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JVM Troubleshooting MOOC:

Troubleshooting Memory Issues in Java Applications

Poonam Parhar
JVM Sustaining Engineer
Oracle

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Lesson 1

HotSpot JVM Memory Management

Poonam Parhar
JVM Sustaining Engineer
Oracle

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Agenda

1. Automatic Memory Management
2. Generational Garbage Collection and Memory Spaces in the HotSpot JVM
3. Garbage Collectors in the HotSpot JVM
4. Garbage Collection Changes Between Java 7, 8 and 9

Lesson 1-1

Automatic Memory Management

Poonam Parhar
JVM Sustaining Engineer
Oracle

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Automatic Memory Management

- Memory Management ? process of allocating, determining when objects are not referenced, and then de-allocating them
- Explicit memory management in some programming languages
- HotSpot JVM employs automatic memory management
- Managed by a sub-system called the garbage collector
- The garbage collector in the HotSpot JVM automatically manages memory freeing the programmer from worrying about the object de-allocations

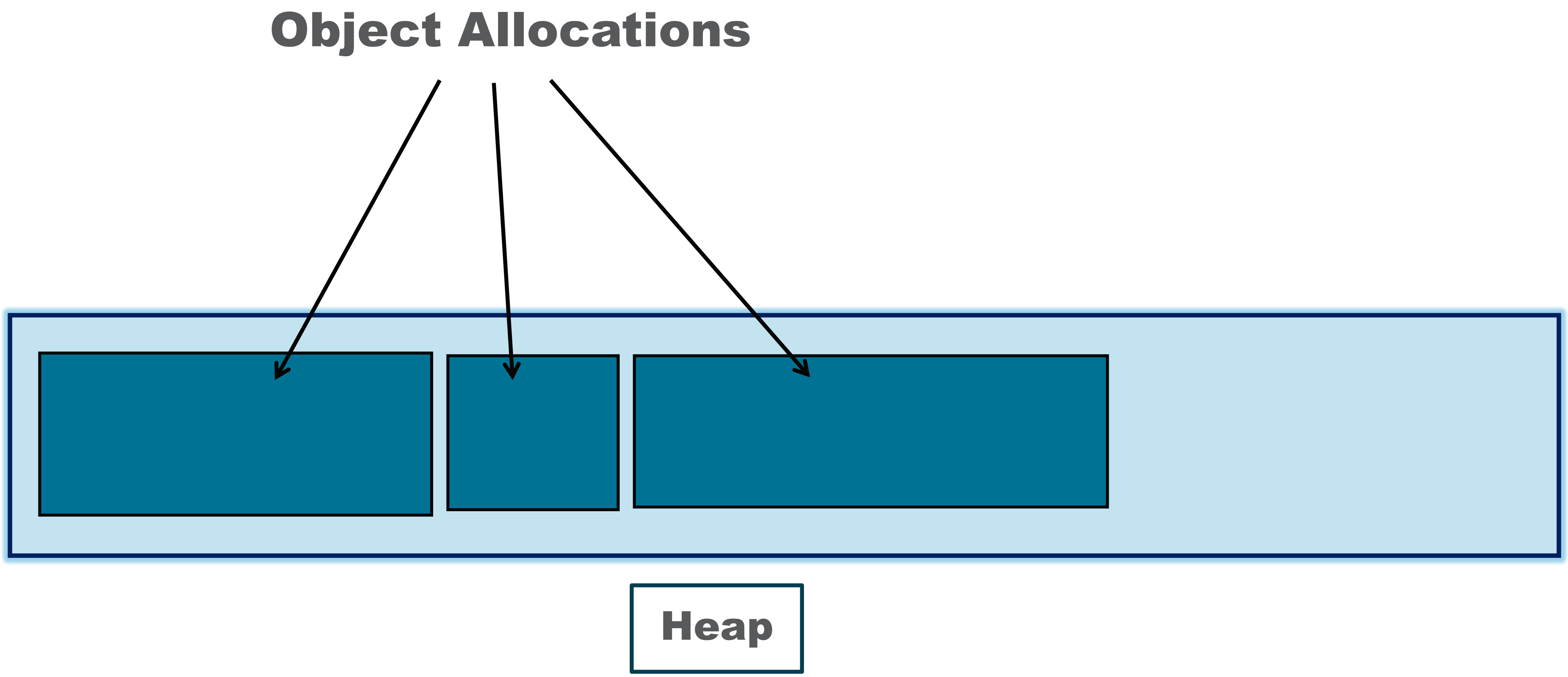
Memory allocation examples

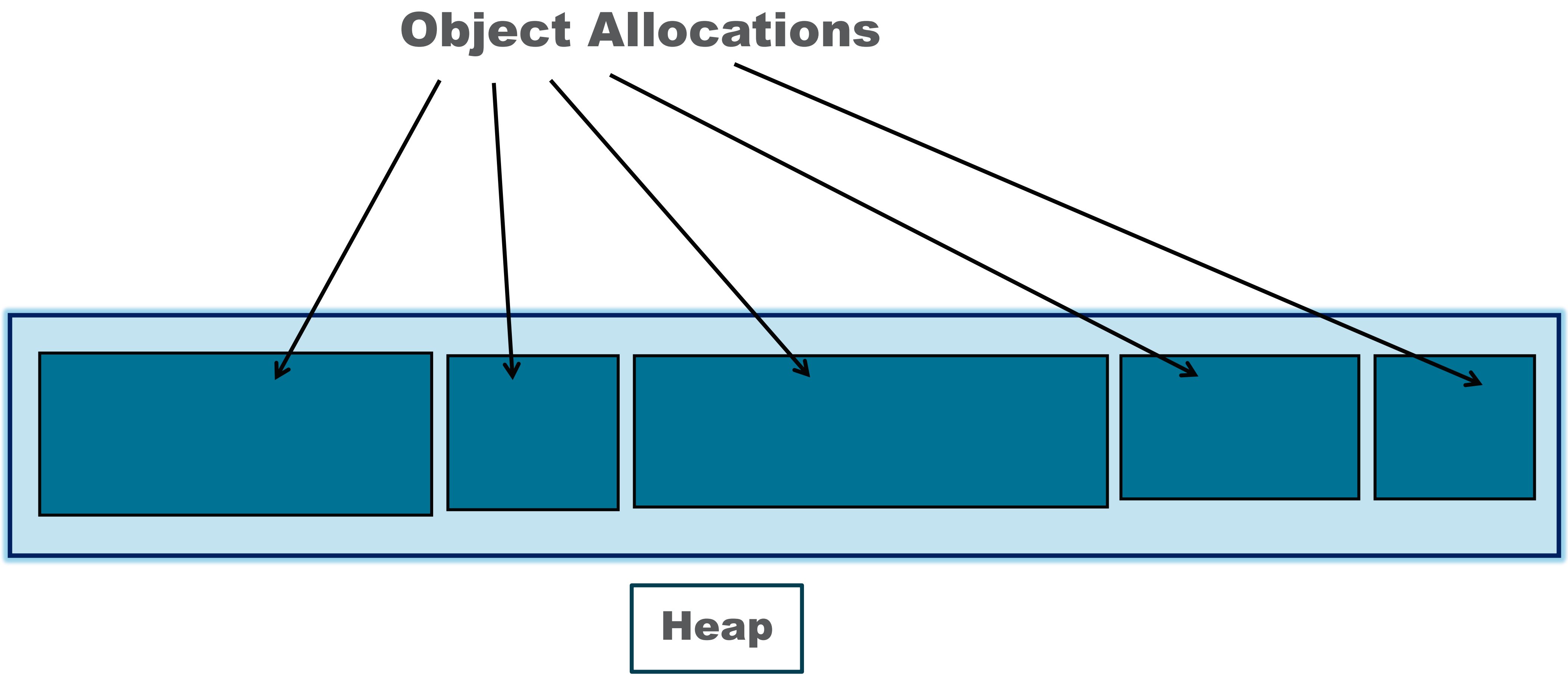
Example in C language:

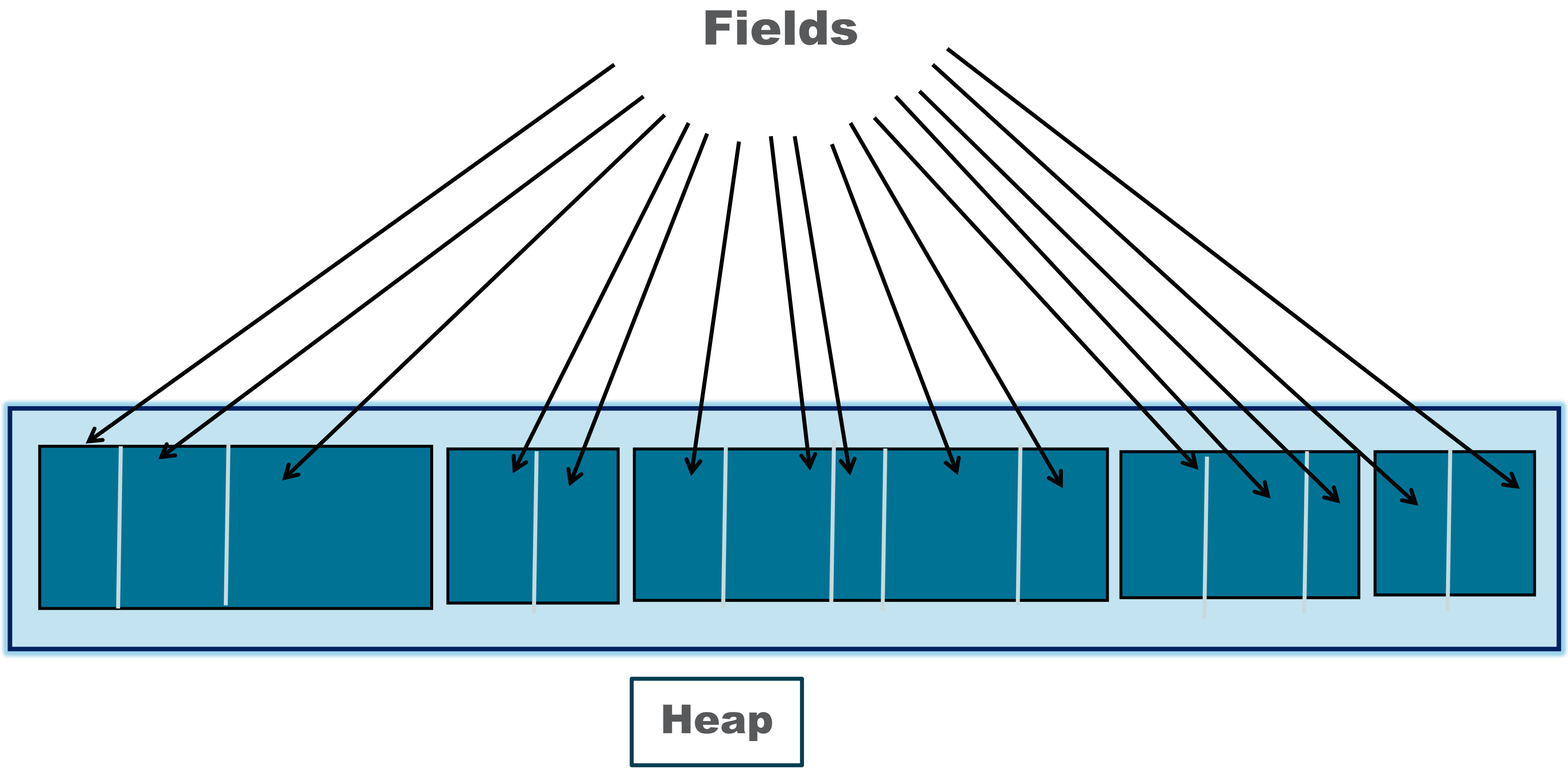
```
//allocate memory
int* array = (int*)malloc(sizeof(int)*20);

//explicitly deallocate memory
free(array);
```

