The Z Garbage Collector

An Introduction

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Safe Harbor Statement

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Agenda

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A Scalable Low Latency Garbage Collector

Goals

TB Multi-terabyte heaps

10ms Max GC pause time

Lay the foundation for future GC features

15% Max application throughput reduction

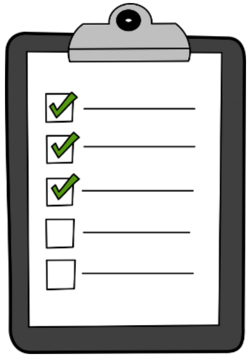
GC pause times **do not** increase with heap or live-set size

At a Glance

- New garbage collector
- Load barriers
- Colored pointers
- Single generation
- Partial compaction
- Region-based
- Immediate memory reuse
- NUMA-aware

- Concurrent
  ✓ Marking
  ✓ Relocation/Compaction
  ✓ Relocation Set Selection
  ✓ Reference Processing
  ✓ JNI WeakRefs Cleaning
  - StringTable/SymbolTable Cleaning
  - Class Unloading

Current Status



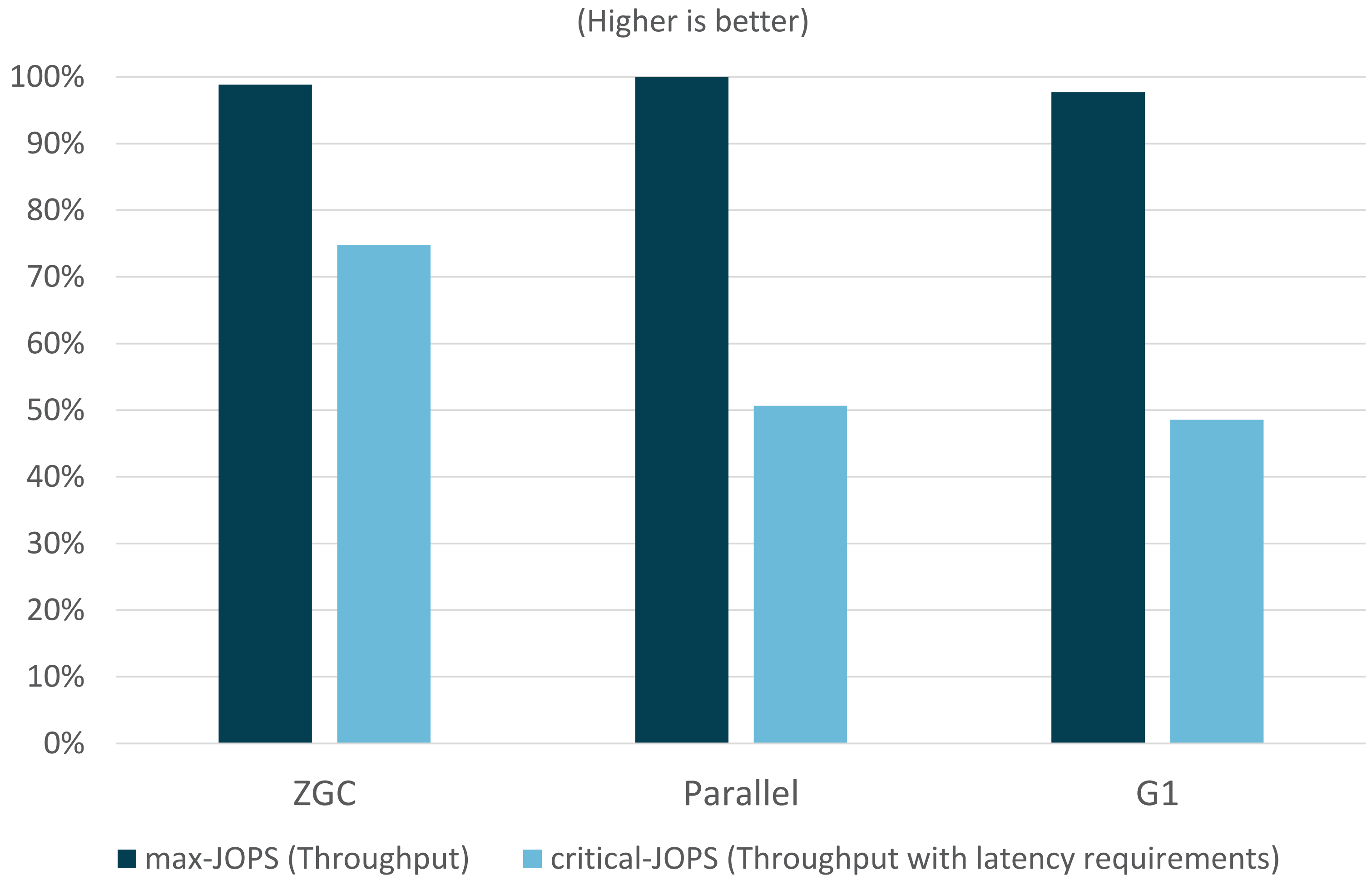
- Design and implementation approaching mature and stable

- Main focus on **Linux/x86_64**
  - Other platforms can be added if there's enough demand

