The Z Garbage Collector

Scalable Low-Latency GC in JDK 11

Erik Österlund
Garbage Collection Engineer
Java Platform Group, Oracle
November 16, 2018

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Agenda

1. What is ZGC?
2. A Peek Under the Hood
3. Performance
4. Using ZGC
5. Future Plans

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What is ZGC?

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New Garbage Collector in **JDK 11**

(Experimental feature, Linux/x86_64 only)

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A Scalable Low-Latency Garbage Collector

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Goals

TB Multi-terabyte heaps

10ms Max GC pause time

Easy to tune

15% Max application throughput reduction

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ZGC at a Glance

Concurrent	Region-based
Tracing	NUMA-aware
Compacting	Load barriers
Single generation	Colored pointers

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

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ZGC pause times **do** increase with the root-set size

(Number of Java Threads)

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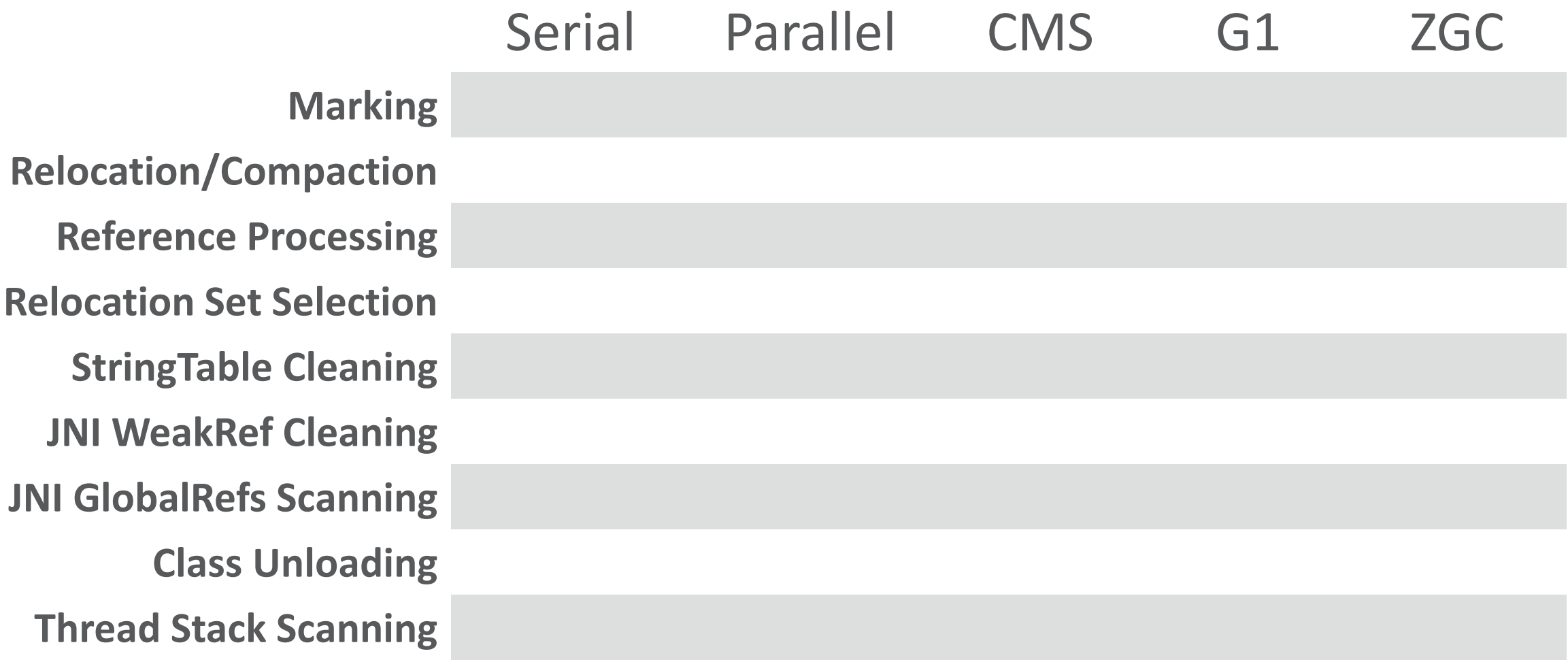
Concurrent?



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Concurrent?

	Serial	Parallel	CMS	G1	ZGC
Marking	-	-			
Relocation/Compaction	-	-			
Reference Processing	-	-			
Relocation Set Selection	-	-			
StringTable Cleaning	-	-			
JNI WeakRef Cleaning	-	-			
JNI GlobalRefs Scanning	-	-			
Class Unloading	-	-			
Thread Stack Scanning	-	-			

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*) Old Gen Only

Concurrent?

	Serial	Parallel	CMS	G1	ZGC
Marking	-	-	✓*	✓*	
Relocation/Compaction	-	-	-	-	
Reference Processing	-	-	-	-	
Relocation Set Selection	-	-	-	-	
StringTable Cleaning	-	-	-	-	
JNI WeakRef Cleaning	-	-	-	-	
JNI GlobalRefs Scanning	-	-	-	-	
Class Unloading	-	-	-	-	
Thread Stack Scanning	-	-	-	-	

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*) Old Gen Only
**) Post JDK 11

Concurrent?

	Serial	Parallel	CMS	G1	ZGC
Marking	-	-	✓*	✓*	✓
Relocation/Compaction	-	-	-	-	✓
Reference Processing	-	-	-	-	✓
Relocation Set Selection	-	-	-	-	✓
StringTable Cleaning	-	-	-	-	✓
JNI WeakRef Cleaning	-	-	-	-	✓
JNI GlobalRefs Scanning	-	-	-	-	✓**
Class Unloading	-	-	-	-	✓**
Thread Stack Scanning	-	-	-	-	-

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A Peek Under the Hood

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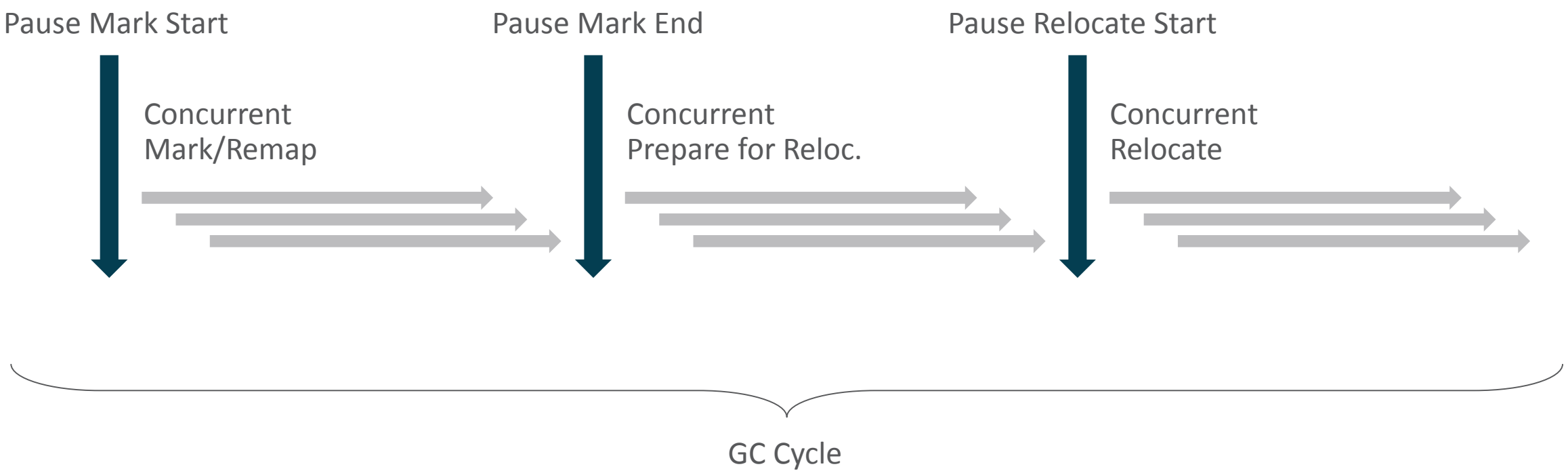
ZGC Phases



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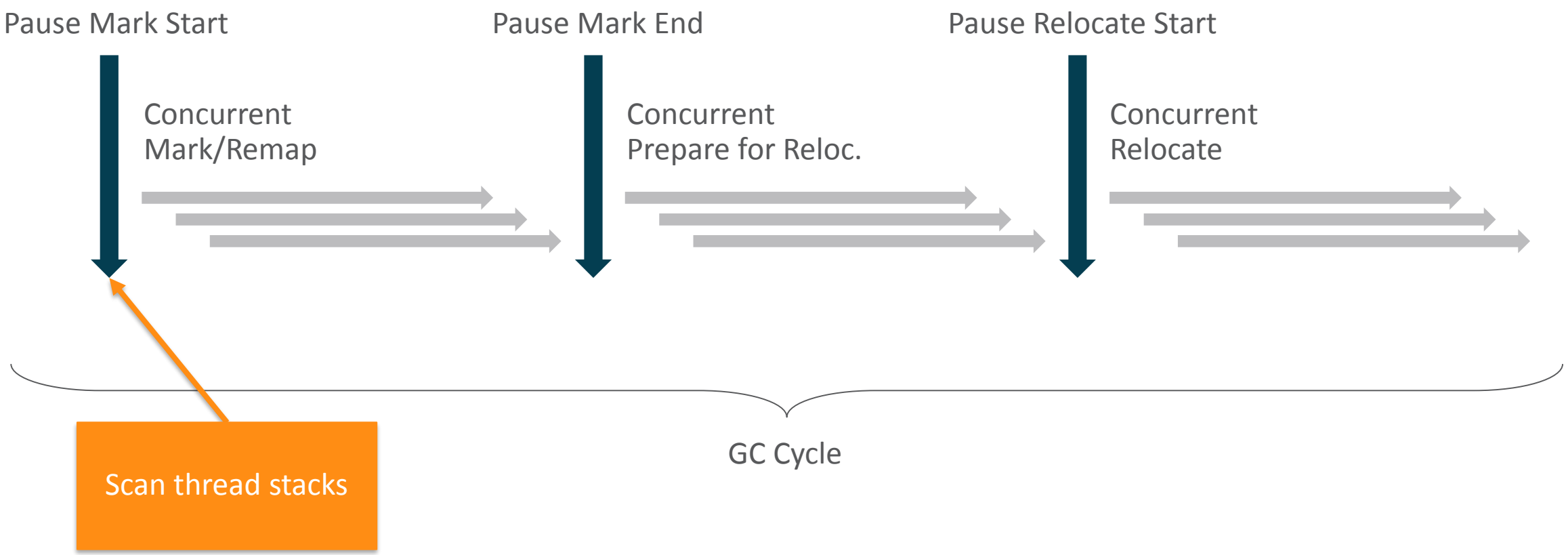
ZGC Phases