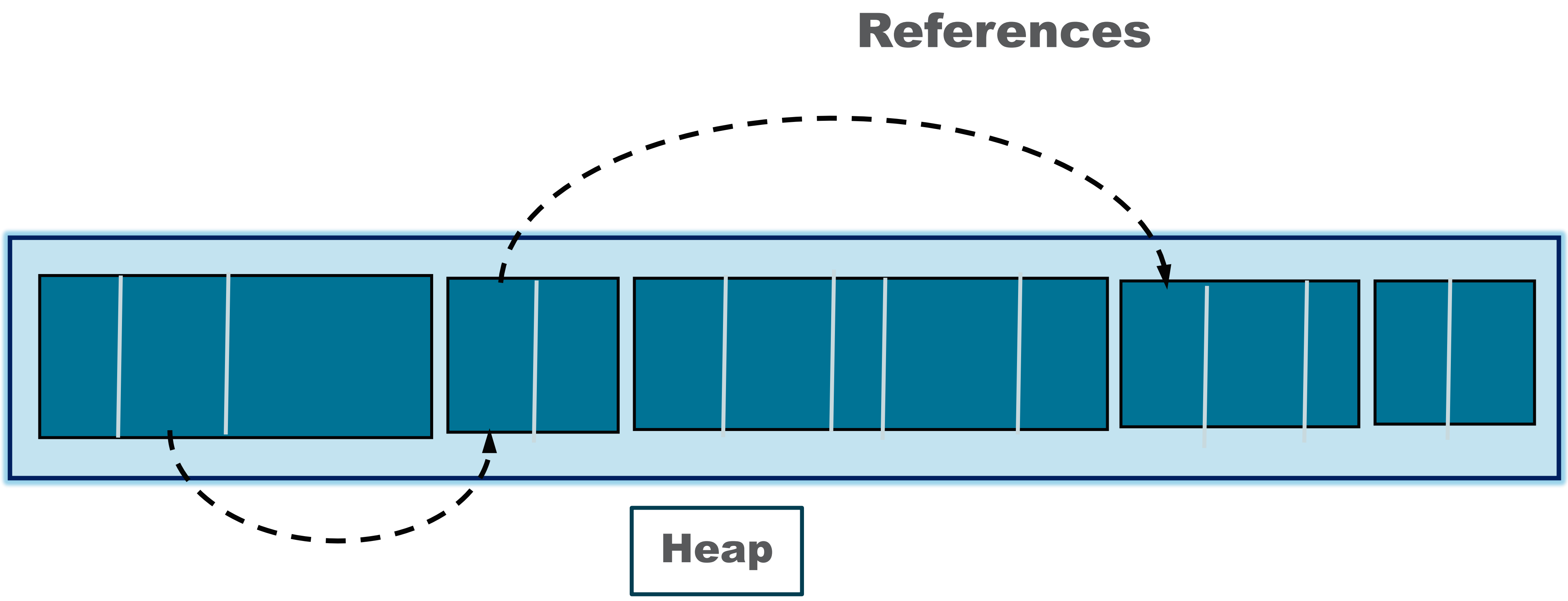
Example in Java that employs automatic memory management:

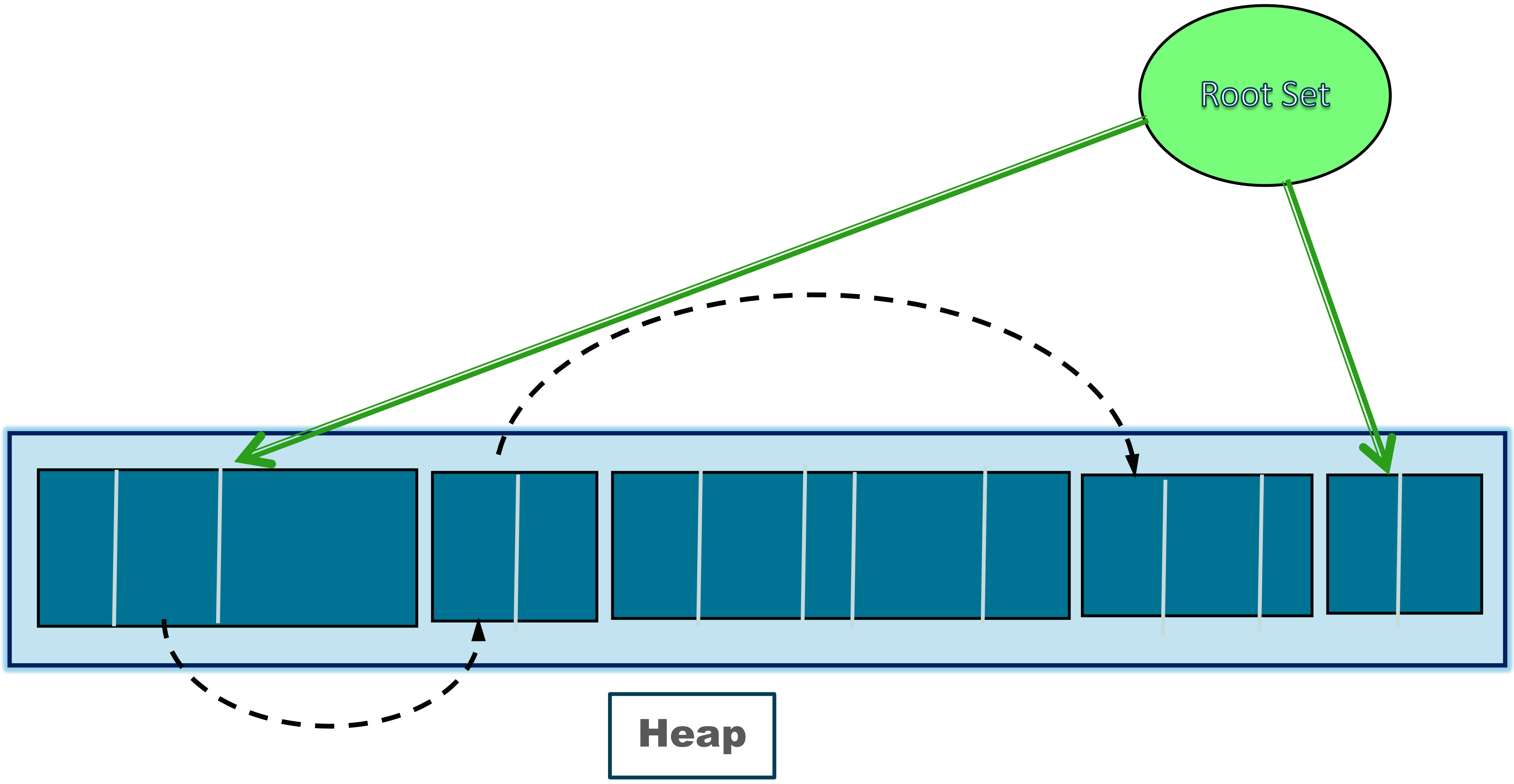
```
//allocate memory for String object
String s = new String("Hello World");

//no need to explicitly free memory occupied by 's'. It would be released by the
  garbage collector when 's' goes out of scope.
```