- Performance looks very good
  - Both in terms of latency and throughput

Agenda

SPECjbb®2015 – Score



Mode: Composite

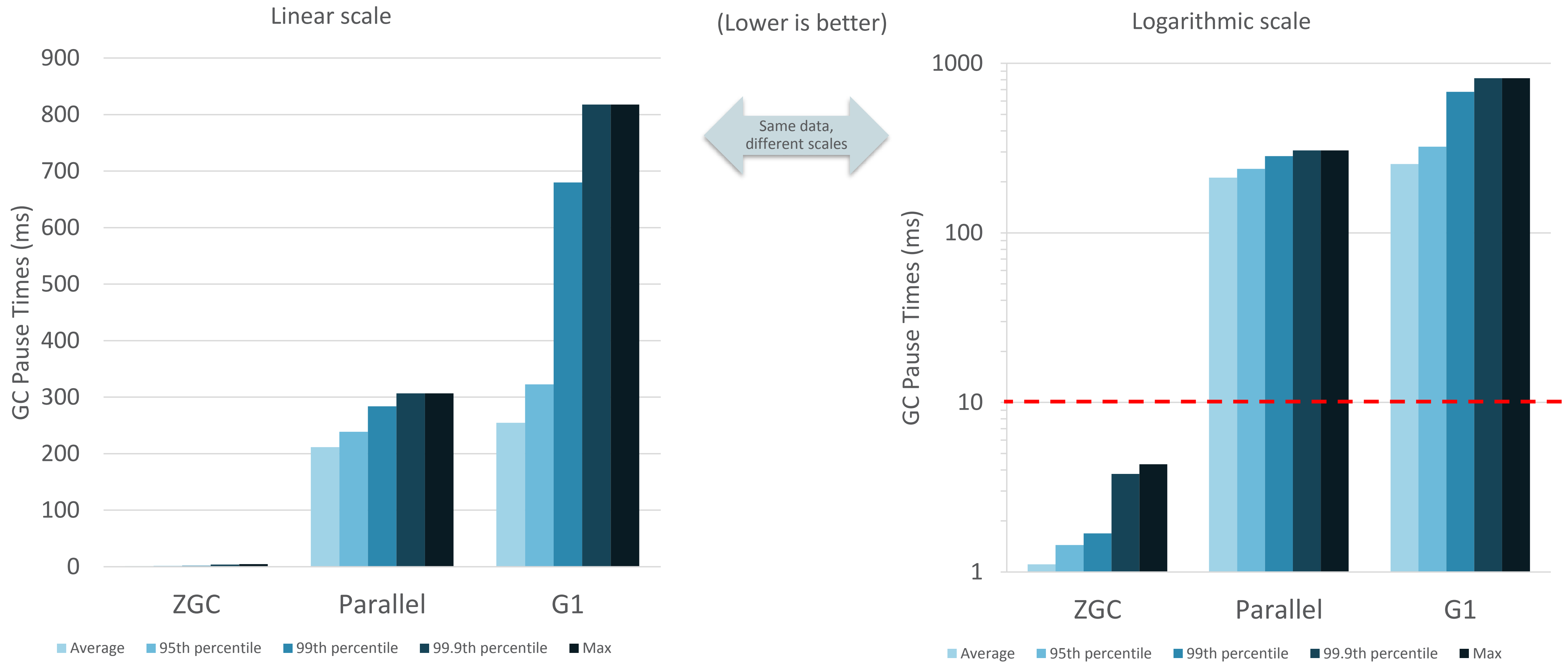
Heap Size: 128G

OS: Oracle Linux 7.4

HW: Intel Xeon E5-2690 2.9GHz
2 sockets, 16 cores (32 hw-threads)

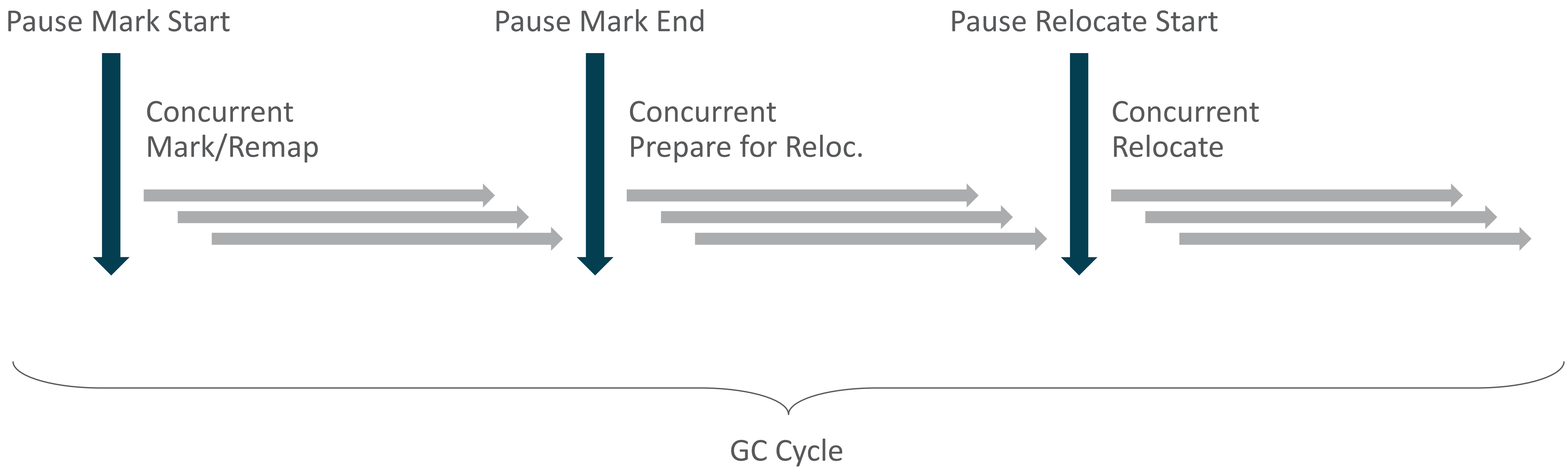
SPECjbb®2015 is a registered trademark of the Standard Performance Evaluation Corporation (spec.org). The actual results are not represented as compliant because the SUT may not meet SPEC's requirements for general availability.

