The Design of ZGC

A Scalable Low-Latency Garbage Collector for Java

Per Lidén (@perliden)
Consulting Member of Technical Staff
Java Platform Group, Oracle
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Live for the Code

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The Design of ZGC

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

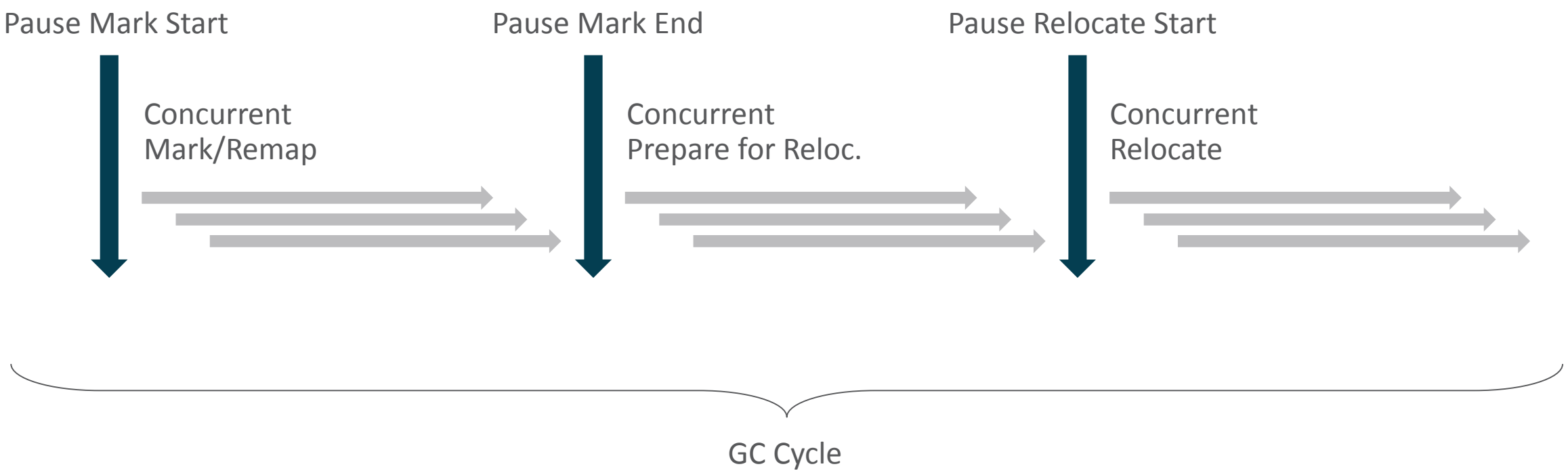
Concurrent	Region-based
Tracing	NUMA-aware
Compacting	Load barriers
Single generation	Colored pointers

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)

ZGC Phases



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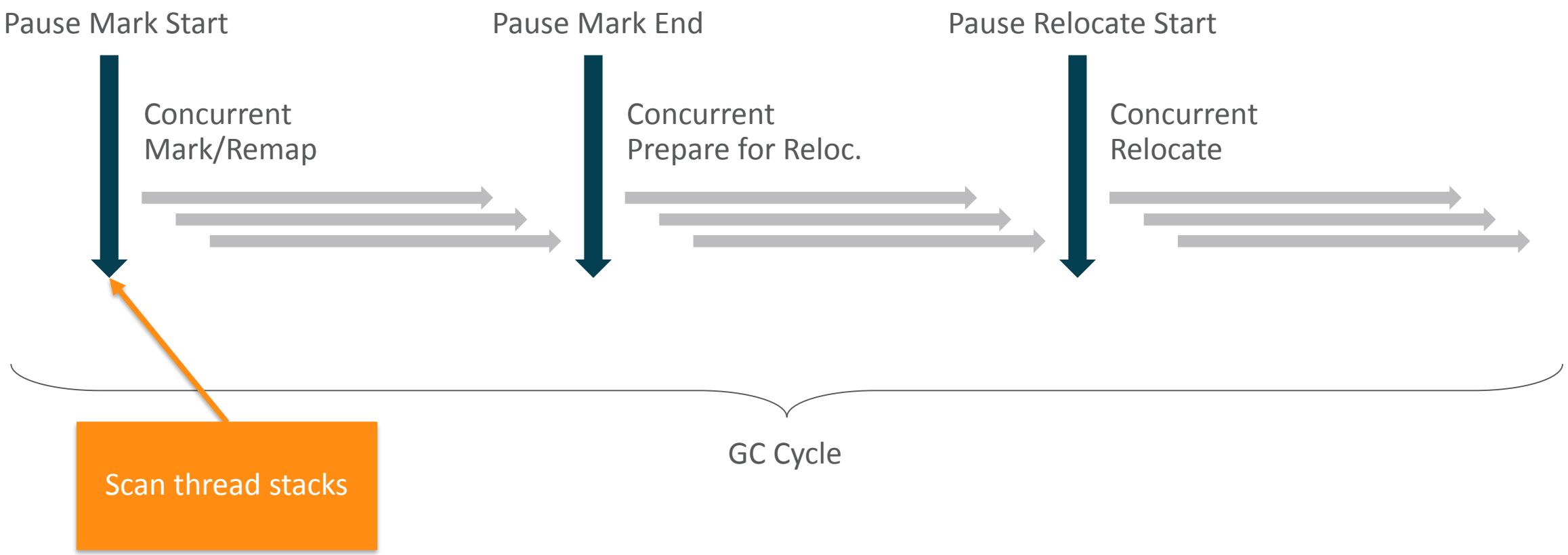

