The Z Garbage Collector

Scalable Low-Latency GC in JDK 11

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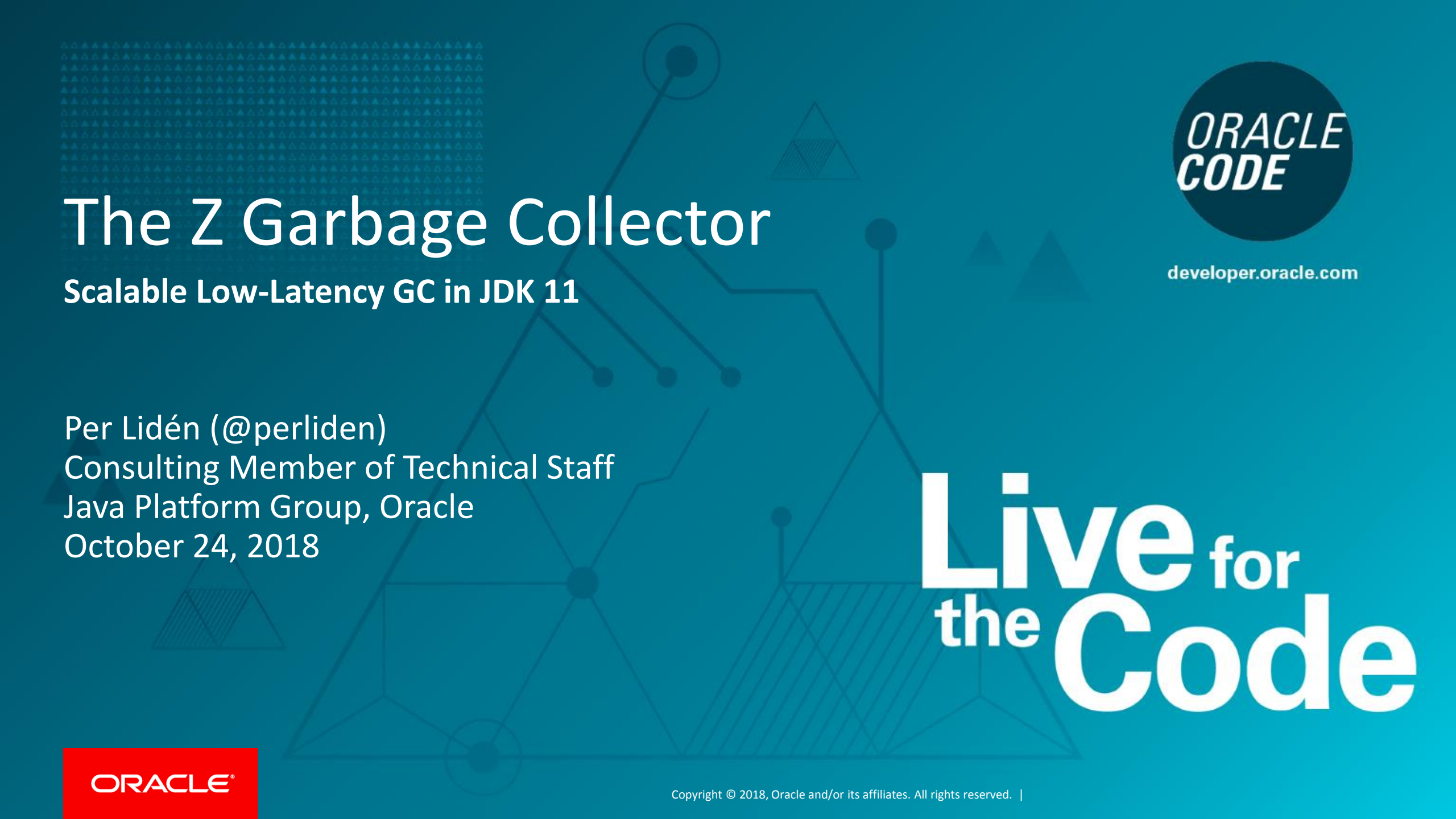
October 24, 2018



Safe Harbor Statement

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Agenda

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

What is ZGC?

New Garbage Collector in **JDK 11**

(Experimental feature, Linux/x86_64 only)

A Scalable Low-Latency Garbage Collector

Goals

TB Multi-terabyte heaps

10ms Max GC pause time

Easy to tune

15% Max application throughput reduction

ZGC at a Glance

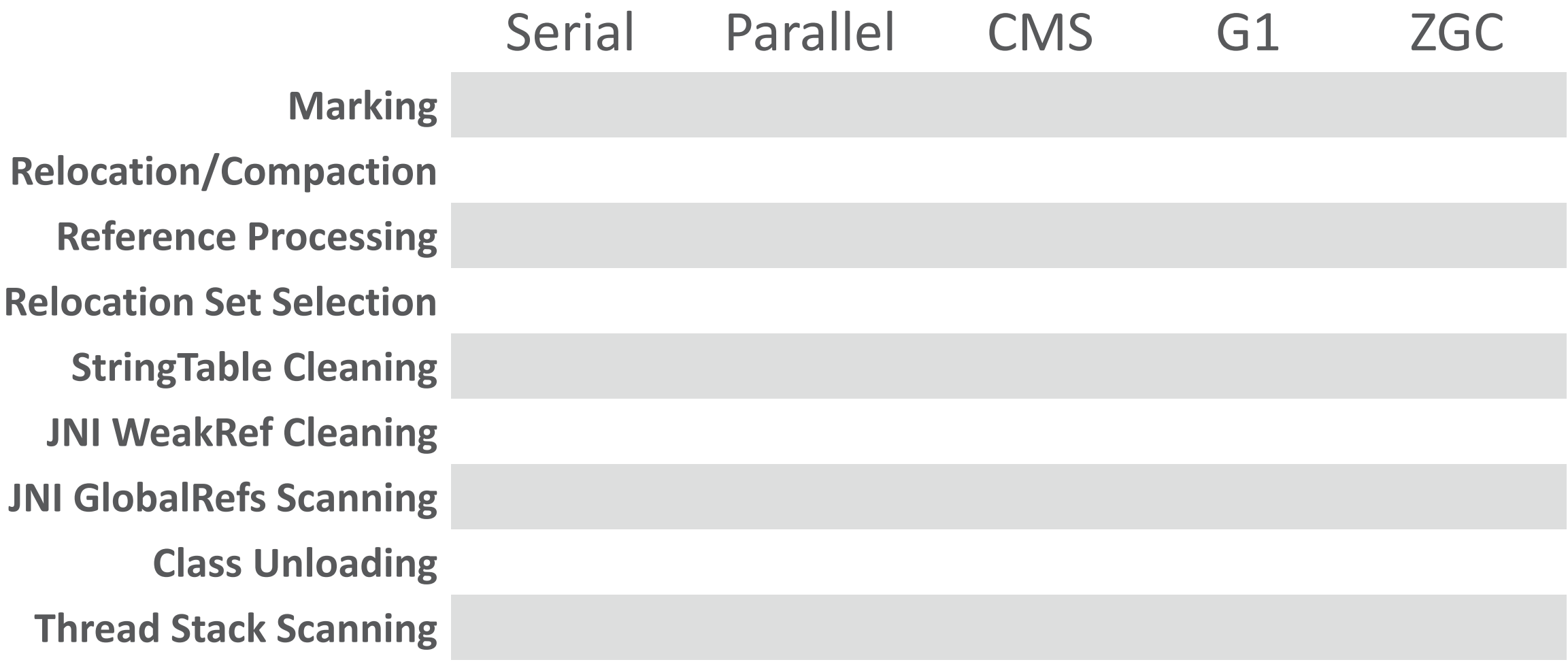
Concurrent	Region-based
Tracing	NUMA-aware
Compacting	Load barriers
Single generation	Colored pointers

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

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

(Number of Java Threads)

Concurrent?