SPECjbb®2015 – Pause Times

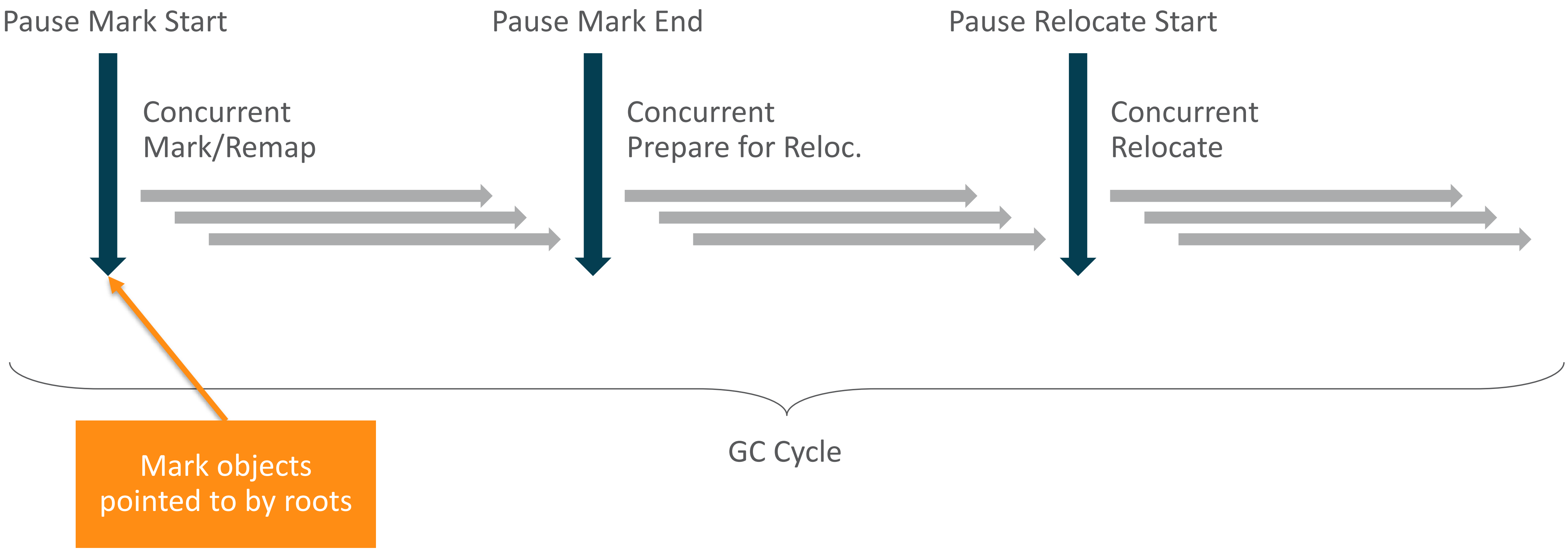


Agenda

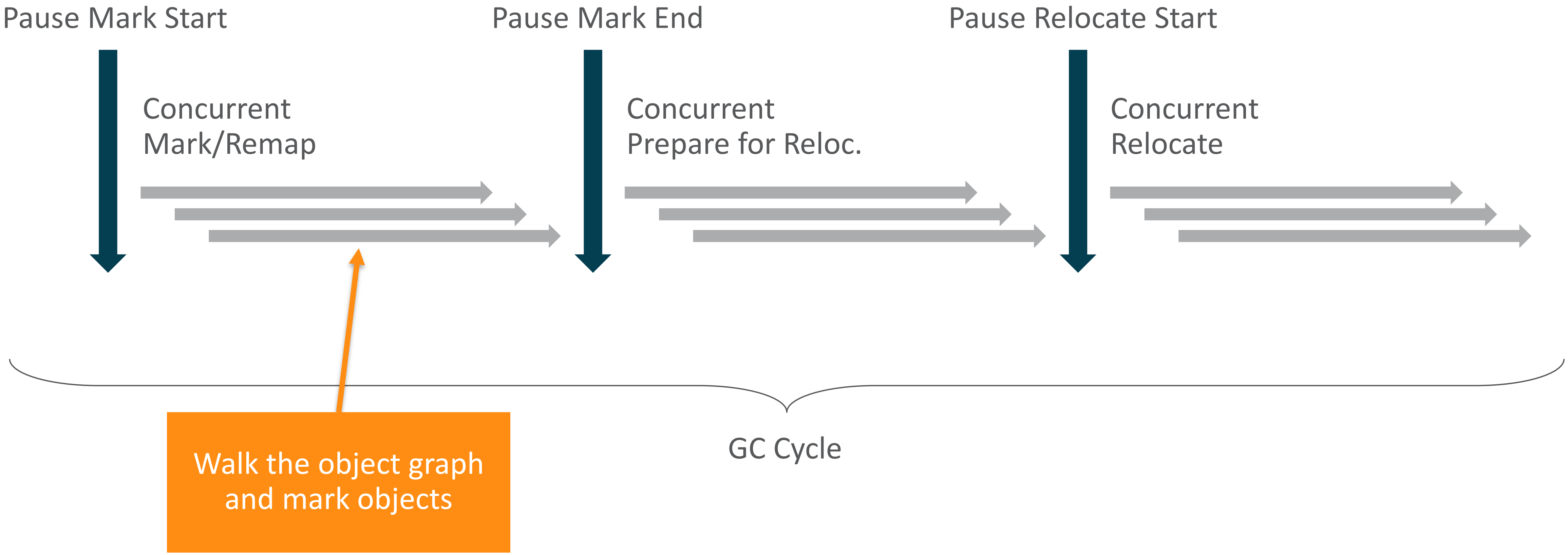
ZGC Phases


Pause Mark Start
Pause Mark End
Pause Relocate Start
Concurrent Mark/Remap
Concurrent Prepare for Reloc.
Concurrent Relocate
GC Cycle

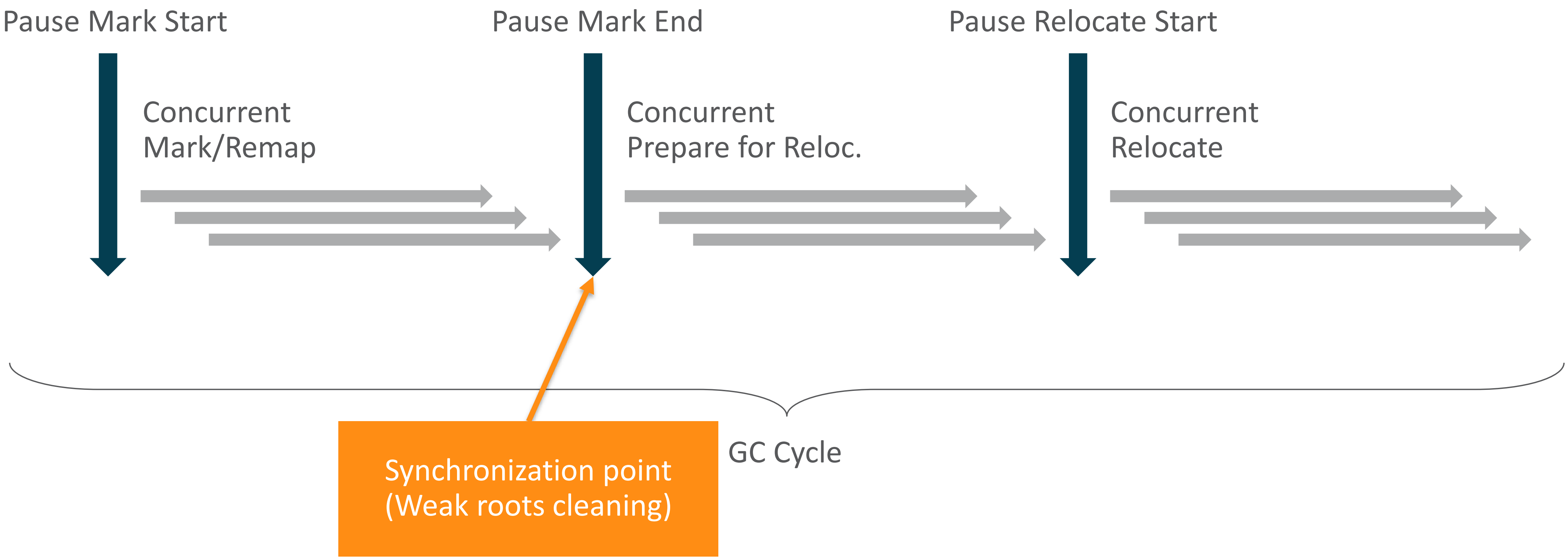
ZGC Phases


Pause Mark Start
Pause Mark End
Pause Relocate Start
Concurrent Mark/Remap
Concurrent Prepare for Reloc.
Concurrent Relocate
GC Cycle
Mark objects pointed to by roots