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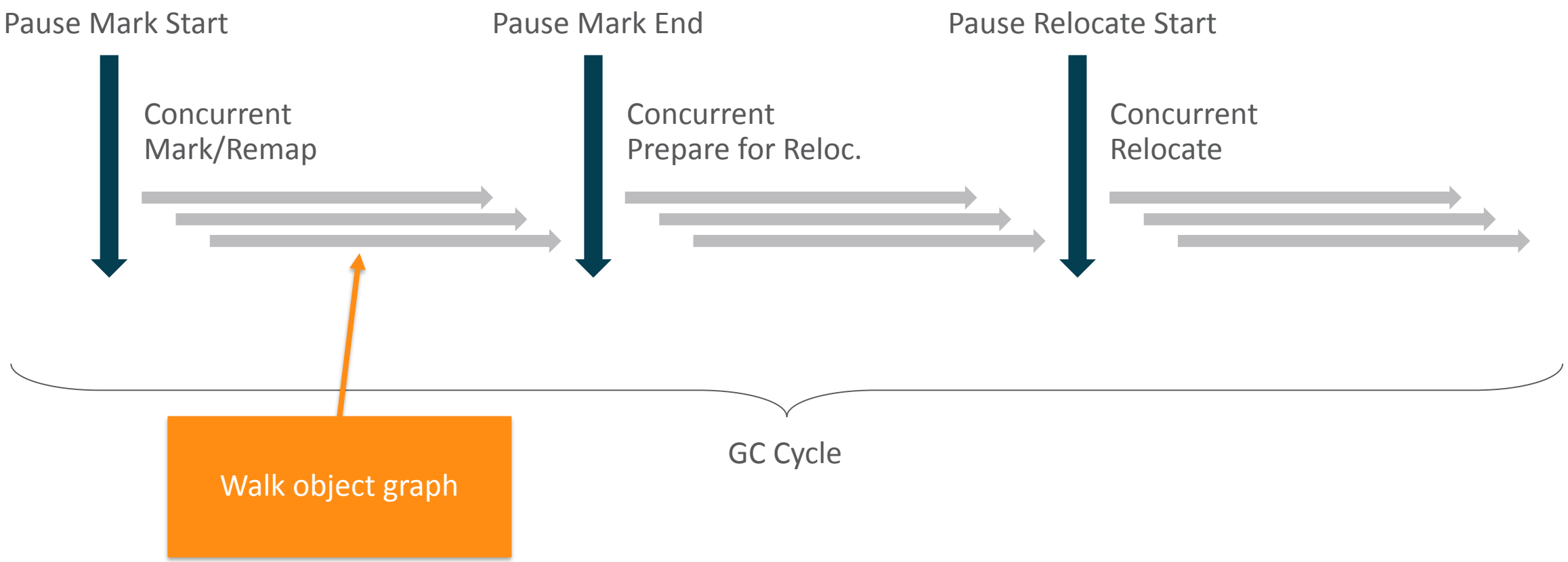

