantifying the volume of requests/responses in relation to time.
- ✓ Transactions per second or TPS is the most common ratio used.
- ✓ A performance test plan usually contains certain throughput goals.
- ✓ Often we see the workload to a web application measured by Throughput

What is Latency (Responsiveness)?

- ✓ Latency is the amount of time a message takes to traverse a system.

- ✓ In a computer network, it is an expression of how much time it takes for a packet of data to get from one designated point to another.

- ✓ It is sometimes measured as the time required for a packet to be returned to its sender.

Performance requirements should be defined SMART - like “95% of the Login requests should respond in less than 2 seconds measured on the web server“.

The JVM Architecture

JRE is the implementation of **Java Virtual Machine** (JVM)

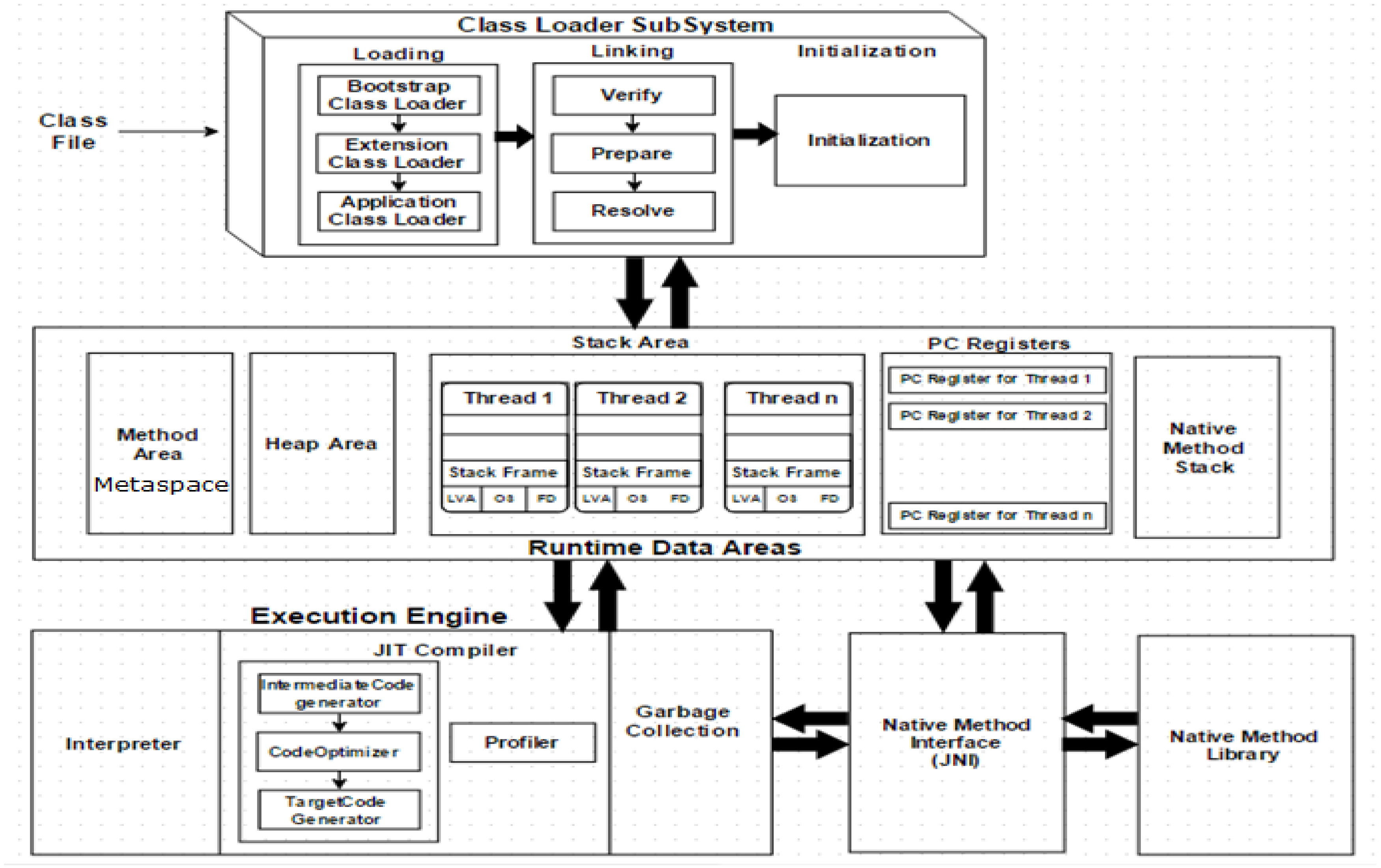
✓ which analyzes the bytecode
✓ interprets the code
✓ and executes it

What is the JVM?

A Virtual Machine is a software implementation of a physical machine. Java was developed with the concept of WORA (Write Once Run Anywhere), which runs on a VM.

The compiler compiles the Java file into a Java .class file, then that .class file is input into the JVM, which Loads and executes the class file.

JVM Architecture Diagram



How Does the JVM Work?

JVM is divided into three main subsystems:

- ✓ Class Loader Subsystem
- ✓ Runtime Data Area
- ✓ Execution Engine

Class Loader Subsystem

Java's dynamic class loading functionality is handled by the class loader subsystem.

It loads, links. and initializes the class file when it refers to a class for the first time at runtime, not compile time.

Class Loading

Classes will be loaded by this component. Boot Strap class Loader, Extension class Loader, and Application class Loader are the three class loader which will help in achieving it.

Boot Strap ClassLoader – Responsible for loading classes from the bootstrap classpath, nothing but rt.jar. Highest priority will be given to this loader.

Extension ClassLoader – Responsible for loading classes which are inside ext folder (jre\lib\ext).

System ClassLoader –Responsible for loading Application Level Classpath, path mentioned Environment Variable etc.

The above Class Loaders will follow Delegation Hierarchy Algorithm.

Note : Use OSGI/ Java Dynamic Modules

Linking

Verify – Bytecode verifier will verify whether the generated bytecode is proper or not if verification fails we will get the verification error.

Prepare – For all static variables memory will be allocated and assigned with default values.

Resolve – Java class is compiled, all references to variables and methods are stored in the class's constant pool as a symbolic reference. All symbolic memory references are replaced with the original references from Method Area.

Initialization

This is the final phase of Class Loading, here all static variables will be assigned with the original values, and the static block will be executed.

Runtime Data Area

The Runtime Data Area is divided into 5 major components:

Method Area (Metaspace)– All the class level data will be stored here, including static variables. There is only one method area per JVM, and it is a shared resource.

Heap Area – All the Objects and their corresponding instance variables and arrays will be stored here. There is also one Heap Area per JVM. Since the Method and Heap areas share memory for multiple threads, the data stored is not thread safe.

Stack Area – For every thread, a separate runtime stack will be created. For every method call, one entry will be made in the stack memory which is called as Stack Frame. All local variables will be created in the stack memory

PC Registers – Each thread will have separate PC Registers, to hold the address of current executing instruction once the instruction is executed the PC register will be updated with the next instruction.

Native Method stacks – Native Method Stack holds native method information.

Execution Engine

The bytecode which is assigned to the Runtime Data Area will be executed by the Execution Engine. The Execution Engine reads the bytecode and executes it piece by piece.

Interpreter – The interpreter interprets the bytecode faster, but executes slowly. The disadvantage of the interpreter is that when one method is called multiple times, every time a new interpretation is required.

JIT Compiler – The JIT Compiler neutralizes the disadvantage of the interpreter. The Execution Engine will be using the help of the interpreter in converting byte code, but when it finds repeated code it uses the JIT compiler, which compiles the entire bytecode and changes it to native code. This native code will be used directly for repeated method calls, which improve the performance of the system.

Intermediate Code generator – Produces intermediate code

Code Optimizer – Responsible for optimizing the intermediate code generated above

Target Code Generator – Responsible for Generating Machine Code or Native Code

Profiler – A special component, responsible for finding hotspots, i.e. whether the method is called multiple times or not.

Garbage Collector: Collects and removes unreferenced objects. Garbage Collection can be triggered by calling "System.gc()", but the execution is not guaranteed. Garbage collection of the JVM collects the objects that are created.

Java Native Interface (JNI): JNI will be interacting with the Native Method Libraries and provides the Native Libraries required for the Execution Engine.

Native Method Libraries:It is a collection of the Native Libraries which is required for the Execution Engine.

GC Tuning

Instead Of :

Experimenting lot of GC-related JVM parameters??

Changing random parts of your application code??

Following a simple process will guarantee that we are actually moving towards the right target while being transparent about the progress:

- State your performance goals
- Run tests
- Measure the results
- Compare the results with the goals
- If goals are not met, make a change and go back to running tests

Performance goals in regards of Garbage Collection fall into three categories:

- Latency
- Throughput
- Capacity

Reliability, Scalability & Resilience

Latency (Responsiveness**)**

Responsiveness refers to how quickly an application or system responds with a requested piece of data. Examples include:

How quickly a desktop UI responds to an event
How fast a website returns a page
How fast a database query is returned

For applications that focus on responsiveness, large pause times are not acceptable. The focus is on responding in short periods of time.

Latency (Responsiveness**)**

Latency goals for the GC have to be derived from generic latency requirements.

Generic latency requirements are typically expressed in a form similar to the following:

- ➢ All user transactions must respond in less than 10 seconds
- ➢ 90% of the invoice payments must be carried out in under 3 seconds
- ➢ Recommended products must be rendered to a purchase screen in less than 100 ms

Throughput

Throughput focuses on maximizing the amount of work by an application in a specific period of time.

Examples of how throughput might be measured include:

The number of transactions completed in a given time.
The number of jobs that a batch program can complete in an hour.

The number of database queries that can be completed in an hour.

High pause times are acceptable for applications that focus on throughput. Since high throughput applications focus on benchmarks over longer periods of time, quick response time is not a consideration.

Throughput

Generic requirements for throughput can be similar to the following:

- ➢ The solution must be able to process 1,000,000 invoices/day

- ➢ The solution must support 1,000 authenticated users each invoking one of the functions A, B or C every five to ten seconds

- ➢ Weekly statistics for all customers have to be composed in not more than six hours each Sunday night between 12 PM and 6 AM

Capacity

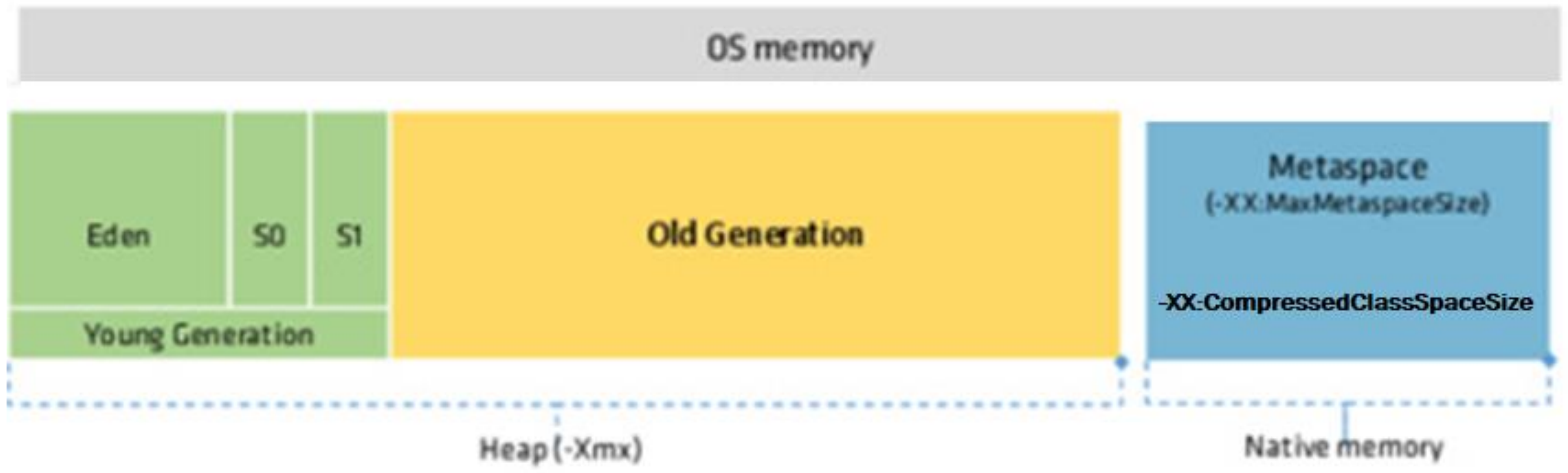
Capacity requirements put additional constraints on the environment where the throughput and latency goals can be met.

These requirements might be expressed either in terms of computing resources or in cold hard cash.

Examples are :

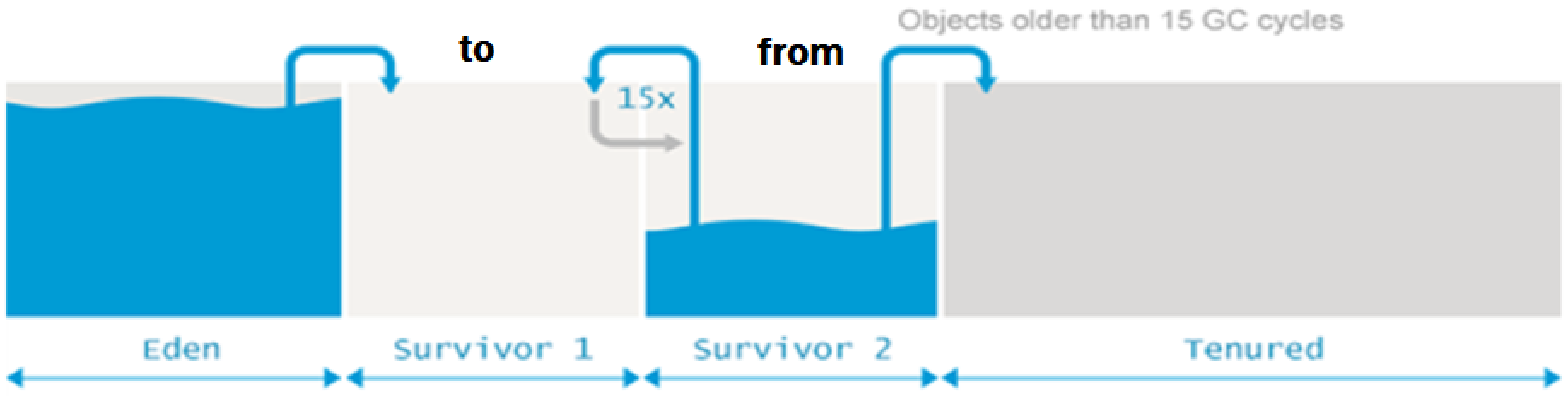
- ➢ The system must be deployed on Android devices with less than 512 MB of memory
- ➢ The system must be deployed on Amazon EC2. The maximum required instance size must not exceed the configuration model c3.xlarge (8 G, 4 cores)
- ➢ The monthly invoice from Amazon EC2 for running the system must not exceed $12,000

JVM memory
JDK8



Eden space reside two **Survivor** spaces called *from* and *to*. It is important to notice that one of the two Survivor spaces is always empty.

The empty Survivor space will start having residents next time the Young generation gets collected. All of the live objects from the whole of the Young generation (that includes both the Eden space and the non-empty 'from' Survivor space) are copied to the 'to' survivor space. After this process has completed, 'to' now contains objects and 'from' does not. Their roles are switched at this time.



-XX:MaxTenuringThreshold=threshold (default:15)

This process of copying the live objects between the two Survivor spaces is repeated several times until some objects are considered to have matured and are 'old enough'.

Does 64-bit JVM perform better than 32-bit JVM?

Most of us think 64-bit is bigger than 32-bit, and that 64-bit JVM performance will be better than 32-bit JVM performance.

Unfortunately, it’s not the case. 64-bit JVM can have a small performance degradation compared to 32-bit JVM.

64-bit JVM performance:

“Generally, the benefits of being able to address larger amounts of memory come with a small performance loss in 64-bit VMs versus running the same application on a 32-bit VM.

32-bit :

Faster if heap < 3GB

Max heap size=4GB

Client Compiler only

64-bit :

it would be faster if using long/double,

heap > 4GB

Client & Server Compiler

Java 64bit environment

The primary advantage of running Java in a 64-bit environment is the larger address space. This allows for a much larger Java heap size and an increased maximum number of Java Threads, which is needed for certain kinds of large or long-running applications.

Generational Hypothesis

✓Most objects die young

✓Old objects rarely reference young objects

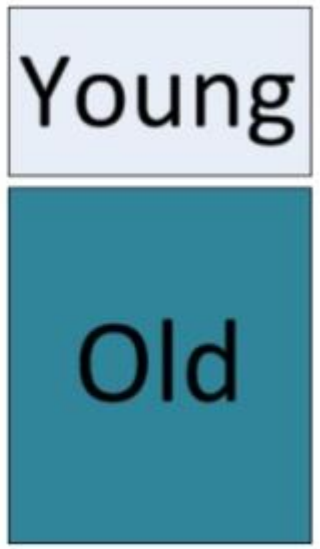
Generational Garbage Collector

✓Split the heap into regions

✓Create new objects in Young

✓Move mature objects to Old

* Different strategies for different regions

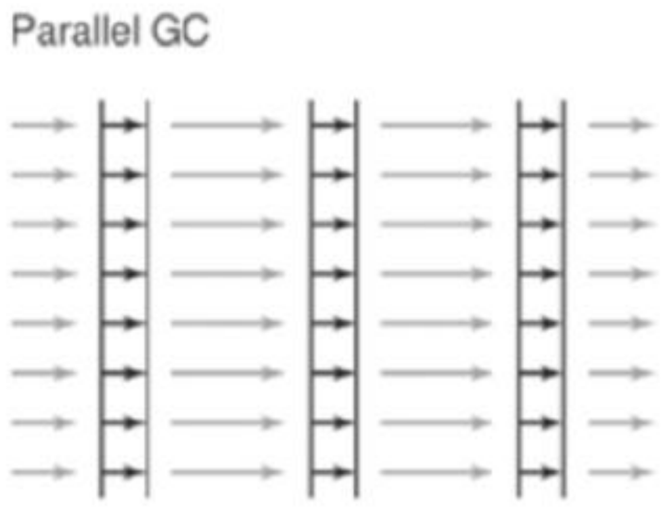


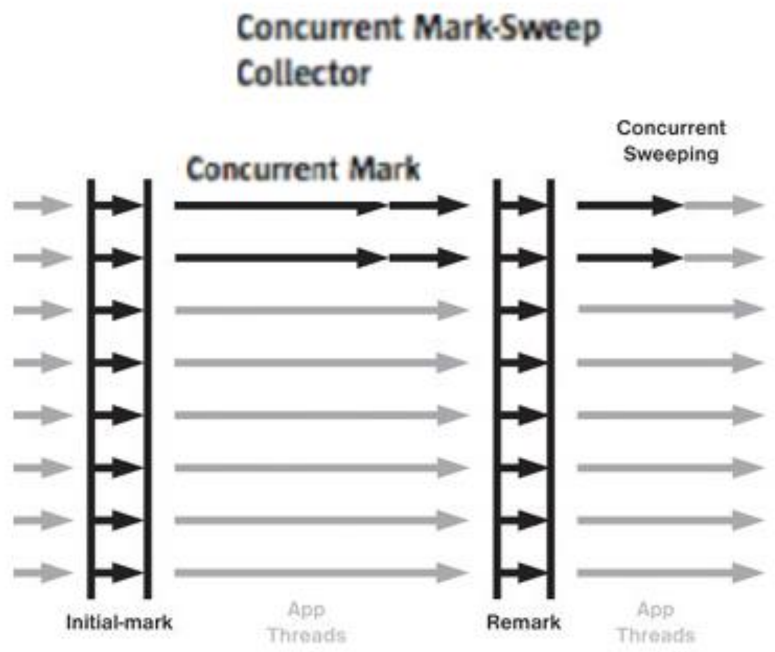
Characteristics of GC’s

✓Concurrent

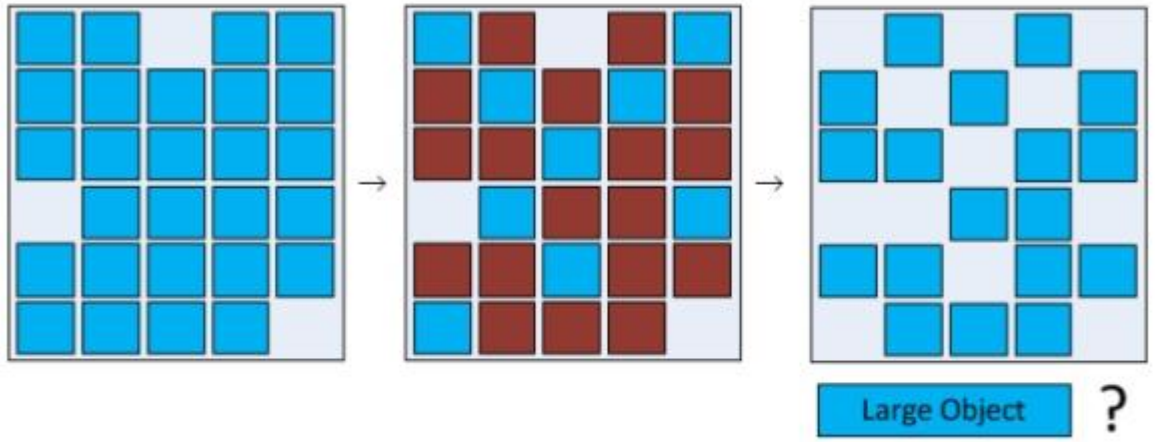
✓Parallel

✓Compacting

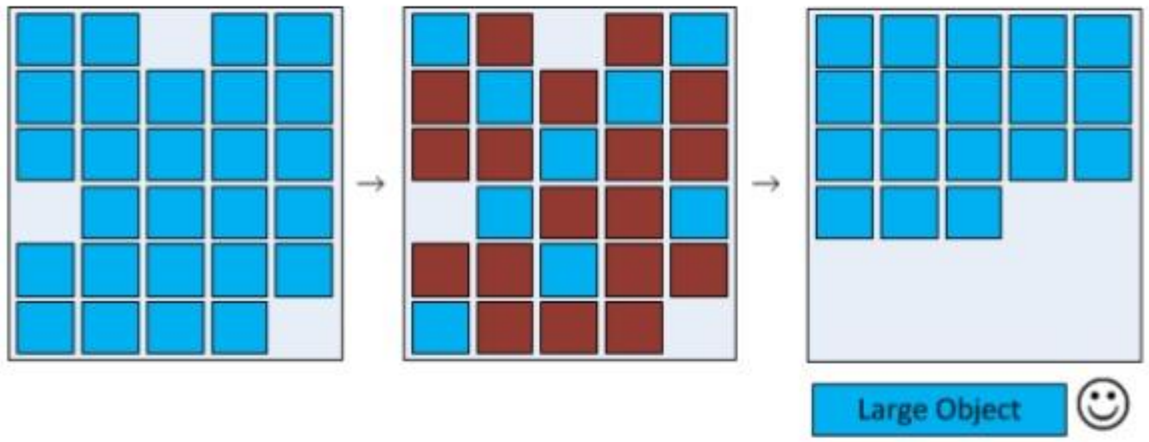

Parallel GC


Concurrent Mark-Sweep
Collector
Concurrent Mark
Concurrent
Sweeping
Initial-mark
App
Threads
Remark
App
Threads

Heap Fragmentation



Heap Compacted



Garbage-Collection Roots—The Source of All Object Trees

Every object tree must have one or more root objects. As long as the application can reach those roots, the whole tree is reachable.