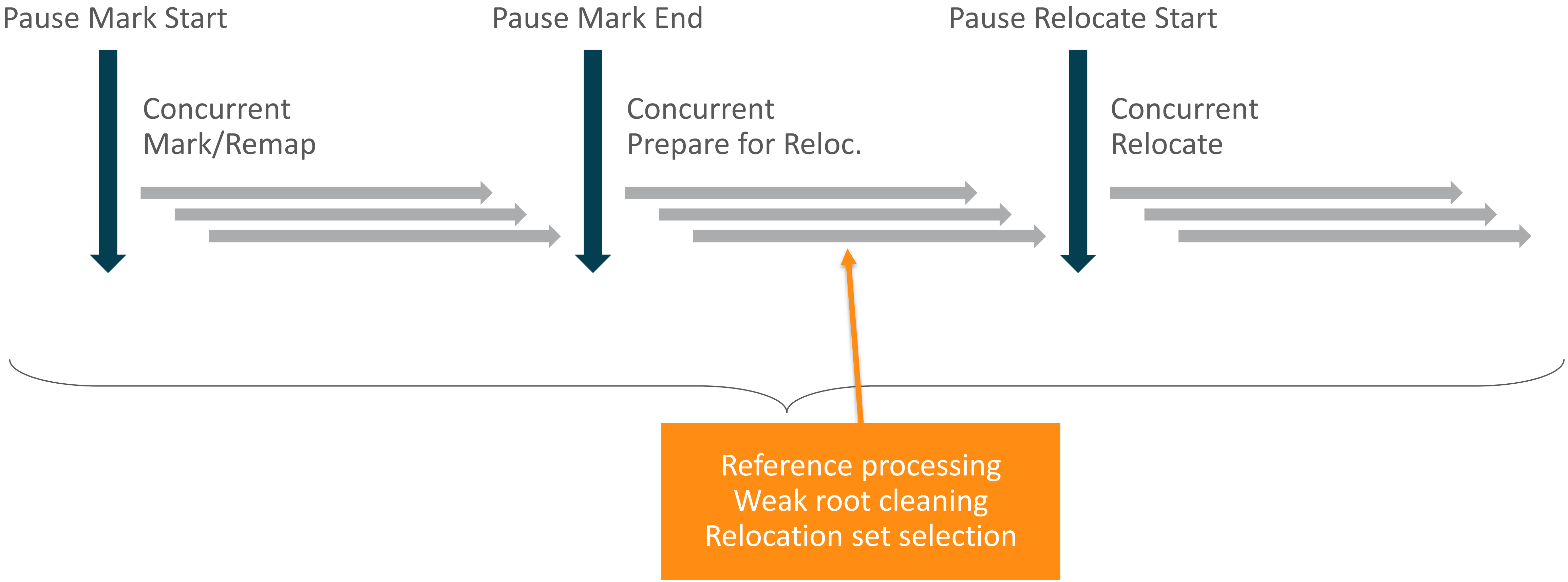
ZGC Phases


Pause Mark Start
Pause Mark End
Pause Relocate Start
Concurrent Mark/Remap
Concurrent Prepare for Reloc.
Concurrent Relocate
GC Cycle
Walk the object graph and mark objects

ZGC Phases

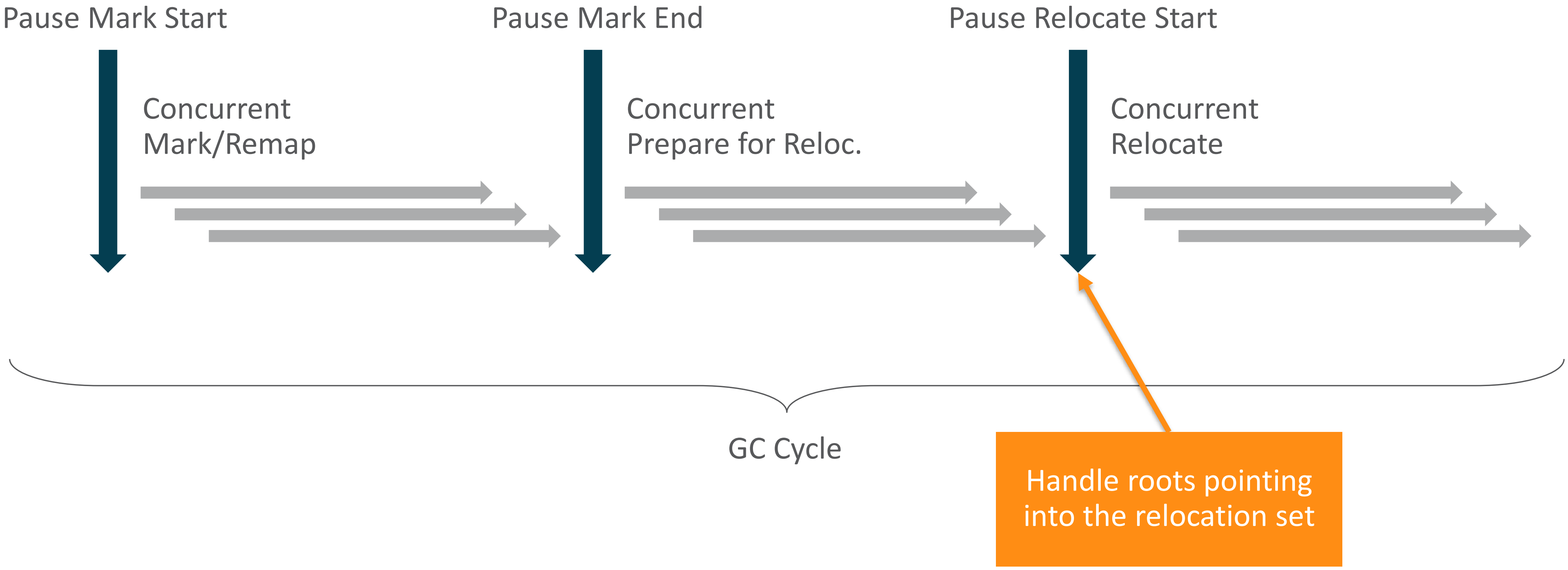

Pause Mark Start
Pause Mark End
Pause Relocate Start
Concurrent
Mark/Remap
Concurrent
Prepare for Reloc.
Concurrent
Relocate
GC Cycle
Synchronization point
(Weak roots cleaning)