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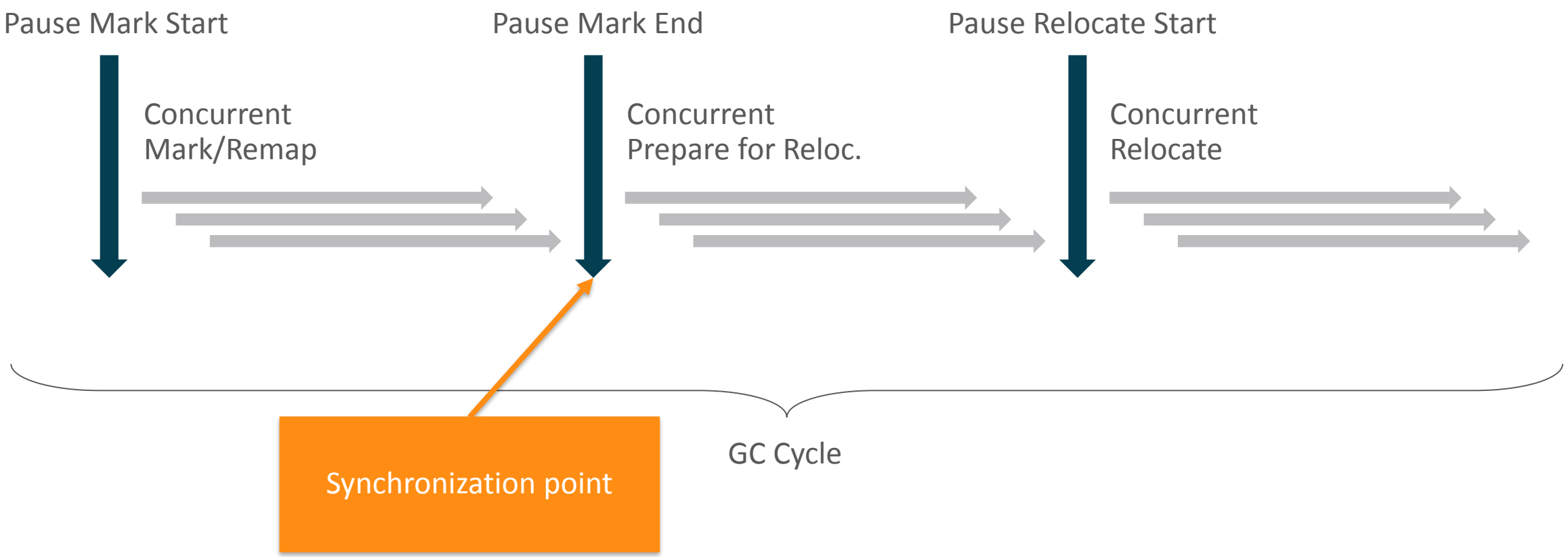

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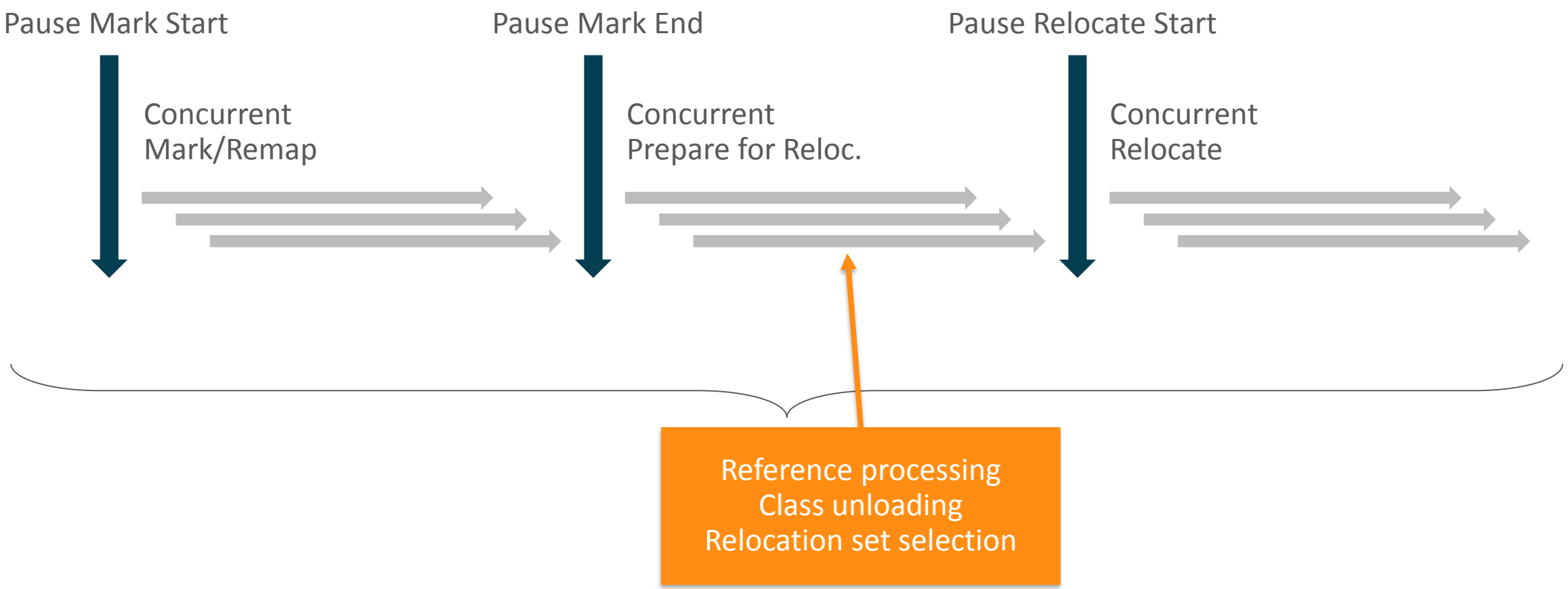