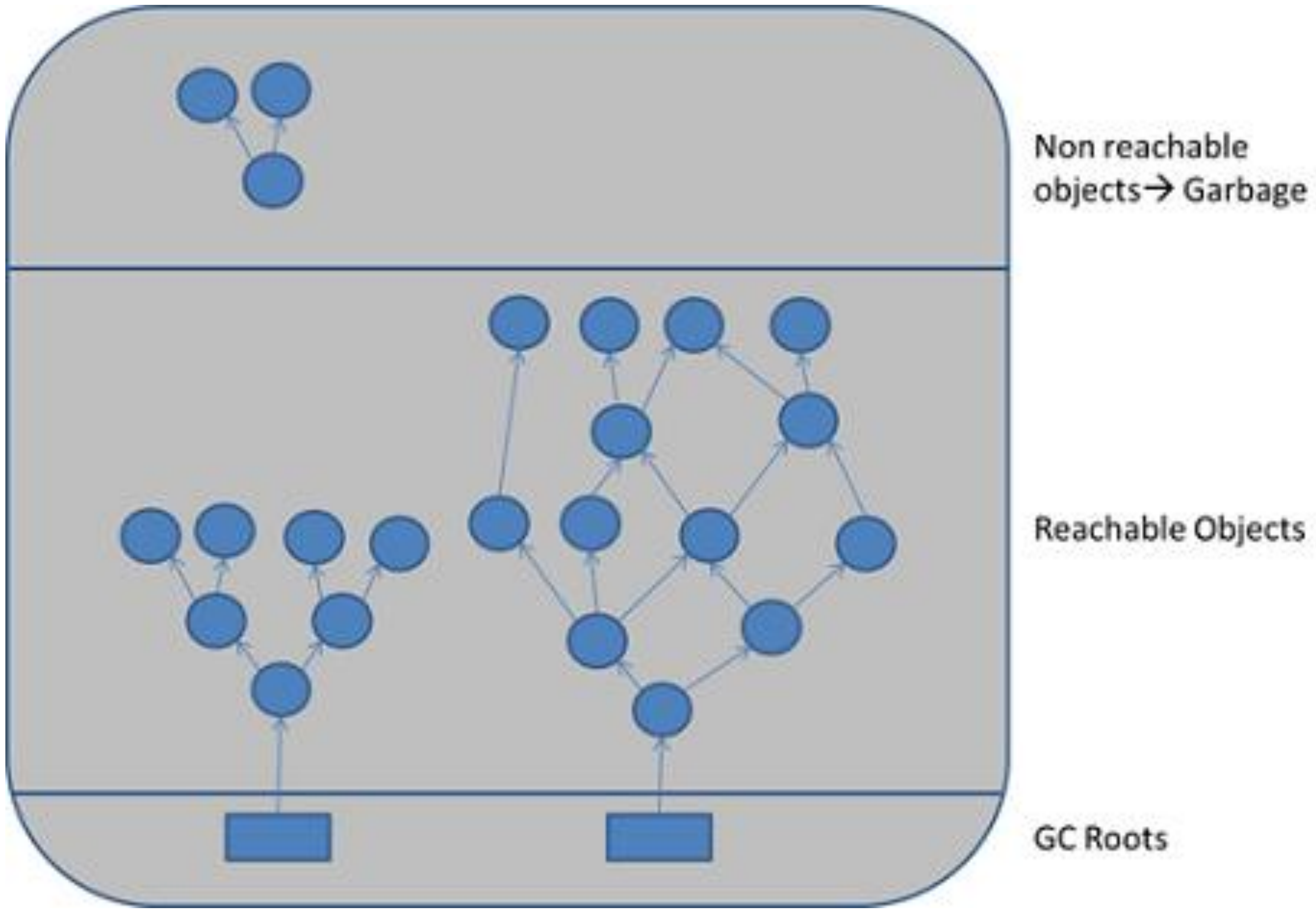
There are four kinds of GC roots in Java:

Local variables are kept alive by the stack of a thread. This is not a real object virtual reference and thus is not visible. For all intents and purposes, local variables are GC roots.

Active Java threads are always considered live objects and are therefore GC roots. This is especially important for thread local variables.

Static variables are referenced by their classes and are GC roots. Classes themselves can be garbage-collected, which would remove all referenced static variables.

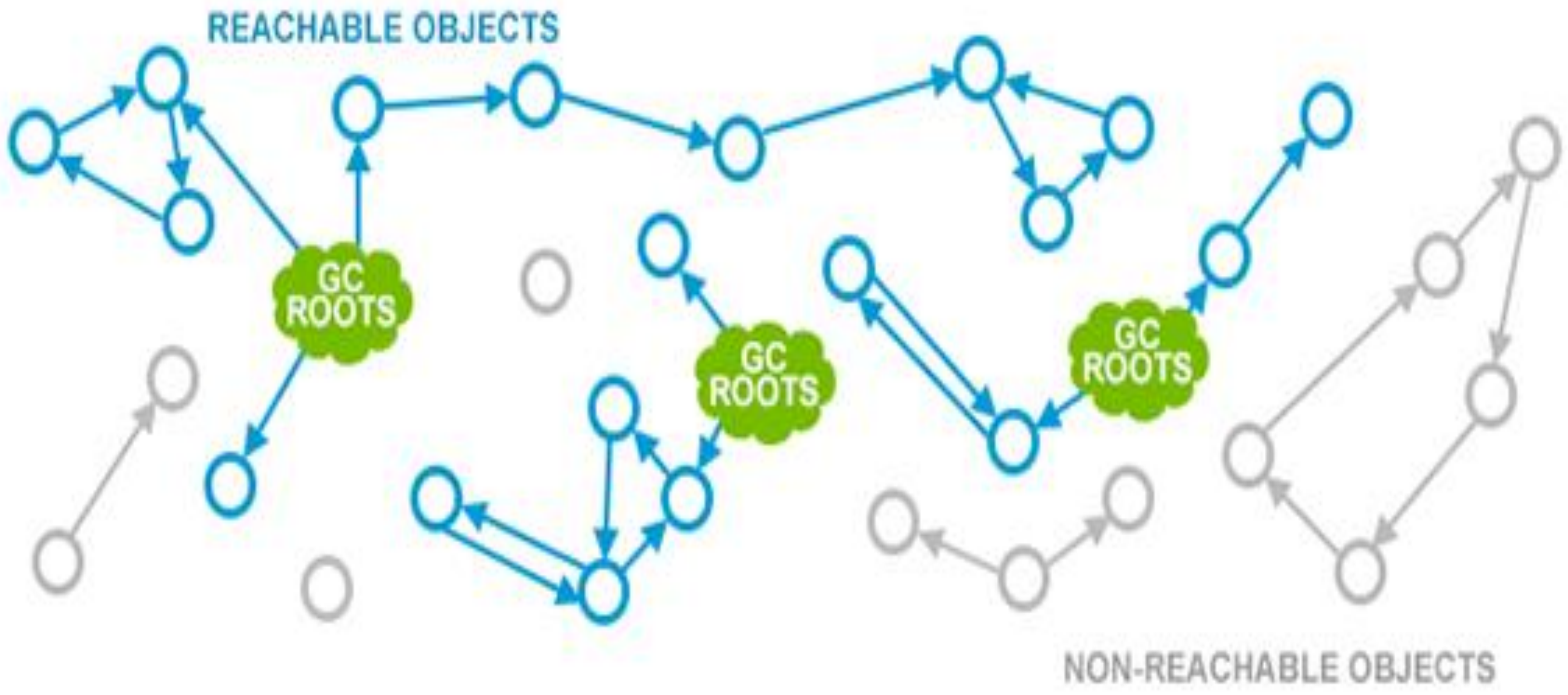
JNI References are Java objects that the native code has created as part of a JNI call. Objects thus created are treated specially because the JVM does not know if it is being referenced by the native code or not.



GC roots are objects that are themselves referenced by the JVM and thus keep every other object from being garbage-collected.

A simple Java application has the following GC roots:

❑ Local variables in the main method
❑ The main thread
❑ Static variables of the main class


REACHABLE OBJECTS
GC ROOTS
GC ROOTS
GC ROOTS
NON-REACHABLE OBJECTS

5 GC algorithms available in the Java Hotspot VM:

The **Serial GC** - recommended for client-style applications that do not have low pause time requirements.

The **Parallel GC** - use when the throughput matters.

The **Mostly-Concurrent GC** (also known as Concurrent Mark-Sweep GC(CMS)) - use when the latency matters.

The **Garbage First GC** (G1) - new GC algorithm, for CMS replacement.

The **Z Garbage Collector** (ZGC) is a scalable low latency garbage collector. ZGC performs all expensive work concurrently, without stopping the execution of application threads for more than 10ms, which makes is suitable for applications which require low latency and/or use a very large heap (multi-terabytes).

Pause times do not increase with the heap or live-set size
(*) Handle heaps ranging from a 8MB to 16TB in size.

Note : jdk 14 onwards [good support for linux platform]

```
-XX:+UnlockExperimentalVMOptions -XX:+UseZGC.
```

How to reach the goal:

To achieve the performance, Garbage Collection is to combine an understanding of the runtime requirements of the application, the physical characteristics of the application and the understanding of G1 to tune a set of options and achieve an optimal running state that satisfies the business requirements.

It’s important to keep in mind that tuning is a constantly evolving process in which we establish a set of baselines and optimal settings through repetitive testing and evaluation.

There is no definitive guide or a magic set of options, we are responsible for evaluating performance, <u>making incremental changes and re-evaluating </u>until we reach our goals.

Check the default GC algorithm (using **java** command)

1. To check the default GC algorithm, issue the below command

```
> java -XX:+PrintCommandLineFlags -XX:+PrintGCDetails -version
```

2. Run the command with G1 collector

```
> java -XX:+PrintCommandLineFlags -XX:+PrintGCDetails
   -XX:+UseG1GC -version
```

Example :

```
set "JAVA_OPTS=-Xms1G -Xmx1G -XX:MetaspaceSize=256m
-XX:MaxMetaspaceSize=256m  -XX:+UseG1GC "
```

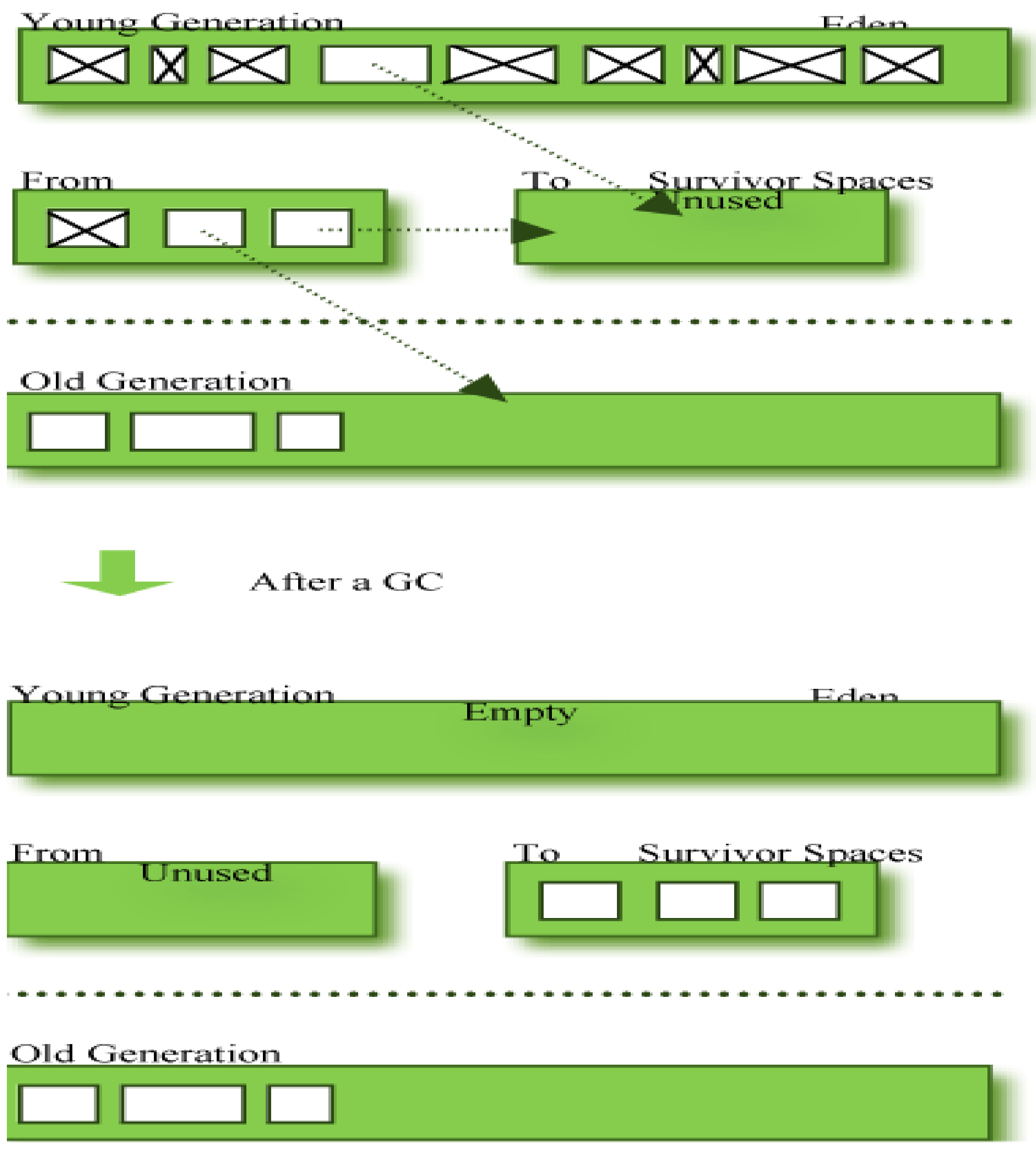
```
 -XX:+UseParallelGC
 -XX:+UseParNewGC
 -XX:+UseConcMarkSweepGC
```

GC for the Old Generation

The old generation basically performs a GC when the data is full. The execution procedure varies by the GC type.

According to JDK 7, there are 5 GC types.

- Serial GC
- Parallel GC
- Parallel Old GC (Parallel Compacting GC)
- Concurrent Mark & Sweep GC (or "CMS")
- Garbage First (G1) GC


Young Generation
Eden
From
To
Survivor Spaces
Unused
Old Generation
After a GC
Young Generation
Eden
Empty
From
Unused
To
Survivor Spaces
Old Generation

Major GC vs Full GC

Major GC is cleaning the Tenured space.
Full GC is cleaning the entire Heap – both Young and Tenured spaces.

-> many Major GCs are triggered by Minor GCs, so separating the two is impossible in many cases.

-> On the other hand – many modern garbage collections perform cleaning the Tenured space partially.

Note : We need to focus on whether the GC at hand stopped all the application threads or was it able to progress concurrently with the application threads.

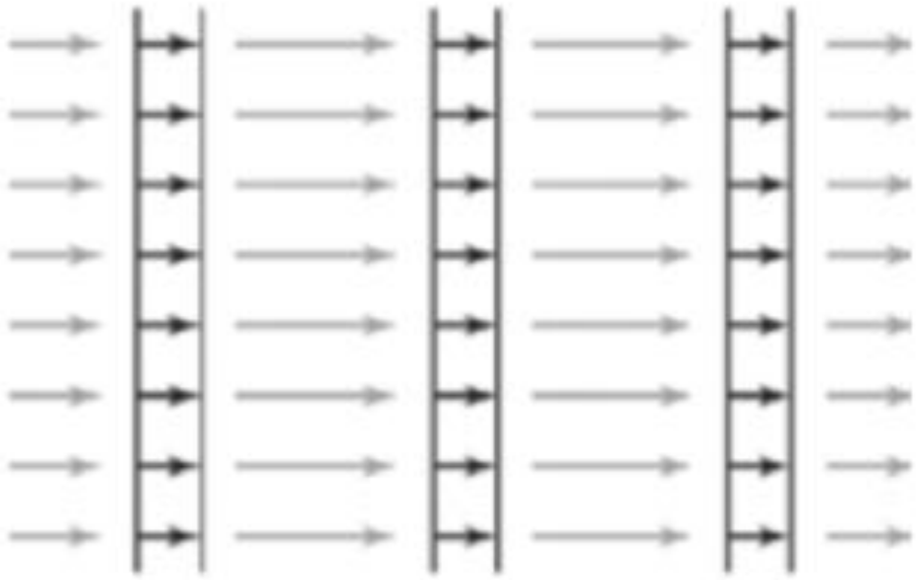
The Parallel Collector

The Parallel Collector

- ✓ It is also referred as "throughput collector"
- ✓ Multiple threads are used to speed up garbage collection.
- ✓ It is enabled with the command-line option -XX:+UseParallelGC.

By default, with this option, both minor and major collections are executed in parallel to further reduce garbage collection overhead.

Parallel GC



The number of garbage collector threads:

- ✓ For N <= 8 parallel GC will use just as many, i.e., N GC threads.
- ✓ For N > 8 available processors, the number of GC threads will be computed as 3+5N/8.

-XX:ParallelGCThreads

The number of garbage collector threads can be controlled with the command-line option -XX:ParallelGCThreads=<N>.

Parallel Collector Ergonomics

- ✓ The parallel collector is selected by default on server-class machines.
- ✓ In addition, the parallel collector uses a method of automatic tuning that allows us to specify specific behaviors instead of generation sizes and other low-level tuning details.
- ✓ We can specify maximum garbage collection pause time, throughput, and footprint (heap size).

Maximum Garbage Collection Pause Time:

-XX:MaxGCPauseMillis=<N> is a hint that pause times of <N> milliseconds or less are desired;

Throughput:

The throughput goal is measured in terms of the time spent doing garbage collection versus the time spent outside of garbage collection (referred to as application time). The goal is specified by the command-line option -XX:GCTimeRatio=<N>, which sets the ratio of garbage collection time to application time to 1 / (1 + <N>).

For example, -XX:GCTimeRatio=19 sets a goal of 1/(1+19) or 5% of the total time in garbage collection. The default value is 99, resulting in a goal of 1% of the time in garbage collection.

GC Ergonomics -> UseParallelGC with -XX:+UseAdaptiveSizePolicy

UseParallelGC with -XX:+UseAdaptiveSizePolicy is the ergonomic (tries to grow or shrink the heap to meet the specified maximum pause time and/or throughput goal) throughput collector.

The default goal is no pause time target and throughput with 99% of the time doing application work and 1% of the time doing GC work.

-XX:AdaptiveSizePolicyOutputInterval=1 which will print the ergonomics details every GC

By default a generation grows in increments of 20% and shrinks in increments of 5%.

The percentage for growing is controlled by the command-line flag

-XX:YoungGenerationSizeIncrement=<Y>

-XX:TenuredGenerationSizeIncrement=<T> for the tenured generation.

The percentage by which a generation shrinks is adjusted by the command-line flag
-XX:AdaptiveSizeDecrementScaleFactor=<D>.

If the growth increment is X percent, then the decrement for shrinking is X/D percent.

-XX:+UseAdaptiveSizePolicy consider three goals:

✓ a desired maximum GC pause goal
✓ a desired application throughput goal
✓ minimum footprint

The implementation checks (in this order):

If the GC pause time is greater than the pause time goal then reduce the generations sizes to better attain the goal.

If the pause time goal is being met then consider the application's throughput goal. If the application's throughput goal is not being met, then increase the sizes of the generations to better attain the goal.

If both the pause time goal and the throughput goal are being met, then the size of the generations are decreased to reduce footprint.

Explicitly setting the Generation sizes :

To disable automatic sizing strategy, use the below option

```
-XX:-UseAdaptiveSizePolicy
```

Now, we can explicitly set the generation sizes:

```
-XX:NewSize=400m -XX:MaxNewSize=400m -XX:SurvivorRatio=6
```

Maximum Garbage Collection Pause Time: The maximum pause time goal is specified with the command-line option -XX:MaxGCPauseMillis=<N>.

This is interpreted as a hint that pause times of <N> milliseconds or less are desired; by default, there is no maximum pause time goal.

If a pause time goal is specified, the heap size and other parameters related to garbage collection are adjusted in an attempt to keep garbage collection pauses shorter than the specified value.

These adjustments may cause the garbage collector to reduce the overall throughput of the application, and the desired pause time goal cannot always be met.

GC Log

```
2016-03-21T13:46:58.371+0000: 500.203: [Full GC [PSYoungGen: 1047584K-
>0K(1048064K)] [ParOldGen: 2097151K->865378K(2097152K)] 3144735K-
>865378K(3145216K) [PSPermGen: 29674K->29634K(262144K)], 1.8485590 secs]
[Times: user=3.17 sys=0.21, real=1.84 secs]
```

1 2016-03-21T13:46:58.371 – *Timestamp at which GC event ran*

2 500.203 – *Number of seconds since application started*

3 Full GC – *Type of GC*

4 PSYoungGen: 1047584K->0K(1048064K) – *Young Gen size dropped from* 1047584K *(i.e.1gb) to 0k. Total allocated Young Gen size is* 1048064K

5 ParOldGen: 2097151K->865378K(2097152K) – Old Gen size dropped from 2097151K (i.e.1.99gb) to 865378K(i.e.845mb). Total allocated Old Gen size is 2097152k (i.e.2gb)

6 3144735K->865378K(3145216K) – overall heap size dropped from 3144735K (i.e.2.99gb) to 865378K (i.e.845mb)

7 PSPermGen: 29674K->29634K(262144K) – Perm Gen Size dropped from 29674K to 29634K. Overall Perm Gen Size is 262144K (i.e.256mb)

8 [Times: user=3.17 sys=0.21, real=1.84 secs]

```
[GC 246656K->243120K(376320K), 0.0929090 secs]
[Full GC 243120K->241951K(629760K), 1.5589690 secs]
```

In the first line, 246656K->243120K(376320K) means that the GC reduced the occupied heap memory from 246656K to 243120K. The heap capacity at the time of GC was 376320K, and the GC took 0.0929090 seconds.

```
[GC
   [PSYoungGen: 142816K->10752K(142848K)] 246648K-
>243136K(375296K),
   0,0935090 secs
]
[Times: user=0.55 sys=0,10, real=0.09 secs]
```

We have a young generation GC which reduced the occupied heap memory from 246648K to 243136K and took 0.0935090 seconds.

In addition to that, we obtain information about the young generation itself: the collector used as well as its capacity and occupancy. In our example, the “PSYoungGen” collector was able to reduce the occupied young generation heap memory from 142816K to 10752K.

Java GC Times

This is the same concept that is applied in GC logging as well. Let’s look at couple examples to understand this concept better.

Example 1:

```
[Times: user=11.53 sys=1.38, real=1.03 secs]
```

In this example: ‘user’ + ‘sys’ is much greater than ‘real’ time. That's because this log time is collected from the JVM, where multiple GC threads are configured on a multi-core/multi-processors server. As multiple threads execute GC in parallel, the workload is shared amongst these threads, thus actual clock time (‘real’) is much less than total CPU time (‘user’ + ‘sys’).

Example 2:

```
[Times: user=0.09 sys=0.00, real=0.09 secs]
```

Above is an example of GC Times collected from a Serial Garbage Collector. As Serial Garbage collector always uses a single thread only, real time is equal to the sum of user and system times.

VM related Problem(sys time can be higher than user time??)