ZGC Phases

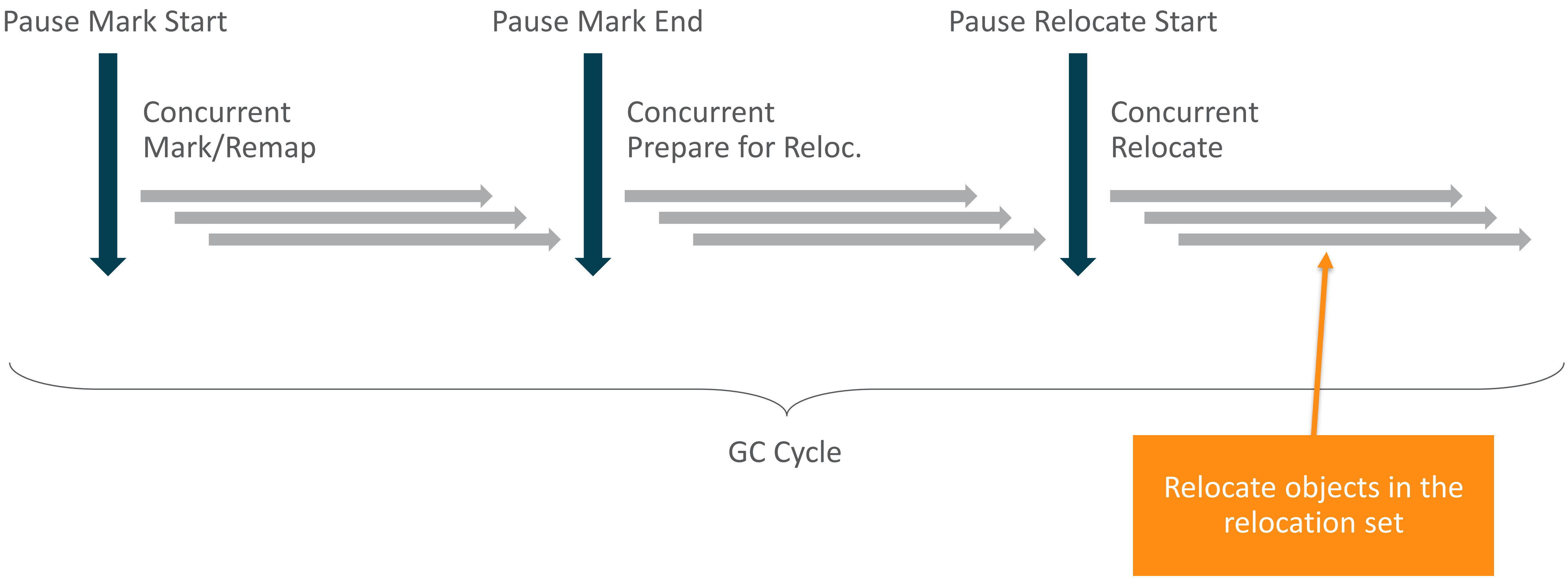


Pause Mark Start
Pause Mark End
Pause Relocate Start
Concurrent
Mark/Remap
Concurrent
Prepare for Reloc.
Concurrent
Relocate
Reference processing
Weak root cleaning
Relocation set selection

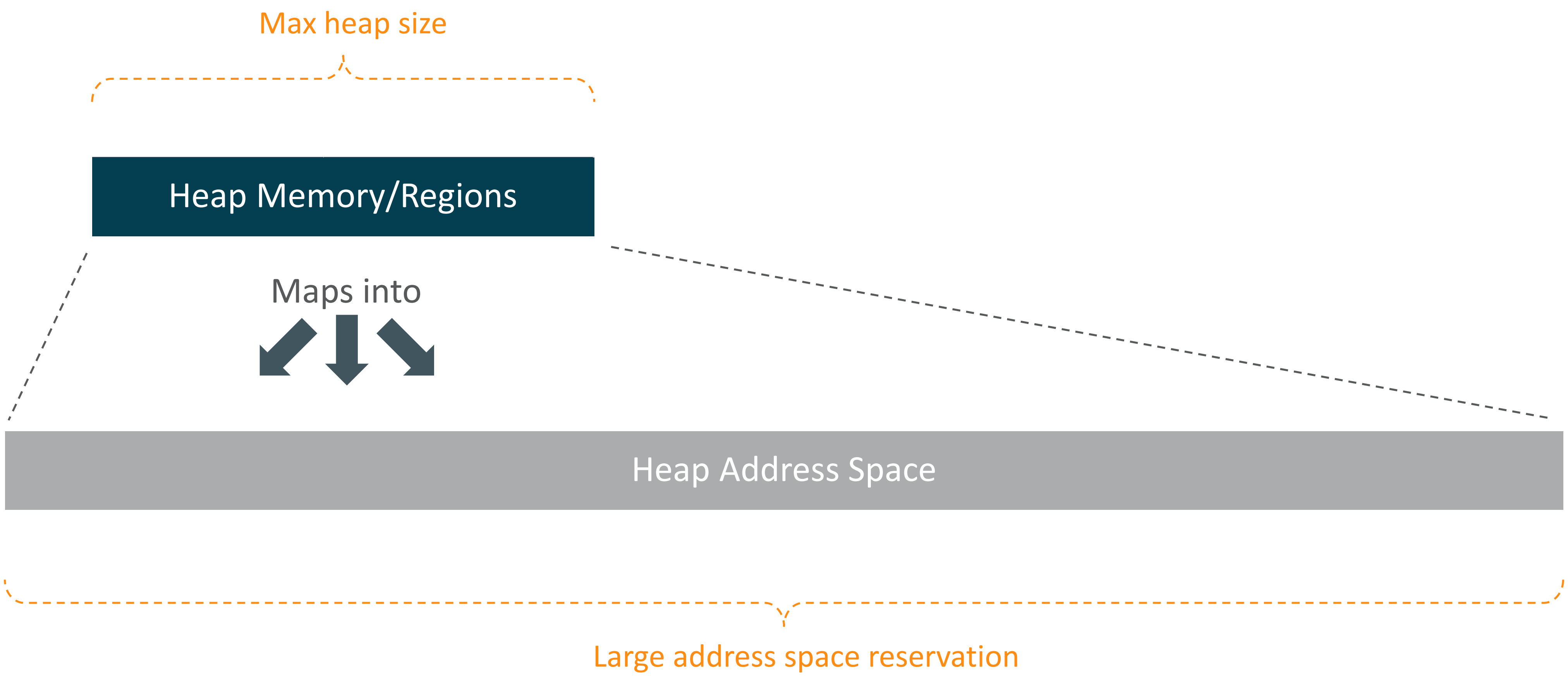
ZGC Phases


Pause Mark Start
Pause Mark End
Pause Relocate Start
Concurrent
Mark/Remap
Concurrent
Prepare for Reloc.
Concurrent
Relocate
GC Cycle
Handle roots pointing
into the relocation set

ZGC Phases


Pause Mark Start
Pause Mark End
Pause Relocate Start
Concurrent Mark/Remap
Concurrent Prepare for Reloc.
Concurrent Relocate
GC Cycle
Relocate objects in the relocation set