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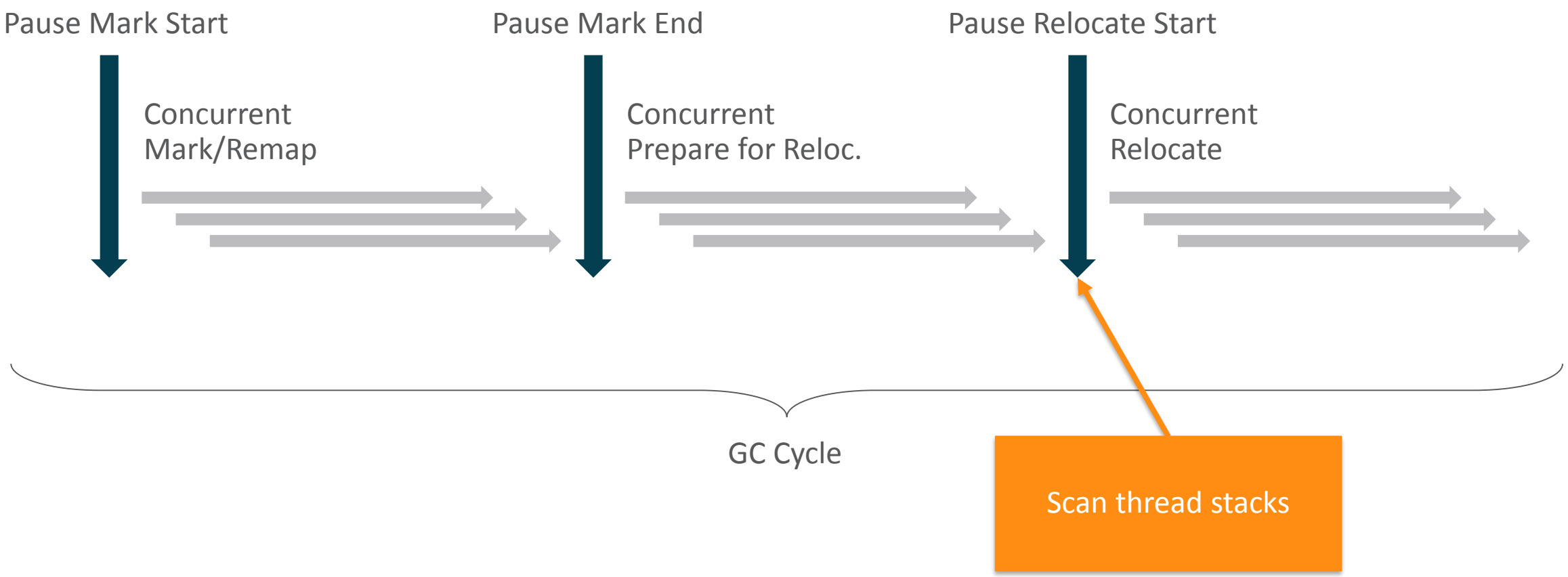