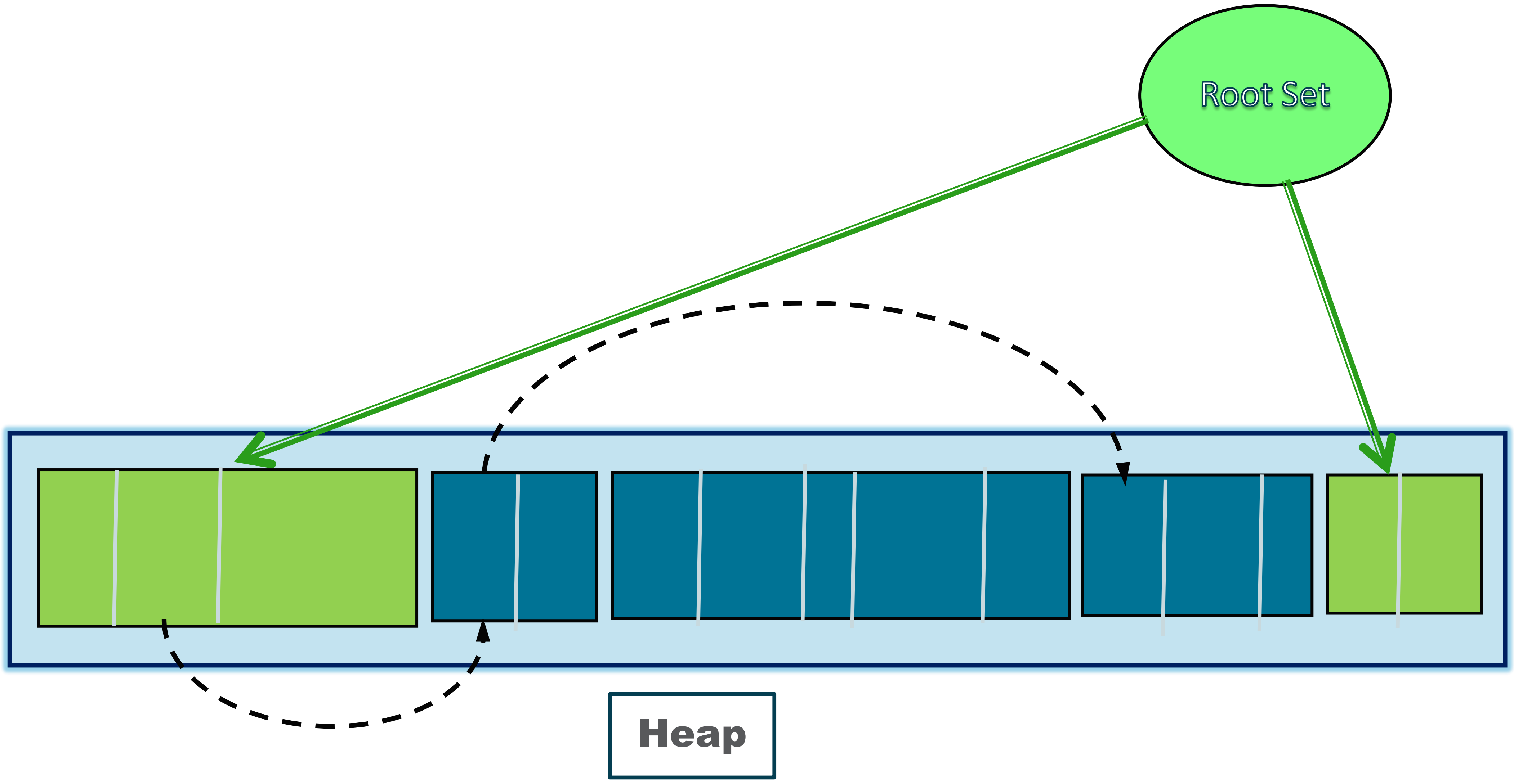

Object Allocations
Heap

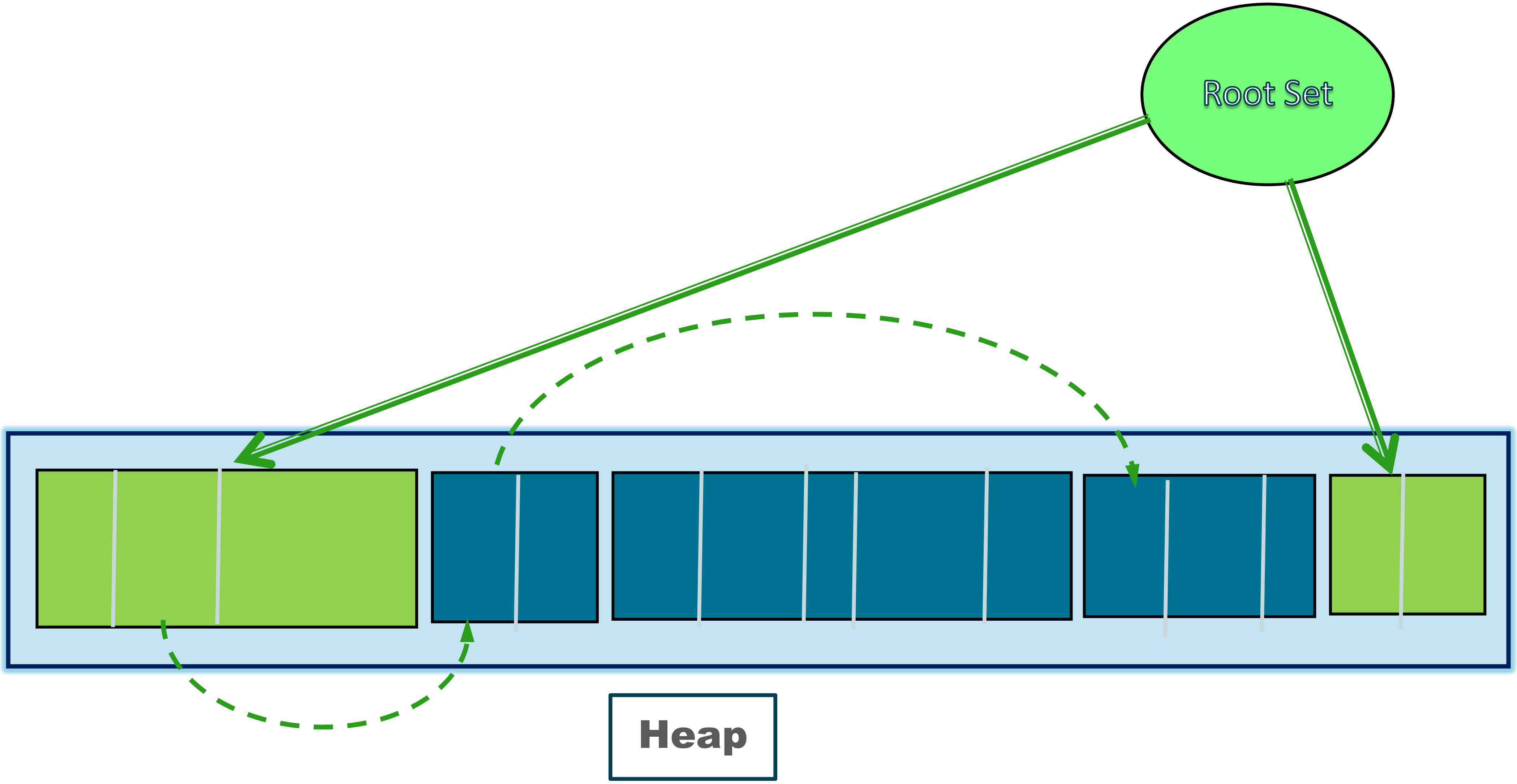

Object Allocations
Heap

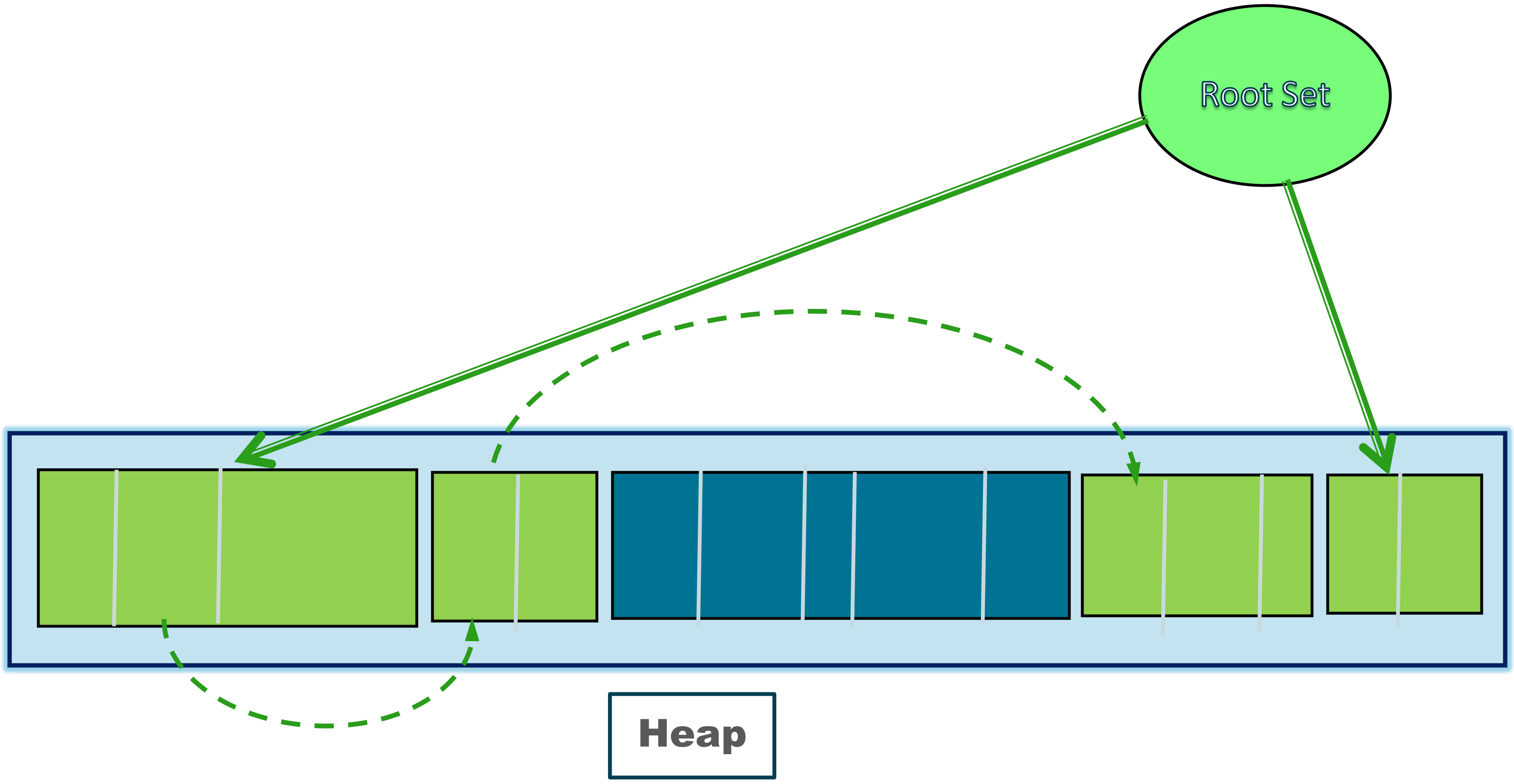

Fields
Heap


References
Heap

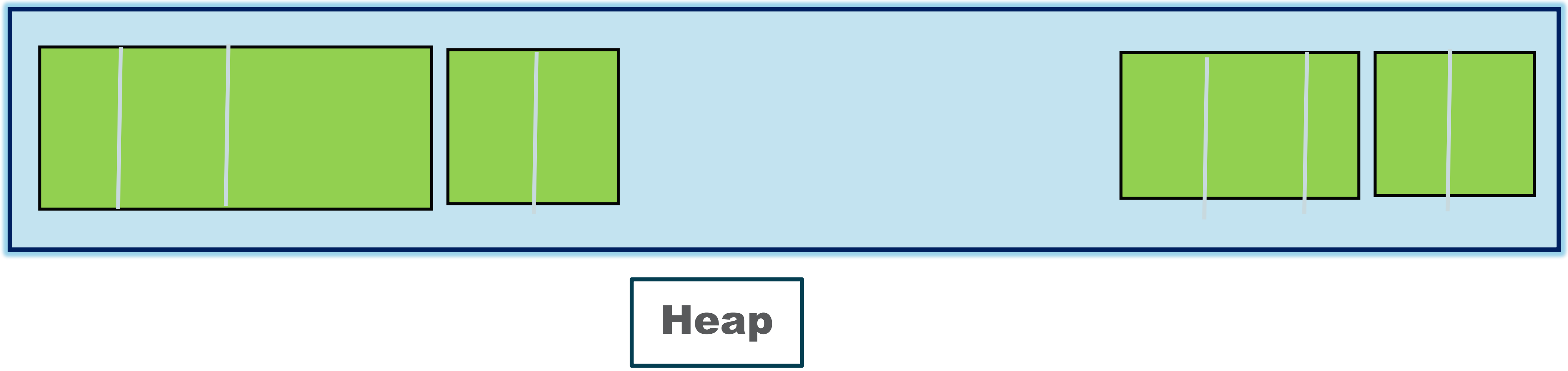

Root Set
Heap


Root Set
Heap

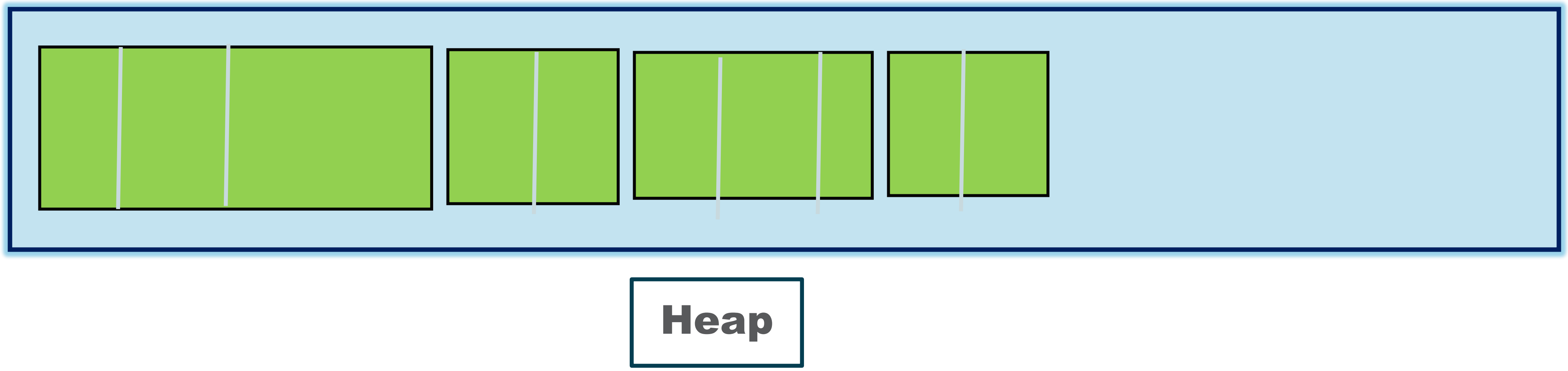

Root Set
Heap


Root Set
Heap

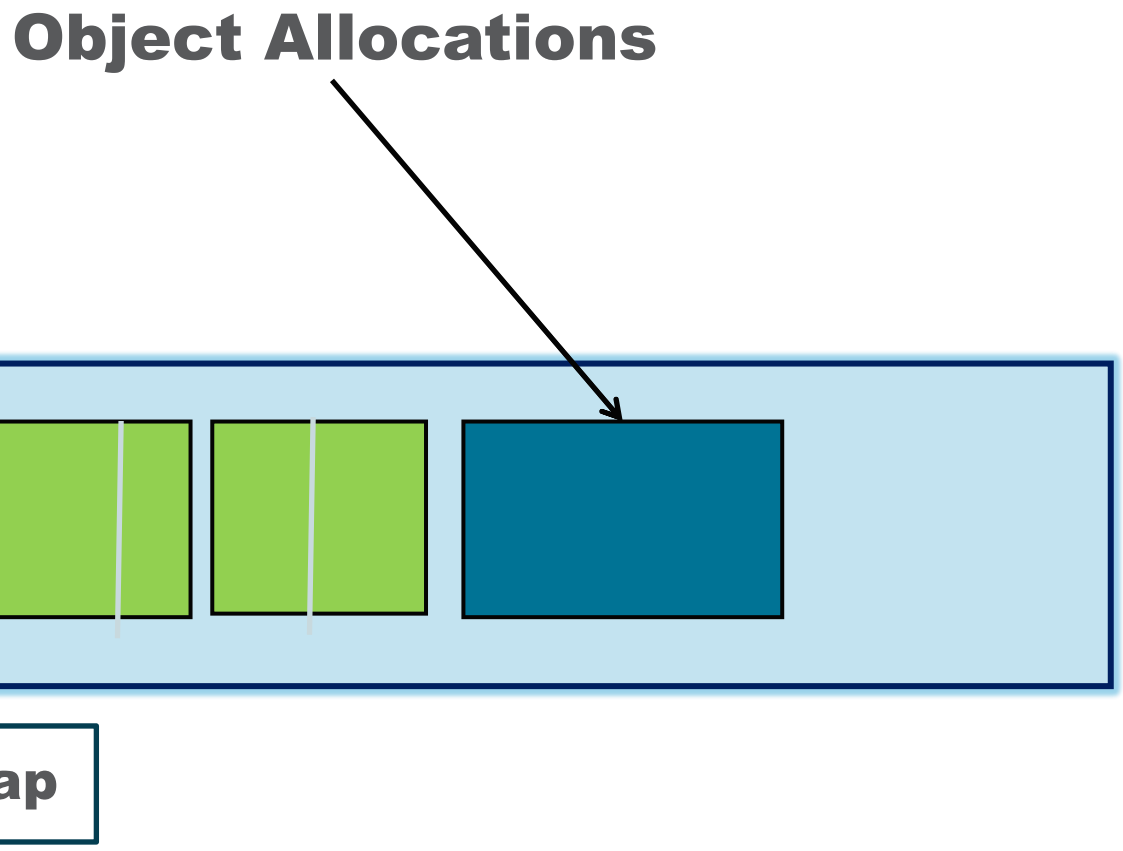
Collect Garbage



Compact



Allocations Continue



Garbage Collector

- Garbage collector is responsible for
  - Memory allocation
  - Keeping the referenced objects in memory
  - Reclaiming the space used by unreachable objects
- Unreachable objects are called garbage
- This whole process of reclaiming memory is garbage collection

Summary: Section 1

- HotSpot JVM uses automatic memory management
- Memory is automatically managed by a sub-system called the garbage collector
- Garbage collector is responsible for
  - Allocations
  - Keeping the alive objects in memory
  - Reclaiming the space used by unreachable objects