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	-	-			

*) 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	-	-	-	-	

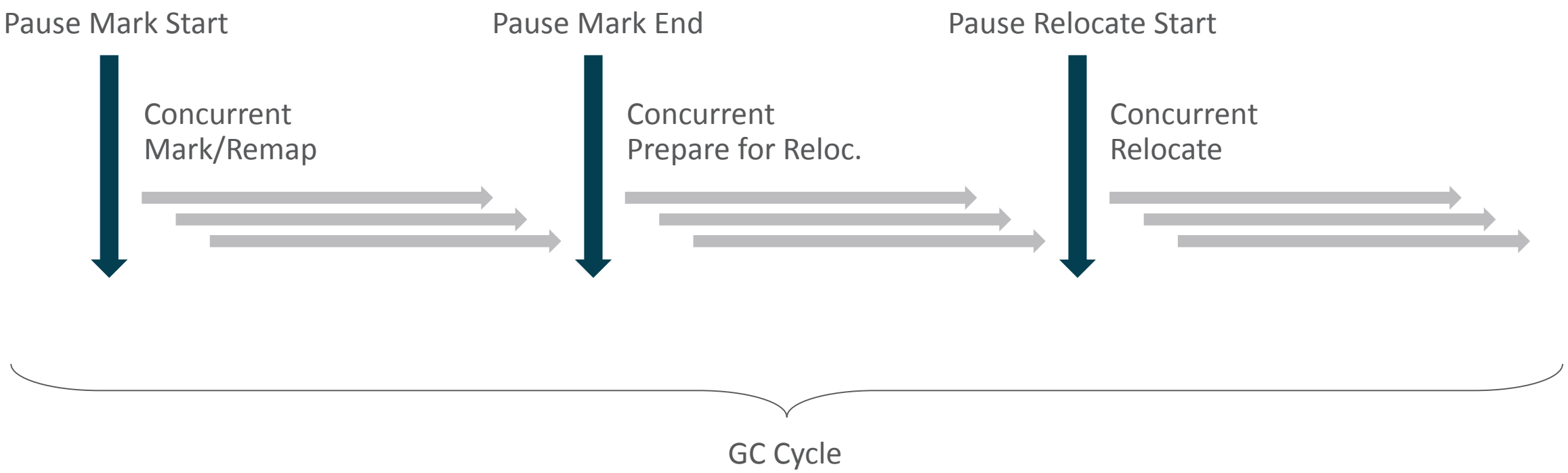
*) Old Gen Only
**) Post JDK 11

Concurrent?

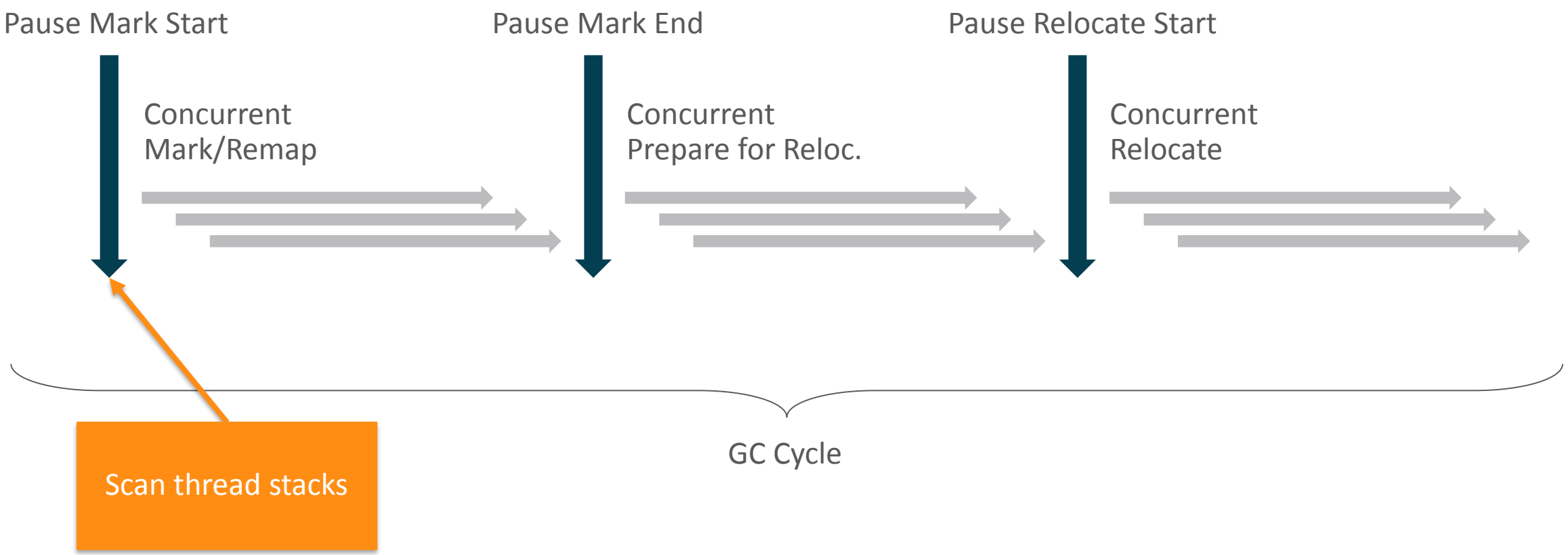
	Serial	Parallel	CMS	G1	ZGC
Marking	-	-	✓*	✓*	✓
Relocation/Compaction	-	-	-	-	✓
Reference Processing	-	-	-	-	✓
Relocation Set Selection	-	-	-	-	✓
StringTable Cleaning	-	-	-	-	✓
JNI WeakRef Cleaning	-	-	-	-	✓
JNI GlobalRefs Scanning	-	-	-	-	✓**
Class Unloading	-	-	-	-	✓**
Thread Stack Scanning	-	-	-	-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

A Peek Under the Hood

ZGC Phases



ZGC Phases



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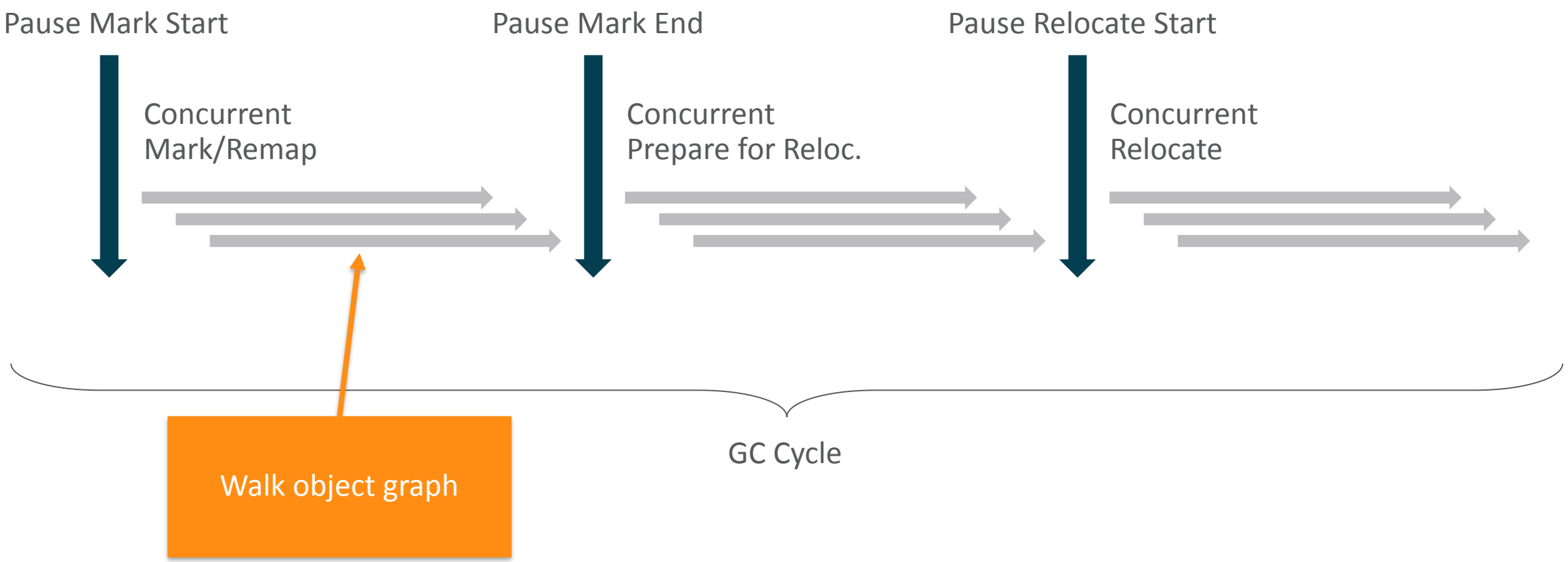