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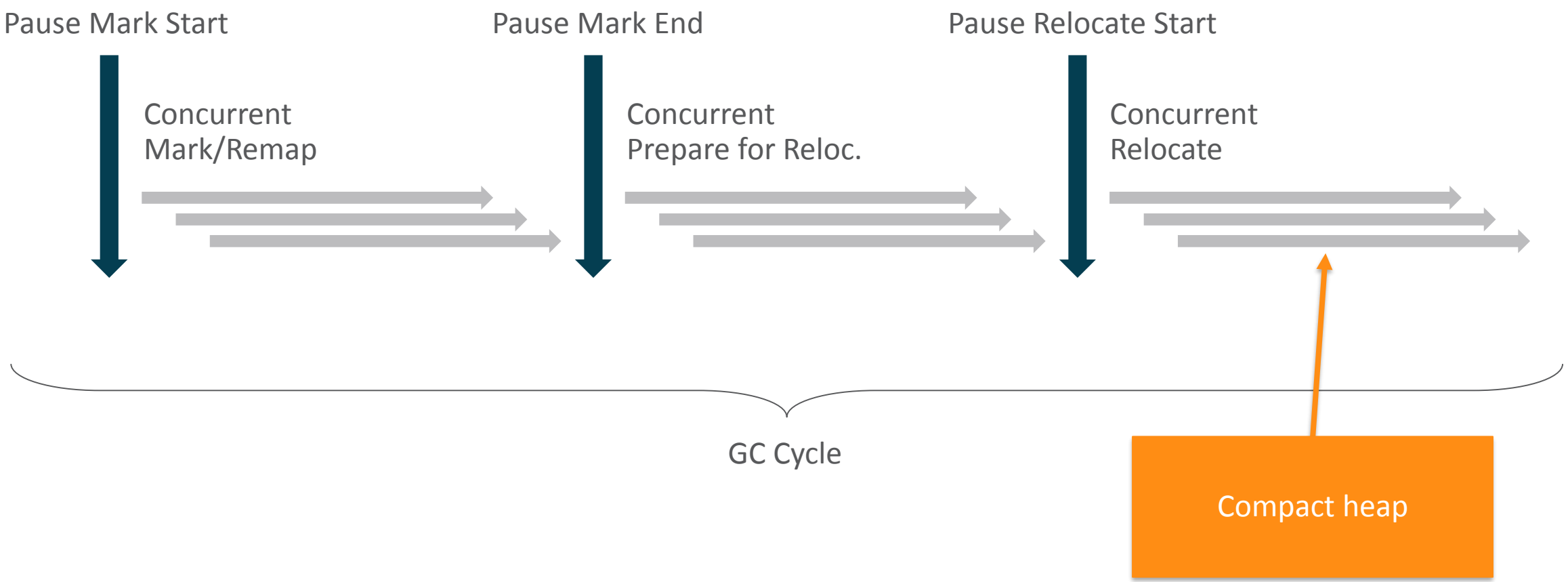

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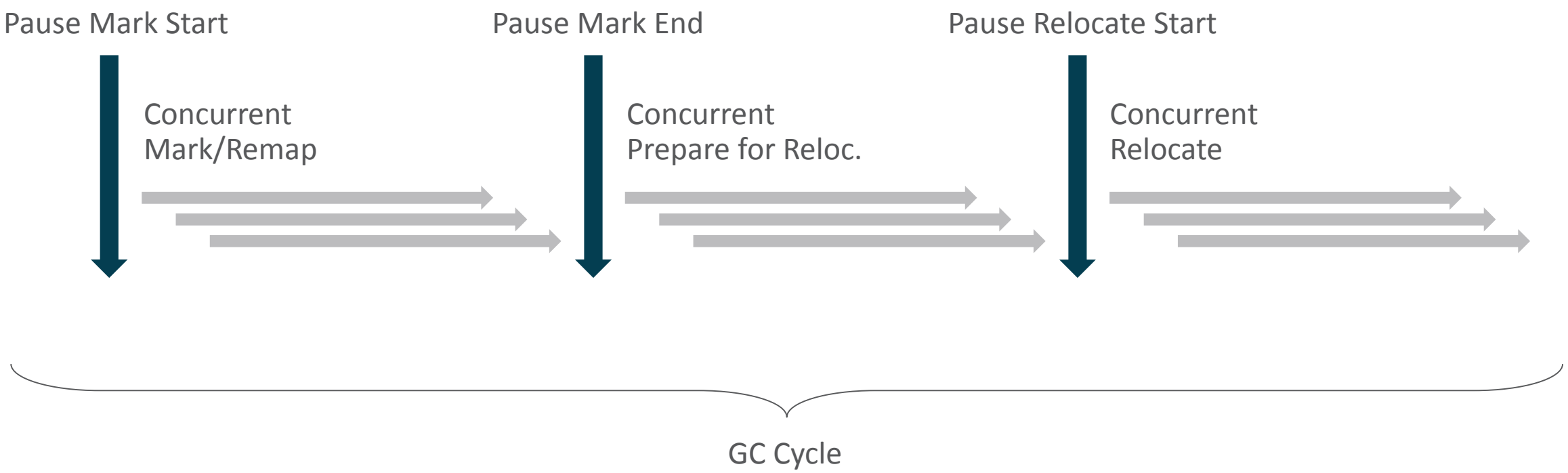