Lesson 1-2

Generational Garbage Collection and Memory Spaces in the HotSpot JVM

Poonam Parhar
JVM Sustaining Engineer
Oracle

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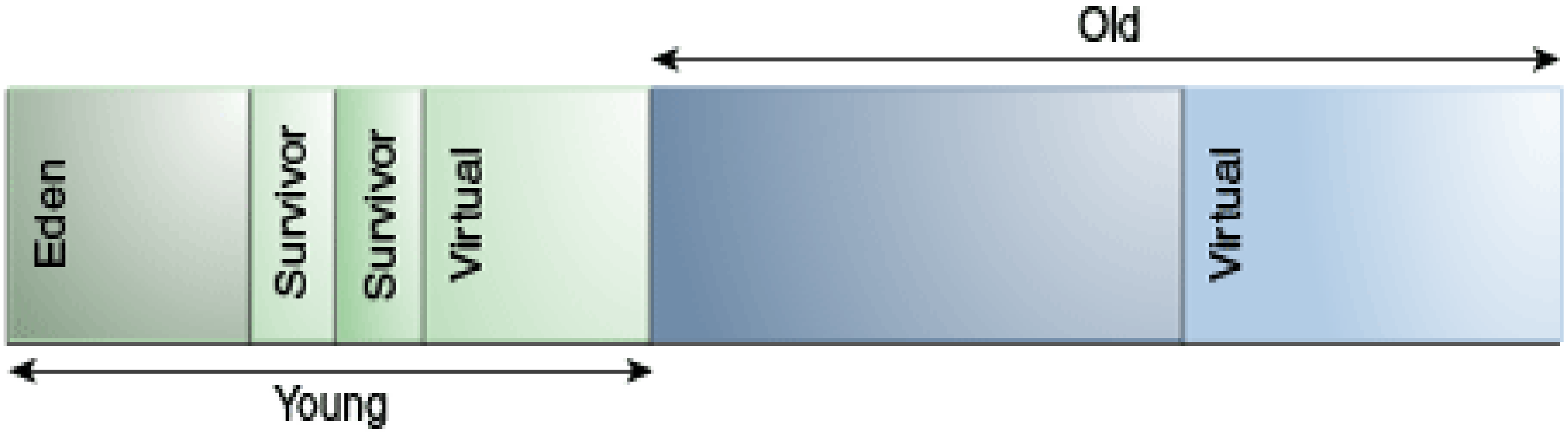
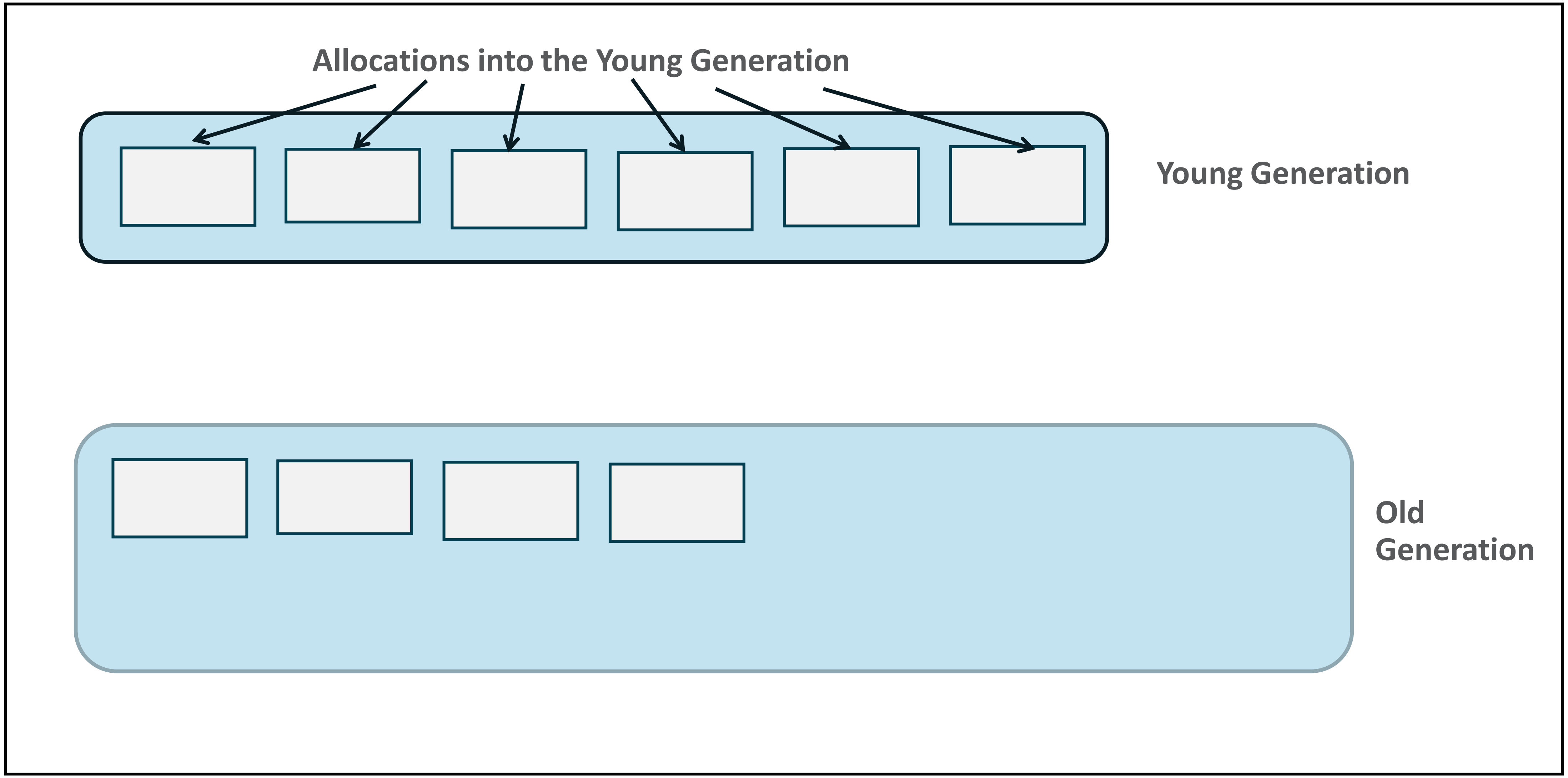
Generational Garbage Collection

- Memory space is divided into generations
- Separate pools holding objects of different age ranges
- Based on hypothesis:
  - Most allocated objects die young
  - Few references from older to younger objects exist
- To take advantage of this hypothesis, heap is divided into two generations
  - Young: small and collected frequently
  - Old : larger and occupancy grows slowly
- Minor(young) and Major(Full) collections