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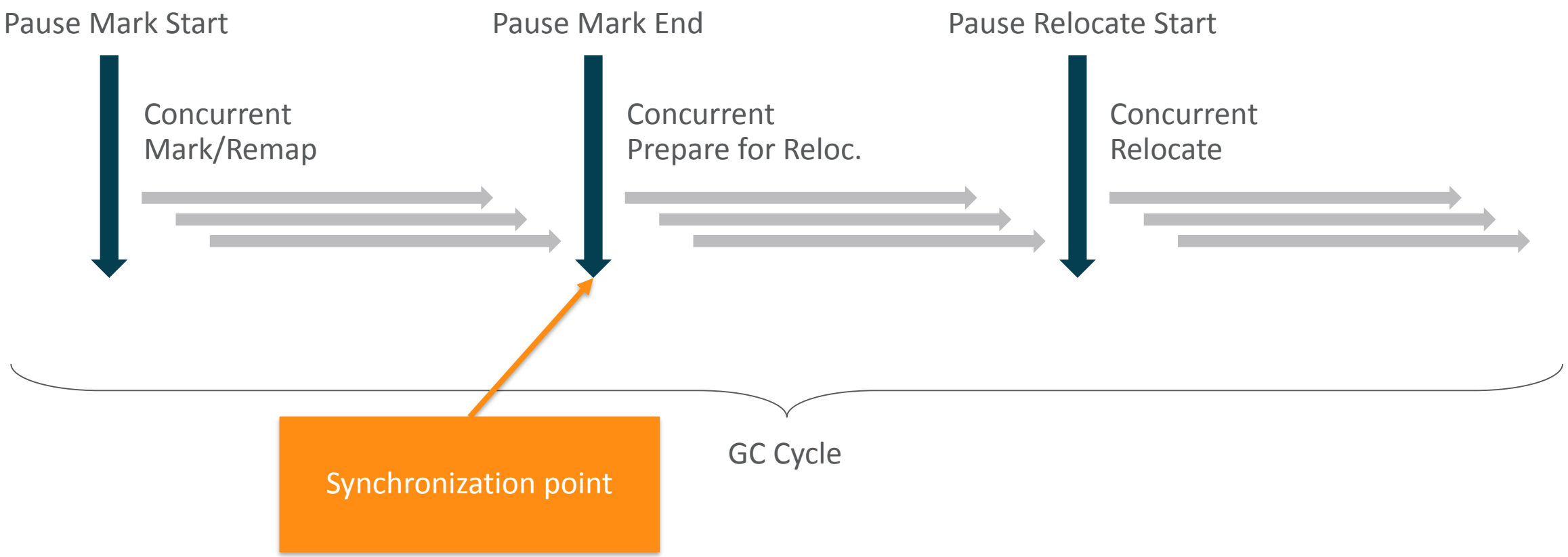

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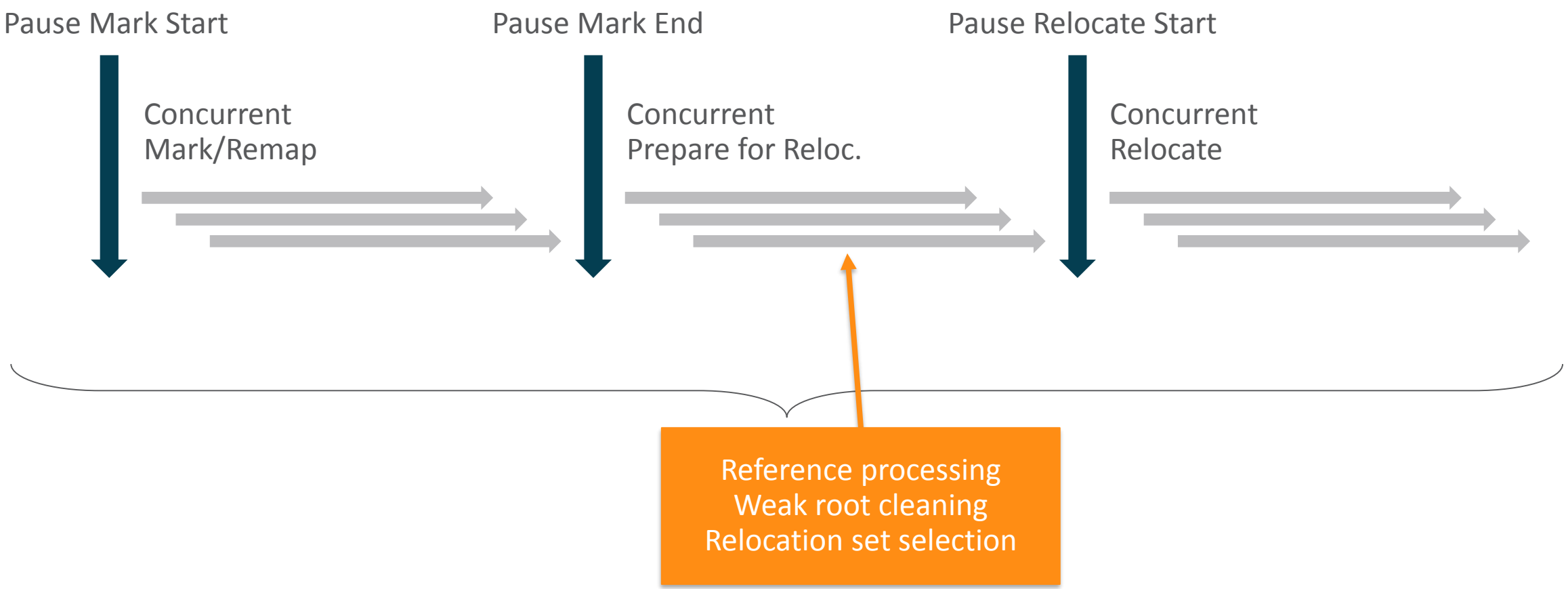
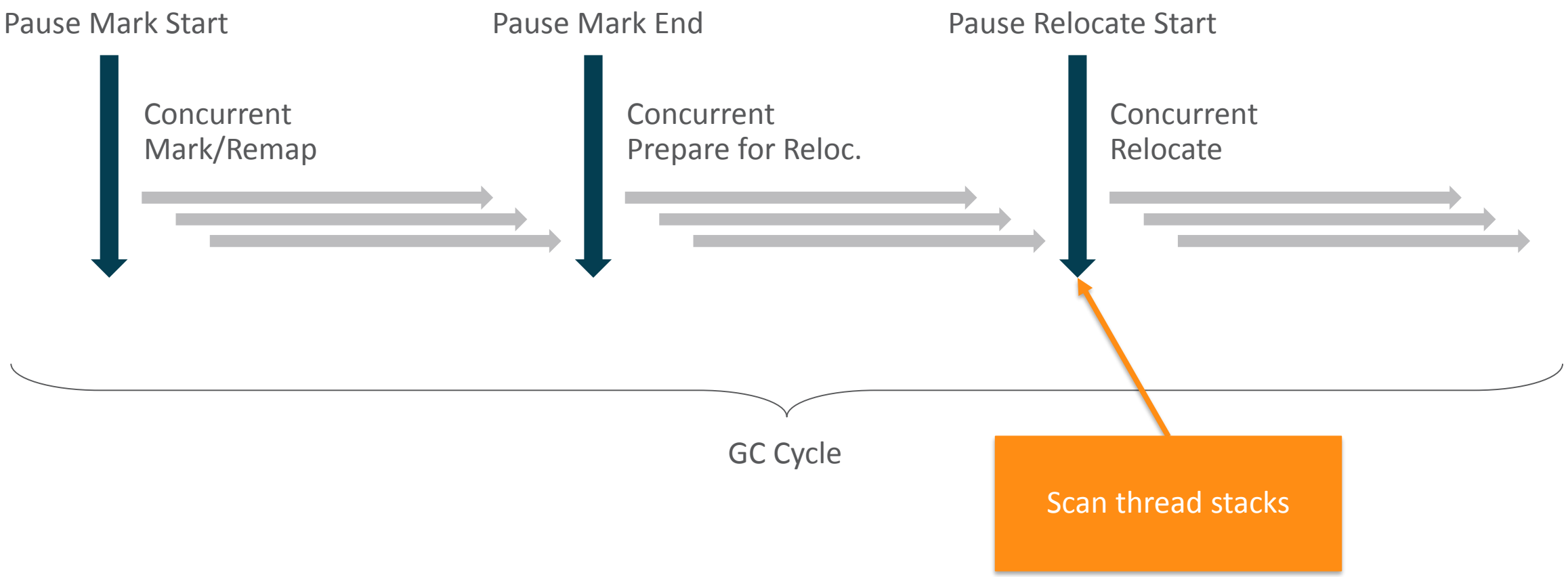