Heap Address Space

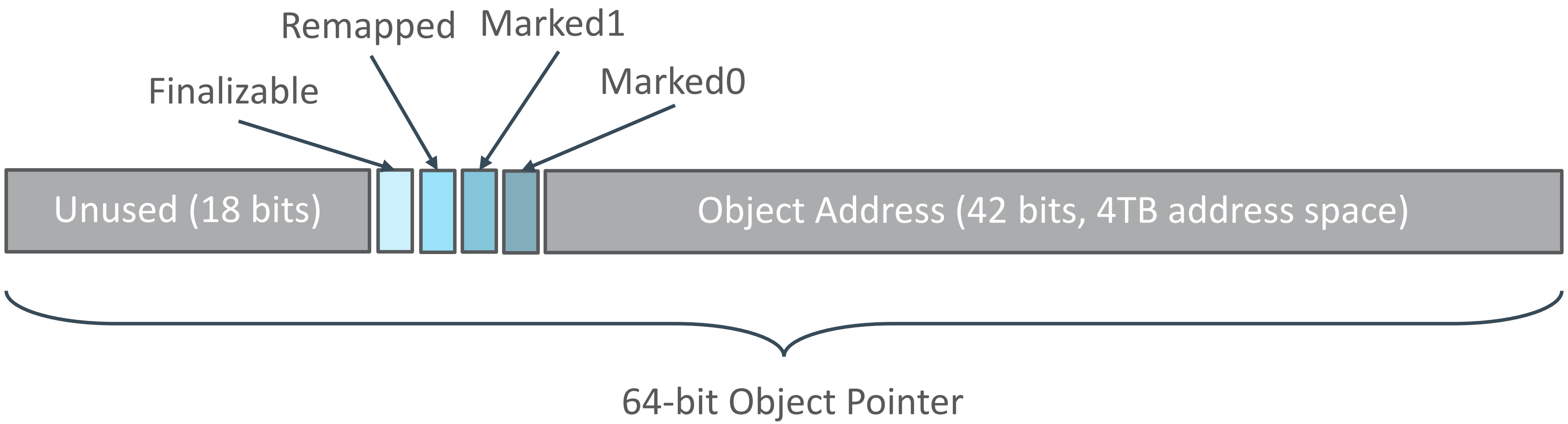


Colored Pointers

- Core design concept in ZGC
- **Metadata** stored in unused bits in 64-bit pointers
  - No support for 32-bit platforms
  - No support for CompressedOops
- **Virtual Address-masking** either in hardware, OS or software
  - Heap multi-mapping on Linux/x86_64
  - Supported in hardware on Solaris/SPARC