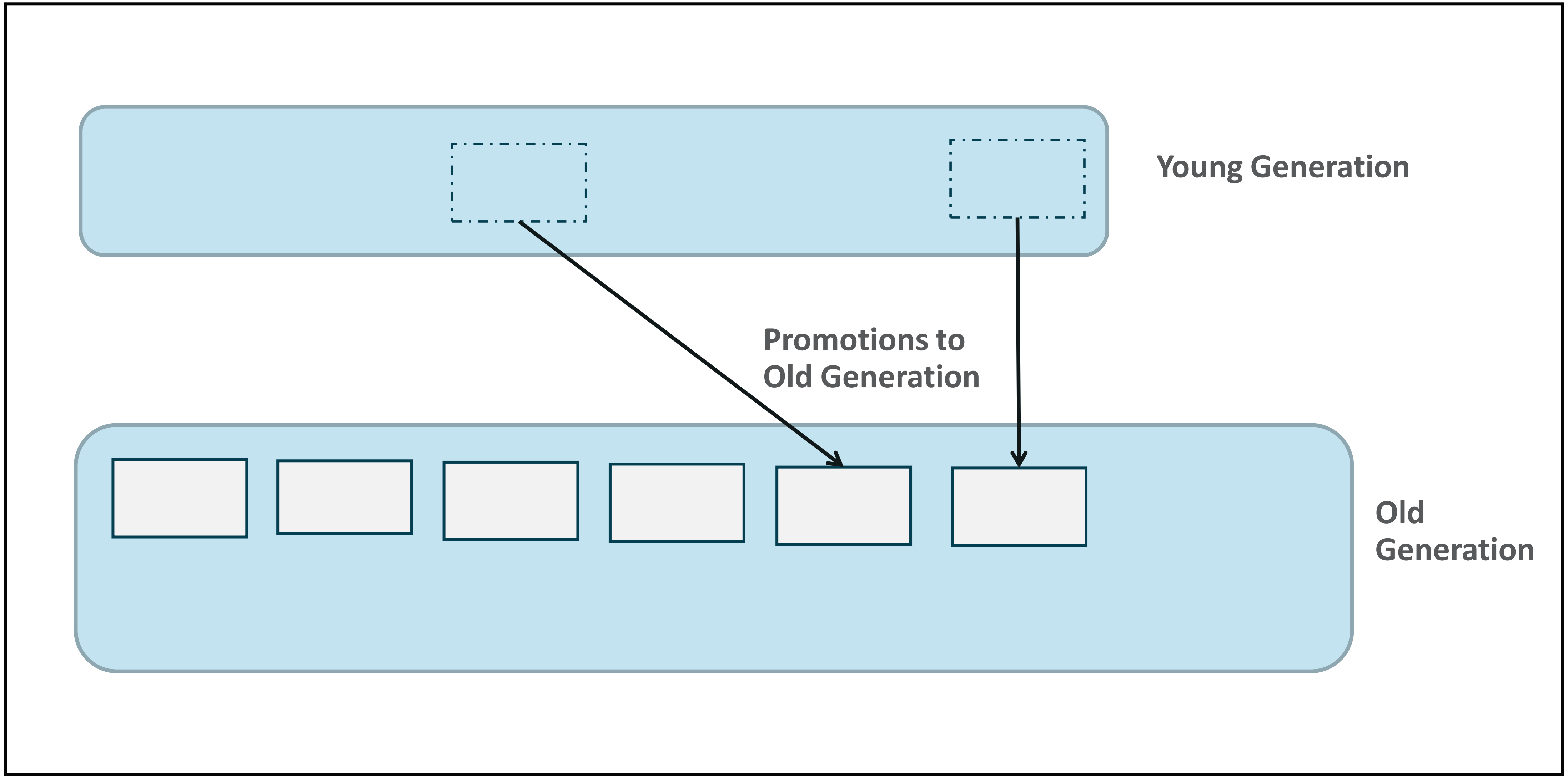
Young and Old Generation



Before Young Collection



After Young Collection



Permanent Generation

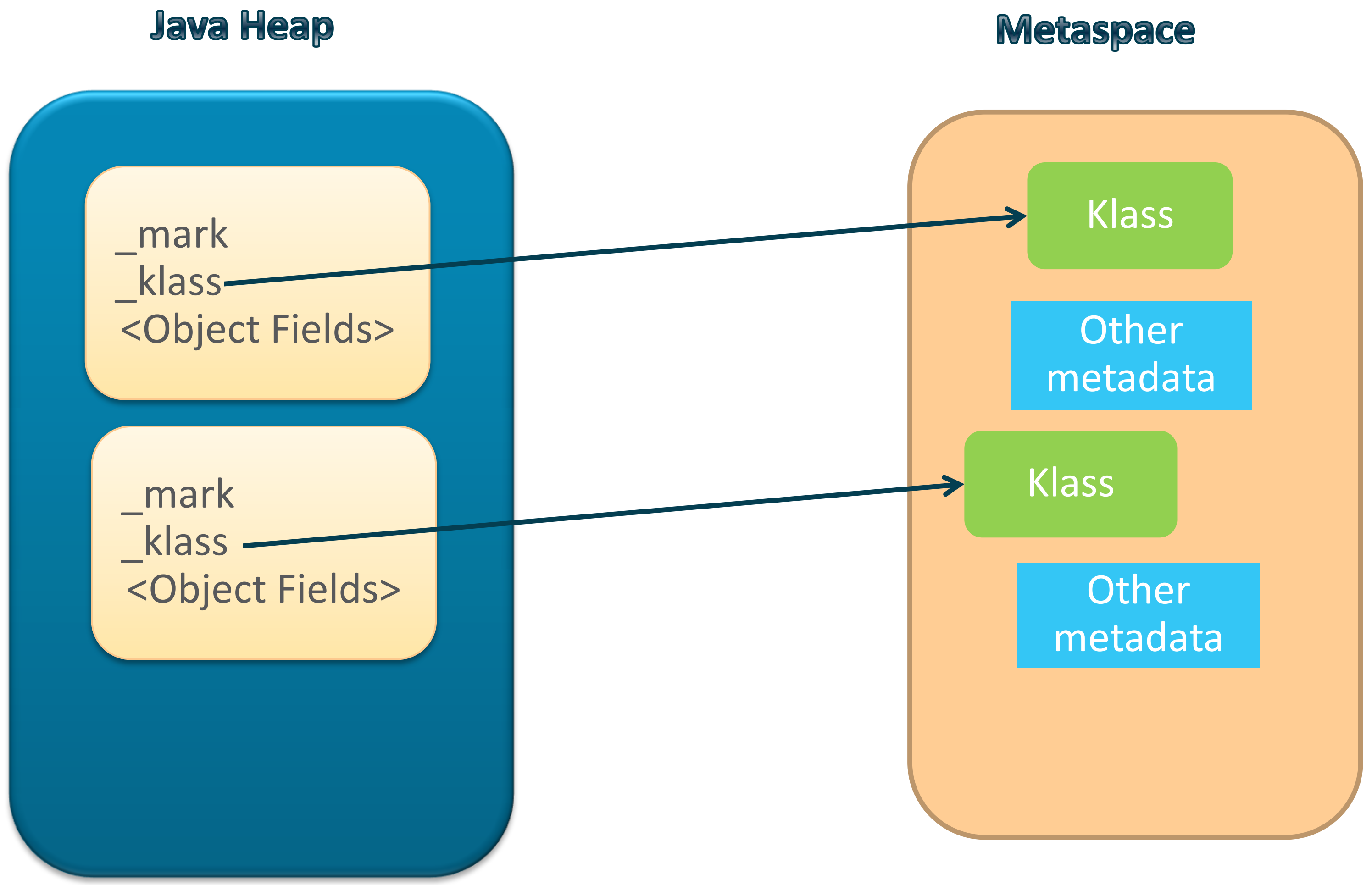
- HotSpot JVM prior to JDK 8 had a third generation called Permanent Generation
- Used for:
  - JVM internal representation of classes and their metadata
  - Class statics
  - Interned strings
- Contiguous with the Java Heap

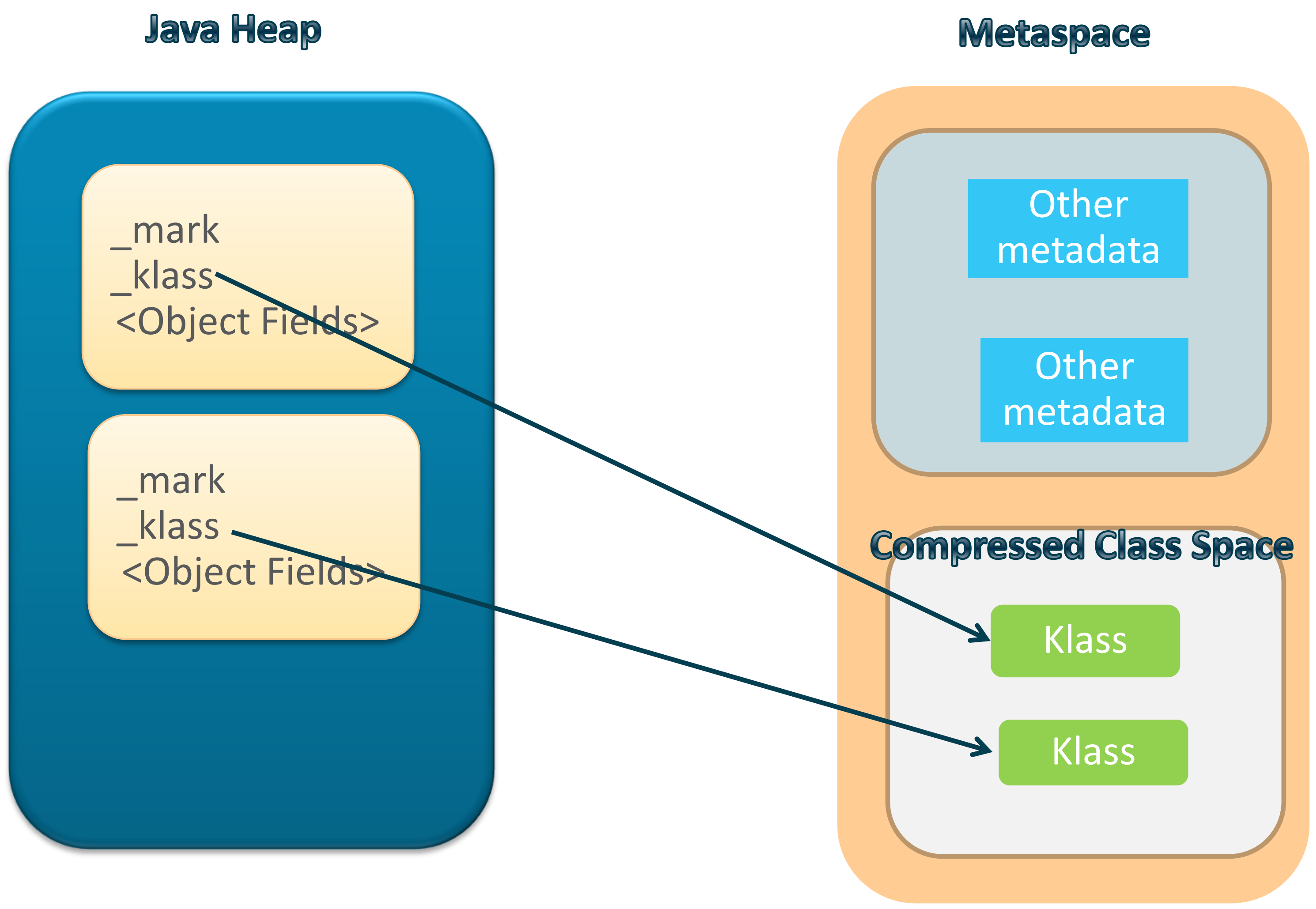
Metaspace

- JDK 8 does not have Permanent Generation
- Class metadata is stored in a new space called Metaspace
- Not contiguous with the Java Heap
- Metaspace is allocated out of native memory
- Maximum space available to the Metaspace is the available system memory
- This can though be limited by **MaxMetaspaceSize** JVM option

Compressed Class Space

- If UseCompressedClassesPointers is enabled then two separate areas of memory are used for the classes and its metadata
  - Metaspace
  - Compressed class space
- 64-bit class pointers are represented with 32-bit offsets
- Class metadata referenced by the 32-bit offsets is stored in the Compressed Class Space
- By default compressed class space is sized at 1GB
- **MaxMetaspaceSize** sets an upper limit on the committed size of both of these spaces.


Java Heap
Metaspace
_mark
_klass
<Object Fields>
_mark
_klass
<Object Fields>
Klass
Other metadata
Klass
Other metadata

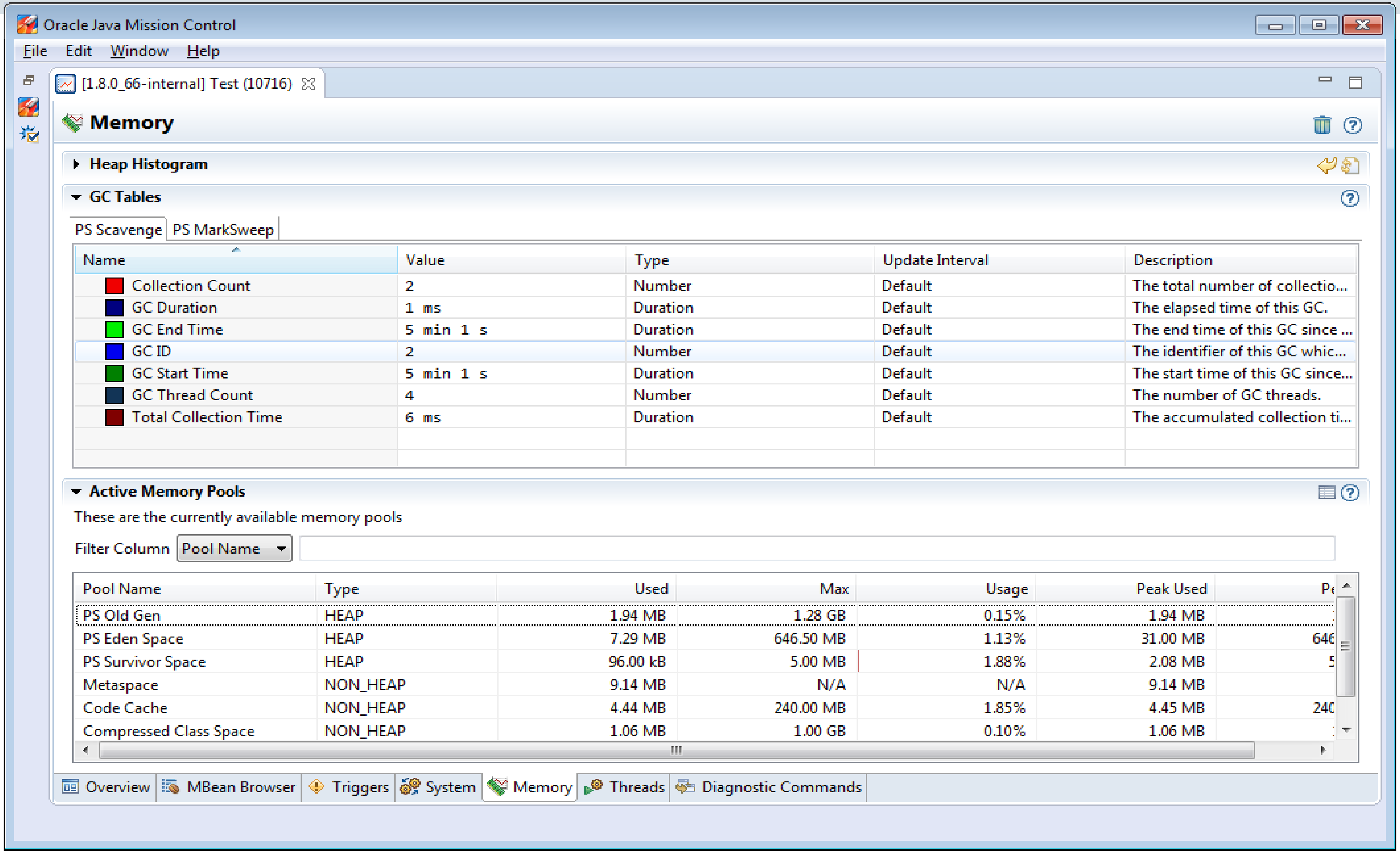

Java Heap
_mark
_klass
<Object Fields>
_mark
_klass
<Object Fields>
Metaspace
Other metadata
Other metadata
Compressed Class Space
Klass
Klass