ZGC Phases



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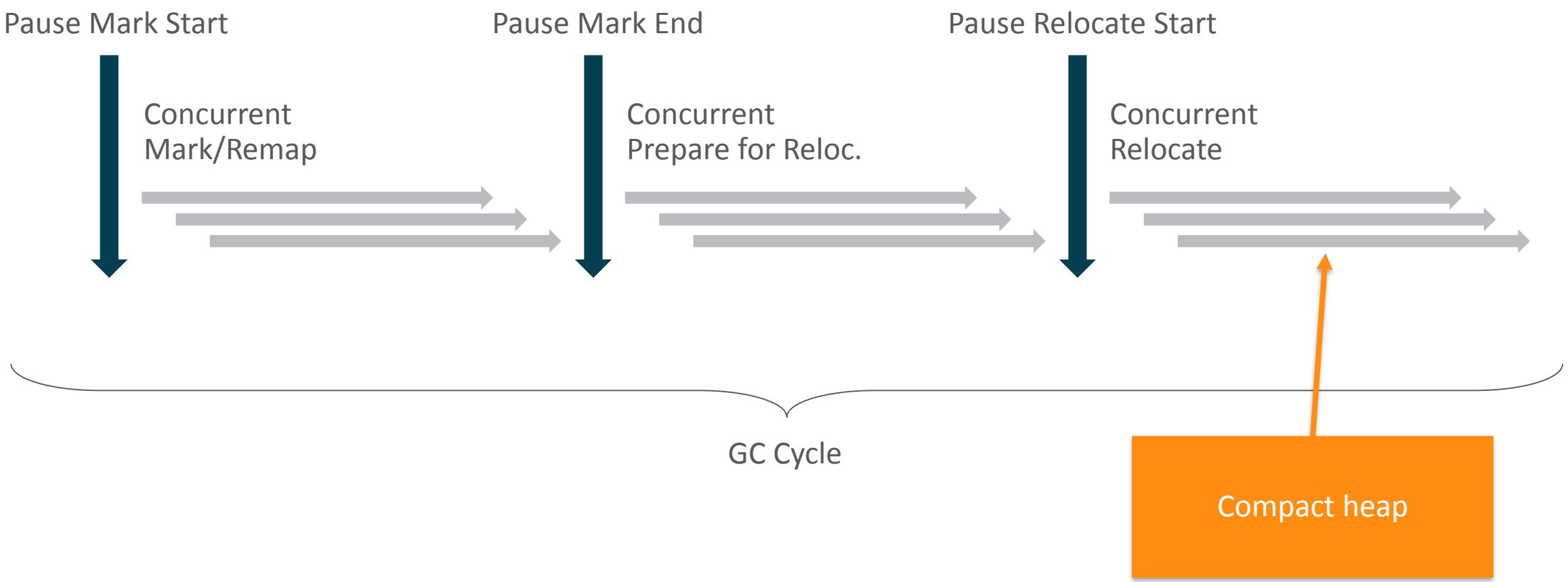

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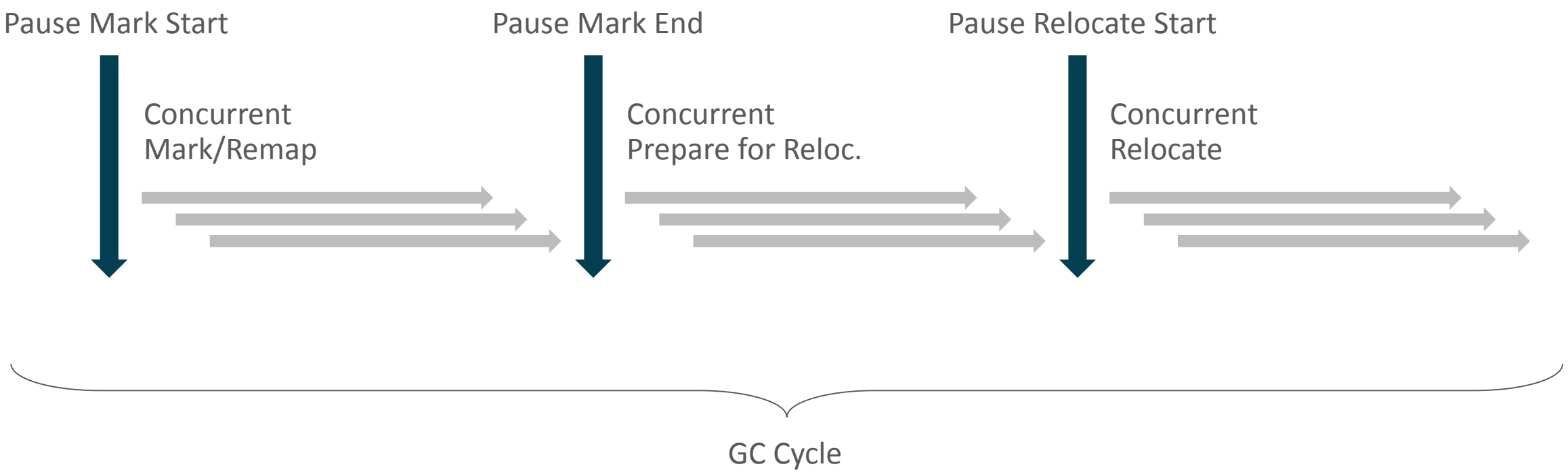
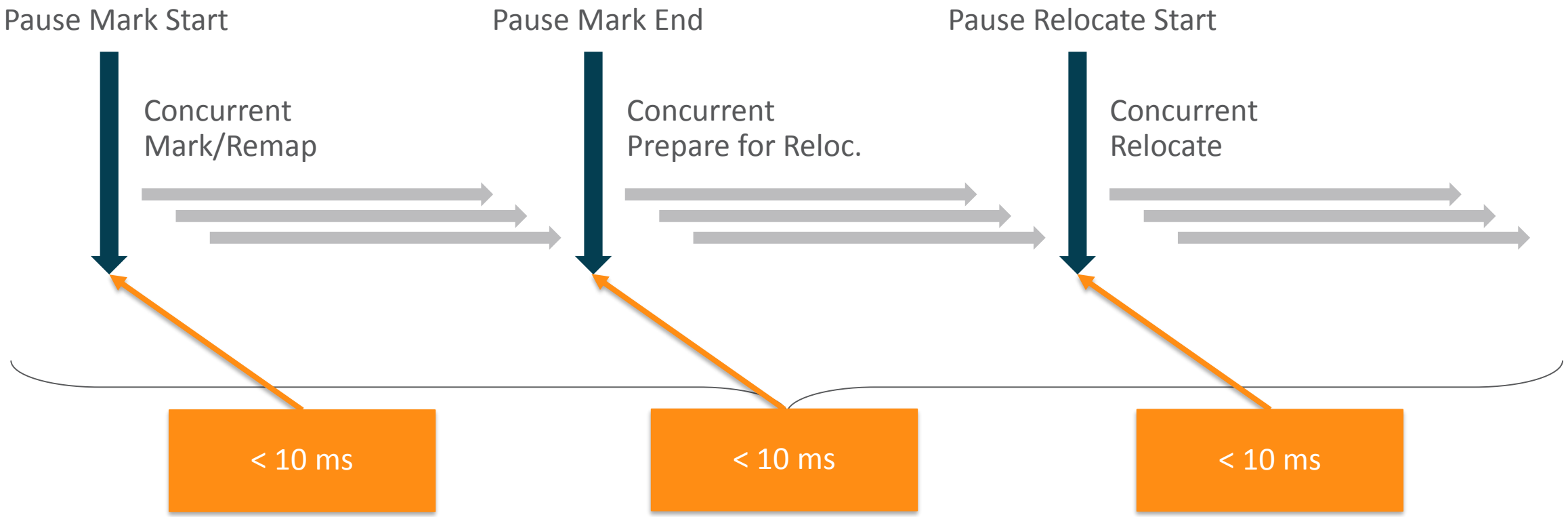
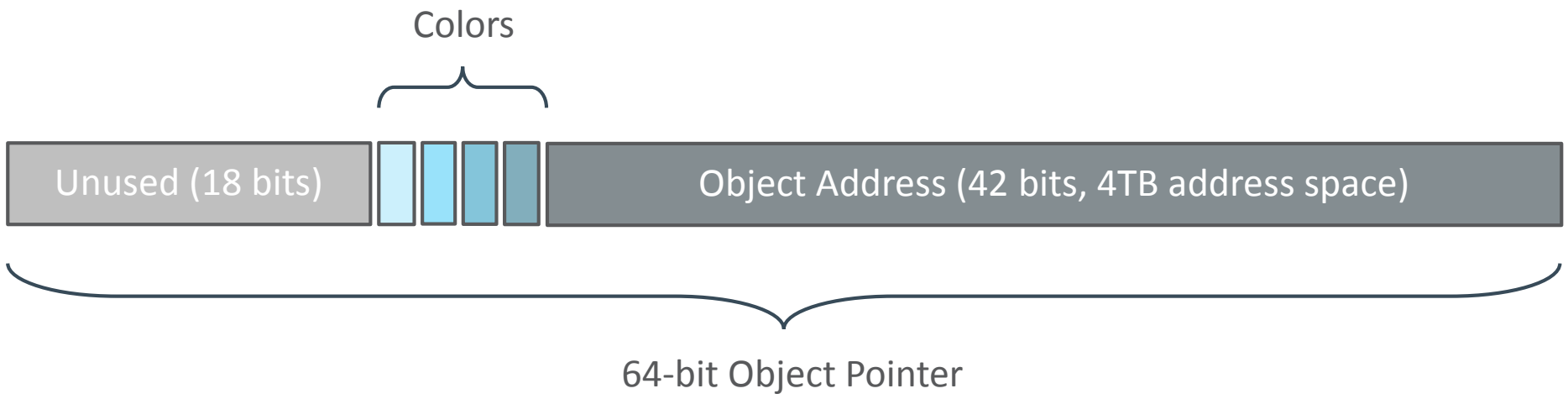