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

An OutOfMemoryError occurring as a result of a too small old generation space:

```
2010-11-25T18:51:03.895-0600: [Full GC
[PSYoungGen: 279700K->267300K(358400K)]
[ParOldGen: 685165K->685165K(685170K)]
964865K->964865K(1043570K)
[PSPermGen: 32390K->32390K(65536K)],
0.2499342 secs]
[Times: user=0.08 sys=0.00, real=0.05 secs]
Exception in thread "main"
java.lang.OutOfMemoryError: Java heap space
```

An OutOfMemoryError occurring as a result of a too small Metaspace:

```
2010-11-25T18:26:37.755-0600: [Full GC
[PSYoungGen: 0K->0K(141632K)]
[ParOldGen: 132538K->132538K(350208K)]
32538K->32538K(491840K)
[PSPermGen: 65536K->65536K(65536K)],
0.2430136 secs]
[Times: user=0.37 sys=0.00, real=0.24 secs]
java.lang.OutOfMemoryError: Metaspace space
```

GC(Allocation Failure)

```
2015-05-26T14:45:37.987-
02001:151.1262:[GC(Allocation Failure) 151.126:
[DefNew:629119K->69888K(629120K), 0.0584157
secs]1619346K->1273247K(2027264K),0.0585007
secs][Times: user=0.06 sys=0.00, real=0.06 secs]
```

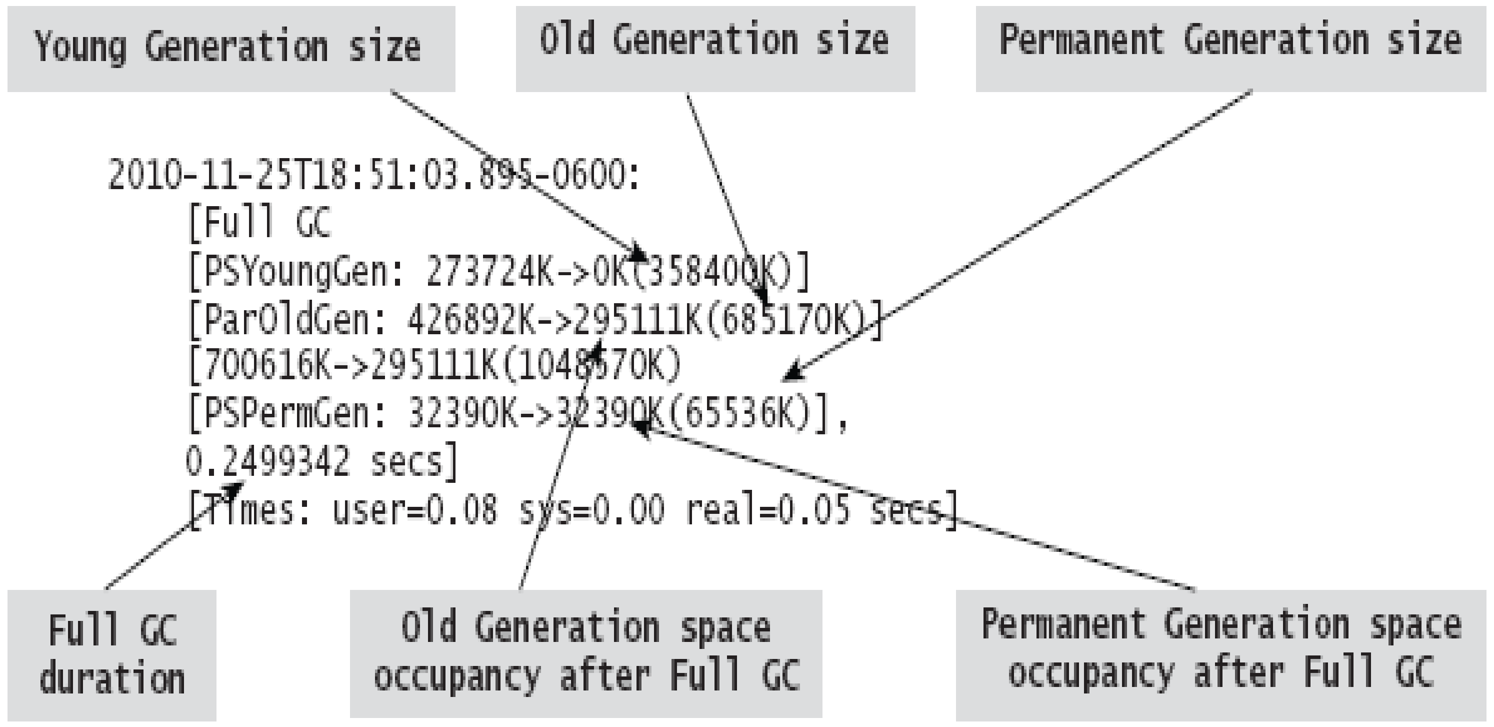
Allocation Failure – Cause of the collection. In this case, the GC is triggered due to a data structure not fitting into any region in Young Generation.

To force full garbage collections, monitor the application with VisualVM or JConsole and click the Perform GC button in the VisualVM or JConsole window.

A command line alternative to force a full garbage collection is to use the Hot-Spot JDK distribution jmap command

```
$ jmap -histo:live 348
```

The jmap command induces a full garbage collection and also produces a heap profile that contains object allocation information.


Young Generation size
Old Generation size
Permanent Generation size
Full GC duration
Old Generation space occupancy after Full GC
Permanent Generation space occupancy after Full GC

```
2010-11-25T18:51:03.895-0600:
    [Full GC
    [PSYoungGen: 273724K->0K(358400K)]
    [ParOldGen: 426892K->295111K(685170K)]
    [700616K->295111K(1048570K)
    [PSPermGen: 32390K->32390K(65536K)],
    0.2499342 secs]
    [Times: user=0.08 sys=0.00 real=0.05 secs]
```

Garbage collection log after full GC event

Concurrent Mark Sweep (CMS) Collector

The *Concurrent Mark Sweep* (CMS) collector is designed to be a lower latency collector(less pause time) than the parallel collectors.

The key part of this design is trying to do part of the garbage collection at the same time as the application is running.

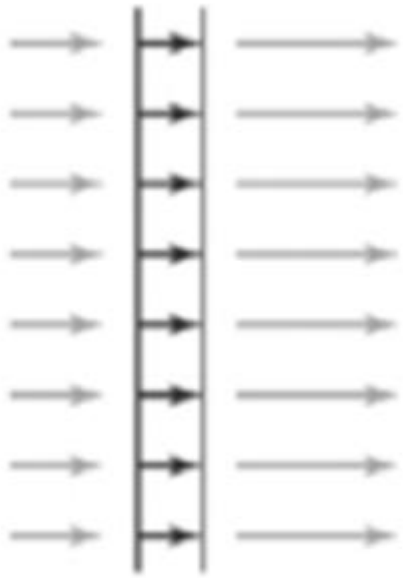
This means that when the collector needs to pause the application's execution it doesn't need to pause for as long.

Typically applications that have a relatively large set of long-lived data (a large tenured generation) and run on machines with two or more processors tend to benefit from the use of this collector.

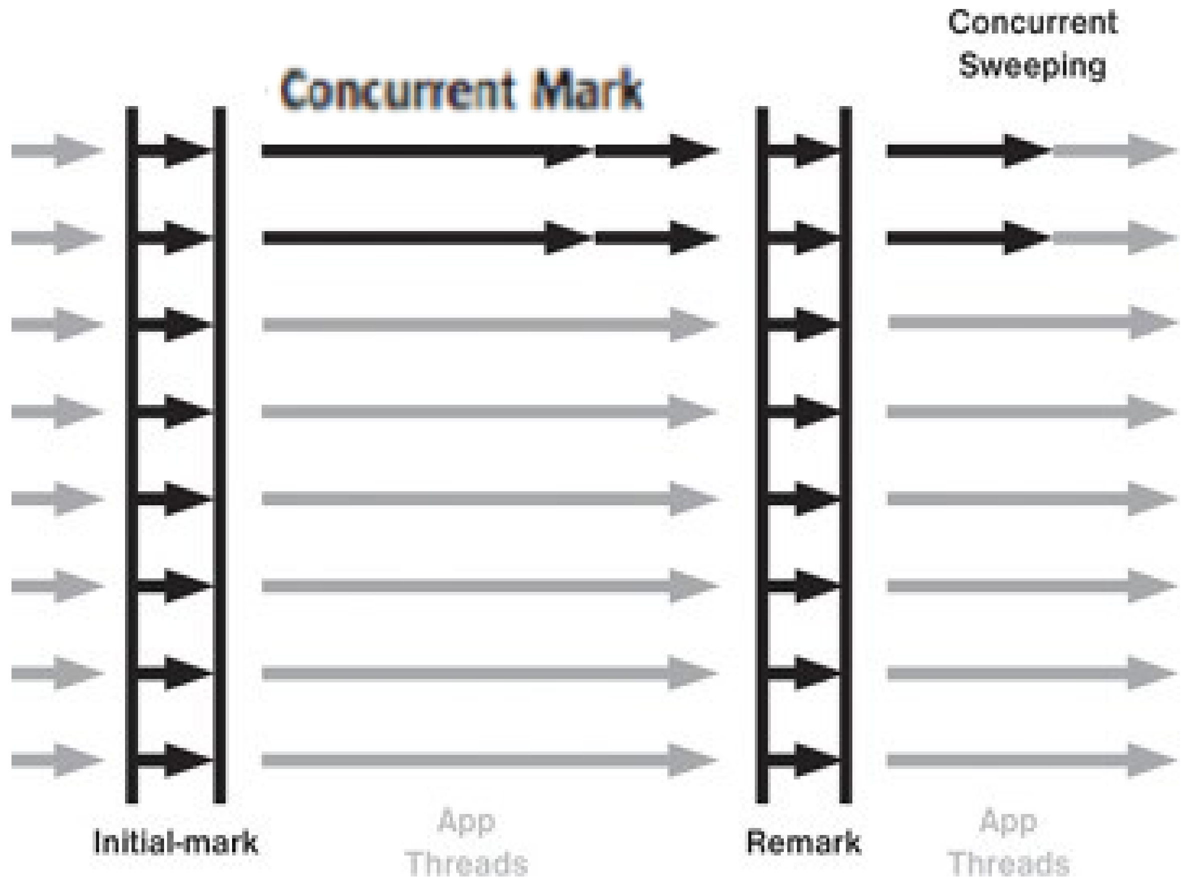
The HotSpot command-line options to support multithreaded initial-mark and remark phases are :

-XX:+CMSParallelInitialMarkEnabled and
 -XX:+CMSParallelRemarkEnabled.

These are automatically enabled by default when CMS GC is enabled by the -XX:+UseConcMarkSweepGC command-line option.



Young Generation



Tenured Generation

Parallel GC vs Concurrent Mark Sweep collector:

The parallel garbage collectors are designed to minimise the amount of time that the application spends undertaking garbage collection, which is termed *throughput*. This isn't an appropriate tradeoff for all applications - some require individual pauses to be short as well, which is known as a *latency* requirement.

The *Concurrent Mark Sweep* (CMS) collector is designed to be a lower latency collector(less pause time) than the parallel collectors. The key part of this design is trying to do part of the garbage collection at the same time as the application is running. This means that when the collector needs to pause the application's execution it doesn't need to pause for as long.

CMS GC (-XX:+UseConcMarkSweepGC)
(“-XX:+UseParNewGC” flag activates the parallel execution of young generation)

I*nitial mark* : The surviving objects among the objects the closest to the classloader are searched. So, the pausing time is very short**. Stop-the-world.**

concurrent mark : The objects referenced by the surviving objects that have just been confirmed are tracked and checked. The difference of this step is that it proceeds while other threads are processed at the same time.

remark step : The objects that were newly added or stopped being referenced in the concurrent mark step are checked. **Stop-the-world**.

***concurrent sweep* step: The garbage collection procedure takes place.**
The garbage collection is carried out while other threads are still being processed.

Note : It uses the parallel stop-the-world mark-copy algorithm in the Young Generation and the mostly concurrent mark-sweep algorithm in the Old Generation

Phase 1 - Initial mark

During   initial mark CMS should collect all root references to start marking of old space.

This includes:

References from thread stacks,
References from young space.

References from stacks are usually collected very quickly (less than 1ms), but time to collect references from young space depends on size of objects in young space.

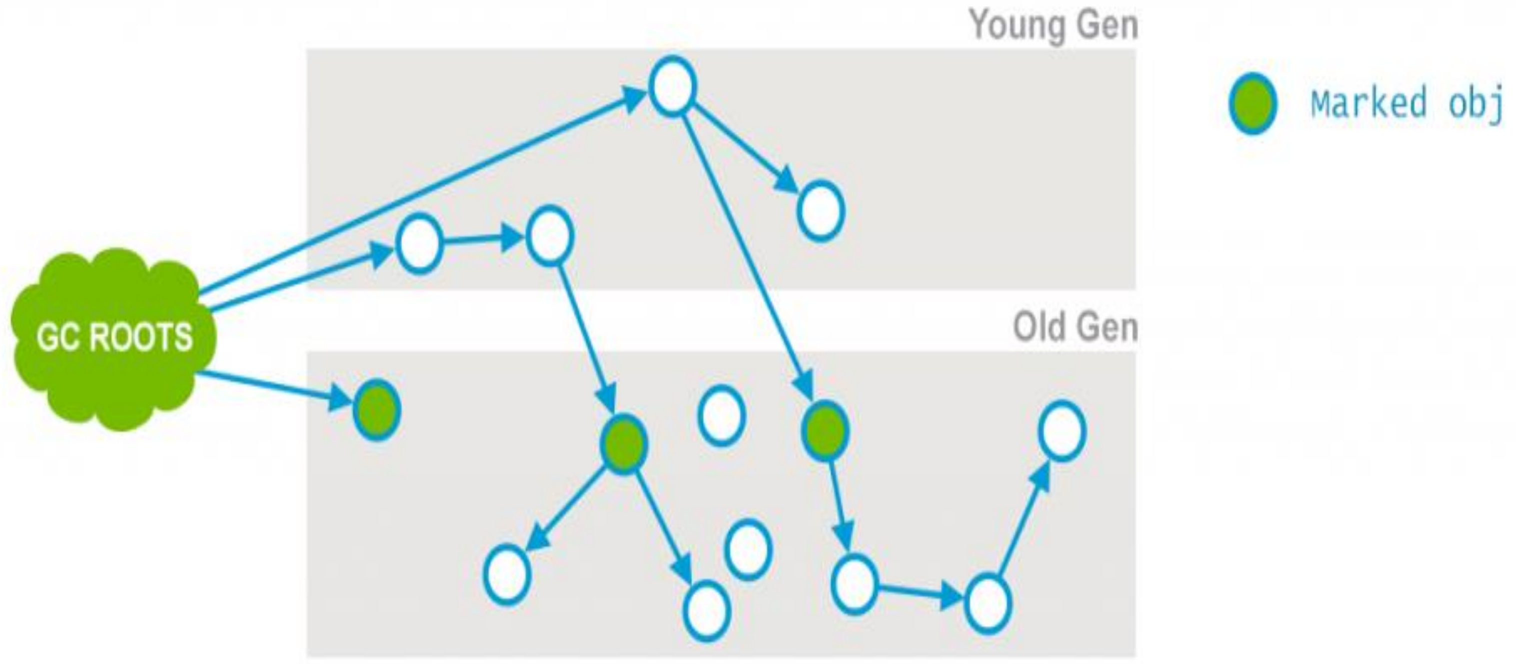
Normally initial mark starts right after young space collection, so Eden space is empty and only live objects are in one of survivor space.

Survivor space is usually small and initial mark after young space collection often takes less than millisecond.

Initial mark (continued)

But if initial mark is started when Eden is full it may take quite long (usually longer than young space collection itself).Once CMS collection is triggered, JVM may wait some time for young collection to happen before it will start initial marking.

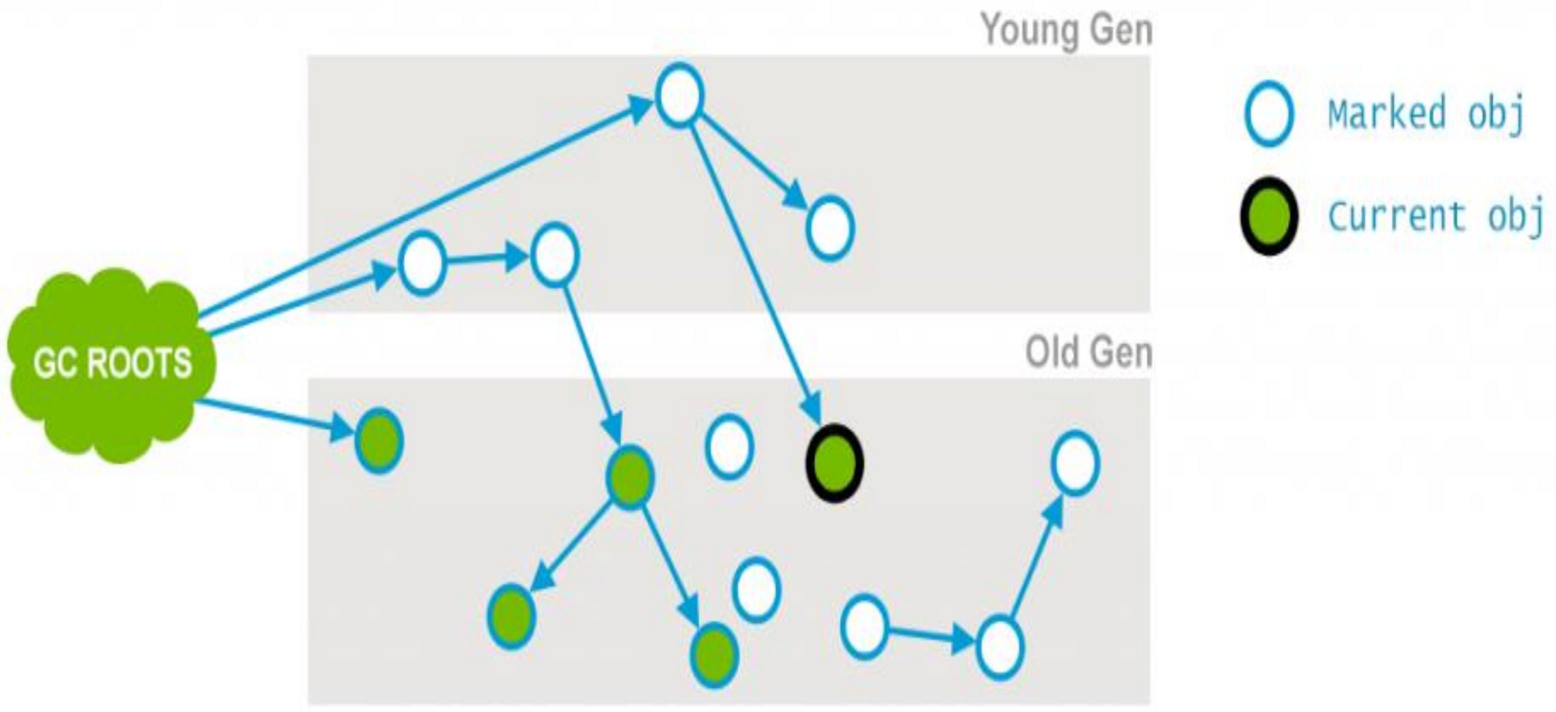
JVM configuration option **–XX:CMSWaitDuration**= <delay in ms> can be used to set how long CMS will wait for young space collection before start of initial marking. If you want to avoid long initial marking pauses, you should configure this time to be longer than typical period of young collections in your application.


Young Gen
Old Gen
GC ROOTS
Marked obj

Phase 2: Concurrent Mark

During this phase the Garbage Collector traverses the Old Generation and marks all live objects, starting from the roots found in the previous phase of “Initial Mark”.

The “Concurrent Mark” phase, as its name suggests, runs concurrently with the application and does not stop the application threads. Note that not all the live objects in the Old Generation may be marked, since the application is mutating references during the marking.


Young Gen
Old Gen
GC ROOTS
Marked obj
Current obj

Concurrent Preclean. This is again a concurrent phase, running in parallel with the application threads, not stopping them.

While the previous phase was running concurrently with the application, some references were changed. Whenever that happens, the JVM marks the area of the heap (called “Card”) that contains the mutated object as “dirty”.

In the pre-cleaning phase, these dirty objects are accounted for, and the objects reachable from them are also marked. The cards are cleaned when this is done.

Additionally, some necessary housekeeping and preparations for the Final Remark phase are performed.

Remark

Most of marking is done in parallel with application, but it may not be accurate because application may modify object graph during marking. When concurrent marking is finished;
garbage collector should stop application and repeat marking to be sure that all reachable objects marked as alive. But collector doesn’t have to traverse through whole object graph;

it should traverse only reference modified since start of marking (actually since start pre clean phase). **Card table** is used to identify modified portions of memory in old space, but thread stacks and young space should be scanned once again.

Usually most time of remark phase is spent of scanning young space. This time will be much shorter if we collect garbage in young space before starting of remark. We can instruct JVM to always force young space collection before CMS remark. Use JVM parameter **–XX:+CMSScavengeBeforeRemark** to enable this option.

Concurrent Sweep. Performed concurrently with the application, without the need for the stop-the-world pauses.

The purpose of the phase is to remove unused objects and to reclaim the space occupied by them for future use.

Concurrent Reset. Concurrently executed phase, resetting inner data structures of the CMS algorithm and preparing them for the next cycle.

–XX:CMSWaitDuration

Normally objects are allocated in old space only during young space collection

But in certain cases object may be allocated directly in old space and CMS cycle could start while Eden has lots of objects. In this case initial mark can take more time.

Usally this is happening due to allocation of very large objects (few megabyte arrays). To avoid these long pauses we should configure reasonable –XX:CMSWaitDuration.

–XX:CMSWaitDuration : Time in milliseconds that CMS thread waits for young GC (default is 2000ms)

The pausing time for GC is very short. The CMS GC is also called the low latency GC, and is **used when the response time from all applications is crucial**.

While this GC type has the advantage of short stop-the-world time, it also has the following disadvantages.

It uses more memory and CPU than other GC types.

CMS is not a compacting collector, which over time can result in *old* generation fragmentation.

CMS collector does most of its tracing and sweeping work with the application threads still running, so only brief pauses are seen by the application threads.

However, if the CMS collector is unable to finish reclaiming the unreachable objects before the tenured generation fills up, or if an allocation cannot be satisfied with the available free space blocks in the tenured generation, then the application is paused and the collection is completed with all the application threads stopped.

The inability to complete a collection concurrently is referred to as <u>concurrent mode failure</u> and indicates the need to adjust the CMS collector parameters.

-XX:+UseConcMarkSweepGC

This flag is needed to activate the CMS Collector in the first place.
By default, HotSpot uses the Throughput Collector instead.

Note:

When the CMS collector is used, “-XX:+UseParNewGC”
flag activates the parallel execution of young generation GCs using multiple threads.

-XX:+CMSConcurrentMTEnabled

When this flag is set, the concurrent CMS phases are run with multiple threads (and thus, multiple GC threads work in parallel with all the application threads).

This flag is already activated by default.

If serial execution is preferred, which may make sense depending on the hardware used, multithreaded execution can be deactivated via -XX:-CMSConcurrentMTEnabled.

-XX:ParallelGCThreads

-XX:ParallelGCThreads=<value> we can specify the number of GC threads to use for parallel GC

default value which is computed based on the number of available (virtual) processors.

The determining factor is the value N returned by the Java method Runtime.availableProcessors().

For N <= 8 parallel GC will use just as many, i.e., N GC threads.
For N > 8 available processors, the number of GC threads will be computed as 3+5N/8.

-XX:ConcGCThreads

The flag -XX:ConcGCThreads=<value>

defines the number of threads with which the concurrent CMS phases are run.

The formula used is ConcGCThreads = (ParallelGCThreads + 3)/4.

-XX:CMSInitiatingOccupancyFraction

This parameter sets the threshold percentage occupancy of the old generation at which the CMS GC is triggered.

The Throughput Collector starts a GC cycle only when the heap is full, i.e., when there is not enough space available to store a newly allocated or promoted object.