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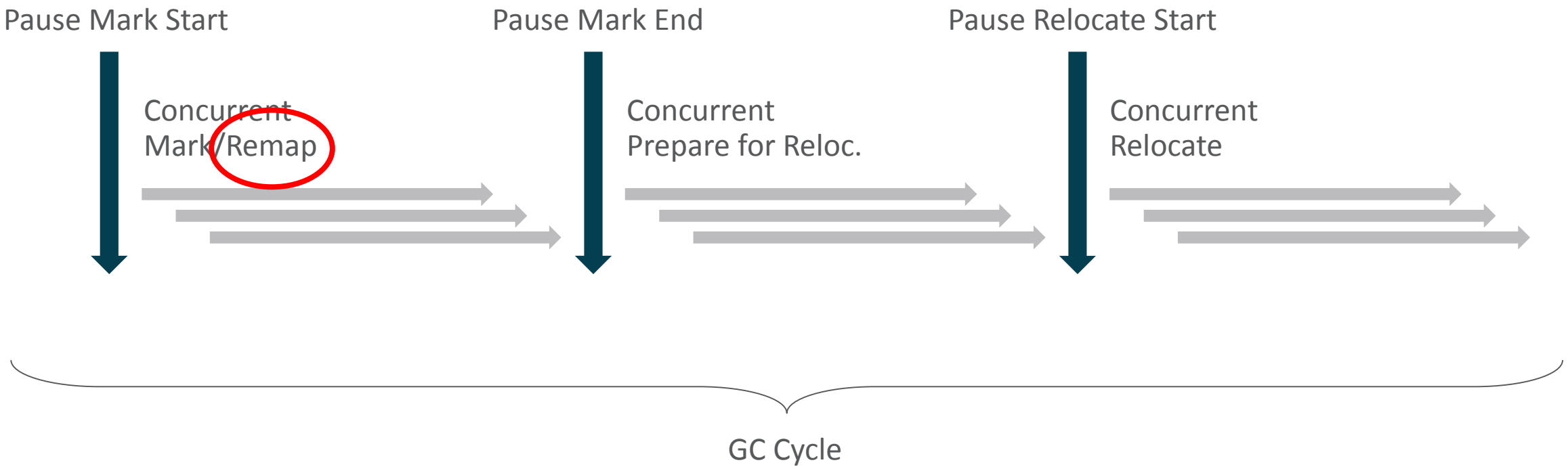

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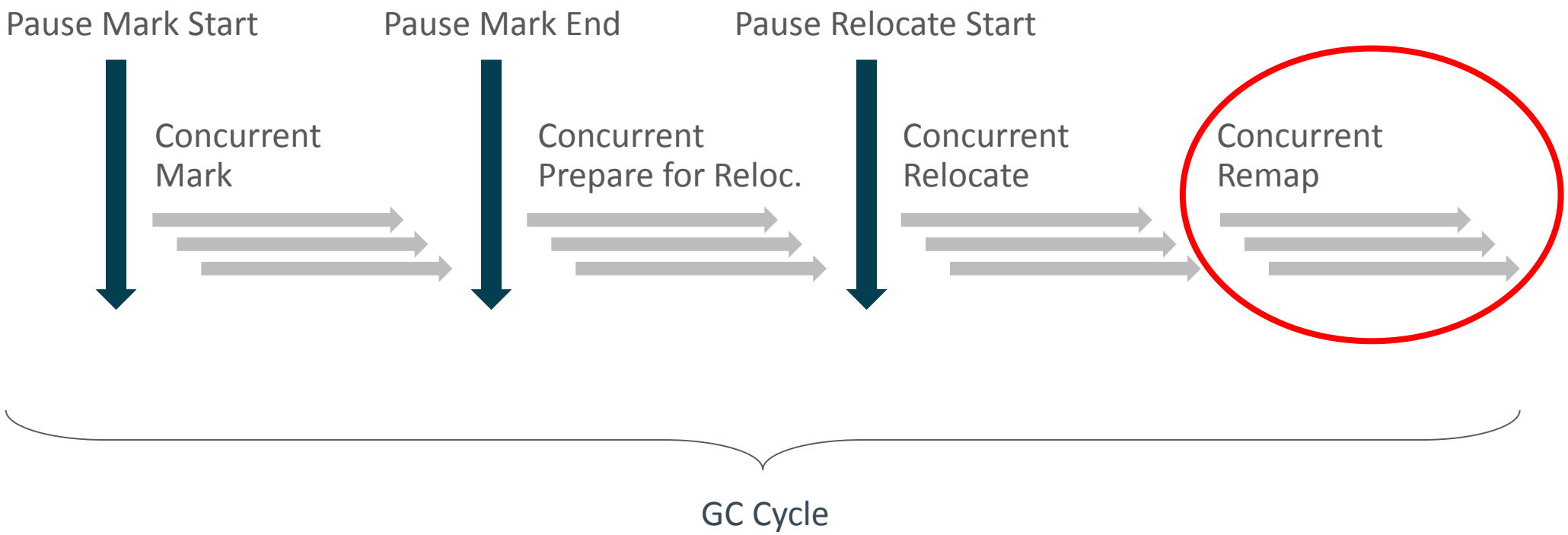