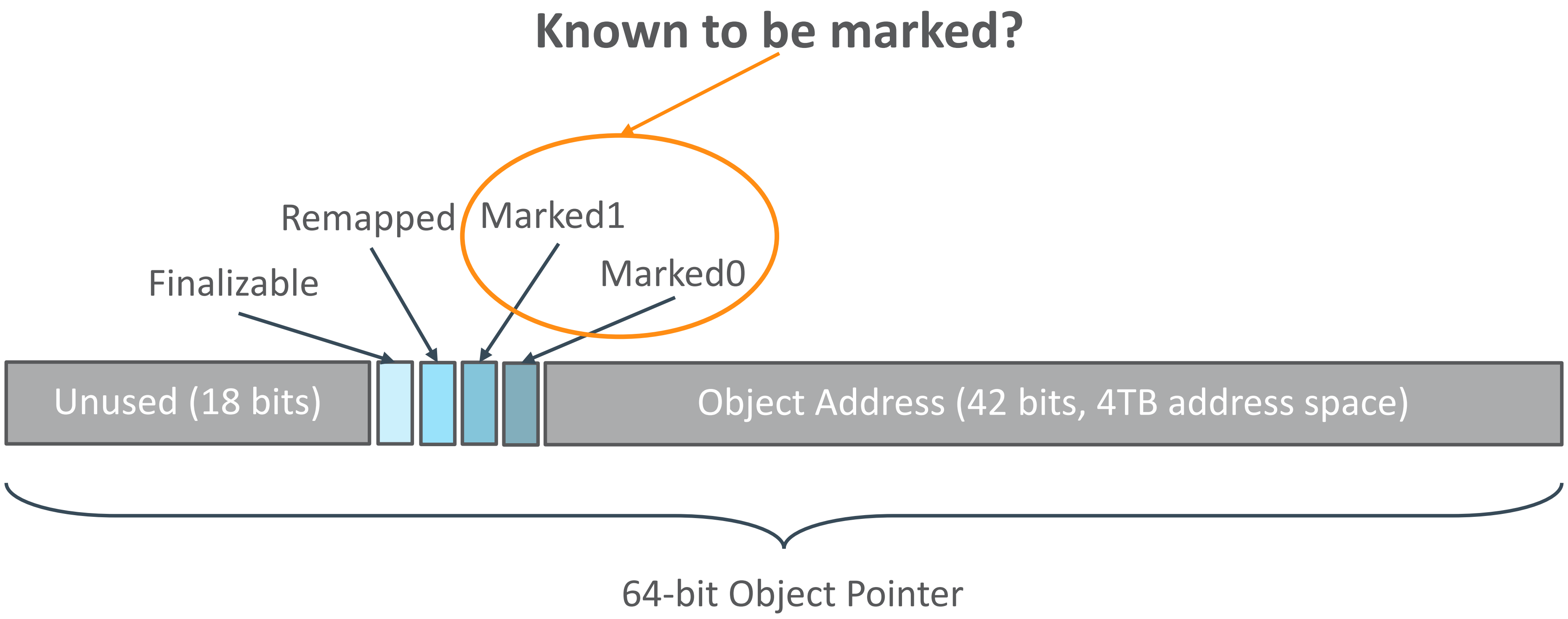
Colored Pointers

Layout on x86_64



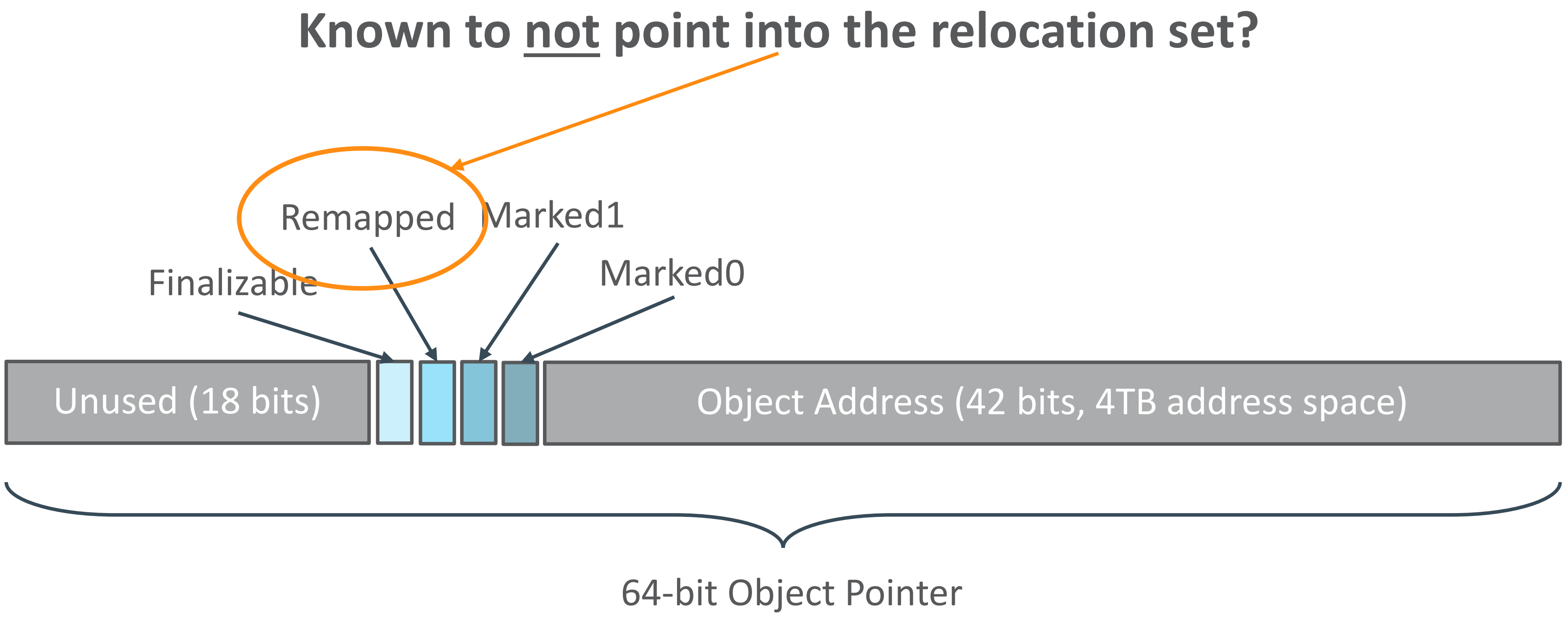
Colored Pointers

Layout on x86_64



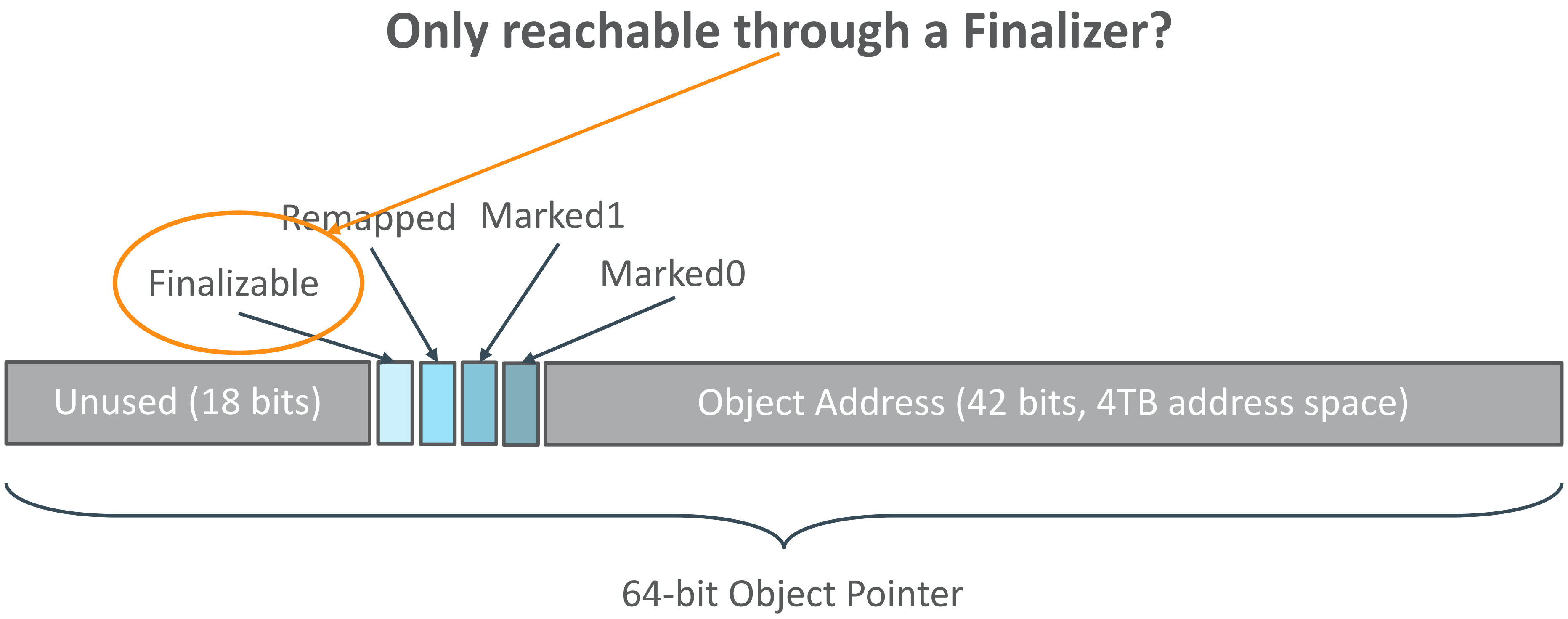
Colored Pointers

Layout on x86_64



Colored Pointers

Layout on x86_64



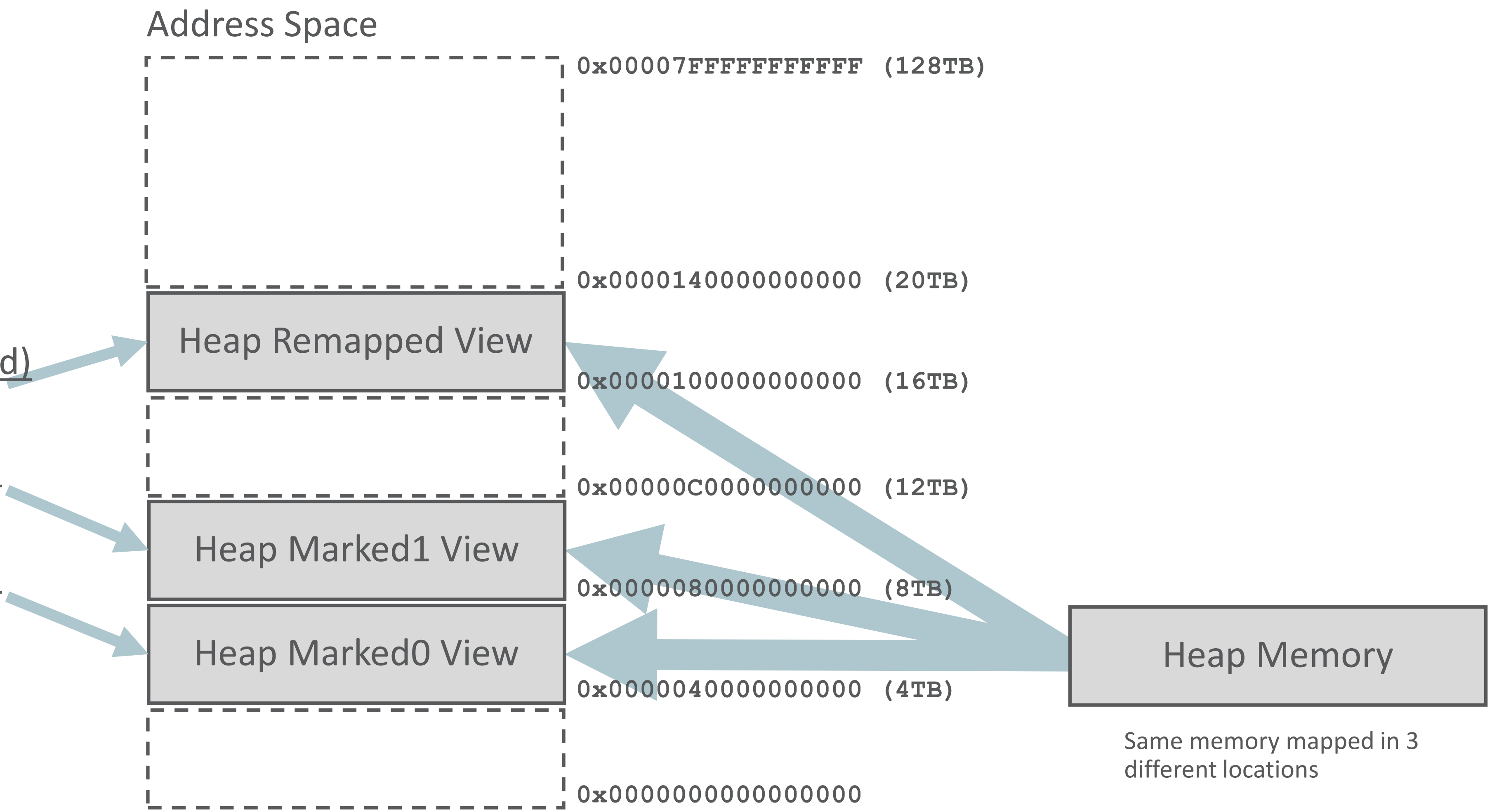
Heap Multi-Mapping on Linux/x86_64

Colorless pointer
0x0000000012345678

Colored pointer (Remapped)
0x0000100012345678

Colored pointer (Marked1)
0x0000080012345678

Colored pointer (Marked0)
0x0000040012345678



Load Barrier

- Applied when **loading an object reference** from the heap
  - **Not** when later using that reference to access the object
  - Conceptually similar to the decoding of compressed oops
- Looks at the color of the pointer
  - Take action if the pointer has a "**bad**" color (mark/relocate/remap)
  - Change to the "**good**" color (repair/heal)
- Optimized for the common case
  - Most object references will have the "**good**" color

Load Barrier

```
Object o = obj.fieldA;          // Loading an object reference from heap
```

Load Barrier

```
Object o = obj.fieldA;          // Loading an object reference from heap
<load barrier needed here>
```

Load Barrier

```
Object o = obj.fieldA;          // Loading an object reference from heap
<load barrier needed here>
Object p = o;                   // No barrier, not a load from heap
o.doSomething();                // No barrier, not a load from heap
int i = obj.fieldB;             // No barrier, not an object reference
```

Load Barrier

```
Object o = obj.fieldA;          // Loading an object reference from heap
<load barrier needed here>
```

Load Barrier

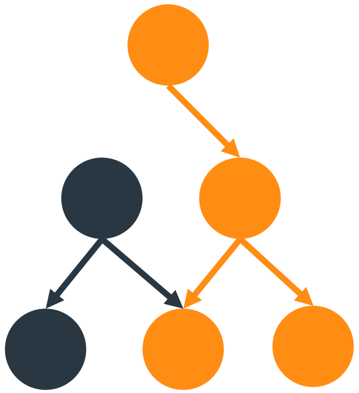
```
mov     0x20(%rax), %rbx          // Object o = obj.fieldA;
test    %rbx, (0x16)%r15          // Bad color?
jnz     slow_path                 // Yes -> Enter slow path and
                                  // mark/relocate/remap, adjust
                                  // 0x20(%rax) and %rbx
```

Load Barrier

```
mov     0x20(%rax), %rbx           // Object o = obj.fieldA;
test    %rbx, (0x16)%r15           // Bad color?
jnz     slow_path                  // Yes -> Enter slow path and
                                   // mark/relocate/remap, adjust
                                   // 0x20(%rax) and %rbx