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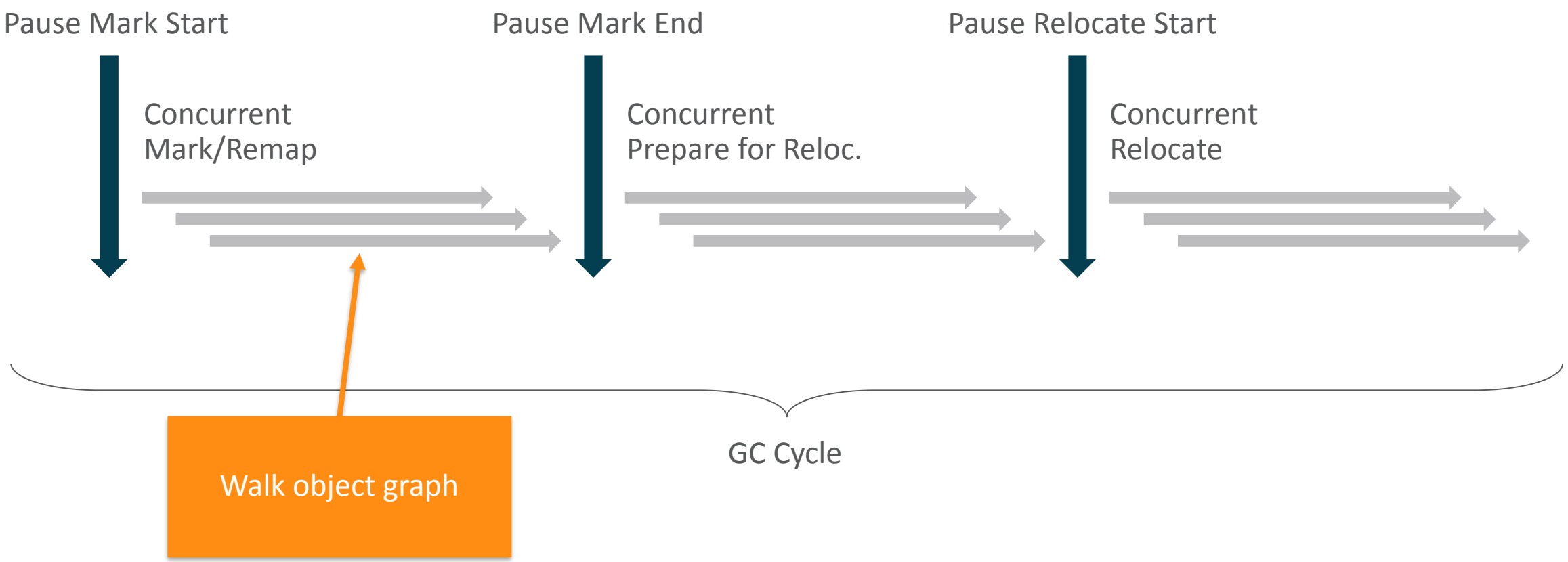
ZGC Phases



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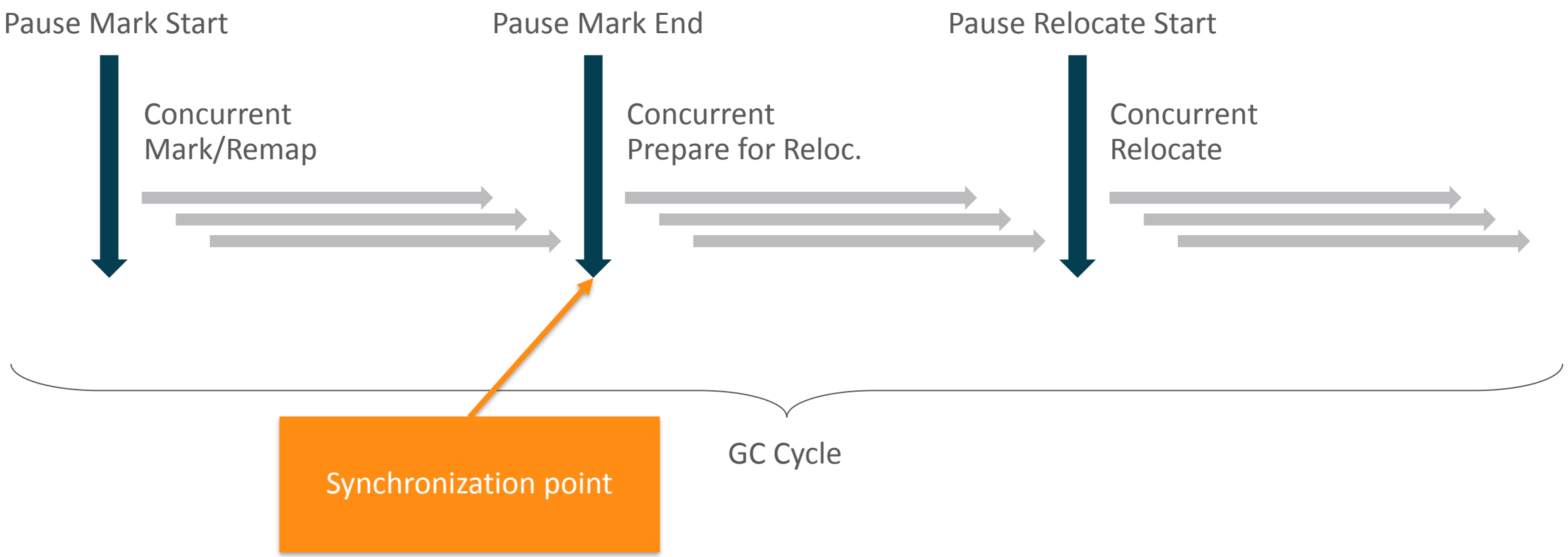
ZGC Phases



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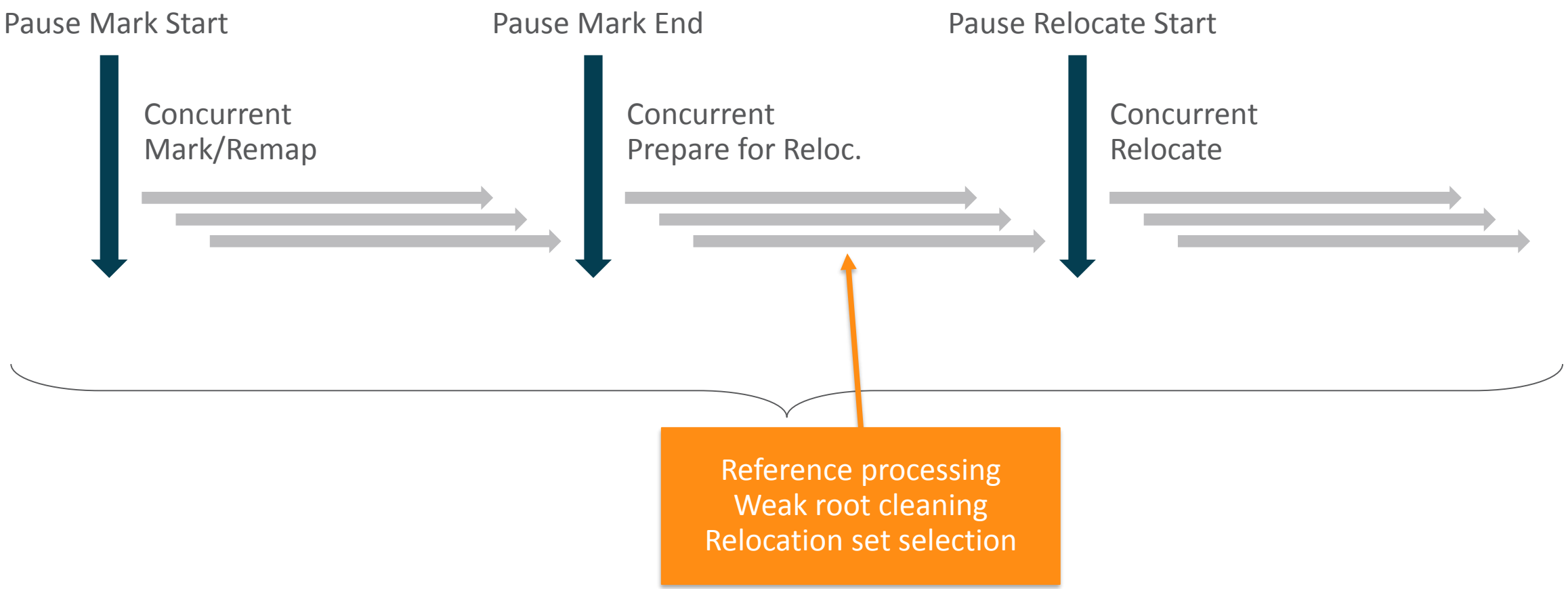
ZGC Phases



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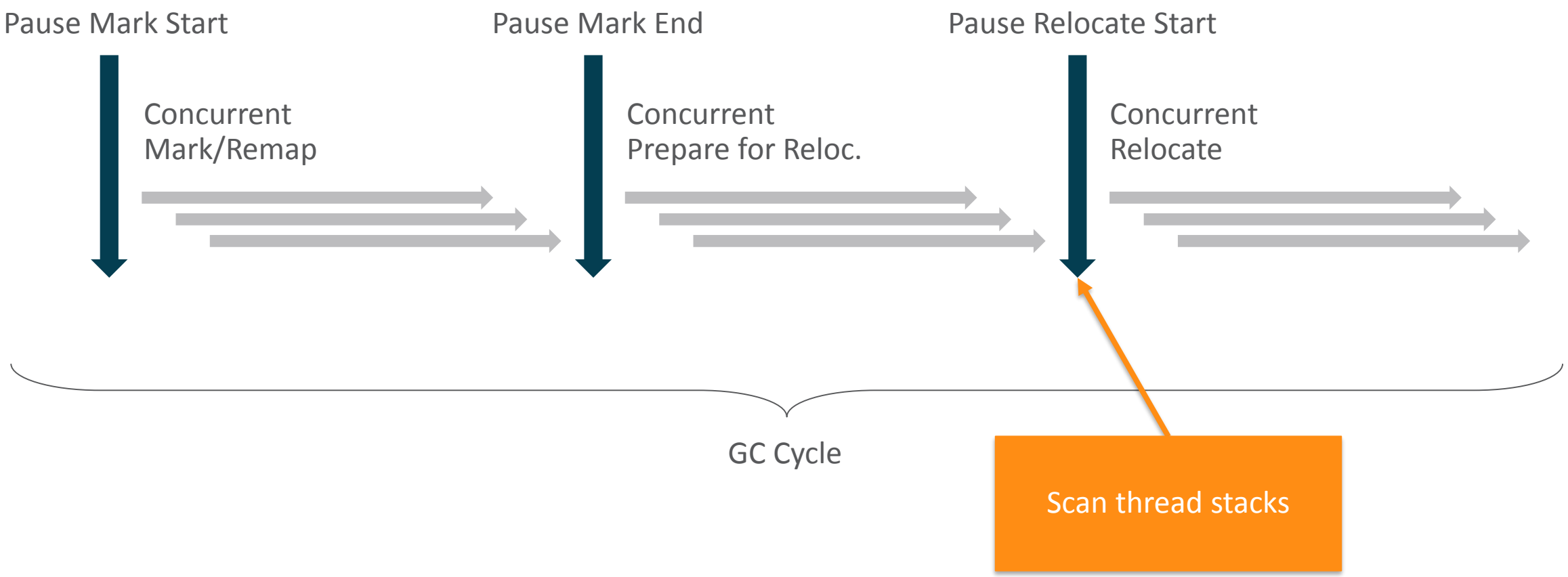
ZGC Phases