ZGC Phases



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



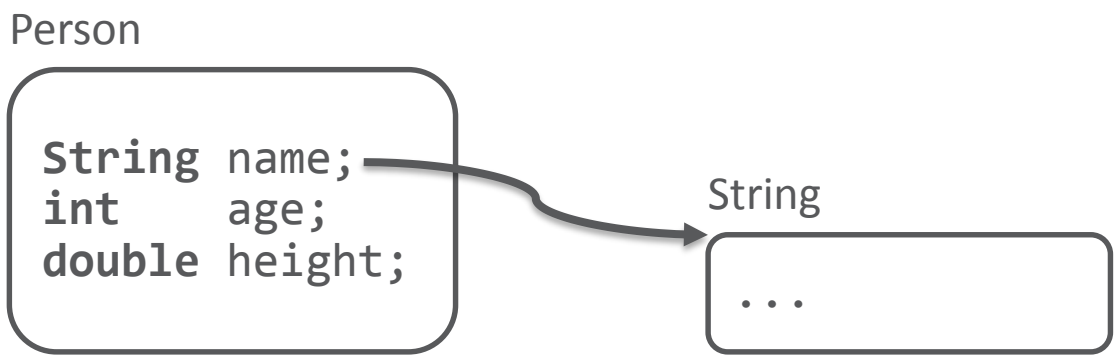
Load Barrier

- 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

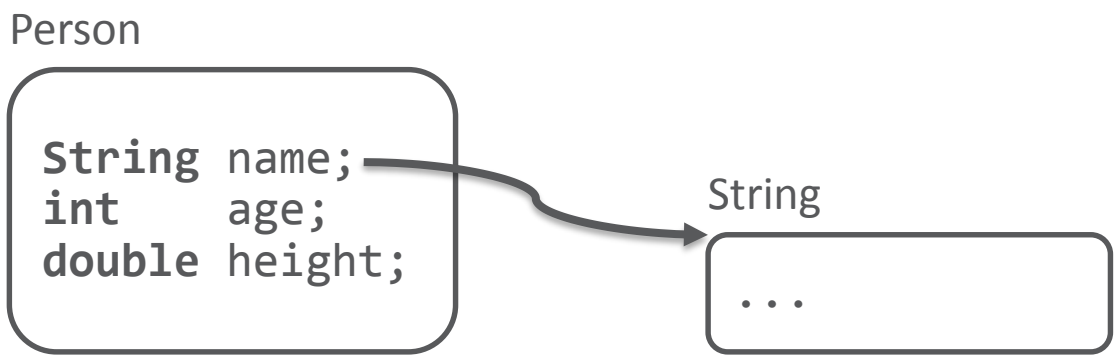
Load Barrier

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



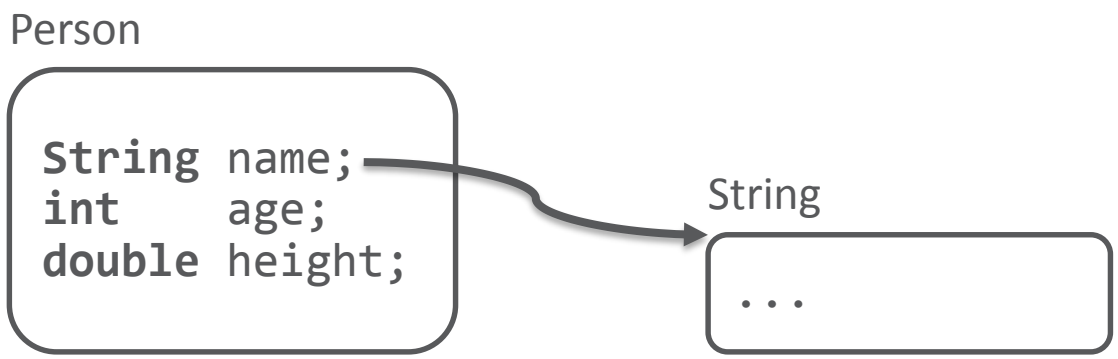
Load Barrier

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



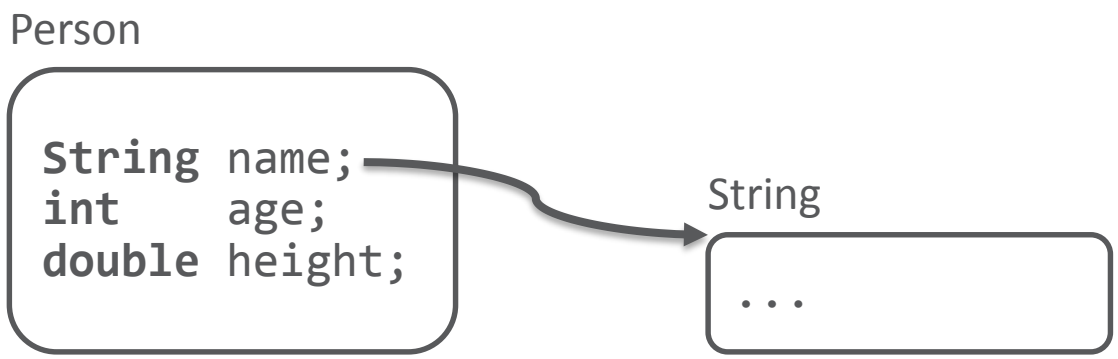
Load Barrier

```
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
```