With the CMS Collector, it is not advisable to wait this long because it the application keeps on running (and allocating objects) during concurrent GC.

Thus, in order to finish a GC cycle before the application runs out of memory, the CMS Collector needs to start a GC cycle much earlier than the Throughput Collector.

set via -XX:CMSInitiatingOccupancyFraction=<value>

Note : the default value of CMSInitiatingOccupancyFraction is 68

-XX:+UseCMSInitiatingOccupancyOnly

We can use the flag –XX:+UseCMSInitiatingOccupancyOnly to instruct the JVM not to base its decision when to start a CMS cycle on run time statistics.

Instead, when this flag is enabled, the JVM uses the value of CMSInitiatingOccupancyFraction for every CMS cycle, not just for the first one

-XX:+CMSClassUnloadingEnabled

In contrast to the Throughput Collector, the CMS Collector does not perform GC in the permanent generation by default.

If permanent generation GC is desired, it can be enabled via -XX:+CMSClassUnloadingEnabled

-XX:+ExplicitGCInvokesConcurrent

The flag -XX:+ExplicitGCInvokesConcurrent instructs the JVM to run a CMS GC instead of a full GC whenever system GC is requested.

-XX:+ExplicitGCInvokesConcurrentAndUnloadsClasses

ensures that the permanent generation is included into the CMS GC in case of a system GC request.

Note : System.gc() triggers a full GC by default, recommended to disable explicit Gc (**-XX:+DisableExplicitGC)**

Challenges

When using the CMS Collector in real-world applications, we face two major challenges that may create a need for tuning:

Heap fragmentation
High object allocation rate

Heap fragmentation

It is possible because, unlike the Throughput Collector, the CMS Collector does not contain any mechanism for defragmentation.

As a consequence, an application may find itself in a situation where an object cannot be allocated even though the total heap space is far from exhausted – simply because there is no consecutive memory area available to fully accommodate the object.

When this happens, the concurrent algorithms do not help anymore and thus, as a last resort, <u>the JVM triggers a full GC.</u>

High object allocation rate

If the rate at which objects get instantiated is higher than the rate at which the collector removes dead objects from the heap, the concurrent algorithm fails once again.

At some point, the old generation will not have enough space available to accommodate an object that is to be promoted from the young generation.

This situation is referred to as “concurrent mode failure”, and the JVM reacts just like in the heap fragmentation scenario: It triggers a full GC.

Solution:

One possible countermeasure is to increase young generation size, in order to prevent premature promotions of short-lived objects into the old generation.

Another approach is to take heap dumps of the running system, to analyze the application for excessive object allocation, identify these objects, and eventually reduce the amount of objects allocated.

Excessive GC Time and OutOfMemoryError

The CMS collector throws an OutOfMemoryError if too much time is being spent in garbage collection: if more than 98% of the total time is spent in garbage collection and less than 2% of the heap is recovered, then an OutOfMemoryError is thrown.

This feature is designed to prevent applications from running for an extended period of time while making little or no progress because the heap is too small.

If necessary, this feature can be disabled by adding the option -XX:-UseGCOverheadLimit to the command line

CMS GC Logs

```
39.910: [GC 39.910: [ParNew: 261760K->0K(261952K), 0.2314667 secs] 262017K->26386K(1048384K), 0.2318679 secs]
```

Young generation (ParNew) collection. Young generation capacity is 261952K and after the collection its occupancy drops down from 261760K to 0. This collection took 0.2318679 secs.

```
40.146: [GC [1 CMS-initial-mark: 26386K(786432K)]
26404K(1048384K), 0.0074495 secs]
```

Beginning of tenured generation collection with CMS collector. This is initial Marking phase of CMS where all the objects directly reachable from roots are marked and this is done with all the application threads stopped.

Capacity of tenured generation space is 786432K and CMS was triggered at the occupancy of 26386K.

40.154: [CMS-concurrent-mark-start]

Start of concurrent marking phase.

In Concurrent Marking phase, application thread stopped in the first phase are started again and all the objects transitively reachable from the objects marked in first phase are marked here.

40.683: [CMS-concurrent-mark: 0.521/0.529 secs]

Concurrent marking took total 0.521 seconds cpu time and 0.529 seconds wall time that includes the yield to other threads also.

40.683: [CMS-concurrent-preclean-start]

Start of precleaning.
Precleaning is also a concurrent phase. Here in this phase we look at the objects in CMS heap which got updated by promotions from young generation or new allocations or got updated by mutators while we were doing the concurrent marking in the previous concurrent marking phase

40.701: [CMS-concurrent-preclean: 0.017/0.018 secs]
Concurrent precleaning took 0.017 secs total cpu time and 0.018 wall time.

```
40.704: [GC40.704: [Rescan (parallel) ,
0.1790103 secs]40.883: [weak refs processing,
0.0100966 secs] [1 CMS-remark:
26386K(786432K)] 52644K(1048384K),
0.1897792 secs]
```

Stop-the-world phase. This phase rescans any residual updated objects in CMS heap, retraces from the roots and also processes Reference objects.

Here the rescanning work took 0.1790103 secs and weak reference objects processing took 0.0100966 secs. This phase took total 0.1897792 secs to complete

40.894: [CMS-concurrent-sweep-start]
Start of sweeping of dead/non-marked objects. Sweeping is concurrent phase performed with all other threads running.

41.020: [CMS-concurrent-sweep: 0.126/0.126 secs]
Sweeping took 0.126 secs.

41.020: [CMS-concurrent-reset-start]
Start of reset.

41.147: [CMS-concurrent-reset: 0.127/0.127 secs]
In this phase, the CMS data structures are reinitialized so that a new cycle may begin at a later time. In this case, it took 0.127 secs.

This was how(previous logs) a normal CMS cycle runs.

Now let us look at some other CMS log entries:

```
197.976: [GC 197.976: [ParNew: 260872K-
>260872K(261952K), 0.0000688 secs]197.976:
[CMS197.981: [CMS-concurrent-sweep:
0.516/0.531 secs]
(concurrent mode failure): 402978K-
>248977K(786432K), 2.3728734 secs] 663850K-
>248977K(1048384K), 2.3733725 secs]
```

Problem:

This shows that a ParNew collection was requested, but it was not attempted because it was estimated that there was not enough space in the CMS generation to promote the worst case surviving young generation objects.

<u>We name this failure as “full promotion guarantee failure”.</u>

Due to this, Concurrent Mode of CMS is interrupted and a Full GC is invoked at 197.981. This mark-sweep-compact stop-the-world Full GC took 2.3733725 secs and the CMS generation space occupancy dropped from 402978K to 248977K.

Solution:

The concurrent mode failure can either be avoided by increasing the tenured generation size or initiating the CMS collection at a lesser heap occupancy by setting CMSInitiatingOccupancyFraction to a lower value and setting UseCMSInitiatingOccupancyOnly to true.

The value for CMSInitiatingOccupancyFraction should be chosen appropriately because setting it to a very low value will result in too frequent CMS collections.

The G1 Garbage Collector

The G1 Garbage Collector

The Garbage-First (G1) collector is a server-style garbage collector, targeted for multi-processor machines with large memories.

It meets garbage collection (GC) pause time goals(defined through -XX:MaxGCPauseMillis) with a high probability, while achieving high throughput.

G1 works to accomplish those goals in a few different ways.

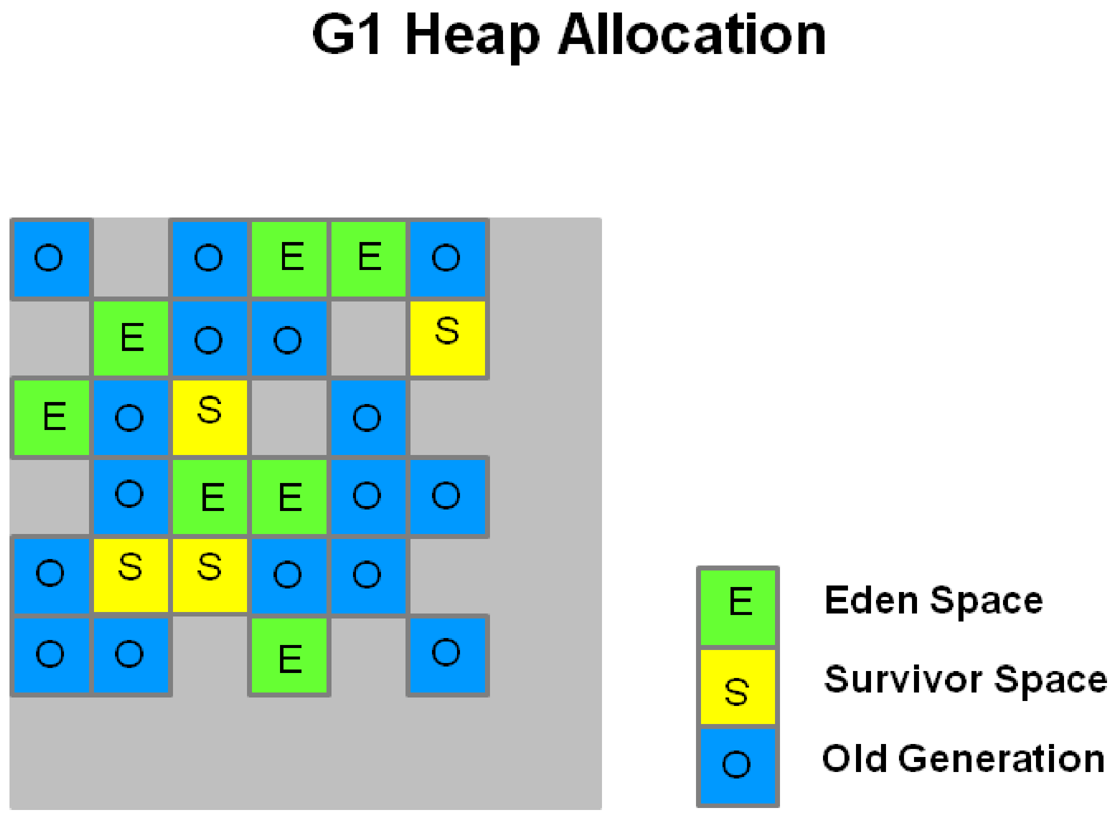
First, being true to its name, G1 collects regions with the least amount of live data (Garbage First!) and compacts/evacuates live data into new regions.

Secondly, it uses a series of incremental, parallel and multi-phased cycles to achieve its soft pause time target.

Regions

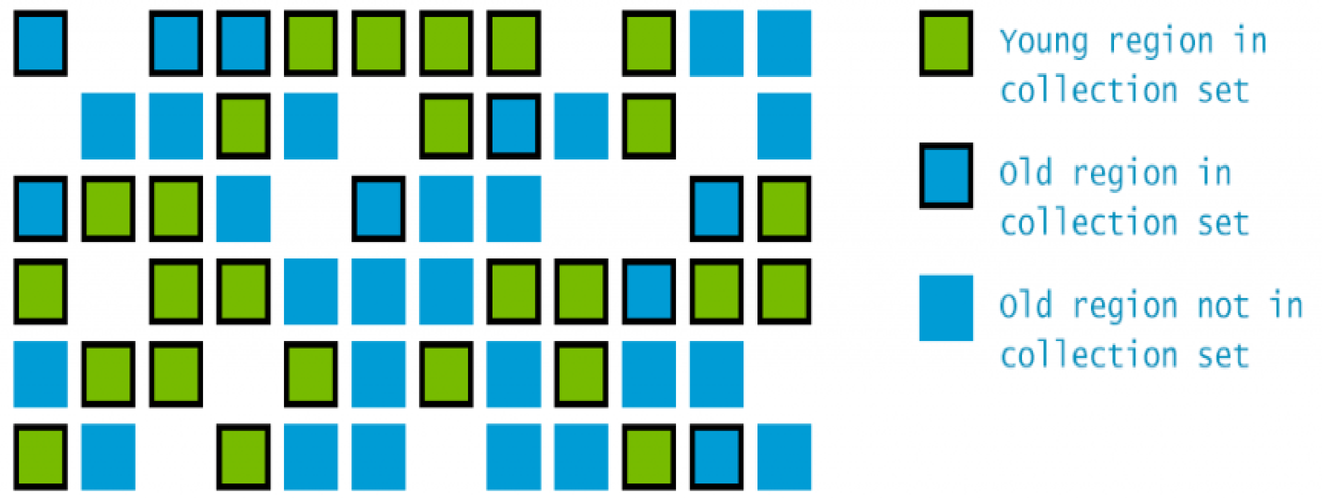
A region represents a block of allocated space that can hold objects of any generation without the need to maintain contiguity with other regions of the same generation.

The heap is one memory area split into many fixed sized regions.



Collection set

To avoid collecting the entire heap at once, only a subset of the regions, called the collection set will be considered at a time.


Young region in collection set
Old region in collection set
Old region not in collection set

Collection Set (continued)

During the concurrent phase it estimates the amount of live data that each region contains. This is used in building the collection set: the regions that contain the most garbage are collected first.

Hence the name: *garbage-first* collection.

Heap Memory allocation:

Allocation is done on a per-thread basis.

Thread Local Area (TLA), is a dedicated partition that a thread allocates freely within, without having to claim a full heap lock. Once the area is full, the thread is assigned a new area until the heap runs out of areas to dedicate.

Note : TLAs are part of the heap. Thread Stacks are not on the heap.

Objects can then be allocated within those thread-local buffers without the need for additional synchronization.

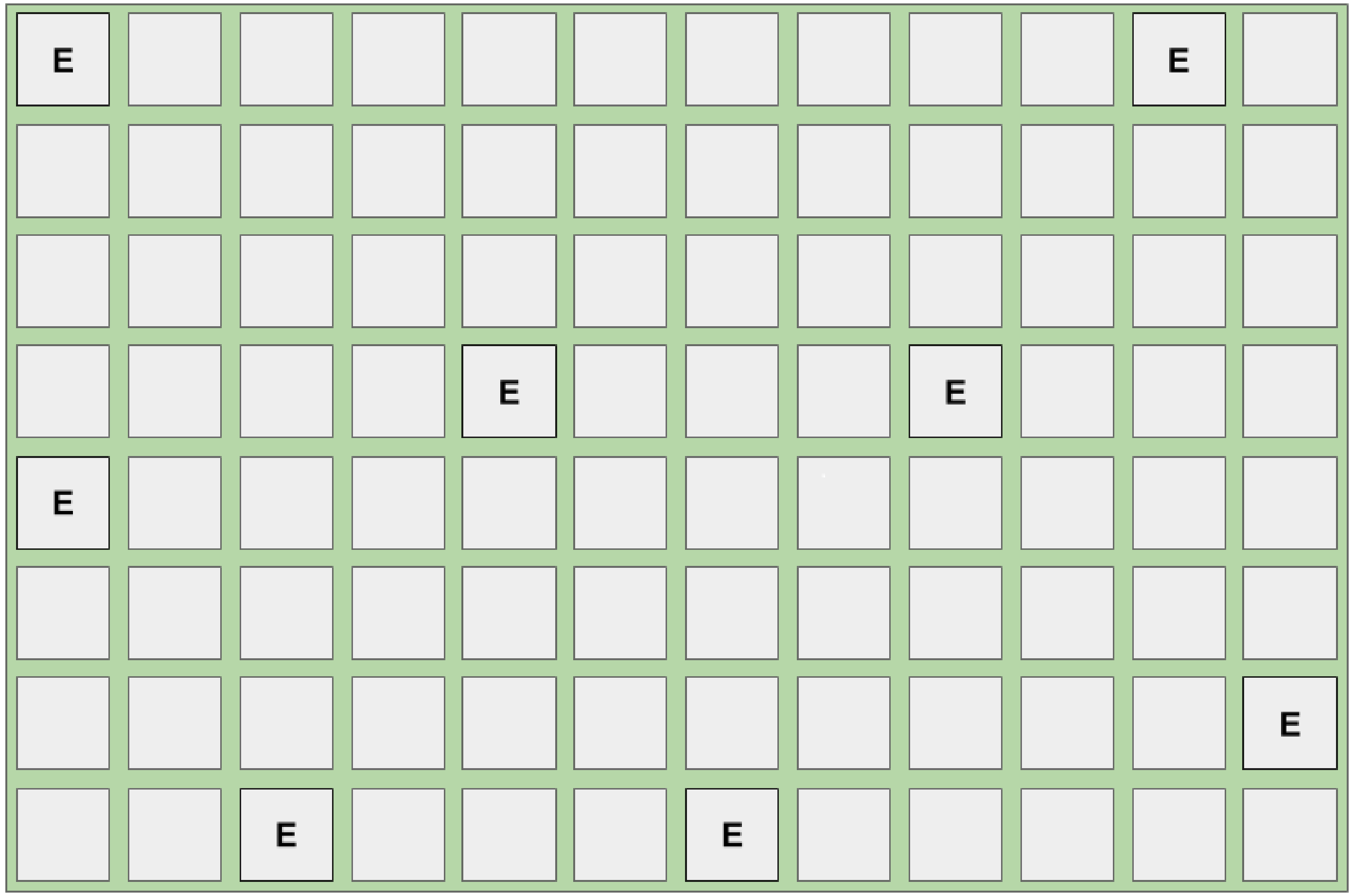
When the region has been exhausted of space, a new region is selected, allocated and filled.

This continues until the cumulative Eden region space has been filled, triggering an evacuation pause (also known as a young collection / young gc / young pause or mixed collection / mixed gc / mixed pause).

The cumulative amount of Eden space represents the number of regions we believe can be collected within the defined soft pause time target.

The percentage of total heap allocated for Eden regions can range from 5% to 60% and gets dynamically adjusted after each young collection based on the performance of the previous young collection.

objects being allocated into non-contiguous Eden regions:



```
GC pause (young); #1
        [Eden: 612.0M(612.0M)->0.0B(532.0M) Survivors: 0.0B->80.0M Heap:
612.0M(12.0G)->611.7M(12.0G)]

GC pause (young); #2
        [Eden: 532.0M(532.0M)->0.0B(532.0M) Survivors: 80.0M->80.0M Heap:
1143.7M(12.0G)->1143.8M(12.0G)]
```

pause #1, evacuation was triggered because Eden reached **612.0M** out of a total of **612.0M** (153 regions).

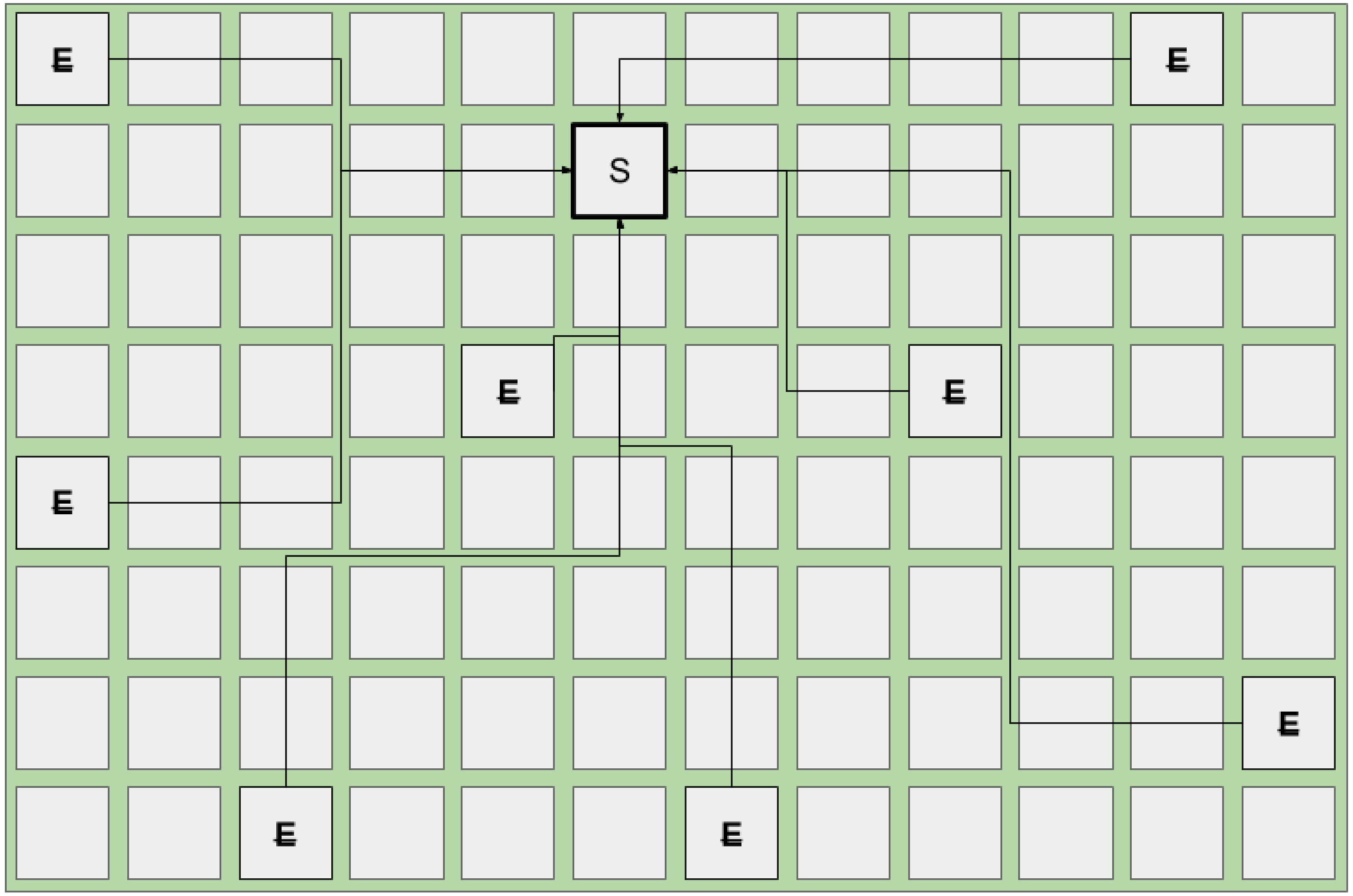
The current Eden space was fully evacuated, **0.0B** and, given the time taken, it also decided to reduce the total Eden allocation to **532.0M** or 133 regions.

In pause #2, we can see the evacuation is triggered when we reach the new limit of **532.0M**. Because we achieved an optimal pause time, Eden was kept at **532.0M**.

Young collection takes place, dead objects are collected and any remaining live objects are evacuated and compacted into the Survivor space.

G1 has an explicit hard-margin, defined by the G1ReservePercent (default 10%), that results in a percentage of the heap always being available for the Survivor space during evacuation.

This principle ensures that after every successful evacuation, all previously allocated Eden regions are returned to the free list and any evacuated live objects end up in Survivor space.