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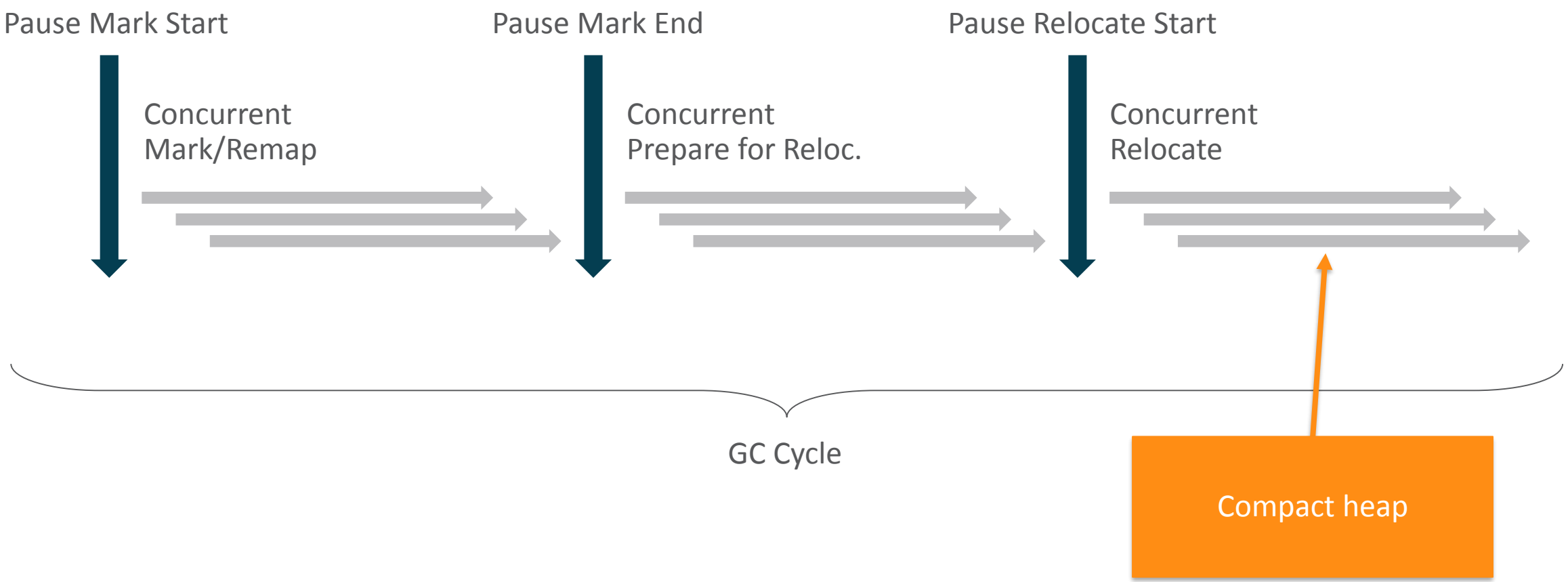
ZGC Phases



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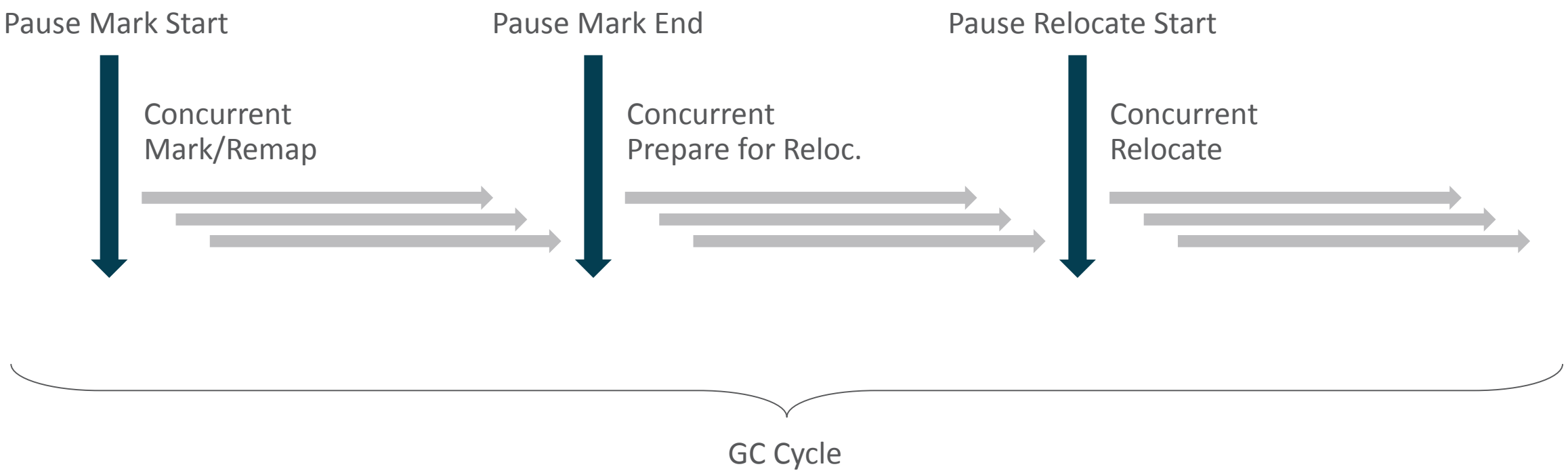
ZGC Phases



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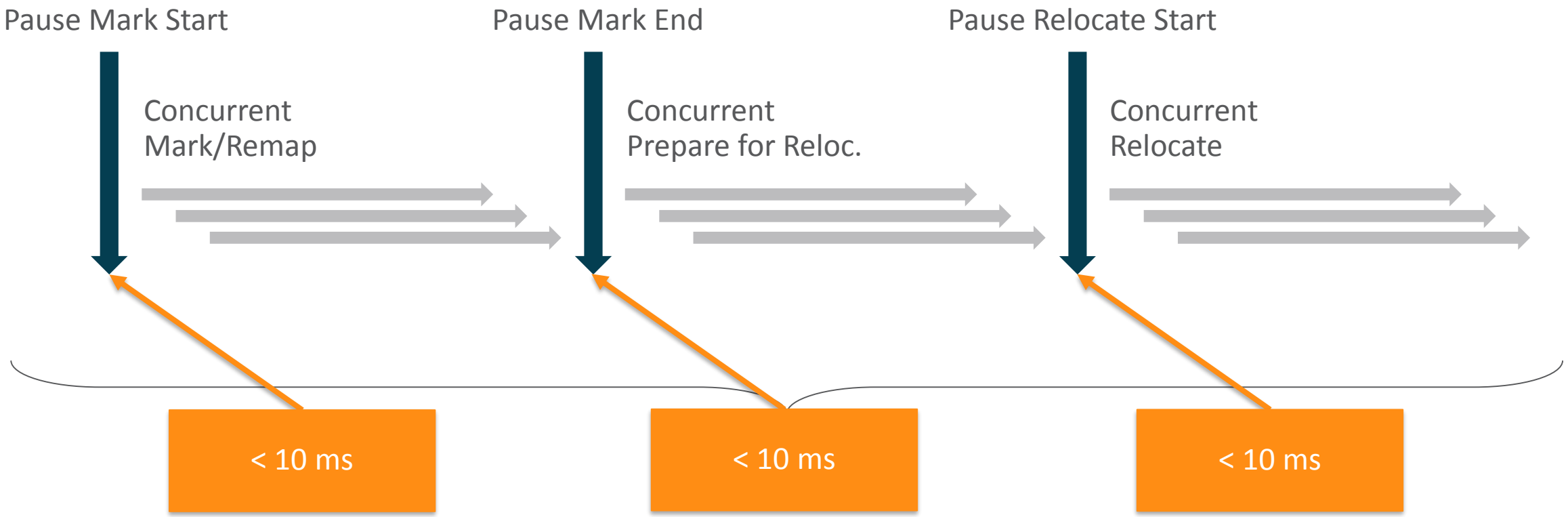
ZGC Phases



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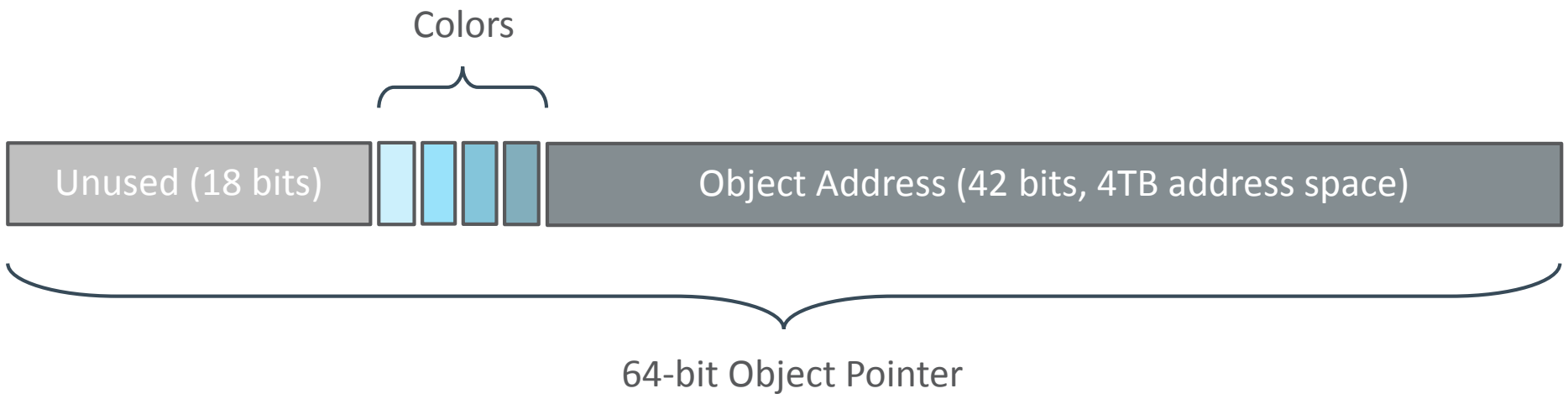
Colored Pointers

- Core design concept in ZGC
- **Metadata** stored in unused bits in 64-bit pointers
  - No support for 32-bit platforms
  - No support for CompressedOops



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Load Barrier

- A small piece of code injected by the JIT in strategic places
  - When **loading an object reference from the heap**

- Checks if the loaded object reference has a **bad** color
  - If so, take **action** and **correct** it

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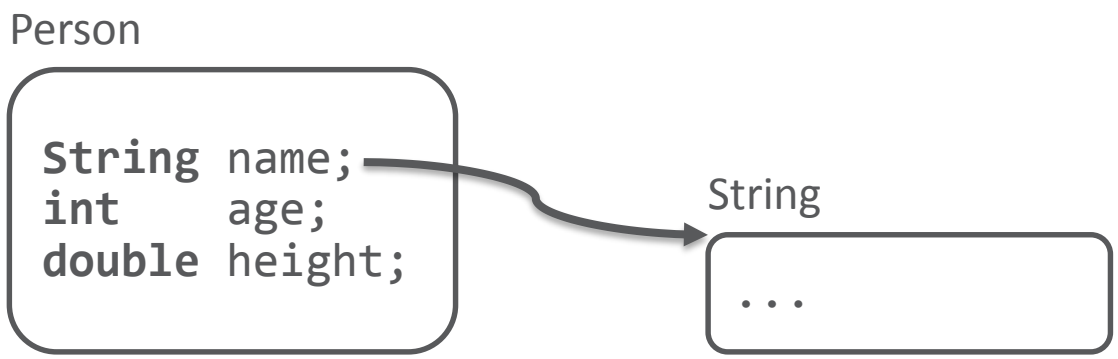
Load Barrier

```
String n = person.name;          // Loading an object reference from heap
```



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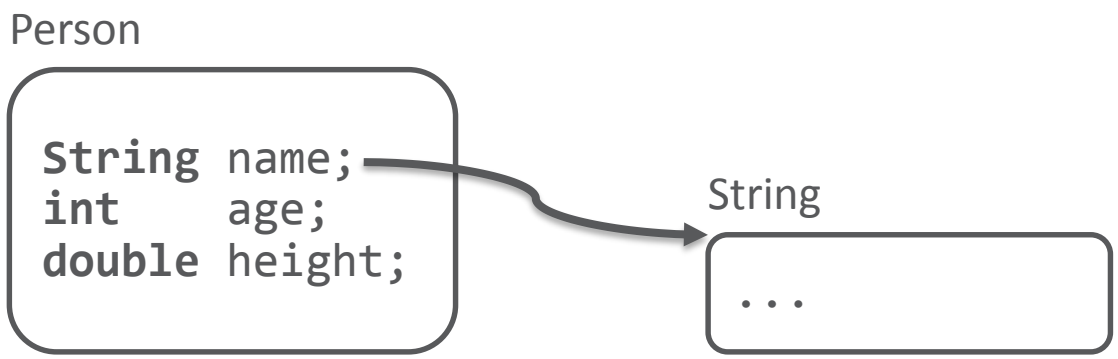
Load Barrier

```
String n = person.name;          // Loading an object reference from heap
<load barrier needed here>
```