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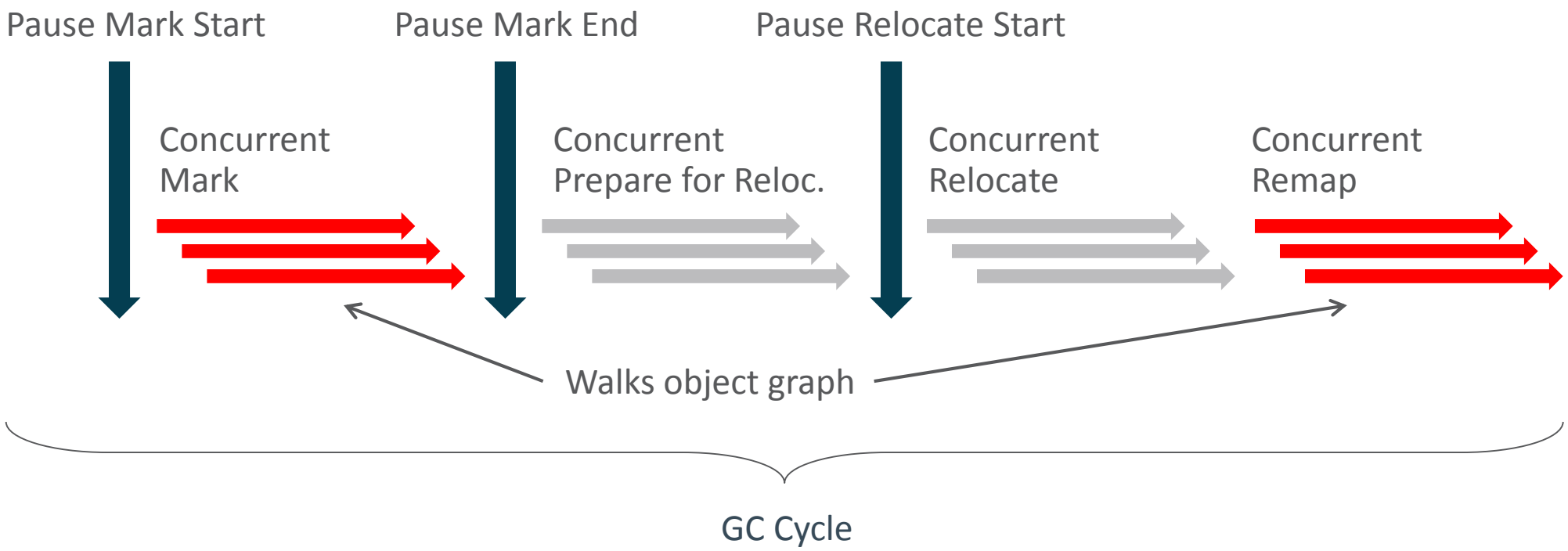

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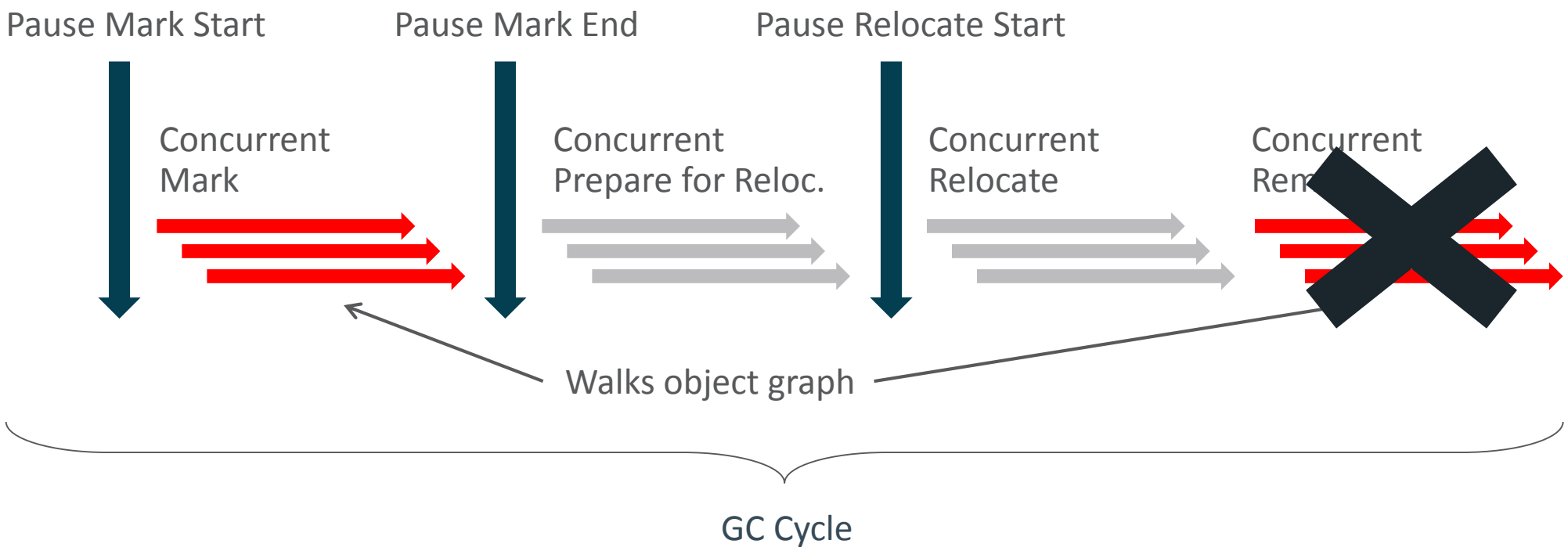