E
E
S
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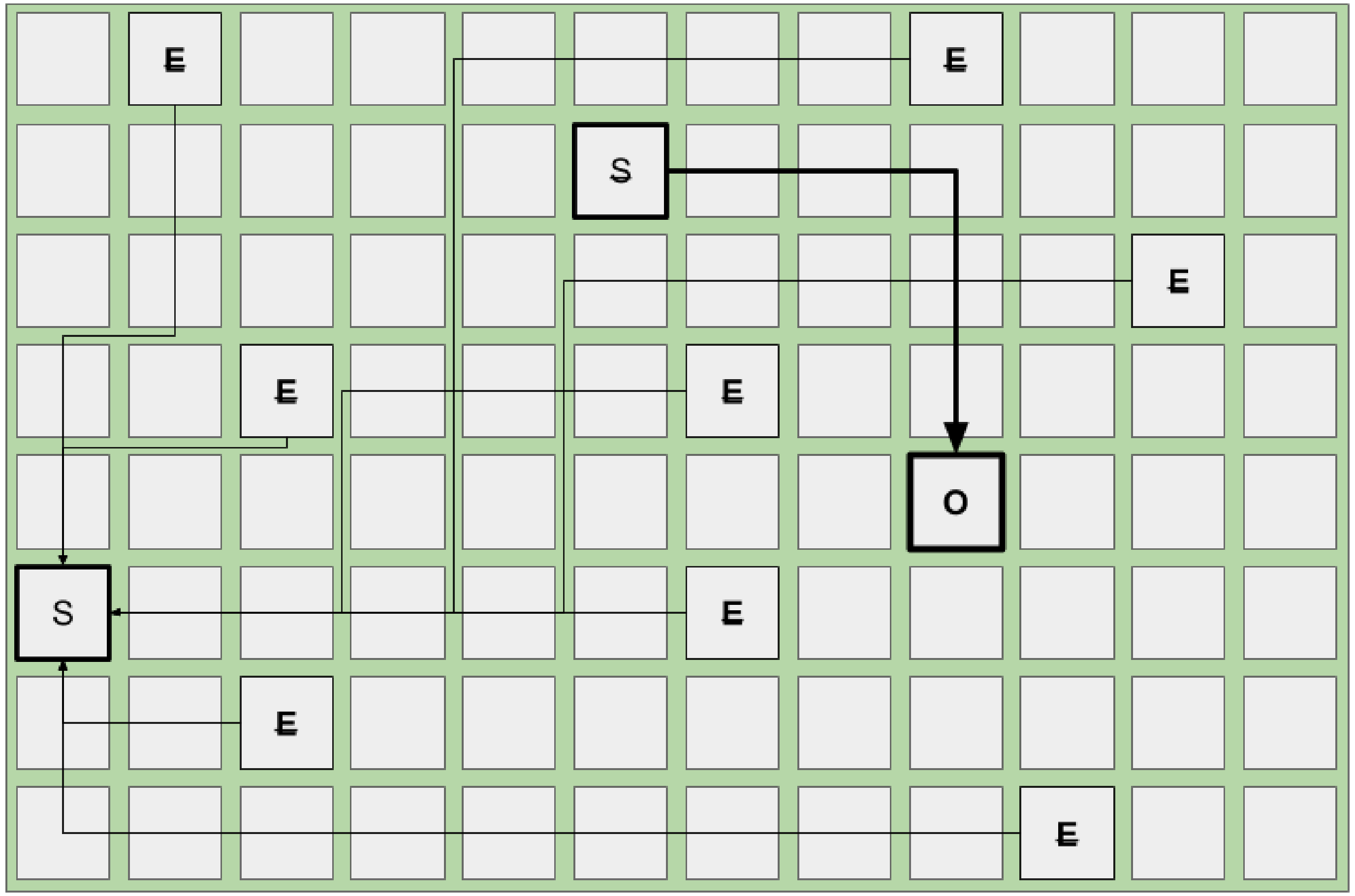
E
E
E
E

Survivor space are evacuated and promoted to a new region in the Old space while live objects from Eden are evacuated into a new Survivor space region.



G1 will continue with this pattern until one of three things happens:

- ✓ It reaches a configurable soft-margin known as the InitiatingHeapOccupancyPercent (IHOP).
- ✓ It reaches its configurable hard-margin (G1ReservePercent)
- ✓ It encounters a humongous allocation

InitiatingHeapOccupancyPercent (The default occupancy is 45 percent of the entire Java heap)

A request is made to start a concurrent marking cycle:

```
8801.974: [G1Ergonomics (Concurrent Cycles) request concurrent cycle
initiation, reason: occupancy higher than threshold, occupancy:
12582912000 bytes, allocation request: 0 bytes, threshold: 12562779330
bytes (45.00 %), source: end of GC]

8804.670: [G1Ergonomics (Concurrent Cycles) initiate concurrent cycle,
reason: concurrent cycle initiation requested]

8805.612: [GC concurrent-mark-start]

8820.483: [GC concurrent-mark-end, 14.8711620 secs]
```

Once the concurrent marking cycle completes, a young collection is immediately triggered, followed by a second type of evacuation, known as **a mixed collection**.

```
8821.975: [G1Ergonomics (Mixed GCs) start mixed GCs, reason: candidate old regions available, candidate old regions: 553 regions, reclaimable: 6072062616 bytes (21.75 %), threshold: 5.00 %]
```

A mixed collection is starting because the number of candidate Old regions (553) have a combined 21.75% reclaimable space. This value is higher than our 5% minimum threshold (5% default in JDK8u40+ / 10% default in JDK7) defined by the **G1HeapWastePercent** and as such, mixed collections will begin.

Overflow and Exhausted Log Messages

When you see to-space overflow/exhausted messages in our logs, the G1 GC does not have enough memory for either survivor or promoted objects, or for both. The Java heap cannot expand since it is already at its max.

Example messages:

```
924.897: [GC pause (G1 Evacuation Pause) (mixed) (to-space exhausted),
0.1957310 secs]
```

OR

```
924.897: [GC pause (G1 Evacuation Pause) (mixed) (to-space overflow),
0.1957310 secs]
```

Solution : try the following adjustments:

Increase the value of the -XX:G1ReservePercent option (and the total heap accordingly) to increase the amount of reserve memory for "to-space".

```
8822.178: [GC pause (mixed) 8822.178: [G1Ergonomics (CSet Construction)
start choosing CSet, _pending_cards: 74448, predicted base time: 170.03 ms,
remaining time: 829.97 ms, target pause time: 1000.00 ms]
```

A mixed collection will look to collect all three generations within the same pause time target.

It manages this through the incremental collection of the Old regions based on the value of G1MixedGCCountTarget (defaults to 8).

Meaning, it will divide the number of candidate Old regions by the **G1MixedGCCountTarget** and try to collect at least that many regions during each cycle.

After each cycle finishes, the liveness of the Old region is re-evaluated.

If the reclaimable space is still greater than the G1HeapWastePercent, mixed collections will continue.

```
8822.704: [G1Ergonomics (Mixed GCs) continue mixed GCs, reason:
candidate old regions available, candidate old regions: 444 regions,
reclaimable: 4482864320 bytes (16.06 %), threshold: 5.00 %]
```

Mixed collections will continue until all eight are completed or until the reclaimable percentage no longer meets the G1HeapWastePercent.

From there, we will see the mixed collection cycle finish and the following events will return to standard young collections.

```
8830.249: [G1Ergonomics (Mixed GCs) do not continue mixed GCs,
reason: reclaimable percentage not over threshold, candidate old
regions: 58 regions, reclaimable: 2789505896 bytes (9.98 %),
threshold: 5.00 %]
```

The above process is for standard use-cases.

Suppose the size of an object is greater than 50% of a single region. In this case, objects are considered to be humongous and are handled by performing specialized humongous allocations.

Region Size: 4096 KB

Object A: 12800 KB

Result: Humongous Allocation across 4 regions

S	E		O		O	O		E			O
					S					S	
O	O		E	H				O		E	
		E		O		E	S			S	
	O			S				O		O	
S			O			E			S		
O		E								E	
	O			O			E		E		

Humongous allocation represents a single object, and as such, must be allocated into contiguous space. This can lead to significant fragmentation.

Humongous objects are allocated to a special humongous region directly within the Old generation. This is because the cost to evacuate and copy such an object across the young generations can be too high.

Even though the object in question is only 12.5 MB, it must consume four full regions accounting for 16 MB of total usage.

Humongous allocations always trigger a concurrent marking cycle, whether the IHOP criteria is met or not.

A steady allocation of them can lead to significant heap fragmentation and a noticeable performance impact. Prior to JDK8u40, humungous objects could only be collected through a Full GC so the potential for this to impact JDK7 and early JDK8 users is very high.

```
4948.653: [G1Ergonomics (Concurrent Cycles) request concurrent cycle initiation, reason: requested by GC cause, GC cause: G1 Humongous Allocation]
```

Full GC (Need to fine tune the application & GC)

Full GC (Need to fine tune the application & GC)

```
6229.578: [GC pause (young) (to-space exhausted),
0.0406140 secs]
6229.691: [Full GC 10G->5813M(12G), 15.7221680 secs]
```

```
57929.136: [GC concurrent-mark-start]
57955.723: [Full GC 10G->5109M(12G), 15.1175910 secs]
57977.841: [GC concurrent-mark-abort]
```

Young GC:
The collection set of the *Young GC* includes only young/survivor regions.

Mixed GC:
The collection set of the *Mixed GC* includes both young/survivor regions, but also old regions.

Humongous Objects and Humongous Allocations

For G1 GC, any object that is more than half a region size is considered a "**Humongous object**". Such an object is allocated directly in the old generation into "**Humongous region**s". *These Humongous regions are a contiguous set of regions.*

G1 Garbage Collector - Big Heaps and Low Pauses?

The **goal of the G1 collector** is to achieve a predictable soft-target pause time, defined through -XX:MaxGCPauseMillis, while also maintaining consistent application throughput.

G1 collects regions with the least amount of live data (Garbage First!) and compacts/evacuates live data into new regions. Secondly, it uses a series of incremental, parallel and multi-phased cycles to achieve its soft pause time target.

The key is that while G1 is a generational collector, the allocation and consumption of space is both non-contiguous and free to evolve as it gains a better understanding of the most efficient young to old ratio.

G1 GC Defaults

-XX:G1HeapRegionSize=n

Sets the size of a G1 region. The value will be a power of two and can range from 1MB to 32MB. The goal is to have around 2048 regions based on the minimum Java heap size

-XX:MaxGCPauseMillis=200

Sets a target value for desired maximum pause time. The default value is 200 milliseconds. The specified value does not adapt to your heap size

-XX:ParallelGCThreads=n

Sets the value of the STW worker threads. Sets the value of n to the number of logical processors. The value of n is the same as the number of logical processors up to a value of 8.

For N > 8 available processors, the number of GC threads will be computed as 3+5N/8.

```
-XX:ConcGCThreads=n
```

Sets the number of parallel marking threads. Sets n to approximately 1/4 of the number of parallel garbage collection threads (ParallelGCThreads).

```
-XX:InitiatingHeapOccupancyPercent=45
```

Sets the Java heap occupancy threshold that triggers a marking cycle. The default occupancy is 45 percent of the entire Java heap.

-XX:MaxTenuringThreshold=n

Maximum value for tenuring threshold. The default value is 15.

-XX:G1ReservePercent=n

Sets the amount of heap that is reserved as a false ceiling to reduce the possibility of promotion failure. The default value is 10.

G1 Tuning options:

<u>Main goal of G1 is low latency, set the Pause goal</u>

```
-XX:MaxGCPauseMillis=300
```

<u>When to start a concurrent GC cycle</u>

```
-XX:InitiatingHeapOccupancyPercent=n
```

(percent of an entire heap, not just old gen)

Too Low -> Unnecessary GC overhead
Too High -> "Space Overflow" -> Full GC

G1 Tuning options (continued)

-XX:G1MixedGCLiveThresholdPercent=65

Sets the occupancy threshold for an old region to be included in a mixed garbage collection cycle. The default occupancy is 65 percent.

-XX:G1HeapWastePercent=10
Sets the percentage of heap that you are willing to waste. The Java HotSpot VM does not initiate the mixed garbage collection cycle when the reclaimable percentage is less than the heap waste percentage.

-XX:G1MixedGCCountTarget=8

Sets the target number of mixed garbage collections after a marking cycle to collect old regions with at most G1MixedGCLIveThresholdPercent live data.

To High-> Unnecessary overhead
To Low-> Long Pauses

-XX:G1OldCSetRegionThresholdPercent=10

By default, G1 will only add up to 10% of the old regions to the Cset, it is for mixed garbage collection cycle.

To High -> More aggressive collecting (More live objects to copy)
To Low -> Wasting some heap

Some options cause "PauseTime Target to be ignored!“

-Xmn (Fixed young generation size)

To enable the G1 Collector use:

```
java -Xmx50m -Xms50m -XX:+UseG1GC -XX:MaxGCPauseMillis=200
```

-XX:+UseG1GC - Tells the JVM to use the G1 Garbage collector.

-XX:MaxGCPauseMillis=200 - Sets a target for the maximum GC pause time. This is a soft goal, and the JVM will make its best effort to achieve it. Therefore, the pause time goal will sometimes not be met. The default value is 200 milliseconds.

-XX:InitiatingHeapOccupancyPercent=45 - Percentage of the (entire) heap occupancy to start a concurrent GC cycle. It is used by G1 to trigger a concurrent GC cycle based on the occupancy of the entire heap, not just one of the generations. A value of 0 denotes 'do constant GC cycles'. The default value is 45 (i.e., 45% full or occupied).

G1 GC Commands :

Option and Default Value	Description
-XX:+UseG1GC	Use the Garbage First (G1) Collector
-XX:MaxGCPauseMillis=n	Sets a target for the maximum GC pause time. This is a soft goal, and the JVM will make its best effort to achieve it.
-XX:InitiatingHeapOccupancyPercent=n	Percentage of the (entire) heap occupancy to start a concurrent GC cycle. It is used by GCs that trigger a concurrent GC cycle based on the occupancy of the entire heap, not just one of the generations (e.g., G1). A value of 0 denotes 'do constant GC cycles'. The default value is 45.
-XX:NewRatio=n	Ratio of new/old generation sizes. The default value is 2.
-XX:SurvivorRatio=n	Ratio of eden/survivor space size. The default value is 8.

-XX:MaxTenuringThreshold=n	Maximum value for tenuring threshold. The default value is 15.
-XX:ParallelGCThreads=n	Sets the number of threads used during parallel phases of the garbage collectors. The default value varies with the platform on which the JVM is running.
-XX:ConcGCThreads=n	Number of threads concurrent garbage collectors will use. The default value varies with the platform on which the JVM is running.
-XX:G1ReservePercent=n	Sets the amount of heap that is reserved as a false ceiling to reduce the possibility of promotion failure. The default value is 10.
-XX:G1HeapRegionSize=n	With G1 the Java heap is subdivided into uniformly sized regions. This sets the size of the individual sub-divisions. The default value of this parameter is determined ergonomically based upon heap size. The minimum value is 1Mb and the maximum value is 32Mb.

Logging GC with G1

(1) -verbosegc (which is equivalent to -XX:+PrintGC) sets the detail level of the log to fine.

-Xloggc:gc.log -XX:+PrintGC

(2) -XX:+PrintGCDetails sets the detail level to finer. The options shows the following information:

-Xloggc:gc.log -XX:+PrintGCDetails

(3) -XX:+UnlockExperimentalVMOptions -XX:G1LogLevel=finest sets the detail level to
its finest. Like finer but includes individual worker thread information.

XX:+PrintAdaptiveSizePolicy : This option will provide many ergonomic details that are purposefully kept out of the **-XX:+PrintGCDetails** option.

The option `–XX:+G1SummarizeRSetStats` can be used to provide a window into the total number of RSet coarsenings to help determine if concurrent refinement threads are able to handle the updated buffers.

-XX:G1SummarizeRSetStatsPeriod=n
This option summarizes RSet statistics every *n*th GC pause

G1 GC Log Format

```
1                                2                              3
2015-09-14T12:32:24.398-0700: 0.356: [GC pause (G1 Evacuation Pause) (young), 0.0215287
secs]
                    4
 [Parallel Time: 20.0 ms, GC Workers: 8]
   [GC Worker Start (ms): Min: 355.9, Avg: 356.3, Max: 358.4, Diff: 2.4]
     [Processed Buffers: Min: 0, Avg: 1.1, Max: 5, Diff: 5, Sum: 9]
                :
                :
    [Free CSet: 0.0 ms]
                                              5
  [Eden: 12.0M(12.0M)->0.0B(14.0M) Survivors: 0.0B->2048.0K Heap: 12.6M(252.0M)-
>7848.3K(252.0M)]                   6
 [Times: user=0.08 sys=0.00, real=0.02 secs]
```

1 **2015-09-14T12:32:24.398-0700: 0.356 –** indicates the time at which this GC event fired. Here **0.356** indicates that 356 milliseconds after the Java process was started this GC event was fired.

2 **GC pause (G1 Evacuation Pause)** — Evacuation Pause is a phase where live objects are copied from one region (young or young + old) to another region.

3 **(young)** – indicates that this is a Young GC event.

4 **GC Workers: 8** – indicates the number of GC worker threads.

5 **[Eden: 12.0M(12.0M)->0.0B(14.0M) Survivors: 0.0B->2048.0K Heap: 12.6M(252.0M)->7848.3K(252.0M)] –** This line indicates the heap size changes:

Eden: 12.0M(12.0M)->0.0B(14.0M) - indicates that Eden generation's capacity was 12mb and all of the 12mb was occupied. After this GC event, young generation occupied size came down to 0. Target Capacity of Eden generation has been increased to 14mb, but not yet committed. Additional regions are added to Eden generation, as demands are made.
Survivors: 0.0B->2048.0K - indicates that Survivor space was 0 bytes before this GC event. But after the event Survivor size increased to 2048kb. It indicates that objects are promoted from Young Generation to Survivor space.
Heap: 12.6M(252.0M)->7848.3K(252.0M) – indicates that capacity of heap size was 252mb, in that 12.6mb was utilized. After this GC event, heap utilization dropped to 7848.3kb (i.e. 5mb (i.e. 12.6mb – 7848.3kb) of objects has been garbage collected in this event). And heap capacity remained at 252mb.

6 **Times: user=0.08, sys=0.00, real=0.02 secs**

JVM Ergonomics

JVM Ergonomics is the process by which the Java Virtual Machine (JVM) and garbage collection tuning, such as behavior-based tuning, improve application performance.

The JVM provides platform-dependent default selections for the garbage collector, heap size, and runtime compiler.

Garbage Collector, Heap, and Runtime Compiler Default Selections

A class of machine referred to as a server-class machine has been defined as a machine with the following:

- 2 or more physical processors
- 2 or more GB of physical memory

On server-class machines, the following are selected by default:

- Throughput garbage collector
- Initial heap size of 1/64 of physical memory up to 1 GB
- Maximum heap size of 1/4 of physical memory up to 1 GB
- Server runtime compiler

The G1 collector is designed for applications that:

Can operate concurrently with applications threads like the CMS collector.

Compact free space without lengthy GC induced pause times.
Need more predictable GC pause durations.
Do not want to sacrifice a lot of throughput performance.
Do not require a much larger Java heap.

G1 is the HotSpot low-pause collector

Long term replacement for CMS

Low pauses valued more than max throughput
> For majority of java apps
> For others, ParallelGC will still be availble

Tuning based on max Stop-The-World Pause
> -XX:MaxGCPauseMillis=<> (default 250 ms)
> ex: java -Xmx32G -XX:MaxGCPauseMillis=100

G1 is planned as the long term replacement for the Concurrent Mark-Sweep Collector (CMS). Comparing G1 with CMS, there are differences that make G1 a better solution.

One difference is that G1 is a compacting collector. G1 compacts sufficiently to completely avoid the use of fine-grained free lists for allocation, and instead relies on regions. This considerably simplifies parts of the collector, and mostly eliminates potential fragmentation issues.

Also, G1 offers more predictable garbage collection pauses than the CMS collector, and allows users to specify desired pause targets.

Tune Latency/Responsiveness

Tune Latency/Responsiveness

step involve several iterations of refining the Java heap size configuration, evaluating garbage collection duration and frequency, possibly switching to a different garbage collector, and further fine-tuning of space sizes in the event of a change to a different garbage collector.

There are two possible outcomes of this step:

✓ Application latency requirements are met

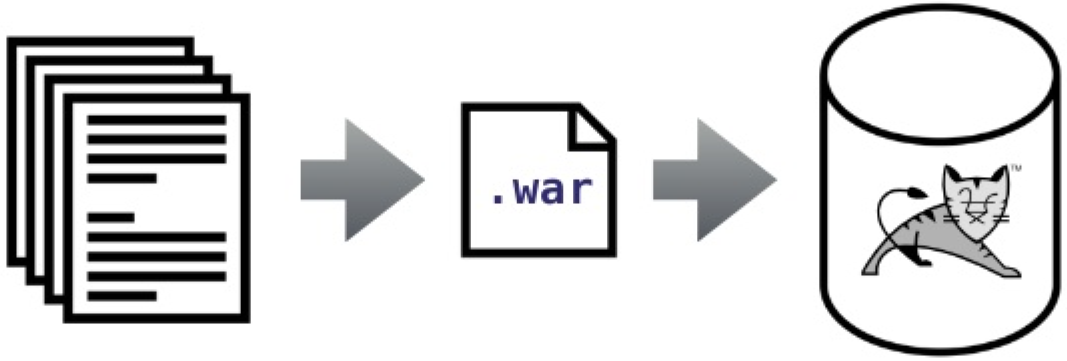
✓ Application latency requirements are not met.

Possible activities that may drive changes to improve the application's latency might include:

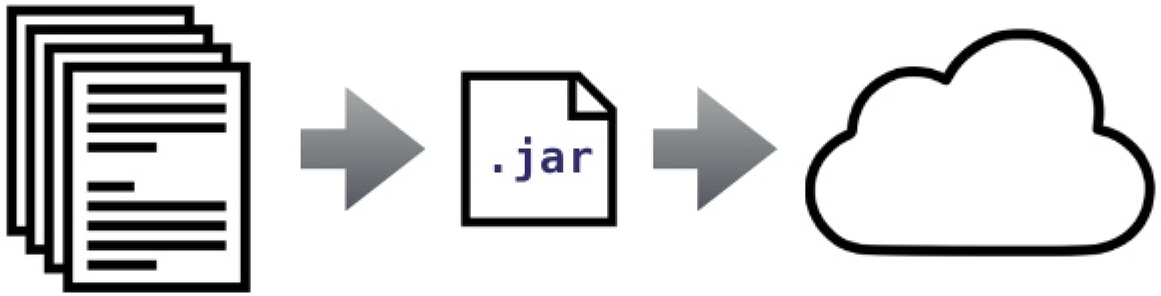
a. Heap profiling and making changes to the application to reduce object allocation or object retention

b. Changing the JVM deployment model to lessen the amount of work or load taken on by a JVM

Traditional JVM Deployment



Modern JVM Deployment



Microservices????

GC Monitoring

What is GC Monitoring?

Garbage Collection Monitoring refers to the process of figuring out how JVM is running GC. For example, we can find out:

when an object in young has moved to old and by how much,or when stop-the-world has occurred and for how long.

<u>Steps to optimize GC</u>

1. Understand the basics of GC

Understanding how GC works is important because of the large number of variables that need to be tuned.

(Ref : http://www.oracle.com/technetwork/java/javase/memorymanagement-whitepaper-150215.pdf)

2. Scope out GC requirements

There are certain characteristics of GC that we should optimize, to reduce its overhead on application performance. Like throughput and latency

Stop-the-world collectors pause the application threads to collect garbage. The duration and frequency of these pauses should not adversely impact the application's ability to adhere to the SLA.

Concurrent GC algorithms contend with the application threads for CPU cycles. This overhead should not affect the application throughput.

Non-compacting GC algorithms can cause heap fragmentation, which leads to long stop-the-world pauses due to full GC. The heap fragmentation should be kept to a minimum.

Garbage collection needs memory to work. Certain GC algorithms have a higher memory footprint than others. If the application needs a large heap, make sure the GC's memory overhead is not large.

A clear understanding of GC logs and commonly used JVM parameters is necessary to easily tune GC behavior should the code complexity grow or workload characteristics change.