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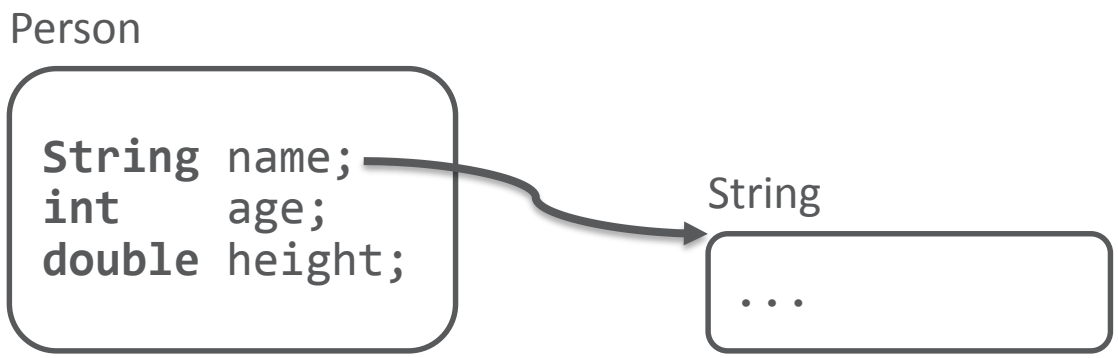
Load Barrier

```
String n = person.name;          // Loading an object reference from heap
<load barrier needed here>
String p = n;                    // No barrier, not a load from heap
n.isEmpty();                     // No barrier, not a load from heap
int age = person.age;            // No barrier, not an object reference
```



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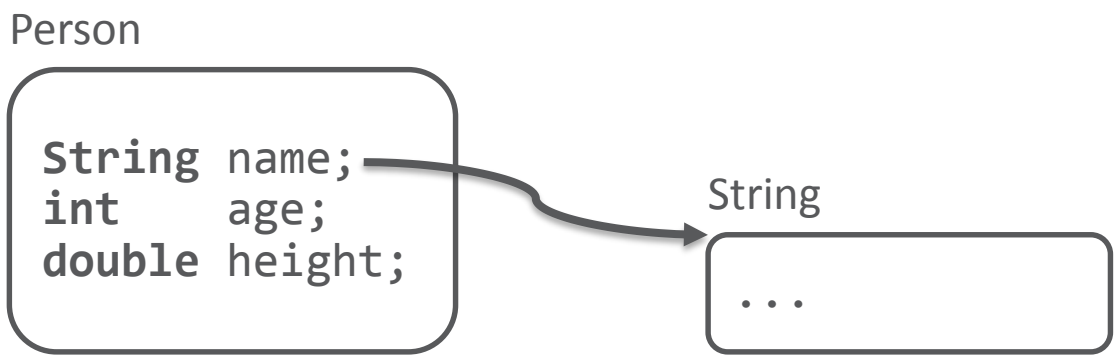
Load Barrier

```
String n = person.name;          // Loading an object reference from heap
<load barrier needed here>
```



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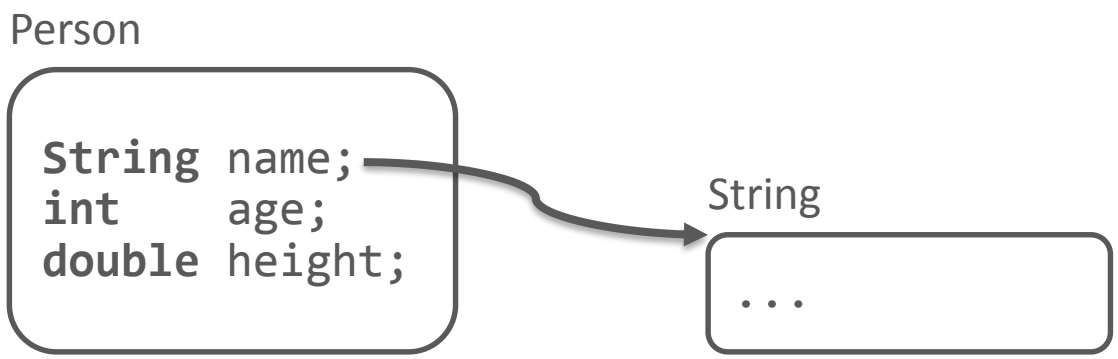
Load Barrier

```
String n = person.name;          // Loading an object reference from heap
if (n & bad_bit_mask) {
  slow_path(register_for(n), address_of(person.name));
}
```



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Load Barrier

```
mov     0x10(%rax), %rbx
test    %rbx, (0x16)%r15
jnz     slow_path
```

```
// String n = person.name;
// Bad color?
// Yes -> Enter slow path and
// mark/relocate/remap, adjust
// 0x10(%rax) and %rbx
```

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Load Barrier

```
mov     0x10(%rax), %rbx
test    %rbx, (0x16)%r15
jnz     slow_path
```

```
// String n = person.name;
// Bad color?
// Yes -> Enter slow path and
// mark/relocate/remap, adjust
// 0x10(%rax) and %rbx
```

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

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Performance

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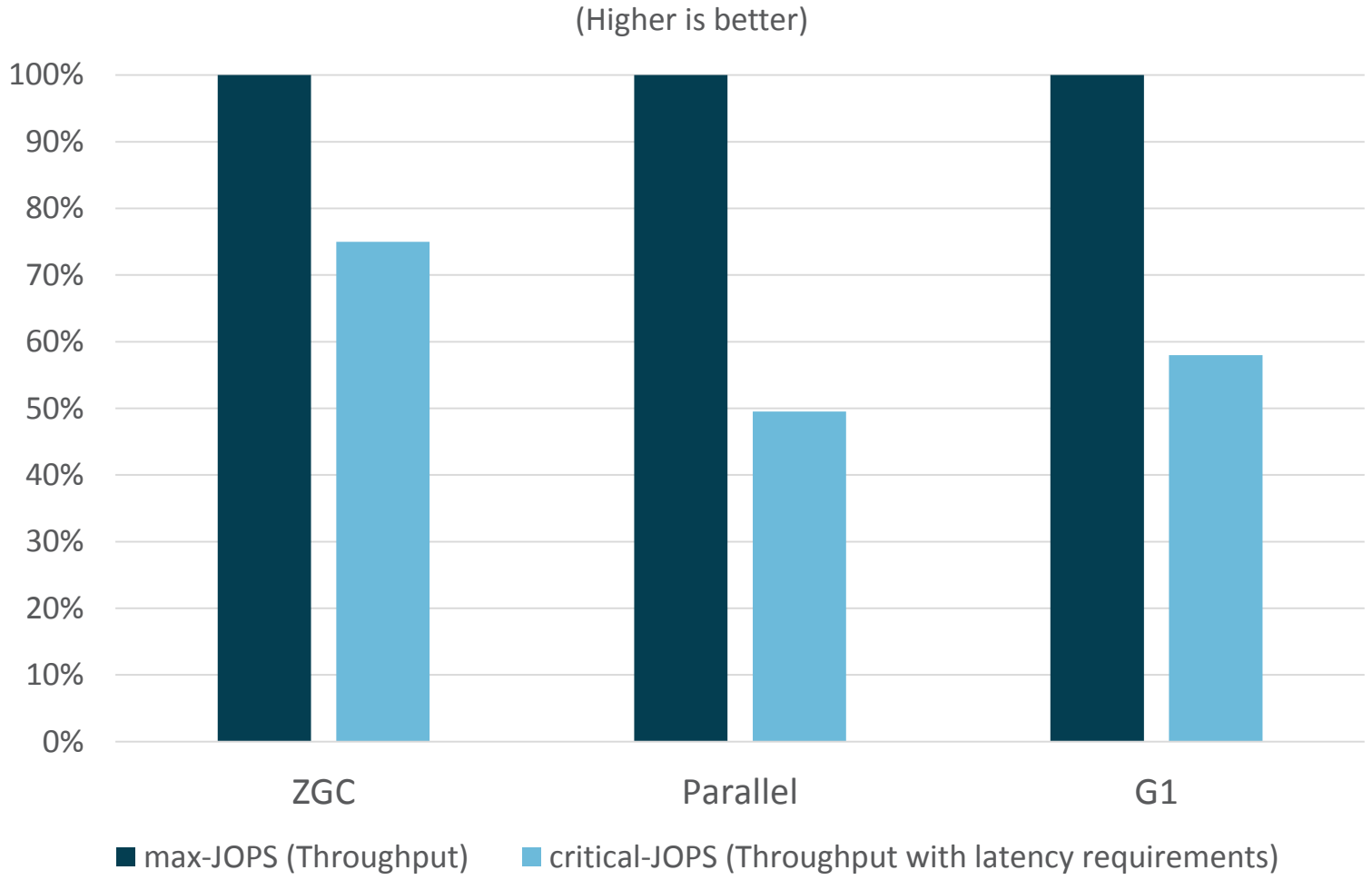
SPECjbb®2015 – Score



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.

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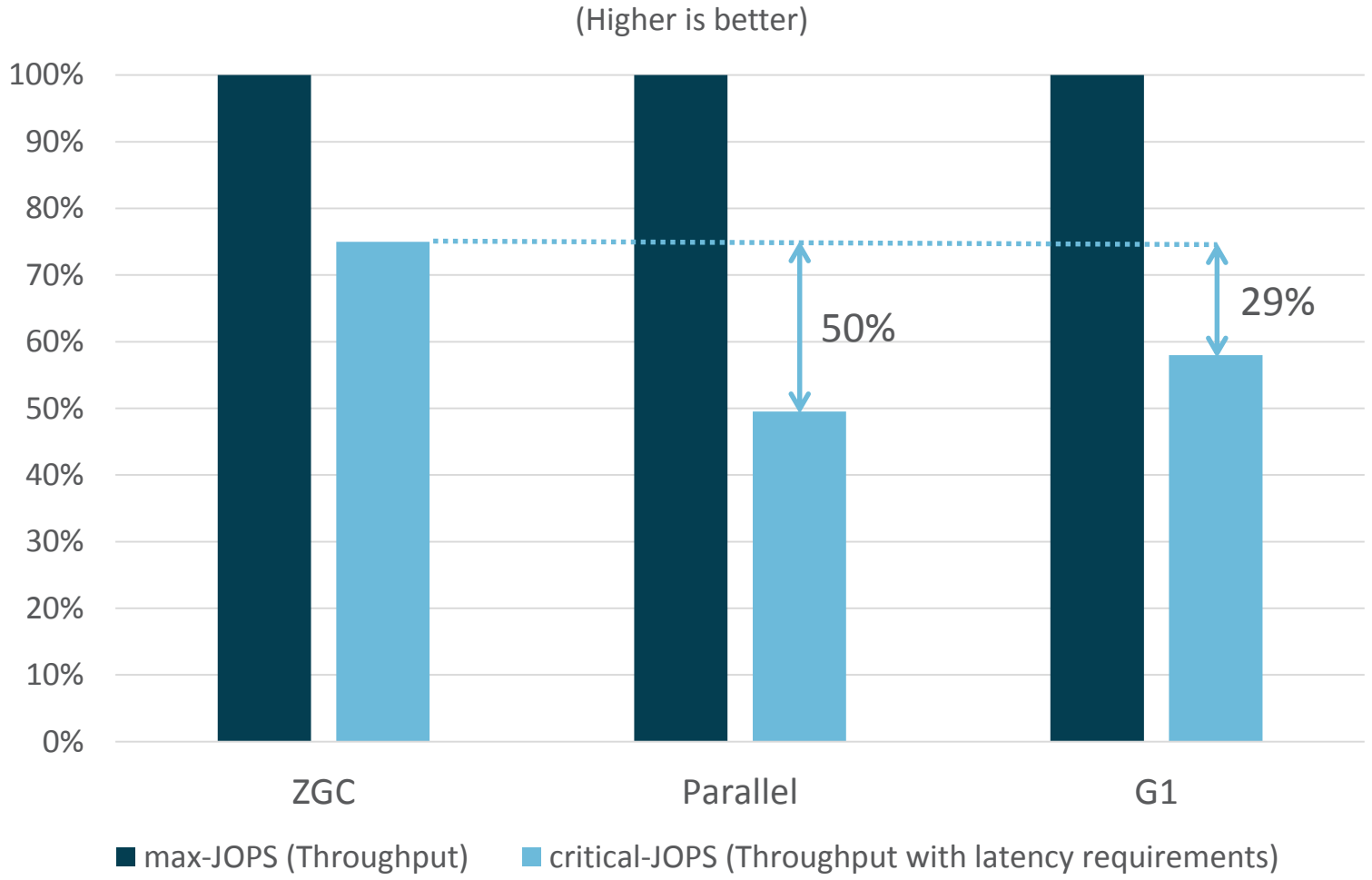
SPECjbb®2015 – Score