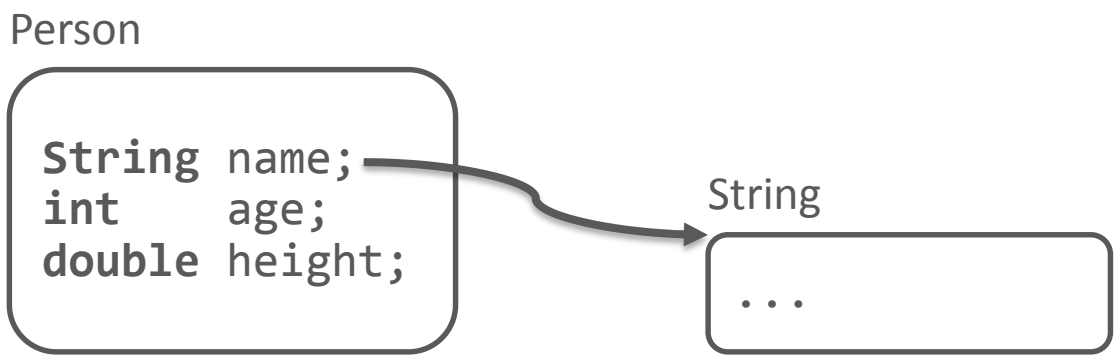
Load Barrier

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



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));
}
```



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
```