GC attacks by Linux

IO Starvation

-> Symptom : GC log shows "low user time, low system time, long pause"

-> Cause :   GC threads stuck in kernal waiting for IO, usually due to journal   commits or FS flush of changes by gzip of log rolling

Memory starvation:

-> Symptom : GC log shows "low user time, high system time, long pause"

-> Cause : Memory pressure triggers swapping or scanning for free memory

Solutions for GC-attacks

IO Starvation

-> Strategy : Even out workload to disk drives
    (flush every 5s rather than 30s)

```
sysctl -w vm.dirty_writeback_centisecs = 500

sysctl -w vm.dirty_expire_centisecs = 500
```

Memory Starvation

-> Strategy : Pre-allocate memory to JVM heap and protect it against swapping or scanning

-> Turn on -XX:+AlwaysPreTouch option in JVM

-> sysctl -w vm.swappiness=0 to protect heap and anonymous memory

-> JVM start up has 2 second delay to allocate all memory (17GB!!)

	Description	Notes
-Xms<size>	Sets the minimum heap size	In production you should set the min and max the same
-Xmx<size>	Sets the maximum heap size	
-XX:NewSize=<size>	Sets the minimum young generation size	In production you should set the min and max the same
-XX:MaxNewSize=<size>	Sets the maximum young generation size	
-XX:NewRatio=<number>	Sets the ratio of the size of the young generation as compared to the tenured generation	Use either the NewSize/MaxSize arguments or the NewRatio argument but not both.

-XX:SurvivorRatio=<numbers>	Sets the ratio of the size of the eden space compared to one survivor spaces	vary the ratio based on the young generation size, a ratio of 8 for small young generations (10MB) and 32 for larger ones (100MB)
-XX:MaxTenuringThreshold=<number>	Indicates the number of minor collections that an object must survive before being automatically placed in the tenured generation	Usually you should use a value of 32
-XX:MaxPermSize=<size>	Sets the size of the permanent generation	Don't set this unless you run out of space
-XX:+DisableExplicitGC	This option forces the JVM to ignore calls to the *System.gc()* method	

--Xss1024k

Thread Stack is the memory that is used by each thread to push/pop functions and variables used for function calls

`-XX:+CMSClassUnloadingEnabled` the GC will sweep PermGen, too, and remove classes which are no longer used.

Code Cache (non-heap): HotSpot JVM also includes a "code cache" containing memory used for compilation and storage of native code

-XX:ReservedCodeCacheSize=32m Reserved code cache size (in bytes)

Permanent Generation (non-heap): holds all the reflective data of the virtual machine itself, such as class and method objects.

-XX:+HeapDumpOnOutOfMemoryError writes heap dump on OutOfMemoryError (recommended)
-XX:+HeapDumpOnCtrlBreak writes heap dump together with thread dump on CTRL+BREAK

Virtual Space-1: (MaxNewSize – NewSize)

The First Virtual Space is actually shows the difference between the -XX:NewSize and -XX:MaxNewSize. Or we can say that it is basically a difference between the Initial Young Size and the Maximum Young Size.

Virtual Space-2: (MaxHeapSize – InitialHeapSize)
The Second Virtual Space is actually the Difference between the Maximum Heap size (**-Xmx**)and the Initial Heap Size(**-Xms**). This is called as virtual space because initially the JVM will allocate the Initial Heap Size and then according to the requirement the Heap size can grow till the MaxHeapSize.

```
JAVA_OPTS="-server –Xms2g –Xmx2g
-XX:+UseParNewGC -XX:+UseConcMarkSweepGC
 -Dsun.rmi.dgc.client.gcInterval=3600000
-Dsun.rmi.dgc.server.gcInterval=3600000

 -XX:PermSize=256m -XX:MaxPermSize=256m
-Dtomcat.util.buf.StringCache.byte.enabled=true
-Dtomcat.util.buf.StringCache.char.enabled=true
-Dtomcat.util.buf.StringCache.trainThreshold=5
-Dtomcat.util.buf.StringCache.cacheSize=2000
-Djava.net.preferIPv4Stack=true"

JAVA_OPTS="$JAVA_OPTS -XXloggc:log/appgc.log -
XX:+PrintGCDetails -XX:ParallelGCThreads=20 -
XX:SurvivorRatio=10 -XX:TargetSurvivorRatio=90
-XX:MaxTenuringThreshold=30
-XX:+HeapDumpOnOutOfMemoryError"
```

Stack size
Each thread in the VM get's a stack. The stack size will limit the number of threads that you can have, too big of a stack size and you will run out of memory as each thread is allocated more memory than it needs.

-Xss determines the size of the stack: -Xss1024k. If the stack space is too small, eventually you will see an exception class java.lang.StackOverflowError .

We can change stack size settings at the OS level for Linux. A call to ulimit may be necessary, and is usually done with a command in /etc/profile:

Limit thread stack size on Linux ulimit -s 2048

NEW : A thread is in a new state when it has just been created and the start()
method hasn't been invoked

RUNNING : A thread is in a runnable state when the start method has been
invoked and the JVM actively schedules it for execution

BLOCKED / WAITING FOR MONITOR ENTRY: Thread enters this state
when it isn't able to acquire the necessary monitors to enter a synchronized block.
A thread waits for other threads to reliquish the monitor. A thread in this state isnt
doing any work

WAITING : A thread enters this state when it relinquishes its control over the
monitor by calling Object.wait(). It waits till the time other threads invoke
Object.notify() or Object.notifyAll(). In this state too the thread isnt doing any work

TIMED WAITING : A thread enters this state when it relinquishes its control over the
monitor by calling Object.wait(long). It waits till the time other threads invoke
Object.notify()
/ Object.notifyAll() or when the wait time expires. In this state too the thread isnt doing
any work

SLEEPING / WAITING ON CONDITION: A thread sleeps when it calls Thread.sleep(long).
As the name suggests the thread isnt doing in this state either Terminated

DEMO - GC Test

Heap	GC Algorithm	Useful Work	Longest Pause
-Xmx2g	-XX:+UseParallelGC	52.82%	0.43515s
-Xmx2g	XX:+UseConcMarkSweepGC	65.29%	0.54668s
-Xmx2g	-XX:+UseG1GC	53.13%	0.51114s
-Xmx4g	-XX:+UseParallelGC	76.55%	0.56021s
-Xmx4g	XX:+UseConcMarkSweepGC	74.23%	1.13218s
-Xmx4g	-XX:+UseG1GC	74.77%	0.95308s

Tuning for Latency

Let us assume we have a requirement stating that all jobs must be processed in under 500ms. Knowing that the actual job processing takes just 50 ms we can simplify and deduct the latency requirement for individual GC pauses.

Our requirement now states that no GC pause can stop the application threads for longer than 450 ms.

-Xmx2g	-XX:+UseParallelGC	52.82%	0.43515s

Tuning for Throughput

Let us assume that we have a throughput goal to process 11,000,000 jobs/hour. The example configurations used again give us a configuration where the requirement is fulfilled:

-Xmx4g	-XX:+UseParallelGC	76.55%	0.56021s

we can see that the CPUs are blocked by GC for 23.45% of the time, leaving 76.55% of the computing power for useful work. For simplicity’s sake we will ignore other safe points in the example. Now we have to take into account that:

1. One job is processed in 100 ms by a single core

2. Thus, in one minute, 60,000 jobs could be processed by one core

3. In one hour, a single core could thus process 3.6 M jobs

4. We have four cores available, which could thus process 4 x 3.6 M = 14.4 M jobs in an hour

With this amount of theoretical processing power we can make a simple calculation and conclude that during one hour we can in reality process 76.55% of the 14.4 M theoretical maximum resulting in 11,023,200 processed jobs/hour, fulfilling our requirement.

Tuning for Capacity

Let us assume we have to deploy our solution to the commodity-class hardware with up to four cores and 4 G RAM available. From this we can derive our capacity requirement that the maximum heap space for the application cannot exceed 2 GB

-Xmx2g	-XX:+UseParallelGC	52.82%	0.43515s
-Xmx2g	XX:+UseConcMarkSweepGC	65.29%	0.54668s
-Xmx2g	-XX:+UseG1GC	53.13%	0.51114s

Java Concurrency- Thread Pool

A thread pool is represented by an instance of the class ExecutorService.

With an ExecutorService, we can submit task that will be completed in the future.

Here are the type of thread pools you can create with the Executors class :

- ✓ Single Thread Executor
- ✓ Cached Thread Pool
- ✓ Fixed Thread Pool
- ✓ Scheduled Thread Pool
- ✓ Single Thread Scheduled Pool

Single Thread Executor : A thread pool with only one thread. So all the submitted task will be executed sequentially.

Method : Executors.newSingleThreadExecutor()

Cached Thread Pool : A thread pool that create as many threads it needs to execute the task in parralel. The old available threads will be reused for the new tasks. If a thread is not used during 60 seconds, it will be terminated and removed from the pool. Method :

Executors.newCachedThreadPool()

Fixed Thread Pool : A thread pool with a fixed number of threads. If a thread is not available for the task, the task is put in queue waiting for an other task to ends. Method :

Executors.newFixedThreadPool()

Scheduled Thread Pool : A thread pool made to schedule future task. Method : Executors.newScheduledThreadPool()
Single Thread Scheduled Pool : A thread pool with only one thread to schedule future task.

Method : Executors.newSingleThreadScheduledExecutor()

Thread Pool Configuration

Thread Pools address two different problems:

➢ deliver improved performance when executing large numbers of asynchronous tasks

➢ due to reduced per-task invocation overhead, and they provide a means of bounding and managing the resources, including Threads, consumed when executing a collection of tasks.

- Bounded Threads configuration
- Unbounded Threads configuration
- Queueless Thread Pool configuration
- Scheduled Thread configuration

Data source connection pool :

```
<datasource jndi-name="MySqlDS" pool-name="MySqlDS_Pool"
enabled="true" jta="true" use-java-context="true" use-ccm="true">
<connection-url>jdbc:mysql://localhost:3306/MyDB
</connection-url>
<driver>mysql</driver>
<pool>
<min-pool-size>10</min-pool-size>
<max-pool-size>30</max-pool-size>
<prefill>true</prefill>
</pool>
<timeout>
<blocking-timeout-millis>30000</blocking-timeout-millis>
<idle-timeout-minutes>5</idle-timeout-minutes>
</timeout>
</datasource>
```

In server log the below error is a strong clue that wen eed to look at connection pooling:

```
21:57:57,781 ERROR [stderr] (http-executor-threads - 7) Caused by: javax.resource.ResourceException: IJ000655: No managed connections available within configured blocking timeout (30000 [ms])
21:57:57,782 ERROR [stderr] (http-executor-threads - 7)        at org.jboss.jca.core.connectionmanager.pool.mcp.SemaphoreArrayListManagedConnectionPool.getConnection
```

EJB connection pool

```
<pools>
<bean-instance-pools>
<strict-max-pool name="slsb-strict-max-pool" max-pool-size="20"
instance-acquisition-timeout="5" instance-acquisition-timeout-
unit="MINUTES"/>
<strict-max-pool name="mdb-strict-max-pool" max-pool-size="20"
instance-acquisition-timeout="5" instance-acquisition-timeout-
unit="MINUTES"/>
</bean-instance-pools>
</pools>
```

EJB does not need a costly initialization, then avoid object pool :

```
<stateless>
<!--
<bean-instance-pool-ref pool-name="slsb-strict-max-pool"/>
-->
</stateless>
```

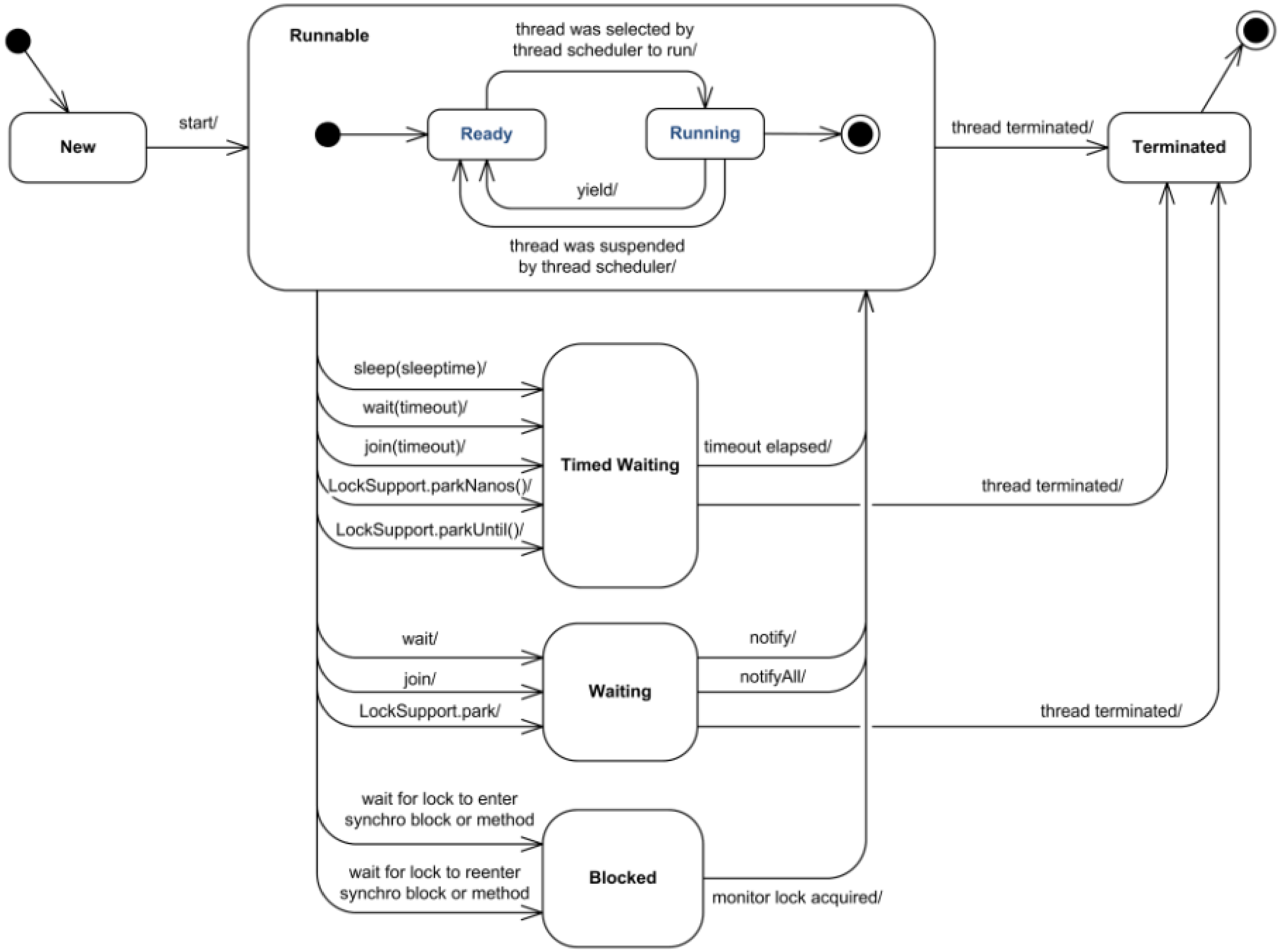
http thread pool

```
<subsystem xmlns="urn:jboss:domain:web:1.0">

 <connector enable-lookups="false" enabled="true"
 executor="http-executor"
 max-connections="200"
 max-post-size="2048" max-save-post-size="4096"
 name="http" protocol="HTTP/1.1"
 proxy-name="proxy" proxy-port="8081"
 redirect-port="8443" scheme="http"
 secure="false" socket-binding="http" />
. . .
</subsystem>
```

```
 <subsystem xmlns="urn:jboss:domain:threads:1.1">
                    <bounded-queue-thread-pool
name="http-executor">
      <core-threads count=“25"/>
      <queue-length count=“50"/>
      <max-threads count="100"/>
      <keepalive-time time="10" unit="seconds" />
      </bounded-queue-thread-pool>
     </subsystem>
```

Understanding Thread States


Runnable
thread was selected by thread scheduler to run/
New
start/
Ready
Running
yield/
thread was suspended by thread scheduler/
thread terminated/
Terminated
sleep(sleeptime)/
wait(timeout)/
join(timeout)/
LockSupport.parkNanos()/
LockSupport.parkUntil()/
Timed Waiting
timeout elapsed/
thread terminated/
wait/
join/
LockSupport.park/
Waiting
notify/
notifyAll/
thread terminated/
wait for lock to enter synchro block or method
wait for lock to reenter synchro block or method
Blocked
monitor lock acquired/

•**`NEW`** : A thread has not started yet.

•**`RUNNABLE`** : Thread is running state but it can be in state of waiting.

•**`BLOCKED`** : Thread is waiting to acquire monitor lock to enter into a synchronized block/method after calling Object.wait()

•**`WAITING`** : A thread is in waiting state due to calling one of the following methods

- **`Object.wait()`** : It causes current thread to wait until it been notified by method *notify()* or *notifyAll().*
- **`Object.join()`** : Waits for current thread to die.
- **`LockSupport.park`** : Disables the current thread for thread scheduling purposes unless the permit is available.

•**`TIMED_WAITING`** : Current thread is waits for another thread for specified time to perform the action.

- **`Thread.sleep (long timeInMilliSecond)`** : Makes current thread to cease the execution for specified time.

- **`Object.wait (long timeInMilliSecond)`** : Causes current thread to wait for specified time until time elapsed or get notified by notify() or notifyAll().

- **`Thread.join (long millis)`** : Current thread waits for specified time to die the thread.

- **`LockSupport.parkNanos (long nanoSeconds)`** : Disables the current thread for thread scheduling purposes, for up to the specified waiting time, unless the permit is available.

- **`LockSupport.parkUntil ()`**

•`TERMINATED` : When thread completed its execution.

NEW : A thread is in a new state when it has just been created and the start() method hasn't been invoked

RUNNING : A thread is in a runnable state when the start method has been invoked and the JVM actively schedules it for execution

BLOCKED / WAITING FOR MONITOR ENTRY: Thread enters this state when it isn't able to acquire the necessary monitors to enter a synchronized block. A thread waits for other threads to relinquish the monitor. A thread in this state isn't doing any work

WAITING : A thread enters this state when it relinquishes its control over the monitor by calling Object.wait(). It waits till the time other threads invoke Object.notify() or Object.notifyAll(). In this state too the thread isn't doing any work

TIMED WAITING : A thread enters this state when it relinquishes its control over the monitor by calling Object.wait(long). It waits till the time other threads invoke Object.notify() / Object.notifyAll() or when the wait time expires. In this state too the thread isnt doing any work
SLEEPING / WAITING ON CONDITION: A thread sleeps when it calls Thread.sleep(long). As the name suggests the thread isnt doing in this state either

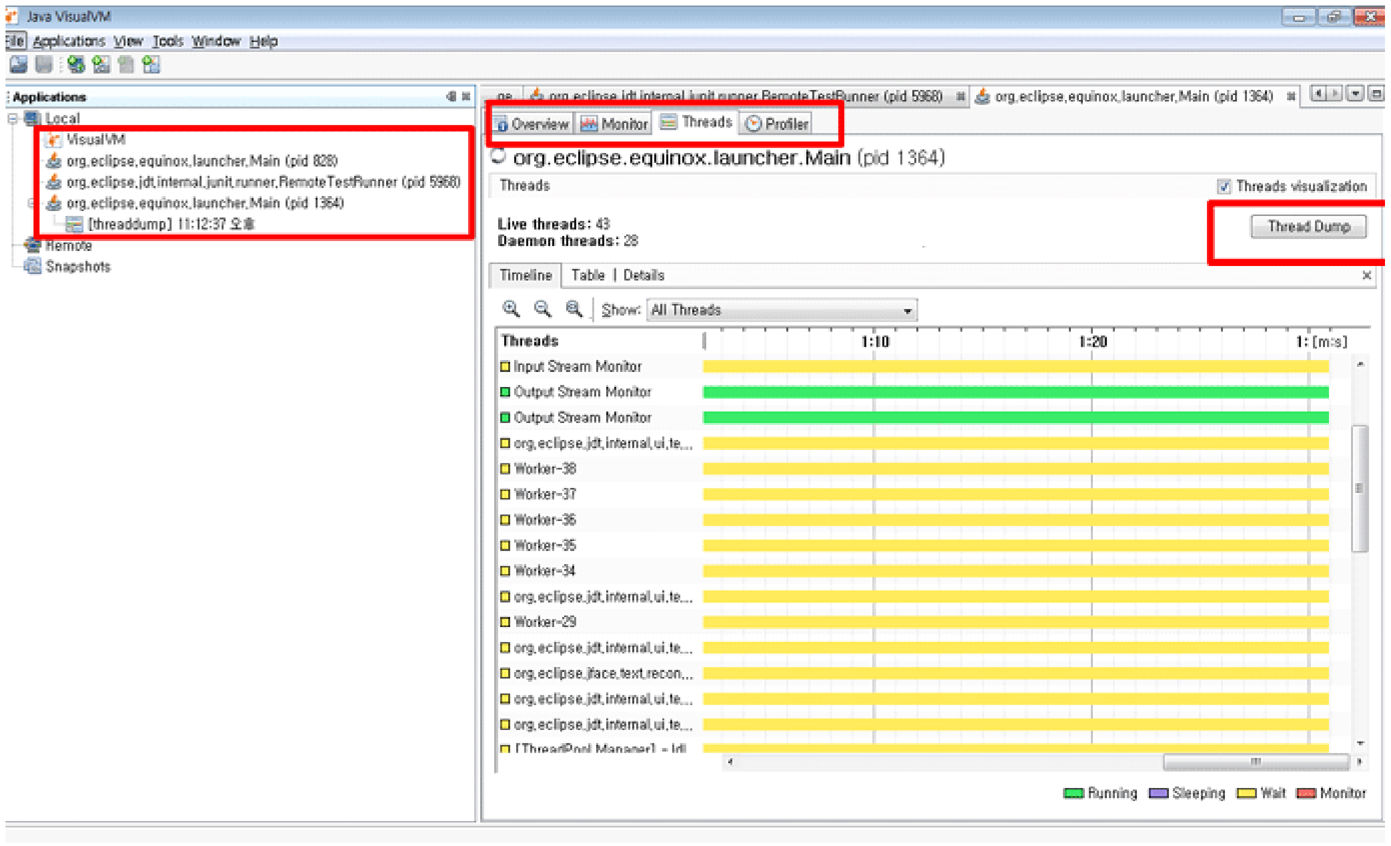
Terminated

Other

Analysing Thread Dumps

Thread Dump Using jVisualVM

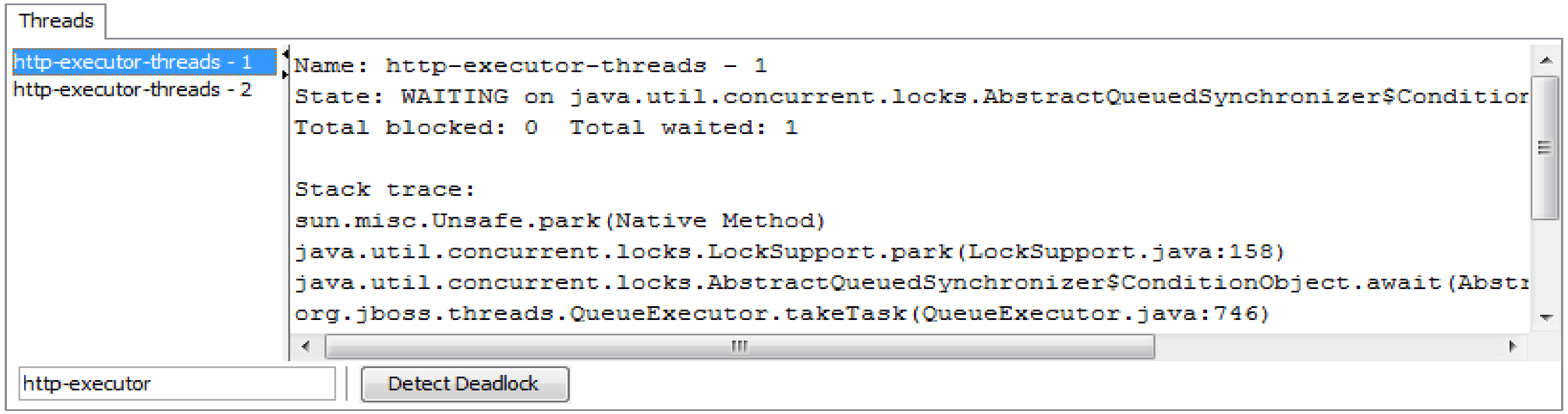
Generate a thread dump by using a program such as jVisualVM.