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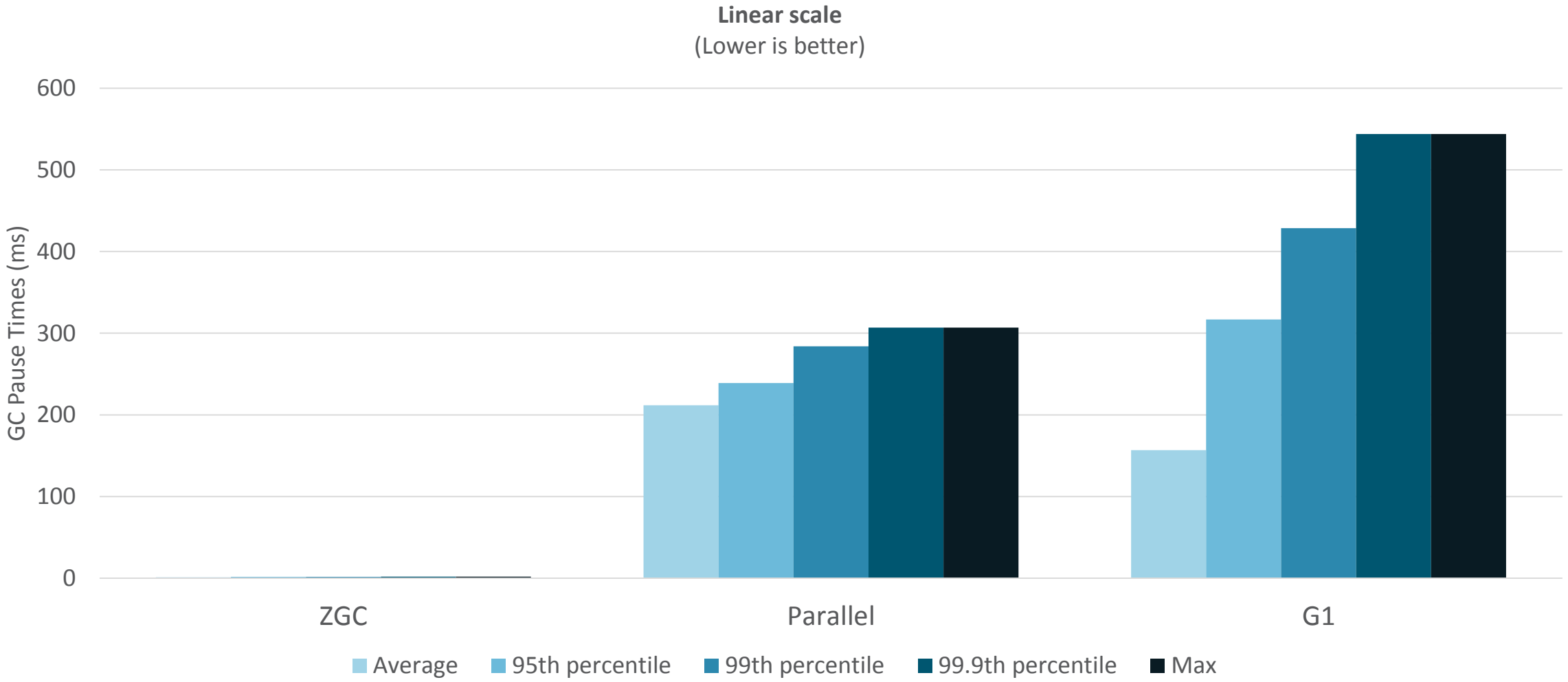
SPECjbb®2015 – Pause Times



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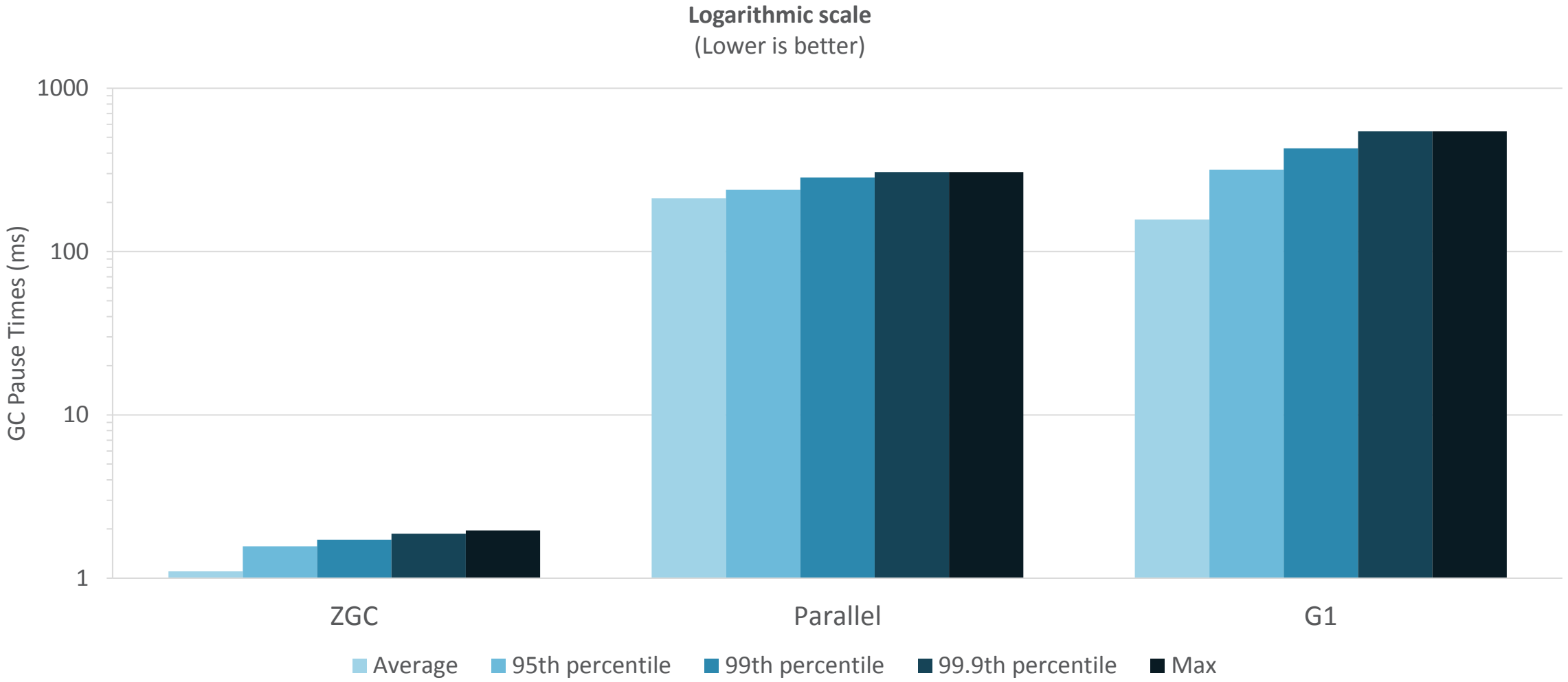
SPECjbb®2015 – Pause Times



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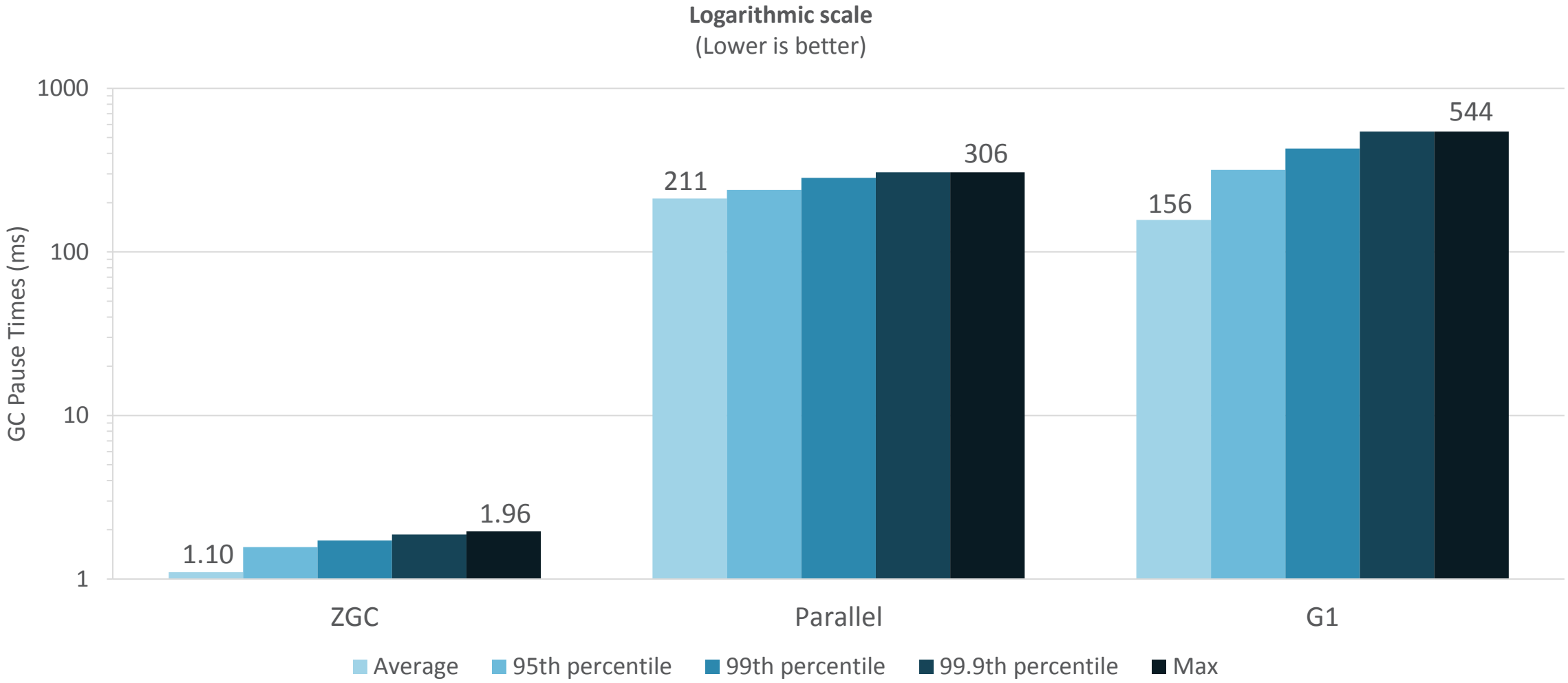
SPECjbb®2015 – Pause Times