Code Cache

- Code Cache is used to store the compiled code generated by the Just-in-time compilers
- It is allocated out of native memory
- Managed by the Code Cache Sweeper

Native Memory

- Available system memory
- Not managed by the JVM memory management



Memory

Heap Histogram

GC Tables

Name	Value	Type	Update Interval	Description
🟥 Collection Count	2	Number	Default	The total number of collectio...
🟦 GC Duration	1 ms	Duration	Default	The elapsed time of this GC.
🟩 GC End Time	5 min 1 s	Duration	Default	The end time of this GC since ...
🟦 GC ID	2	Number	Default	The identifier of this GC whic...
🟩 GC Start Time	5 min 1 s	Duration	Default	The start time of this GC since...
🟦 GC Thread Count	4	Number	Default	The number of GC threads.
🟥 Total Collection Time	6 ms	Duration	Default	The accumulated collection ti...

Active Memory Pools

These are the currently available memory pools

Filter Column: Pool Name

Pool Name	Type	Used	Max	Usage	Peak Used	Pe
PS Old Gen	HEAP	1.94 MB	1.28 GB	0.15%	1.94 MB	
PS Eden Space	HEAP	7.29 MB	646.50 MB	1.13%	31.00 MB	646
PS Survivor Space	HEAP	96.00 kB	5.00 MB	1.88%	2.08 MB	5
Metaspace	NON_HEAP	9.14 MB	N/A	N/A	9.14 MB	
Code Cache	NON_HEAP	4.44 MB	240.00 MB	1.85%	4.45 MB	240
Compressed Class Space	NON_HEAP	1.06 MB	1.00 GB	0.10%	1.06 MB	

Summary: Section 2

- Memory space is divided into memory pools
- Java Heap
  - Young generation
  - Old generation
- Classes and metadata space
  - Permanent Generation (before JDK 8)
  - Metaspace (metaspace + compressed class space) (JDK 8 onwards)
- CodeCache
- Native Memory

Lesson 1-3

Garbage Collectors in the HotSpot JVM

Poonam Parhar
JVM Sustaining Engineer
Oracle

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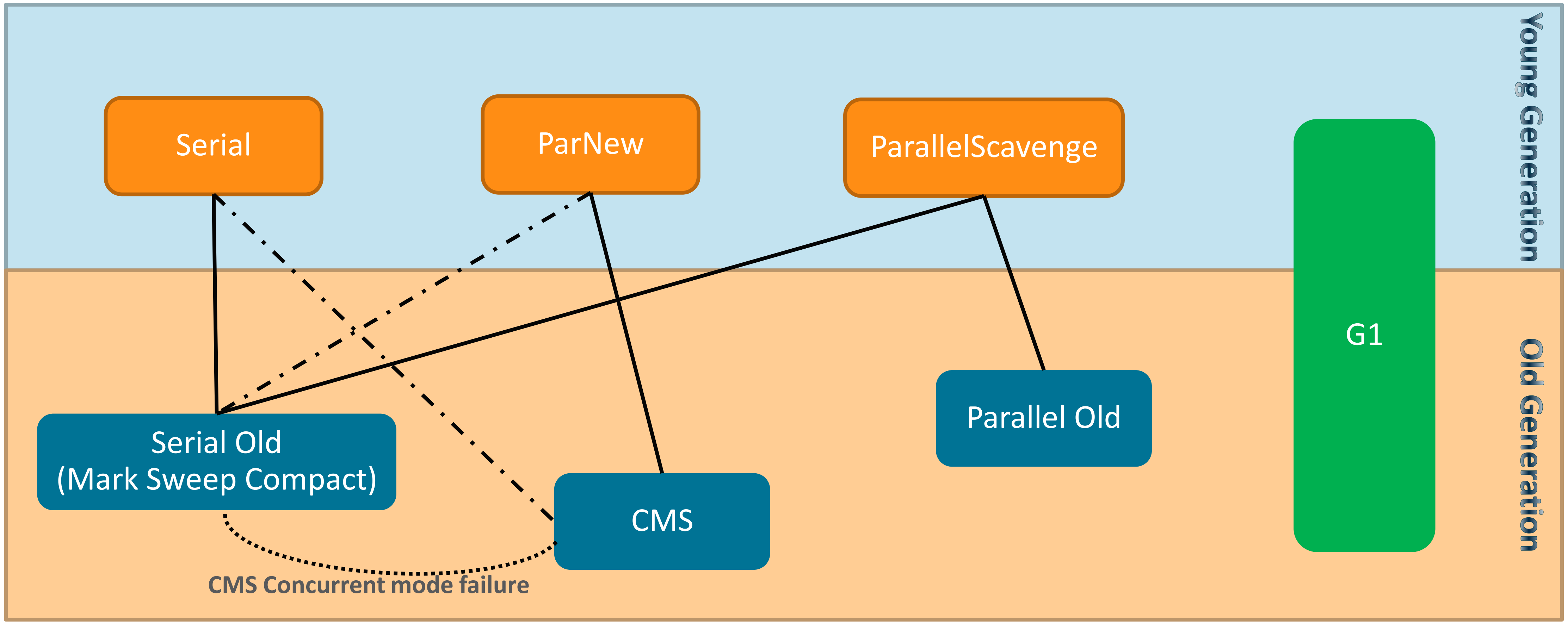
HotSpot Garbage Collectors



- · - · - Combination not available in 9

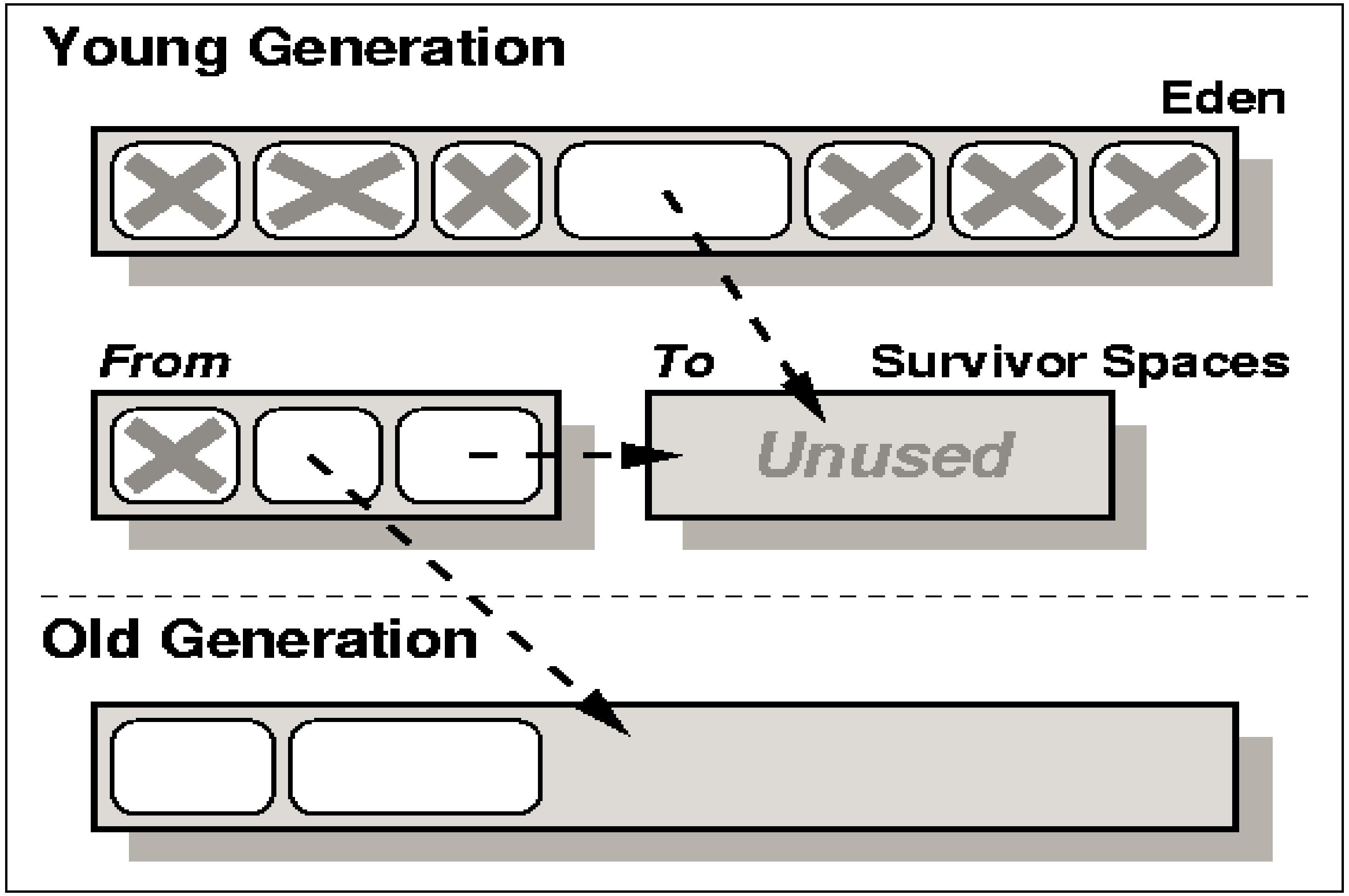
HotSpot Garbage Collection Types

- **Young Generation Collection**
  - **Serial** is a stop-the-world, copying collector that uses a single GC thread
  - **ParNew** is a stop-the-world, copying collector that uses multiple GC threads
  - **Parallel Scavenge** is a stop-the-world, copying collector that uses multiple GC threads
- **Old Generation Collection**
  - **Serial Old** is a stop-the-world, mark-sweep-compact collector that uses a single GC thread
  - **CMS** is a mostly concurrent, low-pause collector
  - **Parallel Old** is a compacting collector that uses multiple GC threads
- **G1** is the Garbage First collector for large heaps and provides reliable short GC pauses
  - Has generations but uses different memory layout