Java VisualVM
File Applications View Tools Window Help
Applications
Local
VisualVM
org.eclipse.equinox.launcher.Main (pid 828)
org.eclipse.jdt.internal.junit.runner.RemoteTestRunner (pid 5968)
org.eclipse.equinox.launcher.Main (pid 1364)
[threaddump] 11:12:37 오후
Remote
Snapshots
Overview Monitor Threads Profiler
org.eclipse.equinox.launcher.Main (pid 1364)
Threads
Threads visualization
Live threads: 43
Daemon threads: 28
Thread Dump
Timeline Table Details
Show: All Threads
Threads
Input Stream Monitor
Output Stream Monitor
Output Stream Monitor
org.eclipse.jdt.internal.ui.te...
Worker-38
Worker-37
Worker-36
Worker-35
Worker-34
org.eclipse.jdt.internal.ui.te...
Worker-29
org.eclipse.jdt.internal.ui.te...
org.eclipse.jface.text.recon...
org.eclipse.jdt.internal.ui.te...
org.eclipse.jdt.internal.ui.te...
Running Sleeping Wait Monitor

Ex1 : C:\Java\jdk1.8.0\bin\jvisualvm

Ex2 : C:\Java\jdk1.8.0\bin\jstat –f <process-id>

idle thread should look like, by looking at its stack trace:



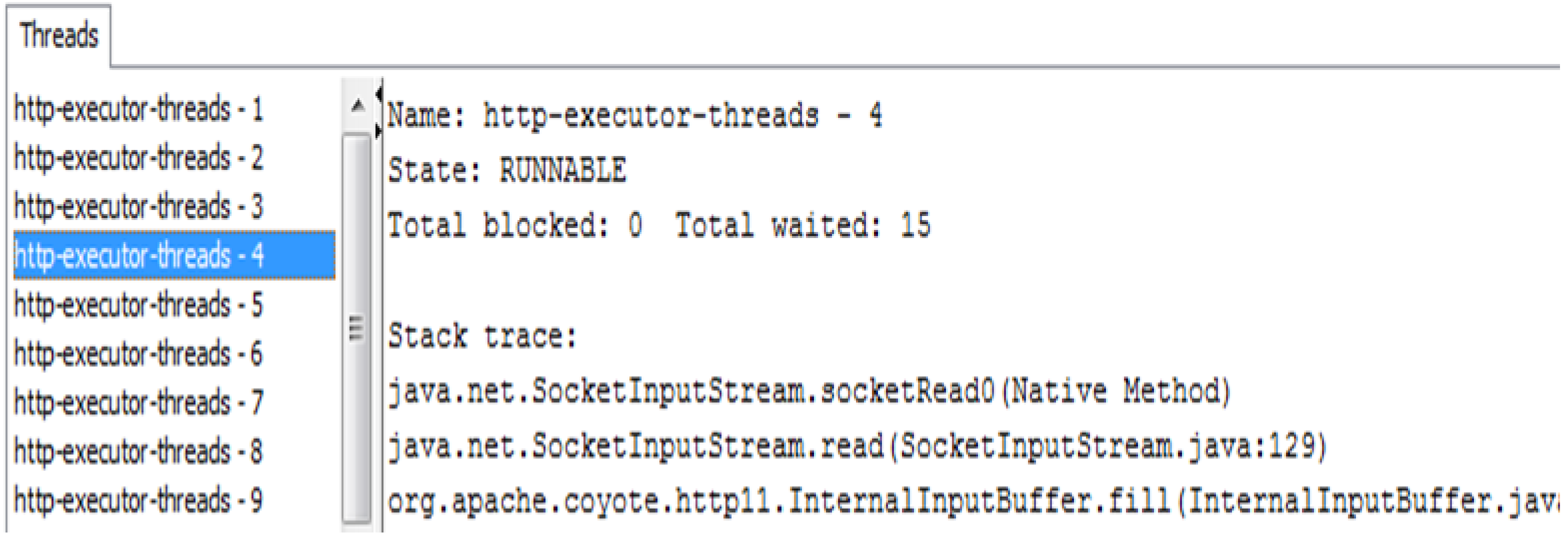
Threads

http-executor-threads - 1
http-executor-threads - 2

```
Name: http-executor-threads - 1
State: WAITING on java.util.concurrent.locks.AbstractQueuedSynchronizer$Conditior
Total blocked: 0  Total waited: 1

Stack trace:
sun.misc.Unsafe.park(Native Method)
java.util.concurrent.locks.LockSupport.park(LockSupport.java:158)
java.util.concurrent.locks.AbstractQueuedSynchronizer$ConditionObject.await(Abstr
org.jboss.threads.QueueExecutor.takeTask(QueueExecutor.java:746)
```

HTTP thread is **busy** at doing input/output operations which could mean, for example, the web server is acquiring data from an external resource.



```
http-executor-threads - 1
http-executor-threads - 2
http-executor-threads - 3
http-executor-threads - 4
http-executor-threads - 5
http-executor-threads - 6
http-executor-threads - 7
http-executor-threads - 8
http-executor-threads - 9
```

```
Name: http-executor-threads - 4
State: RUNNABLE
Total blocked: 0  Total waited: 15

Stack trace:
java.net.SocketInputStream.socketRead0(Native Method)
java.net.SocketInputStream.read(SocketInputStream.java:129)
org.apache.coyote.http11.InternalInputBuffer.fill(InternalInputBuffer.jav
```

Eliminate Runnable threads: Runnable threads are already being actively scheduled and there is no need to extensively focus on them in the first pass.

Eliminate Idle threads: It is natural that some threads in the application are in the idle state. They would either be waiting for an incoming connection or sleeping for a period of time before they wake. Eliminate such threads from your analysis which would be ideally found idling cycles.

The below threads can be safely ignored :

```
"tcpConnection-9011-7736" daemon prio=1 tid=0x351750b8
nid=0x7eab in Object.wait() [0x2fdf4000..0x2fdf50b0]
    at java.lang.Object.wait(Native Method)
    - waiting on <0x43eef7c8> (a java.lang.Object)
    at com.caucho.server.TcpServer.accept(TcpServer.java:648)
```

```
"Store org.hibernate.cache.StandardQueryCache Expiry Thread"
daemon prio=1 tid=0x3becd4e0 nid=0x1c6e waiting on condition
[0x35389000..0x353891b0]  at java.lang.Thread.sleep(Native Method)
```

```
"Store org.hibernate.cache.UpdateTimestampsCache Expiry Thread"
daemon prio=1 tid=0x397868a8 nid=0x1c6c waiting on condition
[0x3548a000..0x3548b0b0]  at java.lang.Thread.sleep(Native Method)
```

Analyse BLOCKED and WAITING threads: This is perhaps the most important part of analysis. It is important to ask the question why are these threads in either the BLOCKED or WAITING state when they should have been in the RUNNABLE state.

These threads are waiting for monitors which have been acquired by other threads.

"tcpConnection-9011-7709" in the BLOCKED state waiting to lock a monitor:

```
"tcpConnection-9011-7709" daemon prio=1 tid=0x35029e40 nid=0x7e61
waiting for monitor entry [0x2fe74000..0x2fe75e30]
    at java.beans.Introspector.getPublicDeclaredMethods(Introspector.java:1249)
    - waiting to lock <0x3d9bb6b0> (a java.lang.Class)
```

"tcpConnection-9011-7640" has obtained the monitor.

```
"tcpConnection-9011-7640" daemon prio=1 tid=0x35177a40 nid=0x7dc7
runnable [0x305fa000..0x305fcf30]
  at java.beans.Introspector.findExplicitBeanInfo(Introspector.java:410)
    - locked <0x3d9bb6b0> (a java.lang.Class)
```

Analyse thread dumps over a duration

Compare the the sanapshot’s :

Snapshot 1:

"tcpConnection-9011-7696" daemon prio=1 tid=0x3466c258 nid=0x7e4f in **Object.wait()** [0x2727b000..0x2727bfb0]

Snapshot 2:

"tcpConnection-9011-7696" daemon prio=1 tid=0x3466c258 nid=0x7e4f **runnable** [0x2727b000..0x2727bfb0]

out-of-threads

Consider the following scenario:

> Response time of your key pages is rapidly dropping

> The application throughput is more or less constant

>The application server and database servers are running with permissible limits of system parameters

# It is possible that you may be seeing a sudden increase of users hitting the application. Based on the analysis the only immediate recourse would be to increase the number of threads in the thread pool to cater to this increased demand. We need to consider the impact of such changes before making the changes.

Resource Contention

Resource contention typically happens when the threads are fighting for the same resources. If a majority of threads in the application are fighting for the same resource this could speak about poor application design.

The most common symptons of resource contention issues are :

> The throughput / responsiveness of the application has fallen considerably and the application is too slow
> The CPU utilization is low
> All the application resources (db connection pools etc) seem to free and available
> In thread dumps most the thread would appear in the BLOCKED / WAITING FOR MONITOR ENTRY state

Problem 1 :

all the threads are waiting to acquire lock on the monitor <0x44008de0>

"**tcpConnection-9011-8009**" daemon prio=1 tid=0x31446a80 nid=0x49f5 **waiting for monitor entry** [0x2edf5000..0x2edf6e30]
    at com.opensymphony.oscache.base.algorithm.AbstractConcurrentReadCache.put(AbstractConcurrentReadCache.java:1648)
waiting to lock <0x44008de0>

This lock is obtained by the below thread:

" **tcpConnection-9011-7817**" daemon prio=1 tid=0x24fee130 nid=0x491c **runnable** [0x1513e000..0x15140130]
    at java.lang.System.identityHashCode(Native Method)
locked < 0x44008de0 >

Analysis :

operating system had run out of file descriptors and hence thread tcpConnection-9011-7817 couldn't really persist the cached object to the disk and release the monitor.

Solutions :

Increasing the limit on the number of file descriptors (ulimit) and restarting the application.

BLOCKED (on object monitor) -> **(lab5 : JFR-Latencies)**

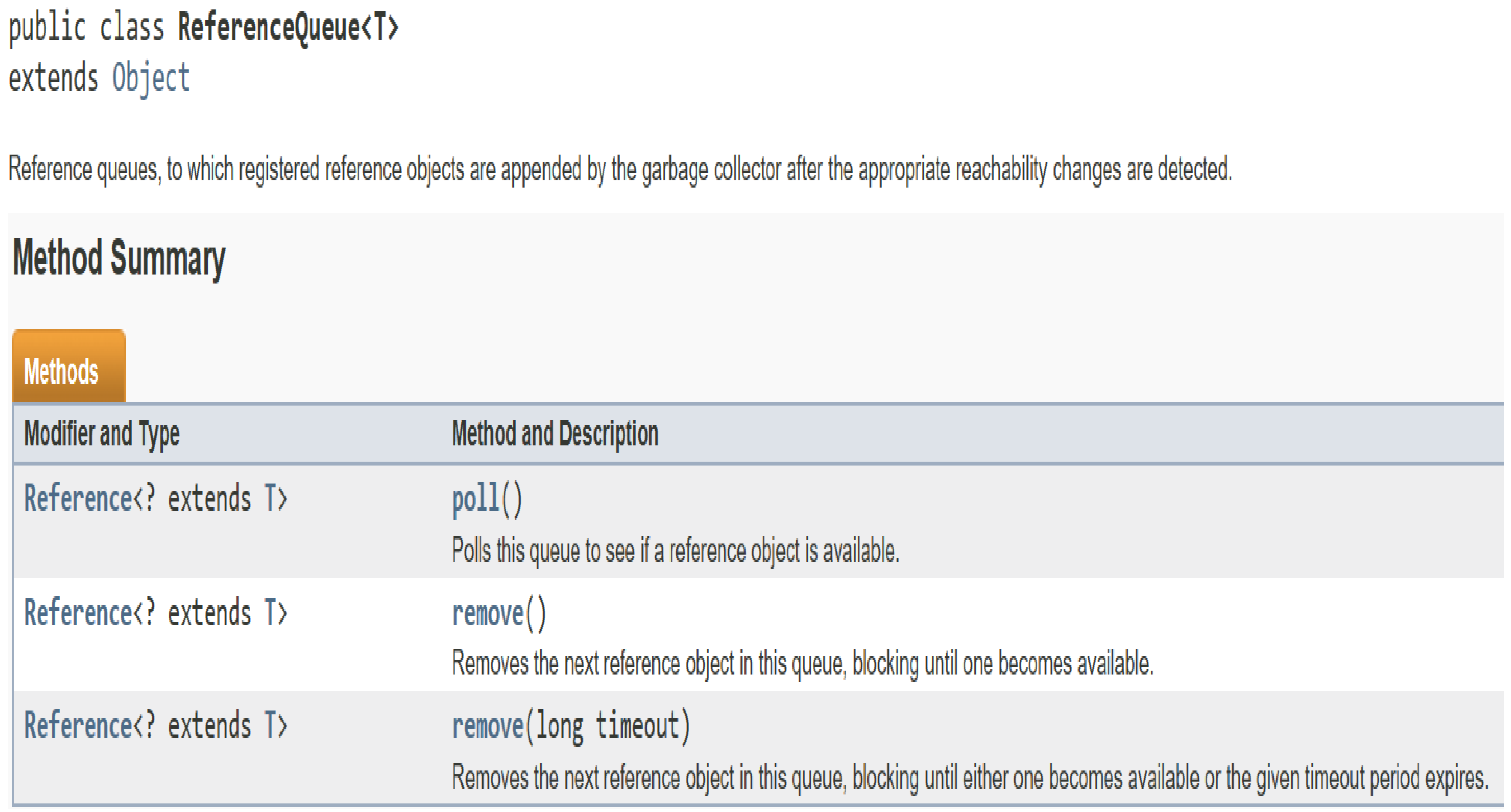
```
"Worker Thread 2" #12 prio=5 os_prio=0 tid=0x000000001b7c4000 nid=0x19b0
waiting for monitor entry [0x000000001c11f000]
java.lang.Thread.State: BLOCKED (on object monitor)
      at Logger.log(Logger.java:17)
          - waiting to lock <0x00000000d5de8788> (a Logger)
at WorkerThread.run(WorkerThread.java:24)
```

Refer to the below thread, which is holding the lock

```
"Worker Thread 0" #10 prio=5 os_prio=0 tid=0x000000001b7bd800 nid=0x2af8
waiting on condition [0x000000001bf1f000]
 java.lang.Thread.State: TIMED_WAITING (sleeping)
           at java.lang.Thread.sleep(Native Method)
               at Logger.log(Logger.java:17)   - locked <0x00000000d5de8788> (a Logger)
                at WorkerThread.run(WorkerThread.java:24)
```

WAITING (on object monitor) -> Tomcat threads

```
"Finalizer" #3 daemon prio=8 os_prio=1 tid=0x0000000019dca800 nid=0x47fc in
Object.wait() [0x000000001b12e000]
java.lang.Thread.State: WAITING (on object monitor)
    at java.lang.Object.wait(Native Method)
      - waiting on <0x00000000d5d88ee0> (a java.lang.ref.ReferenceQueue$Lock
    at java.lang.ref.ReferenceQueue.remove(ReferenceQueue.java:143)
     - locked <0x00000000d5d88ee0> (a java.lang.ref.ReferenceQueue$Lock)
    at java.lang.ref.ReferenceQueue.remove(ReferenceQueue.java:164)
    at java.lang.ref.Finalizer$FinalizerThread.run(Finalizer.java:209)
```



```
public class ReferenceQueue<T>
extends Object
```

Reference queues, to which registered reference objects are appended by the garbage collector after the appropriate reachability changes are detected.

Method Summary

Methods

Modifier and Type	Method and Description
`Reference<? extends T>`	`poll()` Polls this queue to see if a reference object is available.
`Reference<? extends T>`	`remove()` Removes the next reference object in this queue, blocking until one becomes available.
`Reference<? extends T>`	`remove(long timeout)` Removes the next reference object in this queue, blocking until either one becomes available or the given timeout period expires.

Problem : (waiting on object monitor)

The below thread is unable to get database connection:

```
"Thread-1" prio=5 tid=0x00a861b8 nid=0xbdc in Object.wait()
[0x02d0f000..0x02d0fb68]
	at java.lang.Object.wait(Native Method)
	- waiting on <0x22aadfc0> (a
org.tw.testyard.thread.ConnectionPool)
	at java.lang.Object.wait(Unknown Source)
	at
org.tw.testyard.thread.ConnectionPool.getConnection(ConnectionPool.
java:39)
	- locked <0x22aadfc0> (a org.tw.testyard.thread.ConnectionPool)
```

Solution :

We see such things happening often in your application it is time to revisit the connection pool configuration.

In any case the connection pool size should be at least as big as the number of worker threads in your application.

# We may see the similar issues when dealing with resources such as db connections, network connections or file handles.

sun.misc.Unsafe

The biggest competitor to the Java virtual machine might be Microsoft's CLR that hosts languages such as C#. The CLR allows to write unsafe code as an entry gate for low level programming, something that is hard to achieve on the JVM.

If we need such advanced functionality in Java, we might be forced to use the JNI which requires us to know some C and will quickly lead to code that is tightly coupled to a specific platform.

With sun.misc.Unsafe, there is however another alternative to low-level programming on the Java platform using a Java API, even though this alternative is discouraged.

To make our code “trusted”, we can use the option bootclasspath while running the program and specify path to system classes plus the class that will use Unsafe.

```
java -Xbootclasspath:/usr/jdk1.7.0/jre/lib/rt.jar:.
demo.test.UnsafeClient
```

```
Name: http-bio-8080-exec-1
State: WAITING on
java.util.concurrent.locks.AbstractQueuedSynchronizer$ConditionObject@bfc0c12
Total blocked: 30  Total waited: 9

Stack trace:
sun.misc.Unsafe.park(Native Method)
java.util.concurrent.locks.LockSupport.park(LockSupport.java:175)
java.util.concurrent.locks.AbstractQueuedSynchronizer$ConditionObject.await(AbstractQueu
edSynchronizer.java:2039)
java.util.concurrent.LinkedBlockingQueue.take(LinkedBlockingQueue.java:442)
org.apache.tomcat.util.threads.TaskQueue.take(TaskQueue.java:104)
org.apache.tomcat.util.threads.TaskQueue.take(TaskQueue.java:32)
java.util.concurrent.ThreadPoolExecutor.getTask(ThreadPoolExecutor.java:1067)
java.util.concurrent.ThreadPoolExecutor.runWorker(ThreadPoolExecutor.java:1127)
java.util.concurrent.ThreadPoolExecutor$Worker.run(ThreadPoolExecutor.java:617)
org.apache.tomcat.util.threads.TaskThread$WrappingRunnable.run(TaskThread.java:61)
java.lang.Thread.run(Thread.java:745)
```

Unsafe API

Class sun.misc.Unsafe consists of 105 methods. There are, actually, few groups of important methods for manipulating with various entities.

Info: Just returns some low-level memory information.
addressSize
pageSize

Objects: Provides methods for object and its fields manipulation.
allocateInstance
objectFieldOffset

Synchronization: Low level primitives for synchronization.

monitorEnter
tryMonitorEnter
monitorExit
compareAndSwapInt
putOrderedInt

Memory: Direct memory access methods.

allocateMemory
copyMemory
freeMemory
getAddress
getInt
putInt

Thread Stack Trace -> Blocked, Waited count

Blocked count is the total number of times that the thread blocked to enter or reenter a monitor. I.e. the number of times a thread has been in the java.lang.Thread.State.BLOCKED state.

Waited count is the total number of times that the thread waited for notification. i.e. the number of times that a thread has been in the java.lang.Thread.State.WAITING or java.lang.Thread.State.TIMED_WAITING state.

Stuck Thread

What is Stuck Thread?

A Stuck Thread is a thread which is processing a request for more than maximum time that is configured in a server.

hogging thread

A hogging thread is a thread which is taking more than usual time to complete the request and can be declared as Stuck .

In Weblogic:

A thread declared as Stuck if it runs over 600 secs

WebLogic has polar which runs every 2 secs,It checks for the number of requests completed in last two minutes

check how much times each took to complete

Then, it takes the average time of all completed request

Then multiply average time with a the value of the request taken more time.

For example –

At a particular moment, total number of completed requests in last two seconds – 4
Total time took by all 4 requests – 16 secs
Req1 took – 5 secs, Req2 took – 3 secs, Req3 took – 7 secs, Req4 took – 1 sec
Average time = 16/4 = 4 secs
7*4 = 28 secs
Now weblogic check all executed threads to see which taking more than 28 secs, if any then that thread(s) declared as Hogged Thread.

Race Condition

A race condition occurs in programming when two or more execution threads modify a shared, or critical, resource.

Race conditions can result in run time errors that are difficult to isolate and to repair.

The term "race" is used because the threads can be regarded as racing each other to complete operations on a variable or other shared resource.