Load Barrier

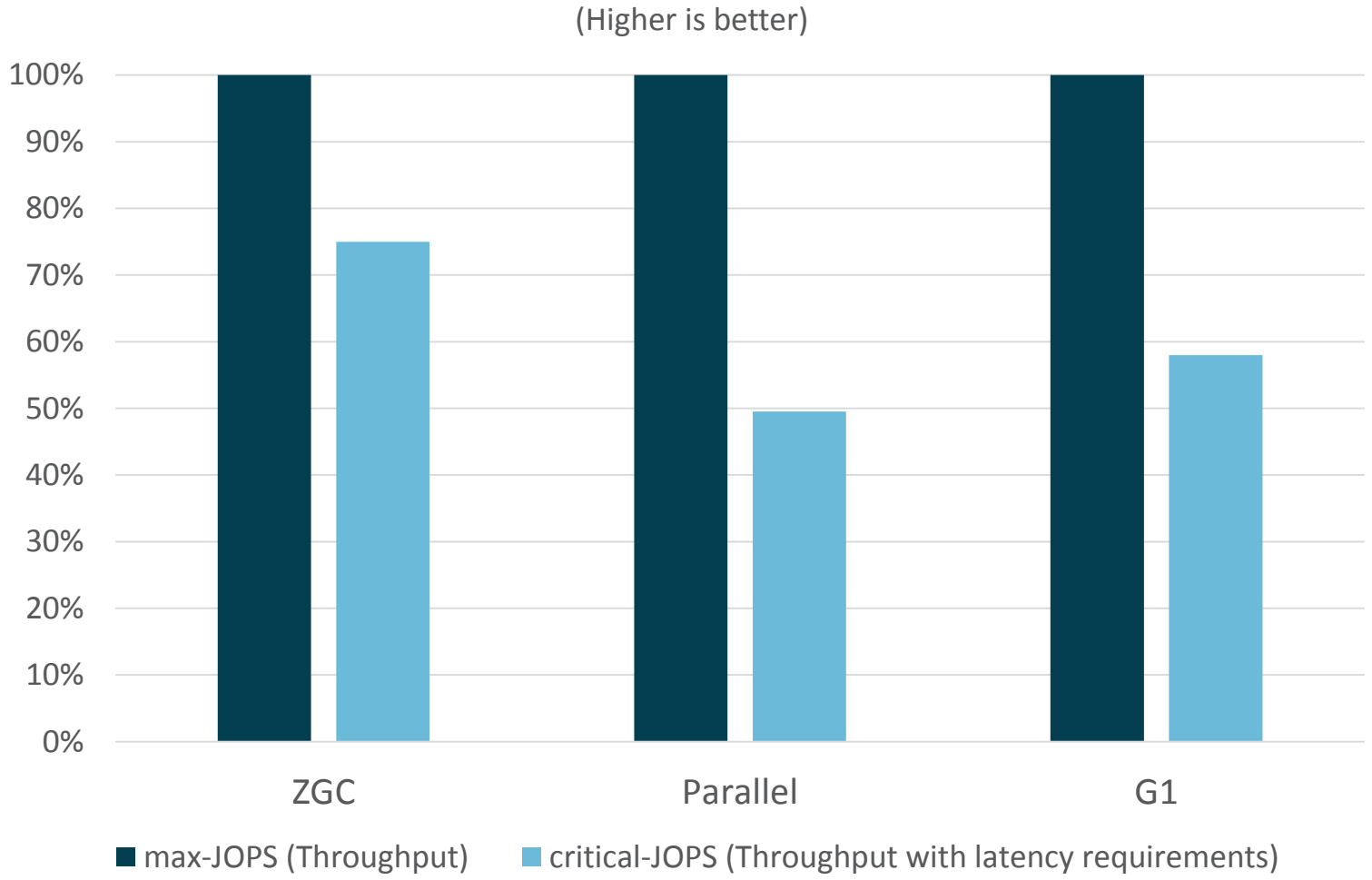
```
mov     0x10(%rax), %rbx
test    %rbx, (0x16)%r15
jnz     slow_path
```

```
// 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**

Performance

SPECjbb®2015 – Score



Mode: Composite

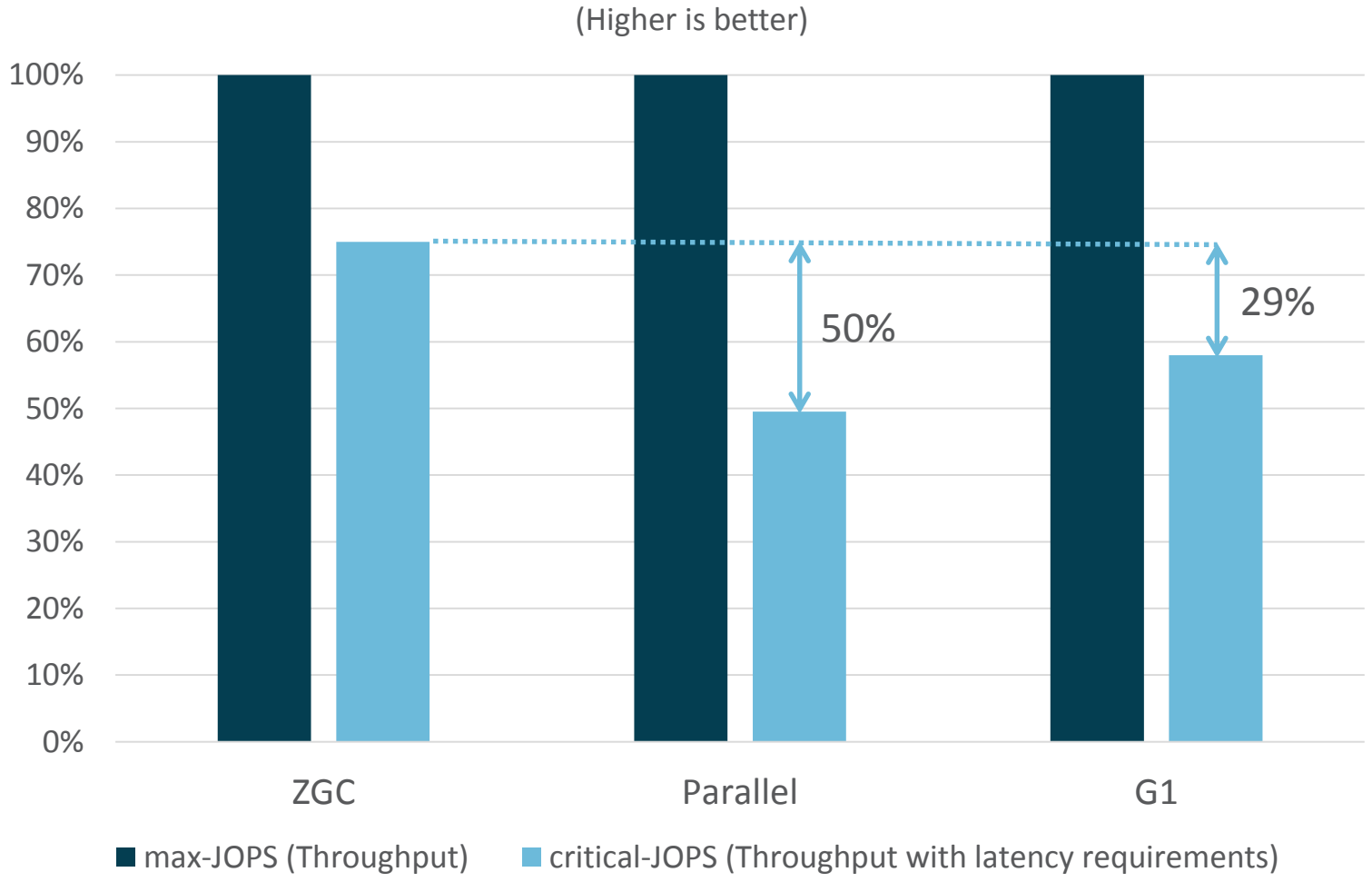
Heap Size: 128G

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 – Score



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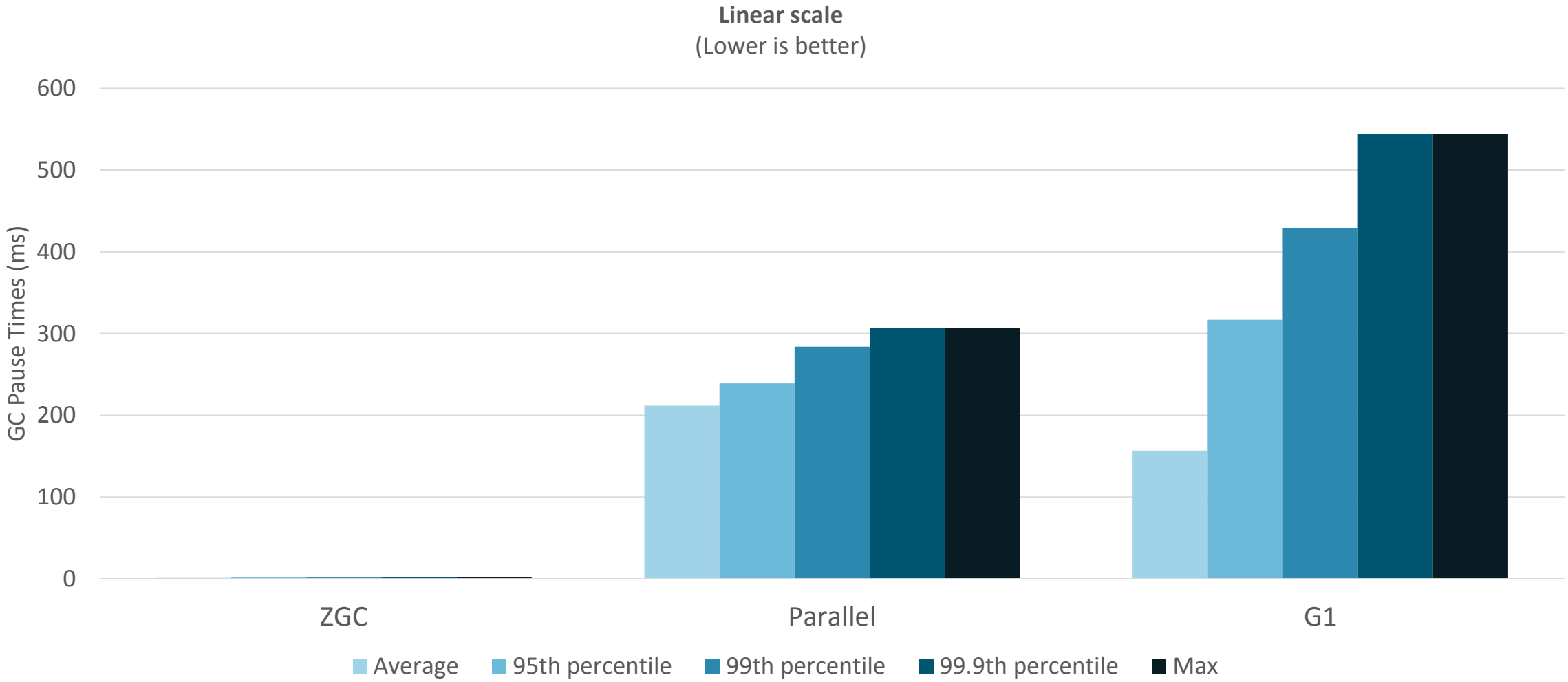
SPECjbb®2015 – Pause Times



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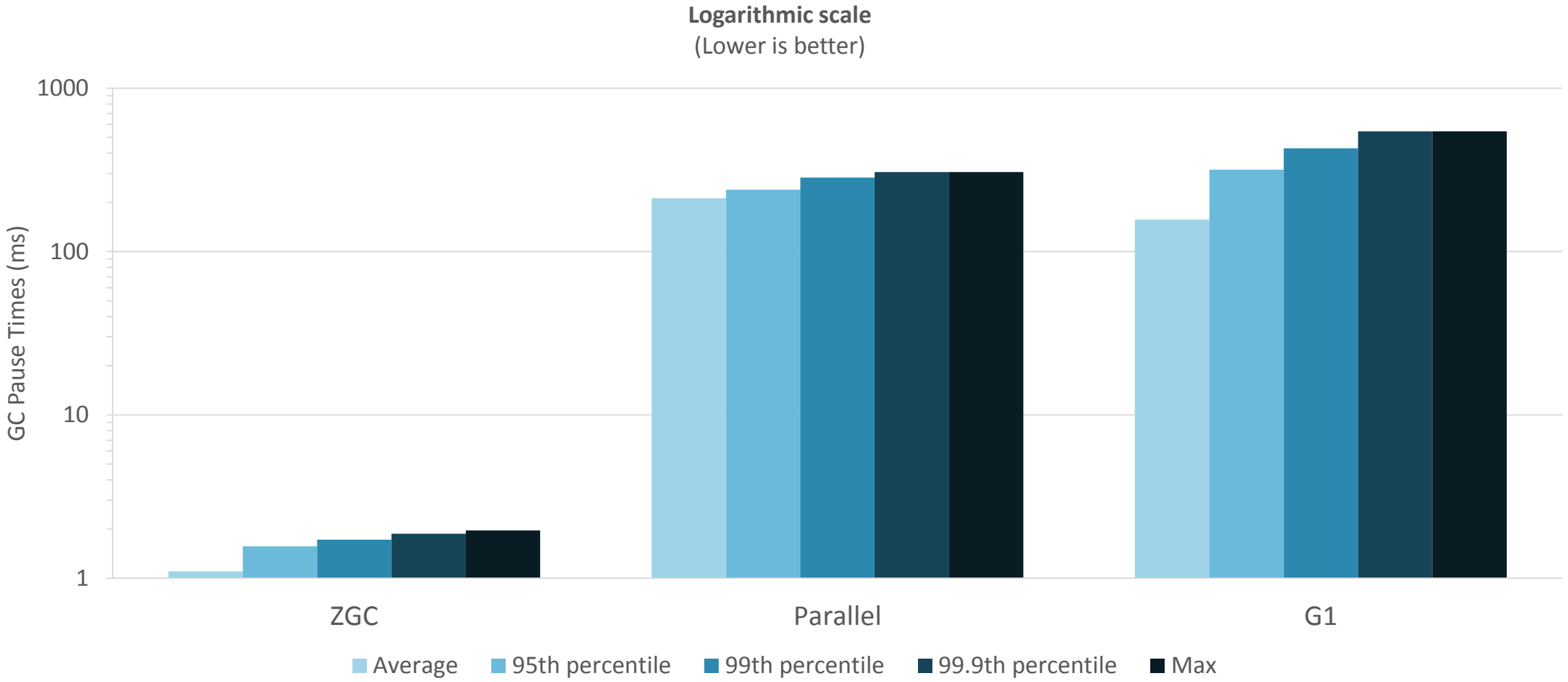

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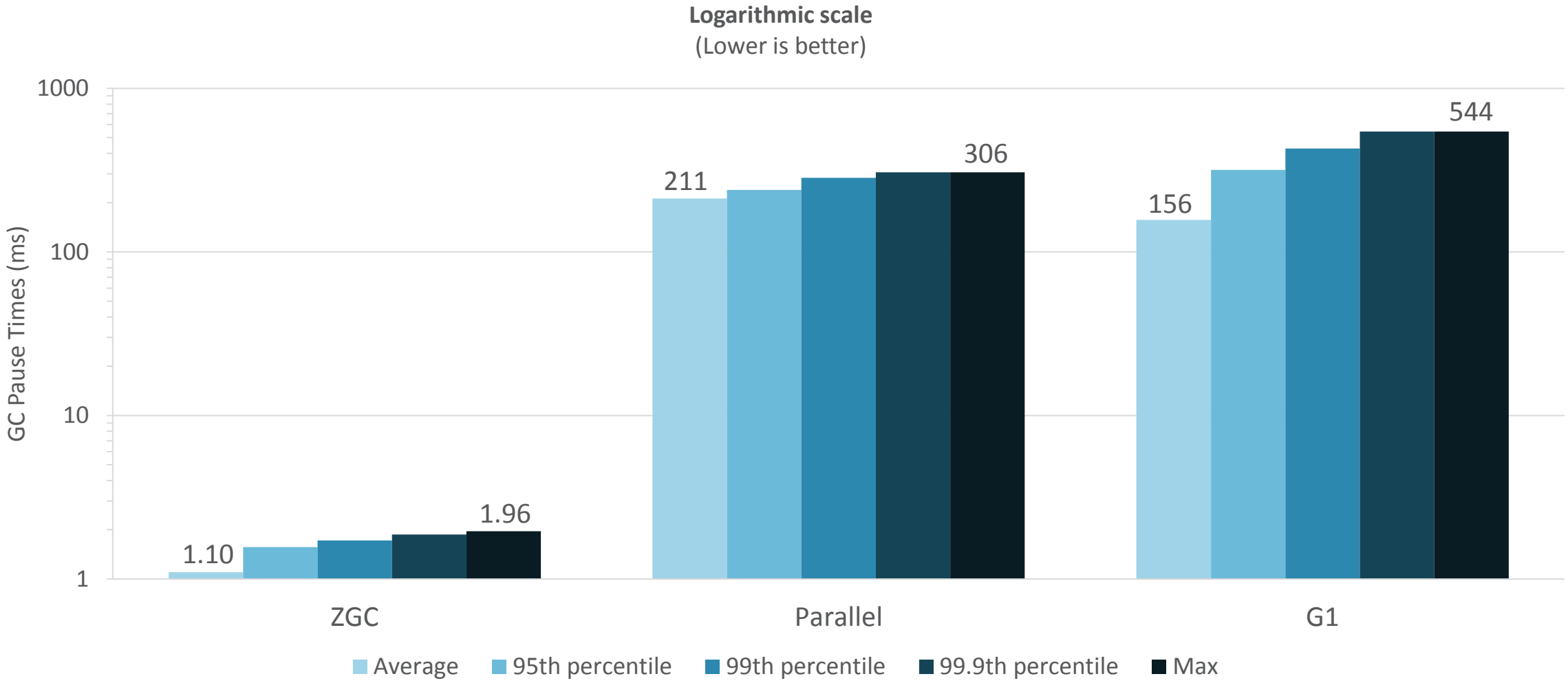

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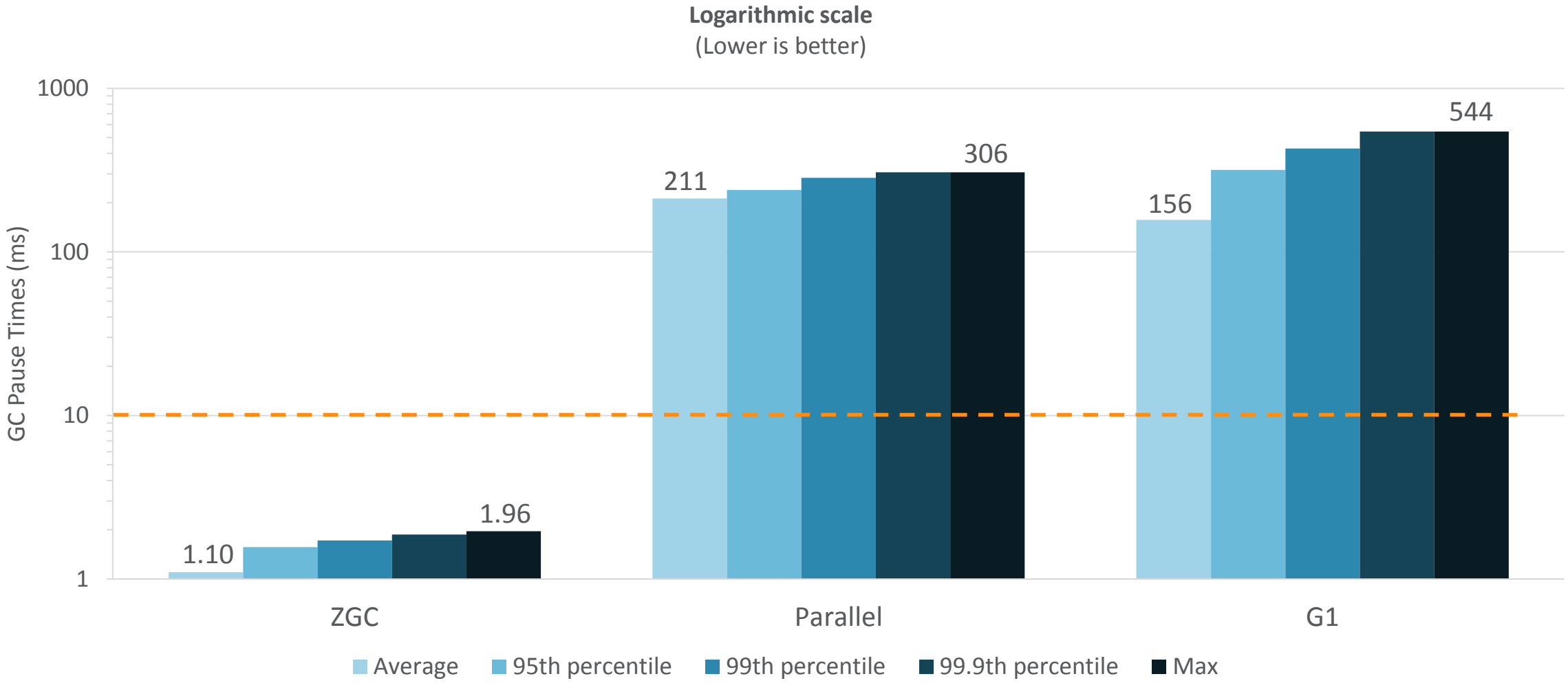

Using ZGC

Enable