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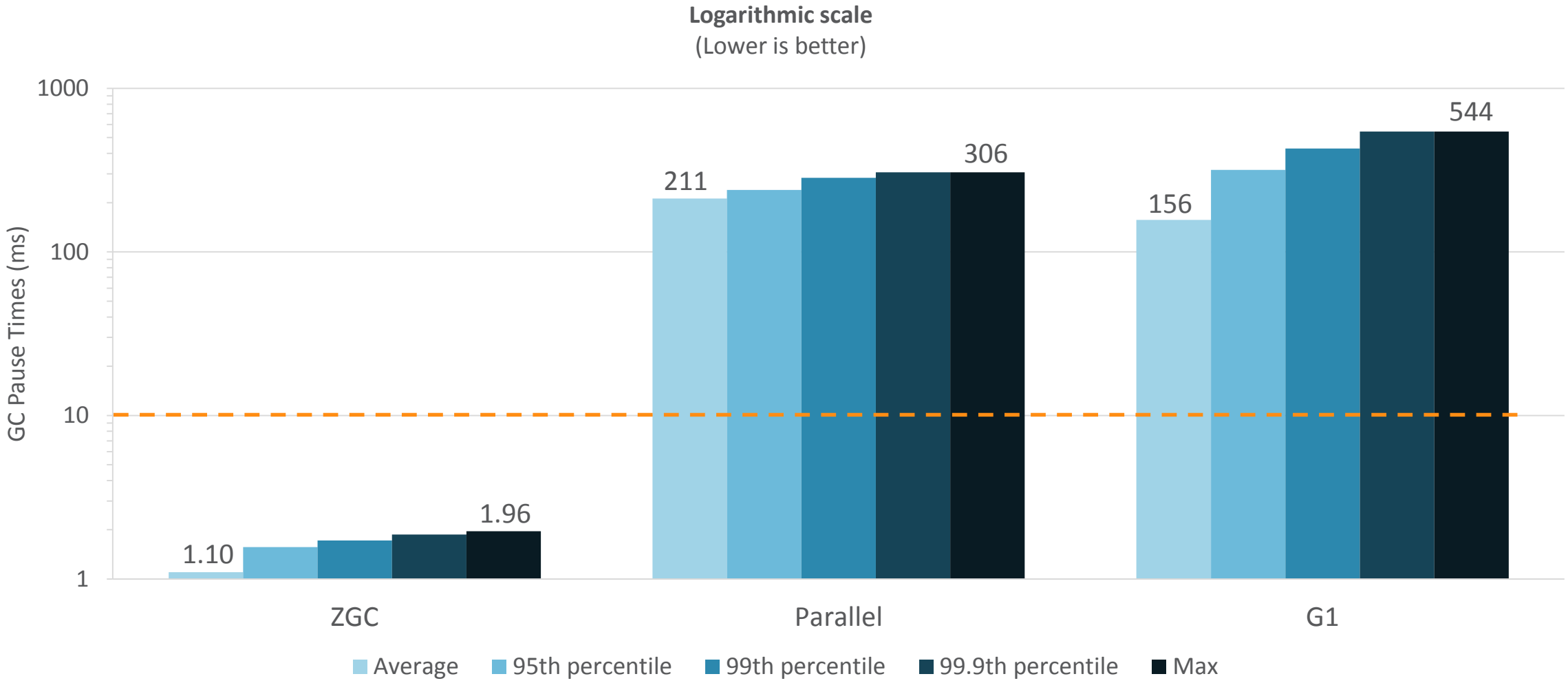
SPECjbb®2015 – Pause Times



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Using ZGC

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Enable

```
-XX:+UseZGC
```

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Enable

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

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Tuning

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Tuning

Set Max Heap Size

```
-Xmx<size>
```

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Tuning

Maybe Set Number of Concurrent GC Threads

```
-Xmx<size>
-XX:ConcGCThreads=<number>
```

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Tuning

That’s it?

```
-Xmx<size>
-XX:ConcGCThreads=<number>
```

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Logging

`-Xlog:gc` (basic)

`-Xlog:gc*` (detailed)

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```
Garbage Collection (Proactive) 13426M(10%)->2492M(2%)
Garbage Collection (Allocation Rate) 87676M(67%)->19578M(15%)
Garbage Collection (Allocation Rate) 55302M(42%)->17646M(13%)
Garbage Collection (Allocation Rate) 61794M(47%)->26794M(20%)
Garbage Collection (Allocation Rate) 60856M(46%)->31926M(24%)
Garbage Collection (Allocation Rate) 52744M(40%)->38050M(29%)
Garbage Collection (Allocation Rate) 42542M(32%)->32204M(25%)
Garbage Collection (Allocation Rate) 49974M(38%)->8534M(7%)
Garbage Collection (System.gc()) 8534M(7%)->282M(0%)
Garbage Collection (Allocation Rate) 95454M(73%)->25660M(20%)
Garbage Collection (Allocation Rate) 42478M(32%)->23812M(18%)
Garbage Collection (Allocation Rate) 56714M(43%)->29090M(22%)
Garbage Collection (Allocation Rate) 62802M(48%)->28648M(22%)
Garbage Collection (Allocation Rate) 59748M(46%)->23770M(18%)
Garbage Collection (Allocation Rate) 74946M(57%)->23284M(18%)
Garbage Collection (System.gc()) 44902M(34%)->422M(0%)
Garbage Collection (Allocation Rate) 94510M(72%)->20456M(16%)
Garbage Collection (Allocation Rate) 59694M(46%)->25834M(20%)
Garbage Collection (Allocation Rate) 63494M(48%)->29128M(22%)
Garbage Collection (Allocation Rate) 59034M(45%)->27094M(21%)
Garbage Collection (Allocation Rate) 66110M(50%)->25278M(19%)
Garbage Collection (Allocation Rate) 73410M(56%)->27968M(21%)
Garbage Collection (Allocation Rate) 70010M(53%)->32236M(25%)
Garbage Collection (Allocation Rate) 64444M(49%)->27612M(21%)
Garbage Collection (Allocation Rate) 64484M(49%)->29910M(23%)
Garbage Collection (Allocation Rate) 64128M(49%)->33184M(25%)
Garbage Collection (Allocation Rate) 59148M(45%)->27800M(21%)
Garbage Collection (Allocation Rate) 63104M(48%)->27976M(21%)
Garbage Collection (Allocation Rate) 64418M(49%)->34390M(26%)
Garbage Collection (Allocation Rate) 52284M(40%)->30654M(23%)
Garbage Collection (Allocation Rate) 58746M(45%)->32028M(24%)
Garbage Collection (Allocation Rate) 59468M(45%)->32804M(25%)
Garbage Collection (Allocation Rate) 53342M(41%)->18436M(14%)
```

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```

Garbage Collection (Allocation Rate) 95454M(73%)->25660M(20%)

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```
Garbage Collection (Allocation Rate)
Pause Mark Start 0.949ms
Concurrent Mark 1151.425ms
Pause Mark End 0.882ms
Concurrent Process Non-Strong References 0.367ms
Concurrent Reset Relocation Set 18.090ms
Concurrent Destroy Detached Pages 0.002ms
Concurrent Select Relocation Set 12.295ms
Concurrent Prepare Relocation Set 70.922ms
Pause Relocate Start 1.419ms
Concurrent Relocate 645.941ms
Load: 15.77/10.68/9.93
MMU: 2ms/0.0%, 5ms/57.5%, 10ms/78.7%, 20ms/87.8%, 50ms/93.7%, 100ms/96.8%
Mark: 4 stripe(s), 2 proactive flush(es), 1 terminate flush(es), 0 completion(s), 0 continuation(s)
Relocation: Successful, 867M relocated
NMethods: 3209 registered, 1559 unregistered
Soft: 466881 encountered, 0 discovered, 0 enqueued
Weak: 5421 encountered, 3526 discovered, 1742 enqueued
Final: 55 encountered, 6 discovered, 0 enqueued
Phantom: 74 encountered, 59 discovered, 0 enqueued
               Mark Start          Mark End        Relocate Start      Relocate End           High                Low
 Capacity:   131072M (100%)     131072M (100%)     131072M (100%)     131072M (100%)     131072M (100%)     131072M (100%)
  Reserve:       72M (0%)           72M (0%)           72M (0%)           72M (0%)           72M (0%)           72M (0%)
     Free:     7654M (6%)         5898M (4%)         24018M (18%)      126296M (96%)      126306M (96%)       5866M (4%)
     Used:   123346M (94%)      125102M (95%)      106982M (82%)        4704M (4%)       125134M (95%)       4694M (4%)
     Live:          -             1722M (1%)         1722M (1%)         1722M (1%)             -                  -
Allocated:          -             1796M (1%)         1962M (1%)         3766M (3%)             -                  -
  Garbage:          -            121623M (93%)      103353M (79%)        127M (0%)            -                  -
Reclaimed:          -                 -             18270M (14%)      121496M (93%)          -                  -
Garbage Collection (Allocation Rate) 123346M(94%)->4704M(4%)
```

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```
Garbage Collection (Allocation Rate)
Pause Mark Start 0.949ms
Concurrent Mark 1151.425ms
Pause Mark End 0.882ms
Concurrent Process Non-Strong References 0.367ms
Concurrent Reset Relocation Set 18.090ms
Concurrent Destroy Detached Pages 0.002ms
Concurrent Select Relocation Set 12.295ms
Concurrent Prepare Relocation Set 70.922
Pause Relocate Start 1.419ms
Concurrent Relocate 645.941ms
Load: 15.77/10.68/9.93
MMU: 2ms/0.0%, 5ms/57.5%, 10ms/78.7%, 20
Mark: 4 stripe(s), 2 proactive flush(es)
Relocation: Successful, 867M relocated
NMethods: 3209 registered, 1559 unregist
Soft: 466881 encountered, 0 discovered,
Weak: 5421 encountered, 3526 discovered,
Final: 55 encountered, 6 discovered, 0 e
Phantom: 74 encountered, 59 discovered,
                Mark Start          Mark                                                    ow
 Capacity:   131072M (100%)     131072M                                                    (100%)
  Reserve:       72M (0%)           72M                                                    (0%)
     Free:     7654M (6%)         5898M                                                    (4%)
     Used:   123346M (94%)      125102M (95%)      106982M (82%)        4704M (4%)       125134M (95%)        4694M (4%)
     Live:         -              1722M (1%)         1722M (1%)         1722M (1%)             -                  -
Allocated:         -              1796M (1%)         1962M (1%)         3766M (3%)             -                  -
  Garbage:         -            121623M (93%)      103353M (79%)         127M (0%)             -                  -
Reclaimed:         -                 -              18270M (14%)      121496M (93%)            -                  -
Garbage Collection (Allocation Rate) 123346M(94%)->4704M(4%)
```