Logging tuning

>Choosing the appropriate handler to output your logs.
>Choose a log level which provides just the amount of information you need and nothing else.
>Choose an appropriate format for your logs

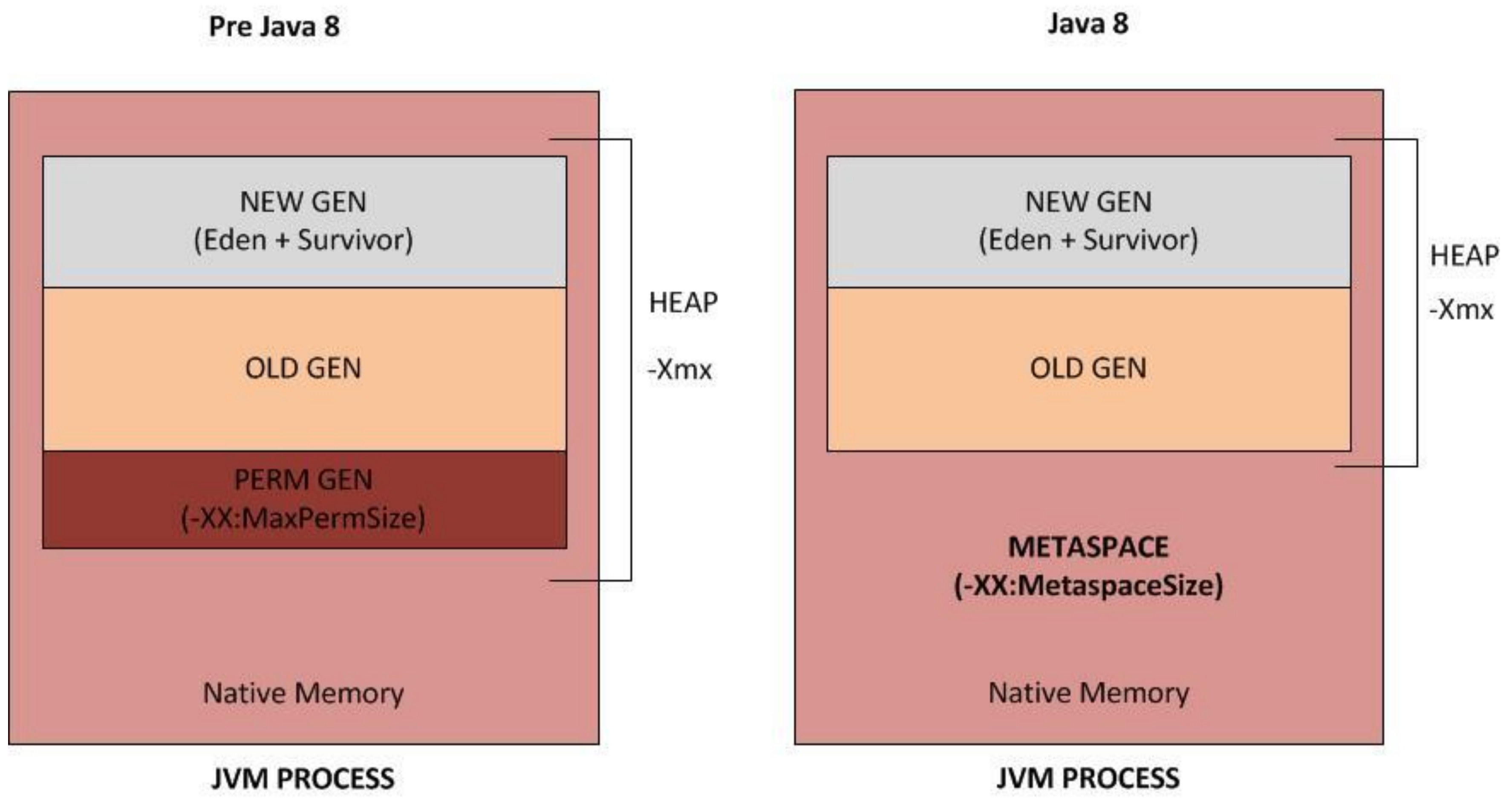
For persistence layer, fine tune :

1. L1 & L2 caches
2. Number of database hits (N+1 query problems)
3. Connection management
4. Lazy initialization exception

Pizza delivery example
–
Do you want your pizza hot?
•
Low latency
–
Or do you want your pizza to be inexpensive?
•
High throughput – lots of pizzas per hour
–
Two different delivery strategies for pizza company

Understand the OutOfMemoryError Exception

JAVA 8 MEMORY MANAGEMENT



One common indication of a memory leak is the java.lang.OutOfMemoryError exception.

✓ Usually, this error is thrown when there is insufficient space to allocate an object in the Java heap. In this case, The garbage collector cannot make space available to accommodate a new object, and the heap cannot be expanded further.

✓ Also, this error may be thrown when there is insufficient native memory to support the loading of a Java class.

✓ In a rare instance, a java.lang.OutOfMemoryError may be thrown when an excessive amount of time is being spent doing garbage collection and little memory is being freed.

Exception in thread thread_name: java.lang.OutOfMemoryError: Java heap space

Cause: The detail message Java heap space indicates object could not be allocated in the Java heap.

This error does not necessarily imply a memory leak.

The problem can be as simple as a configuration issue, where the specified heap size (or the default size, if it is not specified) is insufficient for the application.

In other cases, and in particular for a long-lived application, the message might be an indication that the application is unintentionally holding references to objects, and this prevents the objects from being garbage collected.

This is the Java language equivalent of a memory leak.

Note: The APIs that are called by an application could also be unintentionally holding object references.

One other potential source of this error arises with applications that make excessive use of finalizers.

If a class has a finalize method, then objects of that type do not have their space reclaimed at garbage collection time. Instead, after garbage collection, the objects are queued for finalization, which occurs at a later time.

In the Oracle Sun implementation, finalizers are executed by a daemon thread that services the finalization queue.

If the finalizer thread cannot keep up, with the finalization queue, then the Java heap could fill up and this type of OutOfMemoryError exception would be thrown.

One scenario that can cause this situation is when an application creates high-priority threads that cause the finalization queue to increase at a rate that is faster than the rate at which the finalizer thread is servicing that queue.

Action :

The JConsole management tool can be used to monitor the number of objects that are pending finalization. This tool reports the pending finalization count in the memory statistics on the Summary tab pane. The count is approximate, but it can be used to characterize an application and understand if it relies a lot on finalization.

jmap utility can be used with the -finalizerinfo option to print information about objects awaiting finalization.

Exception in thread thread_name: java.lang.OutOfMemoryError: GC Overhead limit exceeded

Cause: The detail message "GC overhead limit exceeded" indicates that the garbage collector is running all the time and Java program is making very slow progress.

After a garbage collection, if the Java process is spending more than approximately 98% of its time doing garbage collection and if it is recovering less than 2% of the heap and has been doing so far the last 5 (compile time constant) consecutive garbage collections, then a java.lang.OutOfMemoryError is thrown.

This exception is typically thrown because the amount of live data barely fits into the Java heap having little free space for new allocations.

Action: Increase the heap size.

The java.lang.OutOfMemoryError exception for GC Overhead limit exceeded can be turned off with the command line flag -XX:-UseGCOverheadLimit.

Exception in thread thread_name: java.lang.OutOfMemoryError: Metaspace

Cause: Java class metadata (the virtual machines internal presentation of Java class) is allocated in native memory (referred to here as metaspace).

If metaspace for class metadata is exhausted, a java.lang.OutOfMemoryError exception with a detail MetaSpace is thrown.

The amount of metaspace that can be used for class metadata is limited by the parameter MaxMetaSpaceSize, which is specified on the command line.

When the amount of native memory needed for a class metadata exceeds MaxMetaSpaceSize, a java.lang.OutOfMemoryError exception with a detail MetaSpace is thrown.

Action:

If MaxMetaSpaceSize, has been set on the command-line, increase its value.

MetaSpace is allocated from the same address spaces as the Java heap. Reducing the size of the Java heap will make more space available for MetaSpace

Exception in thread thread_name: java.lang.OutOfMemoryError: request size bytes for reason. Out of swap space?

Cause: The detail message "request size bytes for reason. Out of swap space?" appears to be an OutOfMemoryError exception.

However, the Java HotSpot VM code reports this apparent exception when an allocation from the native heap failed and the native heap might be close to exhaustion.

The message indicates the size (in bytes) of the request that failed and the reason for the memory request. Usually the reason is the name of the source module reporting the allocation failure, although sometimes it is the actual reason.

Action: When this error message is thrown, the VM invokes the fatal error handling mechanism

In the case of native heap exhaustion, the heap memory and memory map information in the log can be useful.

we might need to use troubleshooting utilities on the operating system to diagnose the issue further

Exception in thread thread_name: java.lang.OutOfMemoryError: Compressed class space

Cause: On 64-bit platforms a pointer to class metadata can be represented by a 32-bit offset (with UseCompressedOops). This is controlled by the command line flag UseCompressedClassPointers (on by default). If the UseCompressedClassPointers is used, the amount of space available for class metadata is fixed at the amount CompressedClassSpaceSize. If the space needed for UseCompressedClassPointers exceeds CompressedClassSpaceSize, a java.lang.OutOfMemoryError with detail Compressed class space is thrown.

Action: Increase CompressedClassSpaceSize to turn off UseCompressedClassPointers. Note: There are bounds on the acceptable size of CompressedClassSpaceSize. For example -XX: CompressedClassSpaceSize=4g, exceeds acceptable bounds will result in a message such as

Exception in thread thread_name: java.lang.OutOfMemoryError: reason stack_trace_with_native_method

Cause: If the detail part of the error message is "reason stack_trace_with_native_method" and a stack trace is printed in which the top frame is a native method, then this is an indication that a native method has encountered an allocation failure. The difference between this and the previous message is that the allocation failure was detected in a Java Native Interface (JNI) or native method rather than in the JVM code.

Action: If this type of the OutOfMemoryError exception is thrown, we might need to use native utilities of the OS to further diagnose the issue.

Monitoring Tools Overview

jstat –class option

Class Loader Statistics	
Column	Description
Loaded	Number of classes loaded.
Bytes	Number of Kbytes loaded.
Unloaded	Number of classes unloaded.
Bytes	Number of Kbytes unloaded.
Time	Time spent performing class load and unload operations.

-compiler Option

HotSpot Just-In-Time Compiler Statistics	
Column	Description
Compiled	Number of compilation tasks performed.
Failed	Number of compilation tasks that failed.
Invalid	Number of compilation tasks that were invalidated.
Time	Time spent performing compilation tasks.
FailedType	Compile type of the last failed compilation.
FailedMethod	Class name and method for the last failed compilation.

-gc option

Column	Description
S0C	Current survivor space 0 capacity (KB).
S1C	Current survivor space 1 capacity (KB).
S0U	Survivor space 0 utilization (KB).
S1U	Survivor space 1 utilization (KB).
EC	Current eden space capacity (KB).
EU	Eden space utilization (KB).
OC	Current old space capacity (KB).
OU	Old space utilization (KB).
PC	Current permanent space capacity (KB).
PU	Permanent space utilization (KB).
YGC	Number of young generation GC Events.
YGCT	Young generation garbage collection time.
FGC	Number of full GC events.
FGCT	Full garbage collection time.
GCT	Total garbage collection time.

-gccause

Column	Description
LGCC	Cause of last Garbage Collection.
GCC	Cause of current Garbage Collection.

-printcompilation Option

Compiled -> Number of compilation tasks performed by the most recently compiled method.
Size->Number of bytes of bytecode of the most recently compiled method.
Type->Compilation type of the most recently compiled method.
Method->Class name and method name identifying the most recently compiled method. Class name uses "/" instead of "." as namespace separator. Method name is the method within the given class. The format for these two fields is consistent with the HotSpot - XX:+PrintComplation option.

-gcutil

Column	Description
S0	Survivor space 0 utilization as a percentage of the space's current capacity.
S1	Survivor space 1 utilization as a percentage of the space's current capacity.
E	Eden space utilization as a percentage of the space's current capacity.
O	Old space utilization as a percentage of the space's current capacity.
P	Permanent space utilization as a percentage of the space's current capacity.
YGC	Number of young generation GC events.
YGCT	Young generation garbage collection time.
FGC	Number of full GC events.
FGCT	Full garbage collection time.
GCT	Total garbage collection time.

Introduction To JMX

What is JMX ?

Java Management Extensions (JMX) is an upcoming open technology specification that defines the management architecture, which enables managing of applications and services.

This technology also allows Java developers to integrate their applications with existing network management solutions.

Need for JMX

Before JMX, instrumentation is done for each protocol, i.e. instrumentation will be done separately for SNMP access, HTTP access, RMI access and other protocols for the same manageable information.

What is Instrumentation ?

For example, let us take a manageable parameter of a Servlet, say number of concurrent users. This specifies the load or utilization of the servlet or Web application.

Let us say you have a servlet method as listed below:

```
class MySevlet{
  static int concurrentusers; //instrumentation code

   public xxx service(...)
   {
      // start of the method
      concurrentusers++; //instrumentation code

    // end of the method   }

   public int getConcurrentusers()
   {
      return MyServlet.concurrentusers; //instrumentation cod   } }
```

Thus the "concurrentUsers" count can be be accessed with any protocol with the above instrumentation done just once. Thus, "Instrument Once and Access with any Protocol" is made possible with the advent of JMX.

The following points highlights the need for JMX:

JMX allows common instrumentation of management information which is protocol-neutral.

JMX allows a centralized management of managed beans, or MBeans, which act as wrappers for applications, components, or resources in a distributed network.

JMX is becoming a core part of application development and management.

JMX is widely adopted nowadays. It is built into Application Servers.

JMX is Java-based technology.

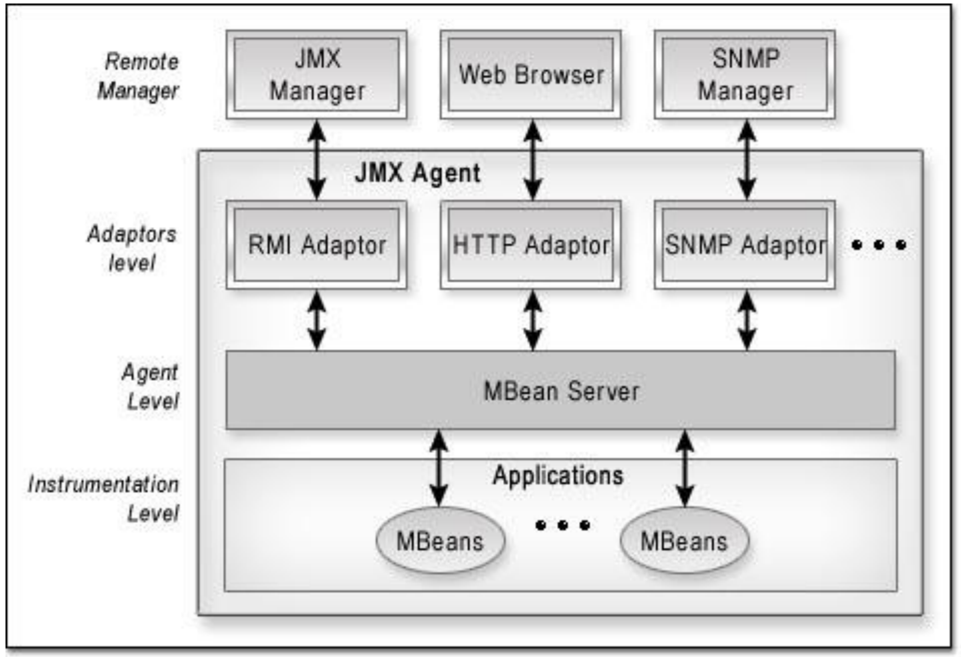
JMX is applicable to many domains -- an application, an EJB, a JSP ...

JMX Architecture

As per JMX specification, JMX architecture is divided into four levels:

1.Instrumentation level
2.Agent level
3.Adaptors level
4.Remote Manager/ distribution level

A diagram representing the JMX architecture is shown below:



The instrumentation level defines an entity known as an MBean.
MBeans represent the managed resources. Thus, the instrumentation level provides a way to access the managed resources (application) via these MBeans.

The Adaptors level is not completely defined in the JMX specification. This level contains the components which help in communicating the MBeans. These components are called protocol adaptors and connectors.

The agent level contains the component called MBeanServer which aids in the communication between the adaptors level and the instrumentation level. The agent level also provides a set of services that can be used by the management clients.

Remote Manager is is where the managers reside. These managers allow user to view the management information and also to manage the resource.

The managers will communicate with the Adaptors level using a common protocol.

The JMX Manager and the RMI Adaptor communicate using RMI protocol.

The Web browser and the HTTP Adaptor communicate using HTTP Protocol. The SNMP Manager and the SNMP Adaptor communicate using SNMP Protocol.

Instrumentation Level

A manageable resource can be a "Servlet, JSP, EJB, Java class, Java method, Java variable, or any legacy non-Java applications". A JMX manageable resource is developed in Java, or at least offers a Java wrapper, and has been instrumented so that it can be managed by JMX-compliant applications.

The instrumentation of a manageable resource is provided by one or more Managed Beans, or MBeans. The instrumentation level provides a specification for defining the MBeans. In addition, the instrumentation level also specifies a notification mechanism which allows MBeans to generate and propogate notification events to components of other levels.

What is an MBean ?

Managed Bean (MBean) represents a manageable resource. An MBean is a Java object, which follows some semantics. The fields or properties of this Java object are called attributes. The methods of this Java object are called operations.

Definition of MBean

MBeans are the JMX objects which exposes the management information in the form of attributes and operations.

Semantics for an MBean

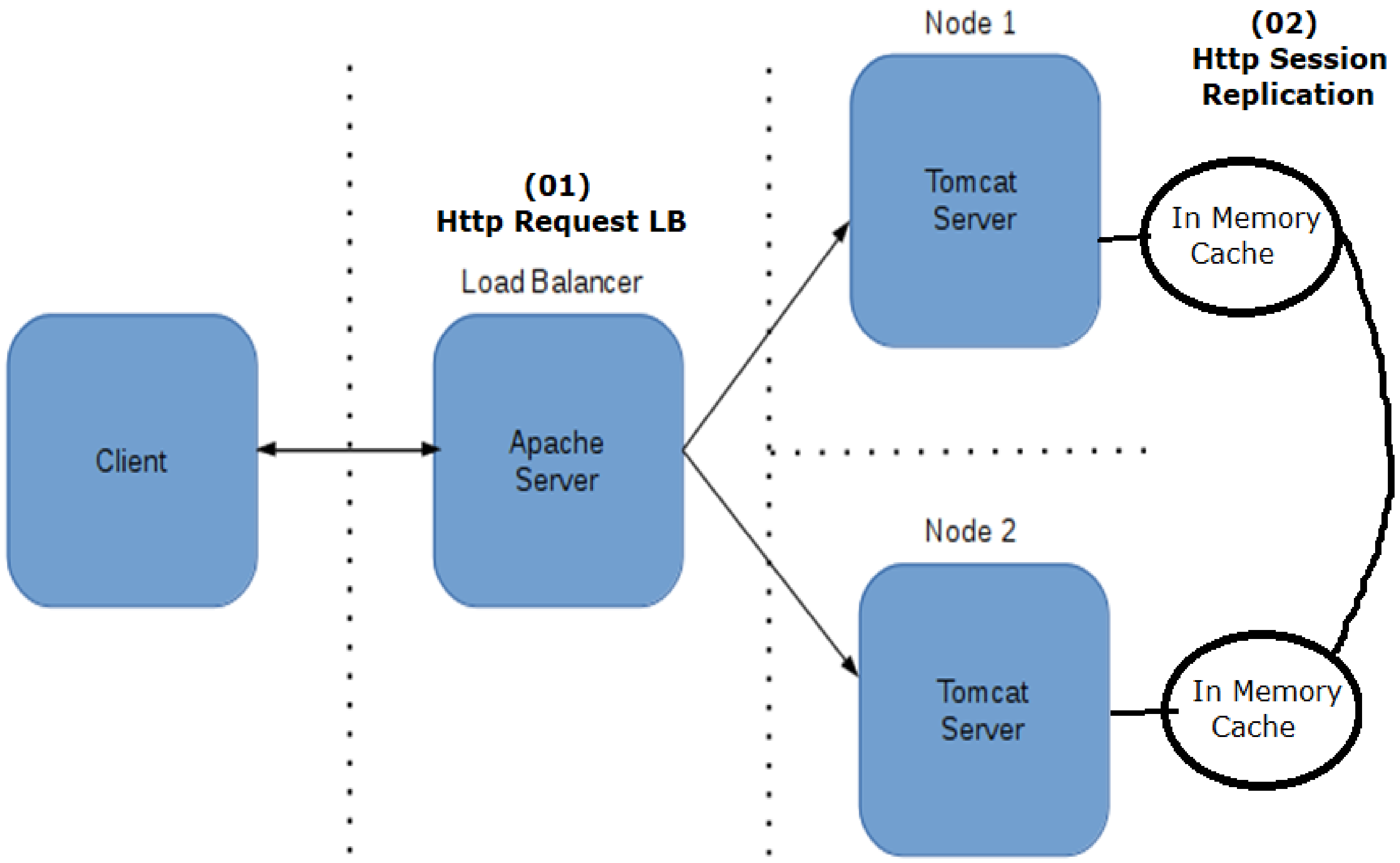
An MBean must be a public, non-abstract class.
An MBean must have atleast one public constructor.
An MBean must implement its own corresponding MBean interface or implement the javax.management.DynamicMBean interface.
Optionally, an MBean can implement the javax.management.NotificationBroadcaster interface.

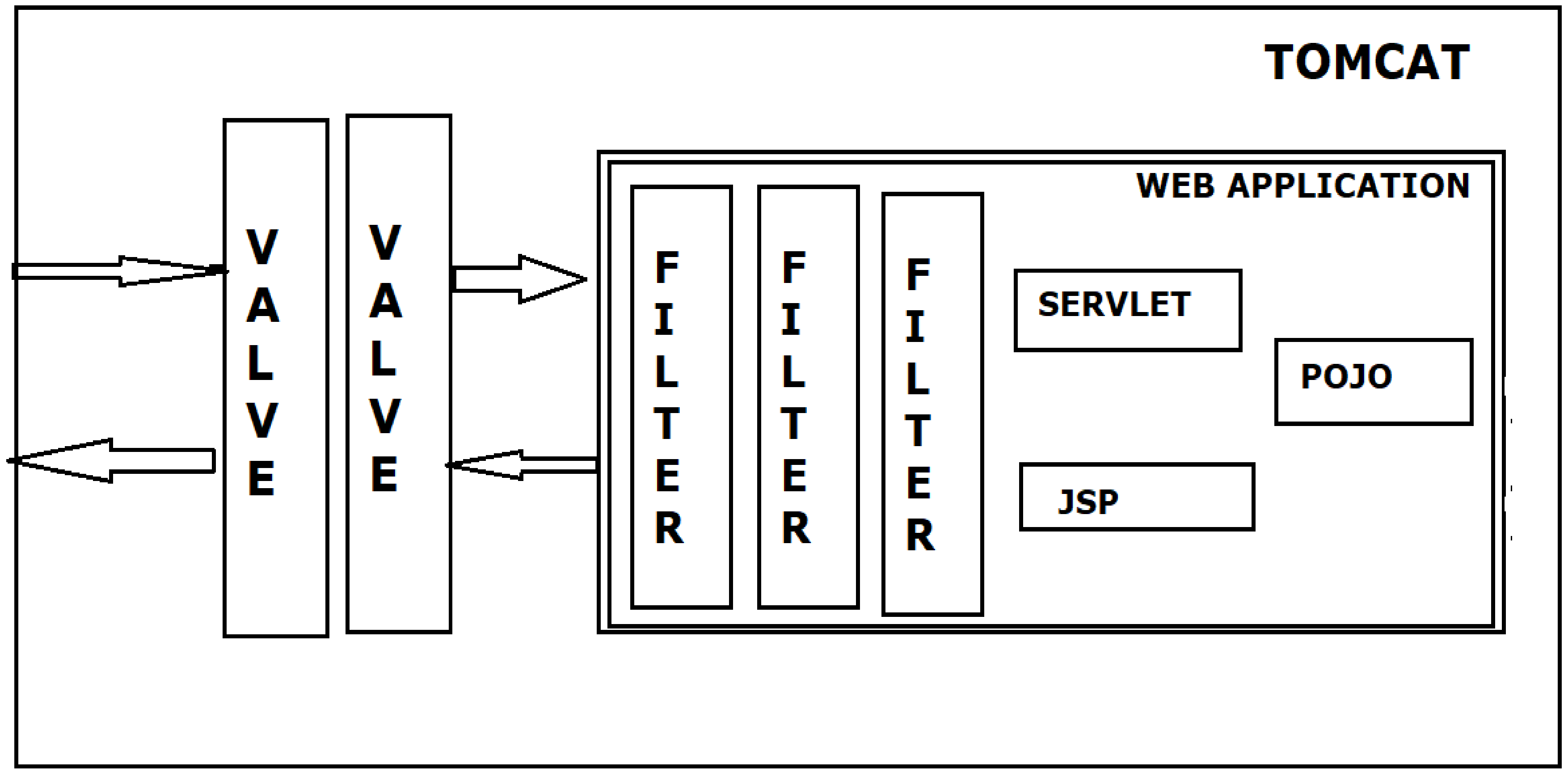
Types of MBeans

MBeans can be classified into four types. They are

1. Standard MBean
2. Dynamic MBean
3. Model MBean
4. Open MBean

Production Architecture


(01)
Http Request LB
Load Balancer
Node 1
(02)
Http Session Replication
Client
Apache Server
Tomcat Server
In Memory Cache
Node 2
Tomcat Server
In Memory Cache


TOMCAT
VALVE
VALVE
WEB APPLICATION
FILTER
FILTER
FILTER
SERVLET
POJO
JSP