```
-XX:+UseZGC
```

Enable

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

Tuning

Tuning

Set Max Heap Size

```
-Xmx<size>
```

Tuning

Maybe Set Number of Concurrent GC Threads

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

Tuning

That’s it?

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

Logging

`-Xlog:gc` (basic)

`-Xlog:gc*` (detailed)

```
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%)
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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%)

```
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%)
```

```
Garbage Collection (Allocation Rate)
Pause Mark Start 0.949ms
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Relocation: Successful, 867M relocated
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Soft: 466881 encountered, 0 discovered,
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Final: 55 encountered, 6 discovered, 0 e
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                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%)
```


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Pause Relocate Start 1.419ms
Concurrent Relocate 645.941ms

```
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%)
```

```
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
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%)
```

```
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%)
```

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
```

```
=== 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
       ...
```

```
=== 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
```

	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

```
      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
      ...
```

```
=== 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
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       Phase: Concurrent Mark Continue                   0.000 / 0.000         0.000 / 0.000         0.000 / 0.000         0.000 / 0.000   ms
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       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
       ...
```

Future Plans

Future Plans

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

Future Plans

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

Available today in the ZGC development repository!

Future Plans

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

Remove experimental status

Future Plans

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  - Concurrent class unloading
  - Turn ZGC into a product feature

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

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

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

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

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

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

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

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

OpenJDK

Get Involved!

Java™ ORACLE

ZGC Project

Follow, Participate, Give Feedback

zgc-dev@openjdk.java.net

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

ZGC Project

Source Code

OpenJDK

Latest Stable

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

Bleeding Edge

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

Java™ ORACLE

Thanks!

Questions?


Java™
ORACLE®