```
Pause Mark Start 0.949ms
Concurrent Mark 1151.425ms
Pause Mark End 0.882ms
Concurrent Process Non-Strong References 0.367ms
Concurrent Reset Relocation Set 18.090ms
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Pause Relocate Start 1.419ms
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```
Garbage Collection (Allocation Rate)
Pause Mark Start 0.949ms
Concurrent Mark 1151.425ms
Pause Mark End
Concurrent Proc
Concurrent Rese
Concurrent Dest
Concurrent Sele
Concurrent Prep
Pause Relocate
Concurrent Relo
Load: 15.77/10.
MMU: 2ms/0.0%,
Mark: 4 stripe(
Relocation: Suc
NMethods: 3209 registered, 1555 unregistered
Soft: 466881 encountered, 0 discovered, 0 enqueued
Weak: 5421 encountered, 3526 discovered, 1742 enqueued
Final: 55 encountered, 6 discovered, 0 enqueued
Phantom: 74 encountered, 59 discovered, 0 enqueued
```

	Mark Start	Mark End	Relocate Start	Relocate End	High	Low
Capacity:	131072M (100%)	131072M (100%)	131072M (100%)	131072M (100%)	131072M (100%)	131072M (100%)
Reserve:	72M (0%)	72M (0%)	72M (0%)	72M (0%)	72M (0%)	72M (0%)
Free:	7654M (6%)	5898M (4%)	24018M (18%)	126296M (96%)	126306M (96%)	5866M (4%)
Used:	123346M (94%)	125102M (95%)	106982M (82%)	4704M (4%)	125134M (95%)	4694M (4%)
Live:	-	1722M (1%)	1722M (1%)	1722M (1%)	-	-
Allocated:	-	1796M (1%)	1962M (1%)	3766M (3%)	-	-
Garbage:	-	121623M (93%)	103353M (79%)	127M (0%)	-	-
Reclaimed:	-	-	18270M (14%)	121496M (93%)	-	-

```
Garbage Collection (Allocation Rate) 123346M(94%)->4704M(4%)
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Garbage Collection (Allocation Rate)
Pause Mark Start 0.949ms
Concurrent Mark 1151.425ms
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Concurrent Proc
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Pause Relocate
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Load: 15.77/10.
MMU: 2ms/0.0%,
Mark: 4 stripe(
Relocation: Suc
NMethods: 3209 registered, 1599 unregistered
Soft: 466881 encountered, 0 discovered, 0 enqueued
Weak: 5421 encountered, 3526 discovered, 1742 enqueued
Final: 55 encountered, 6 discovered, 0 enqueued
Phantom: 74 encountered, 59 discovered, 0 enqueued
```

	Mark Start	Mark End	Relocate Start	Relocate End
Capacity:	131072M (100%)	131072M (100%)	131072M (100%)	131072M (100%)
Reserve:	72M (0%)	72M (0%)	72M (0%)	72M (0%)
Free:	7654M (6%)	5898M (4%)	24018M (18%)	126296M (96%)
Used:	123346M (94%)	125102M (95%)	106982M (82%)	4704M (4%)
Live:	-	1722M (1%)	1722M (1%)	1722M (1%)
Allocated:	-	1796M (1%)	1962M (1%)	3766M (3%)
Garbage:	-	121623M (93%)	103353M (79%)	127M (0%)
Reclaimed:	-	-	18270M (14%)	121496M (93%)

	Mark Start	Mark End	Relocate Start	Relocate End	High	Low
Capacity:	131072M (100%)	131072M (100%)	131072M (100%)	131072M (100%)	131072M (100%)	131072M (100%)
Reserve:	72M (0%)	72M (0%)	72M (0%)	72M (0%)	72M (0%)	72M (0%)
Free:	7654M (6%)	5898M (4%)	24018M (18%)	126296M (96%)	126306M (96%)	5866M (4%)
Used:	123346M (94%)	125102M (95%)	106982M (82%)	4704M (4%)	125134M (95%)	4694M (4%)
Live:	-	1722M (1%)	1722M (1%)	1722M (1%)	-	-
Allocated:	-	1796M (1%)	1962M (1%)	3766M (3%)	-	-
Garbage:	-	121623M (93%)	103353M (79%)	127M (0%)	-	-
Reclaimed:	-	-	18270M (14%)	121496M (93%)	-	-

```
Garbage Collection (Allocation Rate) 123346M(94%)->4704M(4%)
```

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```
Garbage Collection (Allocation Rate)
Pause Mark Start 0.949ms
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Concurrent Destroy Detached Pages 0.002ms
Concurrent Select Relocation Set 12.295ms
Concurrent Prepare Relocation Set 70.922ms
Pause Relocate Start 1.419ms
Concurrent Relocate 645.941ms
Load: 15.77/10.68/9.93
MMU: 2ms/0.0%, 5ms/57.5%, 10ms/78.7%, 20ms/87.8%, 50ms/93.7%, 100ms/96.8%
Mark: 4 stripe(s), 2 proactive flush(es), 1 terminate flush(es), 0 completion(s), 0 continuation(s)
Relocation: Successful, 867M relocated
NMethods: 3209 registered, 1559 unregistered
Soft: 466881 encountered, 0 discovered, 0 enqueued
Weak: 5421 encountered, 3526 discovered, 1742 enqueued
Final: 55 encountered, 6 discovered, 0 enqueued
Phantom: 74 encountered, 59 discovered, 0 enqueued
               Mark Start          Mark End        Relocate Start      Relocate End           High            Low
 Capacity:   131072M (100%)     131072M (100%)     131072M (100%)     131072M (100%)     131072M (100%)     131072M (100%)
  Reserve:       72M (0%)           72M (0%)           72M (0%)           72M (0%)           72M (0%)           72M (0%)
     Free:     7654M (6%)         5898M (4%)         24018M (18%)      126296M (96%)      126306M (96%)       5866M (4%)
     Used:   123346M (94%)      125102M (95%)      106982M (82%)        4704M (4%)       125134M (95%)       4694M (4%)
     Live:          -             1722M (1%)         1722M (1%)         1722M (1%)             -                  -
Allocated:          -             1796M (1%)         1962M (1%)         3766M (3%)             -                  -
  Garbage:          -            121623M (93%)      103353M (79%)        127M (0%)            -                  -
Reclaimed:          -                 -              18270M (14%)      121496M (93%)          -                  -
Garbage Collection (Allocation Rate) 123346M(94%)->4704M(4%)
```

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GC Statistics

```
=== Garbage Collection Statistics =======================================================================================================================
                                                              Last 10s              Last 10m              Last 10h                Total
                                                              Avg / Max             Avg / Max             Avg / Max               Avg / Max
   Collector: Garbage Collection Cycle                1906.804 / 1906.804   1871.019 / 2184.368   2764.747 / 4655.377   2764.747 / 4655.377    ms
  Contention: Mark Segment Reset Contention               3 / 24                0 / 34                0 / 73                0 / 73            ops/s
  Contention: Mark SeqNum Reset Contention                0 / 0                 0 / 0                 0 / 2                 0 / 2             ops/s
  Contention: Relocation Contention                      27 / 275               9 / 1137             14 / 9460             14 / 9460          ops/s
    Critical: Allocation Stall                      0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000        ms
    Critical: Allocation Stall                      0 / 0                 0 / 0                 0 / 0                 0 / 0              ops/s
    Critical: GC Locker Stall                       0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000        ms
    Critical: GC Locker Stall                       0 / 0                 0 / 0                 0 / 0                 0 / 0              ops/s
      Memory: Allocation Rate                      1458 / 1672            1089 / 1904           1679 / 7914           1679 / 7914         MB/s
      Memory: Heap Used After Mark               125102 / 125102        97411 / 125102        70566 / 125102        70566 / 125102       MB
      Memory: Heap Used After Relocation           4704 / 4704            4019 / 4814           17042 / 34092         17042 / 34092        MB
      Memory: Heap Used Before Mark              123346 / 123346        95981 / 123346        61669 / 123346        61669 / 123346       MB
      Memory: Heap Used Before Relocation        106982 / 106982        85095 / 106982        60136 / 106982        60136 / 106982       MB
      Memory: Out Of Memory                        0 / 0                 0 / 0                 0 / 0                 0 / 0              ops/s
      Memory: Page Cache Flush                     0 / 0                 0 / 0                 0 / 0                 0 / 0              MB/s
      Memory: Page Cache Hit L1                  710 / 1037              499 / 1037            771 / 3777            771 / 3777          ops/s
      Memory: Page Cache Hit L2                   12 / 77                3 / 179               5 / 517               5 / 517             ops/s
      Memory: Page Cache Miss                      8 / 81                19 / 651              29 / 1932             29 / 1932           ops/s
      Memory: Undo Object Allocation Failed        1 / 12                0 / 18                0 / 64                0 / 64              ops/s
      Memory: Undo Object Allocation Succeeded    26 / 263               9 / 1137              13 / 9460             13 / 9460           ops/s
      Memory: Undo Page Allocation                 3 / 30                5 / 249               9 / 1027              9 / 1027            ops/s
       Phase: Concurrent Destroy Detached Pages    0.002 / 0.002         0.001 / 0.002         0.041 / 2.230         0.041 / 2.230        ms
       Phase: Concurrent Mark                   1151.425 / 1151.425   1163.417 / 1452.750   1584.987 / 3028.289   1584.987 / 3028.289    ms
       Phase: Concurrent Mark Continue             0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000        ms
       Phase: Concurrent Prepare Relocation Set   70.922 / 70.922       67.627 / 74.532       81.298 / 374.926      81.298 / 374.926     ms
       Phase: Concurrent Process Non-Strong References  0.367 / 0.367    0.391 / 0.463         0.394 / 0.774         0.394 / 0.774        ms
       Phase: Concurrent Relocate               645.941 / 645.941     602.340 / 645.941     1051.985 / 2198.100   1051.985 / 2198.100    ms
       Phase: Concurrent Reset Relocation Set     18.090 / 18.090       13.636 / 18.090       11.832 / 28.342       11.832 / 28.342      ms
       Phase: Concurrent Select Relocation Set    12.295 / 12.295       15.162 / 28.735       20.960 / 57.464       20.960 / 57.464      ms
       Phase: Pause Mark End                       0.882 / 0.882         0.997 / 1.095         0.941 / 1.199         0.941 / 1.199        ms
       Phase: Pause Mark Start                     0.949 / 0.949         0.875 / 0.983         0.832 / 1.013         0.832 / 1.013        ms
       Phase: Pause Relocate Start                 1.419 / 1.419         1.532 / 2.091         1.474 / 2.127         1.474 / 2.127        ms
    Subphase: Concurrent Mark                   1151.055 / 1151.287   1162.724 / 1452.499   1059.510 / 3028.035   1059.510 / 3028.035    ms
    Subphase: Concurrent Mark Idle                 1.058 / 1.060         1.088 / 2.320         2.727 / 22.115        2.727 / 22.115       ms
    Subphase: Concurrent Mark Try Flush            0.779 / 1.862         0.603 / 5.825         8.556 / 50.035        8.556 / 50.035       ms
    Subphase: Concurrent Mark Try Terminate        0.849 / 1.062         0.940 / 2.321         2.766 / 45.114        2.766 / 45.114       ms
```