```

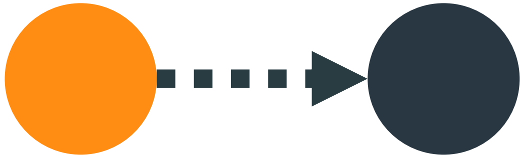
~4% execution overhead on **SPECjbb®2015**

Mark



- Concurrent & Parallel
- Load barrier
  – Detects loads of non-marked object pointers
- Finalizable mark
  – Enabler for Concurrent Reference Processing
- Thread local handshakes
  – Used to synchronize end of concurrent mark

Relocation



- Concurrent & Parallel
- Load barrier
  - Detects loads of object pointers pointing into the relocation set
  - Java threads help out with relocation if needed
- Off-heap forwarding tables
  - No forwarding information stored in old copies of objects
  - Important for immediate reuse of heap memory

Agenda

1. What is ZGC?
2. Some Numbers
3. A Peek Under The Hood
4. Going Forward
5. How To Get Started

In The Works

- GC Barrier API
  - Make it **easier** to plug in new GCs (ZGC, Shenandoah, Epsilon)
- Concurrent class unloading & weak roots
  - Traditionally done in a Stop-The-World pause
  - Impacts **JITs** and **Runtime** subsystems
- Addressing non-GC induced latencies
  - Time to safepoint/unsafepoint, object monitor deflation, etc.

Foundation for Future GC Features

Colored Pointers + Load Barriers

- Thread local GC scheme
- Track heap access patterns
- Use non-volatile memory for rarely used parts of the heap
- Compress or archive parts of the heap
- Object properties encoded in pointers
- Allocation tricks
- etc.

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1. What is ZGC?
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3. A Peek Under The Hood
4. Going Forward
5. **How To Get Started**

How To Get Started

Download

- Official **early access builds** will be available soon-ish, but until then…
- Download & build

```
$ hg clone http://hg.openjdk.java.net/zgc/zgc
$ cd zgc
$ sh configure
$ make images
```

- Run

```
$ ./build/linux-x86_64-<...>/images/jdk/bin/java
```

How To Get Started

JVM Options

- Enable ZGC: **`-XX:+UseZGC`**
- Tuning
  - If you care about latency, do **not** overprovision your machine
  - Max heap size: **`-Xmx<size>`**
  - Number of concurrent GC threads: **`-XX:ConcGCThreads=<number>`**
- Logging
  - Basic logging: **`-Xlog:gc`**
  - Detailed logging useful when tuning: **`-Xlog:gc*`**

Feedback Welcome!

http://openjdk.java.net/projects/zgc/

OpenJDK