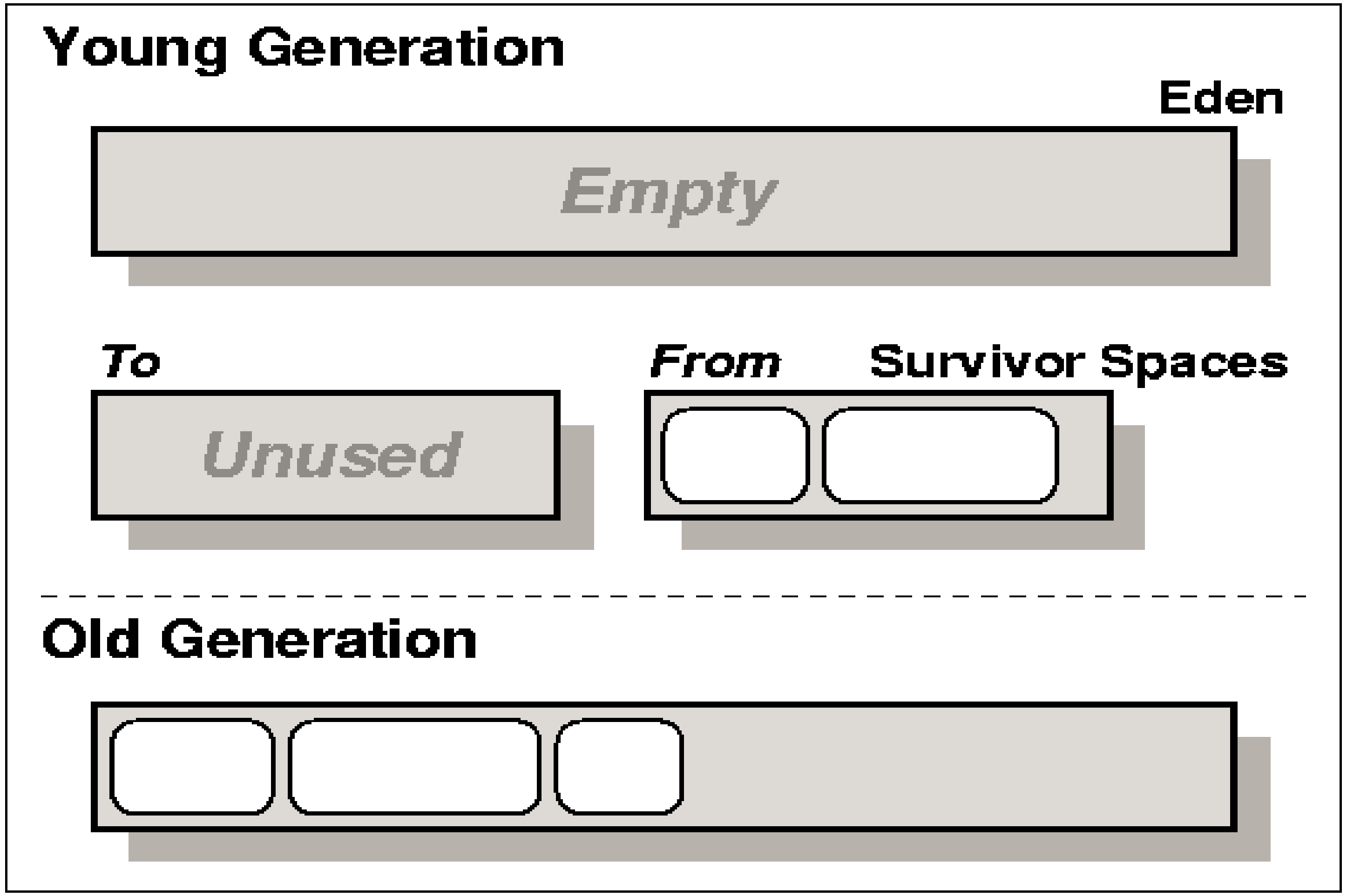
How to enable the Collectors

- UseSerialGC : Serial + Serial Old
- UseParNewGC : ParNew + Serial Old
- UseConcMarkSweepGC : ParNew + CMS + Serial Old. CMS is used most of the time to collect the old generation. Serial Old is used when a concurrent mode failure occurs.
- UseParallelGC : Parallel Scavenge + Parallel Old
- UseG1GC : G1 GC for both generations

Young Collections



Young Collections



Mark-Sweep-Compact Collector

- -XX:+UseSerialGC or –XX:+UseParNewGC selects Serial Old collector for old generation
- Stop-the-world old generation collector.
- Old is collected using mark-sweep-compact.
- Mark phase: marks all live objects.
- Sweep phase: sweeps over the heap identifying garbage.
- Slide phase: the GC performs a sliding compaction, sliding the live objects towards the start of the Heap.

Parallel Collector

- *-XX:+UseParallelGC*
  - Young Generation collected with Parallel Scavenge
  - Old Generation collected with Parallel collector
- It is also called the throughput collector
- Stop-the-world collections
- Default on Server type machines up until JDK 9
- Collection is performed in parallel on multiple cores

Concurrent Mark Sweep Collector

- *-XX:+UseConcMarkSweepGC*
  - Young gen – ParNew collector
  - Old gen – CMS collector
- Low-latency collector, Mostly concurrent
- No heap compaction – fragmentation
- Free lists link unallocated regions
- Allocations expensive as compared to bump-the-pointer allocations
- Additional overhead on young collections
- Larger heap size requirement and floating garbage
- Deprecated in Java 9

G1 Collector

- Server-style garbage collector, targeted for multi-processor machines with large memories
- Meets garbage collection (GC) pause time goals with a high probability, while achieving high throughput.
- Better GC ergonomics
- Low pauses without fragmentation
- Parallelism and concurrency in collections
- G1 is a compacting collector.
- Fully supported in Oracle JDK 7 update 4 and later releases
- Default collector in JDK 9

Summary: Section 3

- Serial Collector
- Parallel Collector – throughput collector
- Low Pause Collectors
  - G1 Garbage Collector – default in Java 9
  - CMS – deprecated in Java 9

References

- GC Tuning Guide
  - https://docs.oracle.com/javase/9/gctuning/toc.htm
- Books
  - Garbage Collection: Algorithms for Automatic Dynamic Memory Management. Wiley, Chichester, July 1996. With a chapter on Distributed Garabge Collection by R. Lins. Richard Jones, Antony Hosking, and Elliot Moss.
  - The Garbage Collection Handbook: The Art of Automatic Memory Management. CRC Applied Algorithms and Data Structures. Chapman & Hall, January 2012

Lesson 1-4

Garbage Collection Changes Between Java 7, 8 and 9

Poonam Parhar
JVM Sustaining Engineer
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JDK 7 Changes

Permanent Generation Partially Removed

- In JDK 7, some things were moved out of PermGen
  - Symbols were moved to native memory
  - Interned strings were moved to the Java Heap
  - Class statics were moved to the Java Heap
- Might contribute to slight increase in the young collections pause times
- Can revert this change with –XX:+JavaObjectsInPerm

JDK 8 Changes

Permanent Generation Removed

- Permanent Generation has been removed in JDK 8
- PermGen tuning options are now obsolete in JDK 8

MetaSpace in JDK 8

- Metaspace added in JDK 8
- Classes and metadata stored in the Metaspace
- It replaces PermGen
- New Metaspace tuning JVM options added
  - MetaspaceSize
  - MaxMetaspaceSize

Class Unloading Related Changes

- Until JDK 8u40, G1 unloads classes only at Full GCs
  - Classes don’t get unloaded during the young or mixed collections and a Full GC is required to unload classes
- G1 supports concurrent unloading of classes from JDK 8

JDK 9 Changes

G1 Garbage Collector

- JDK 9 makes the G1 Garbage collector the default garbage collector
- It is surely possible to explicitly pick the garbage collector of your choosing
- For example:

  -XX:+UseParallelGC would select Parallel GC as the garbage collector

CMS Collector

- JDK 9 deprecates the CMS garbage collector
- Warning message is issued when -XX:+UseConcMarkSweepGC is used
- Planned for removal in a future major release

GC Combinations Removed in Java 9

- DefNew + CMS : -XX:-UseParNewGC -XX:+UseConcMarkSweepGC
- ParNew + SerialOld : -XX:+UseParNewGC
- ParNew + iCMS : -Xincgc
- ParNew + iCMS : -XX:+CMSIncrementalMode -XX:+UseConcMarkSweepGC
- DefNew + iCMS : -XX:+CMSIncrementalMode -XX:+UseConcMarkSweepGC -XX:-UseParNewGC
- CMS foreground : -XX:+UseCMSCompactAtFullCollection
- CMS foreground : -XX:+CMSFullGCsBeforeCompaction
- CMS foreground : -XX:+UseCMSCollectionPassing

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