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```
=== Garbage Collection Statistics ==========================================================================================
                                                  Last 10s              Last 10m              Last 10h                Total
                                                  Avg / Max             Avg / Max             Avg / Max             Avg / Max
   Collector: Garbage Collection Cycle        1906.804 / 1906.804   1871.019 / 2184.368   2764.747 / 4655.377   2764.747 / 4655.377    ms
  Contention: Mark Segment Reset Contention          3 / 24                0 / 34                0 / 73                0 / 73          ops/s
  Contention: Mark SeqNum Reset Contention           0 / 0                 0 / 0                 0 / 2                 0 / 2           ops/s
  Contention: Relocation Contention                 27 / 275               9 / 1137             14 / 9460             14 / 9460        ops/s
    Critical: Allocation Stall                  0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000       ms
    Critical: Allocation Stall                       0 / 0                 0 / 0                 0 / 0                 0 / 0           ops/s
    Critical: GC Locker Stall                   0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000       ms
    Critical: GC Locker Stall                        0 / 0                 0 / 0                 0 / 0                 0 / 0           ops/s
      Memory: Allocation Rate                    1458 / 1672           1089 / 1904           1679 / 7914           1679 / 7914        MB/s
      Memory: Heap Used After Mark             125102 / 125102        97411 / 125102        70566 / 125102        70566 / 125102      MB
      Memory: Heap Used After Relocation         4704 / 4704           4019 / 4814          17042 / 34092         17042 / 34092       MB
      Memory: Heap Used Before Mark            123346 / 123346        95981 / 123346        61669 / 123346        61669 / 123346      MB
      Memory: Heap Used Before Relocation      106982 / 106982        85095 / 106982        60136 / 106982        60136 / 106982      MB
      Memory: Out Of Memory                          0 / 0                 0 / 0                 0 / 0                 0 / 0           ops/s
      Memory: Page Cache Flush                       0 / 0                 0 / 0                 0 / 0                 0 / 0           MB/s
      Memory: Page Cache Hit L1                    710 / 1037            499 / 1037            771 / 3777            771 / 3777        ops/s
      Memory: Page Cache Hit L2                     12 / 77                3 / 179               5 / 517               5 / 517         ops/s
      Memory: Page Cache Miss                        8 / 81               19 / 651              29 / 1932             29 / 1932        ops/s
      Memory: Undo Object Allocation Failed          1 / 12                0 / 18                0 / 64                0 / 64          ops/s
      Memory: Undo Object Allocation Succeeded      26 / 263               9 / 1137             13 / 9460             13 / 9460        ops/s
      Memory: Undo Page Allocation                   3 / 30                5 / 249               9 / 1027              9 / 1027        ops/s
       Phase: Concurrent Destroy Detached Pages  0.002 / 0.002         0.001 / 0.002         0.041 / 2.230         0.041 / 2.230       ms
       Phase: Concurrent Mark                 1151.425 / 1151.425   1163.417 / 1452.750   1584.987 / 3028.289   1584.987 / 3028.289    ms
       Phase: Concurrent Mark Continue            0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000       ms
       Phase: Concurrent Prepare Relocation Set  70.922 / 70.922        67.627 / 74.532       81.298 / 374.926      81.298 / 374.926     ms
       Phase: Concurrent Process Non-Strong References 0.367 / 0.367    0.391 / 0.463         0.394 / 0.774         0.394 / 0.774       ms
       Phase: Concurrent Relocate             645.941 / 645.941     602.340 / 645.941    1051.985 / 2198.100   1051.985 / 2198.100    ms
       Phase: Concurrent Reset Relocation Set   18.090 / 18.090       13.636 / 18.090       11.832 / 28.342       11.832 / 28.342      ms
       Phase: Concurrent Select Relocation Set  12.295 / 12.295       15.162 / 28.735       20.960 / 57.464       20.960 / 57.464      ms
       Phase: Pause Mark End                      0.882 / 0.882         0.997 / 1.095         0.941 / 1.199         0.941 / 1.199       ms
       Phase: Pause Mark Start                    0.949 / 0.949         0.875 / 0.983         0.832 / 1.013         0.832 / 1.013       ms
       Phase: Pause Relocate Start                1.419 / 1.419         1.532 / 2.091         1.474 / 2.127         1.474 / 2.127       ms
       ...
```

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```
=== Garbage Collection Statistics =======================================================================================================================
                                                              Last 10s              Last 10m              Last 10h                Total
                                                              Avg / Max             Avg / Max             Avg / Max               Avg / Max
   Collector: Garbage Collection Cycle                  1906.804 / 1906.804   1871.019 / 2184.368   2764.747 / 4655.377   2764.747 / 4655.377   ms
  Contention: Mark Segment Reset Contention                    3 / 24                0 / 34                0 / 73                0 / 73        ops/s
  Contention: Mark SeqNum Reset Contention                     0 / 0                 0 / 0                 0 / 2                 0 / 2         ops/s
  Contention: Relocation Contention                           27 / 275               9 / 1137             14 / 9460             14 / 9460       ops/s
    Critical: Allocation Stall                         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000   ms
    Critical: Allocation Stall                               0 / 0                 0 / 0                 0 / 0                 0 / 0         ops/s
    Critical: GC Locker Stall                          0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000   ms
    Critical: GC Locker Stall                                0 / 0                 0 / 0                 0 / 0                 0 / 0         ops/s
      Memory: Allocation Rate                            1458 / 1672           1089 / 1904           1679 / 7914           1679 / 7914     MB/s
      Memory: Heap Used After Mark                     125102 / 125102       97411 / 125102        70566 / 125102        70566 / 125102  MB
      Memory: Heap Used After Relocation                 4704 / 4704           4019 / 4814           17042 / 34092         17042 / 34092   MB
      Memory: Heap Used Before Mark                    123346 / 123346       95981 / 123346        61669 / 123346        61669 / 123346  MB
      Memory: Heap Used Before Relocation              106982 / 106982       85095 / 106982        60136 / 106982        60136 / 106982  MB
      Memory: Out Of Memory                                    0 / 0                 0 / 0                 0 / 0                 0 / 0         ops/s
      Memory: Page Cache Flush                                 0 / 0                 0 / 0                 0 / 0                 0 / 0         MB/s
      Memory: Page Cache Hit L1                          710 / 1037            499 / 1037            771 / 3777            771 / 3777      ops/s
      Phase: Concurrent Mark Continue                    0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000   ms
      Phase: Concurrent Prepare Relocation Set           70.922 / 70.922       67.627 / 74.532       81.298 / 374.926      81.298 / 374.926  ms
      Phase: Concurrent Process Non-Strong References    0.367 / 0.367         0.391 / 0.463         0.394 / 0.774         0.394 / 0.774   ms
      Phase: Concurrent Relocate                         645.941 / 645.941     602.340 / 645.941     1051.985 / 2198.100   1051.985 / 2198.100  ms
      Phase: Concurrent Reset Relocation Set             18.090 / 18.090       13.636 / 18.090       11.832 / 28.342       11.832 / 28.342  ms
      Phase: Concurrent Select Relocation Set            12.295 / 12.295       15.162 / 28.735       20.960 / 57.464       20.960 / 57.464  ms
      Phase: Pause Mark End                              0.882 / 0.882         0.997 / 1.095         0.941 / 1.199         0.941 / 1.199   ms
      Phase: Pause Mark Start                            0.949 / 0.949         0.875 / 0.983         0.832 / 1.013         0.832 / 1.013   ms
      Phase: Pause Relocate Start                        1.419 / 1.419         1.532 / 2.091         1.474 / 2.127         1.474 / 2.127   ms
      ...
```

	Last 10s Avg / Max	Last 10m Avg / Max	Last 10h Avg / Max	Total Avg / Max	
Allocation Rate	1458 / 1672	1089 / 1904	1679 / 7914	1679 / 7914	MB/s

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```
=== Garbage Collection Statistics =======================================================================================================================
                                                              Last 10s              Last 10m              Last 10h                Total
                                                              Avg / Max             Avg / Max             Avg / Max               Avg / Max
   Collector: Garbage Collection Cycle                  1906.804 / 1906.804   1871.019 / 2184.368   2764.747 / 4655.377   2764.747 / 4655.377   ms
  Contention: Mark Segment Reset Contention                    3 / 24                0 / 34                0 / 73                0 / 73          ops/s
  Contention: Mark SeqNum Reset Contention                     0 / 0                 0 / 0                 0 / 2                 0 / 2           ops/s
  Contention: Relocation Contention                           27 / 275               9 / 1137              14 / 9460             14 / 9460       ops/s
    Critical: Allocation Stall                         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         ms
    Critical: Allocation Stall                               0 / 0                 0 / 0                 0 / 0                 0 / 0           ops/s
```

	Last 10s Avg / Max	Last 10m Avg / Max	Last 10h Avg / Max	Total Avg / Max	
Pause Mark End	0.882 / 0.882	0.997 / 1.095	0.941 / 1.199	0.941 / 1.199	ms
Pause Mark Start	0.949 / 0.949	0.875 / 0.983	0.832 / 1.013	0.832 / 1.013	ms
Pause Relocate Start	1.419 / 1.419	1.532 / 2.091	1.474 / 2.127	1.474 / 2.127	ms

```
      Memory: Page Cache Miss                                    8 / 81                19 / 651              29 / 1932             29 / 1932       ops/s
      Memory: Undo Object Allocation Failed                      1 / 12                0 / 18                0 / 64                0 / 64          ops/s
      Memory: Undo Object Allocation Succeeded                  26 / 263               9 / 1137              13 / 9460             13 / 9460       ops/s
      Memory: Undo Page Allocation                               3 / 30                5 / 249               9 / 1027              9 / 1027        ops/s
       Phase: Concurrent Destroy Detached Pages          0.002 / 0.002         0.001 / 0.002         0.041 / 2.230         0.041 / 2.230         ms
       Phase: Concurrent Mark                         1151.425 / 1151.425   1163.417 / 1452.750   1584.987 / 3028.289   1584.987 / 3028.289   ms
       Phase: Concurrent Mark Continue                   0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         ms
       Phase: Concurrent Prepare Relocation Set         70.922 / 70.922       67.627 / 74.532       81.298 / 374.926      81.298 / 374.926      ms
       Phase: Concurrent Process Non-Strong References   0.367 / 0.367         0.391 / 0.463         0.394 / 0.774         0.394 / 0.774         ms
       Phase: Concurrent Relocate                     645.941 / 645.941     602.340 / 645.941     1051.985 / 2198.100   1051.985 / 2198.100   ms
       Phase: Concurrent Reset Relocation Set          18.090 / 18.090       13.636 / 18.090       11.832 / 28.342       11.832 / 28.342       ms
       Phase: Concurrent Select Relocation Set         12.295 / 12.295       15.162 / 28.735       20.960 / 57.464       20.960 / 57.464       ms
       Phase: Pause Mark End                             0.882 / 0.882         0.997 / 1.095         0.941 / 1.199         0.941 / 1.199         ms
       Phase: Pause Mark Start                           0.949 / 0.949         0.875 / 0.983         0.832 / 1.013         0.832 / 1.013         ms
       Phase: Pause Relocate Start                       1.419 / 1.419         1.532 / 2.091         1.474 / 2.127         1.474 / 2.127         ms
       ...
```

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Future Plans

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Future Plans

- **Short-term**
  - Concurrent class unloading
  - Turn ZGC into a product feature

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Future Plans

- **Short-term**
  - Concurrent class unloading
  - Turn ZGC into a product feature

Available today in the ZGC development repository!

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Future Plans

- **Short-term**
  - Concurrent class unloading
  - Turn ZGC into a product feature

Remove experimental status

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Future Plans

- **Short-term**
  - Concurrent class unloading
  - Turn ZGC into a product feature

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Future Plans

- **Short-term**
  - Concurrent class unloading
  - Turn ZGC into a product feature

- **Long-term**
  - Generational
  - Sub-millisecond max pause times
  - Additional platform support
  - Graal JIT support

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Generational
- Withstand higher allocation rates
- Lower heap overhead
- Lower CPU usage

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Sub-millisecond max pause times
- Within reach
- Reduce root set size
- Time-to-Safepoint, etc

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Additional platform support
- macOS?
- Windows?
- Sparc?
- Aarch64?

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OpenJDK

Get Involved!

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ZGC Project

Follow, Participate, Give Feedback

zgc-dev@openjdk.java.net

http://wiki.openjdk.java.net/display/zgc/Main

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ZGC Project

Source Code

OpenJDK

http://hg.openjdk.java.net/jdk/jdk

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

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Thanks!

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Questions?

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