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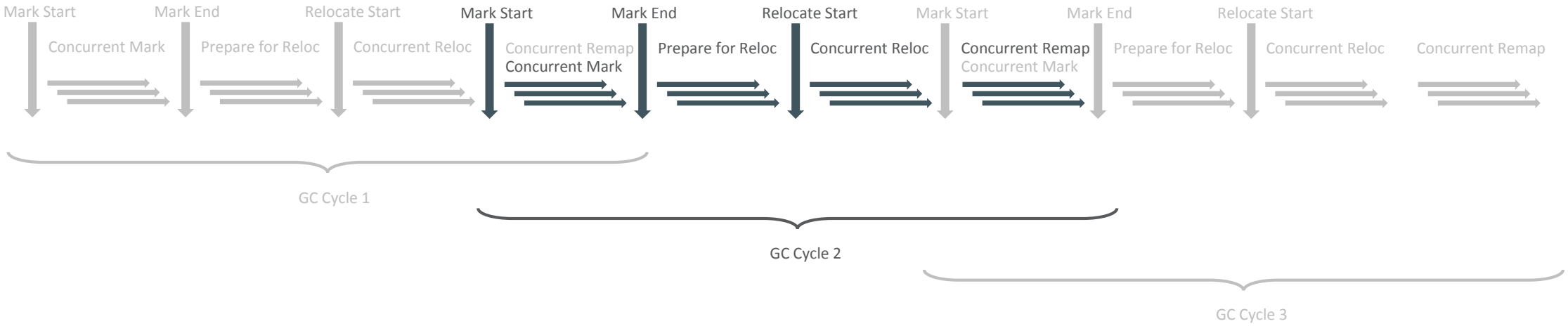
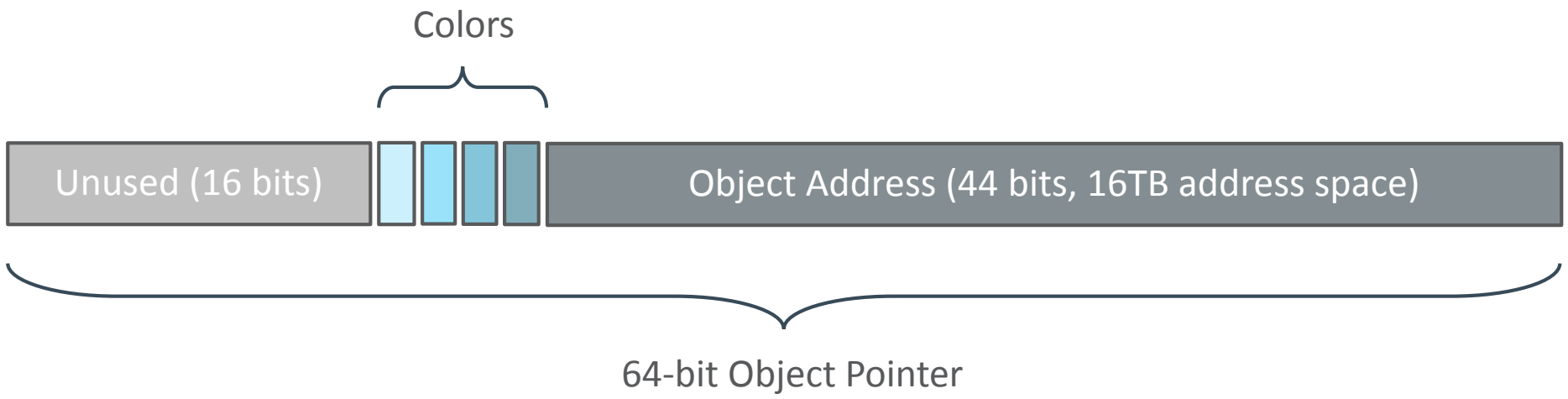


Colored Pointers

- 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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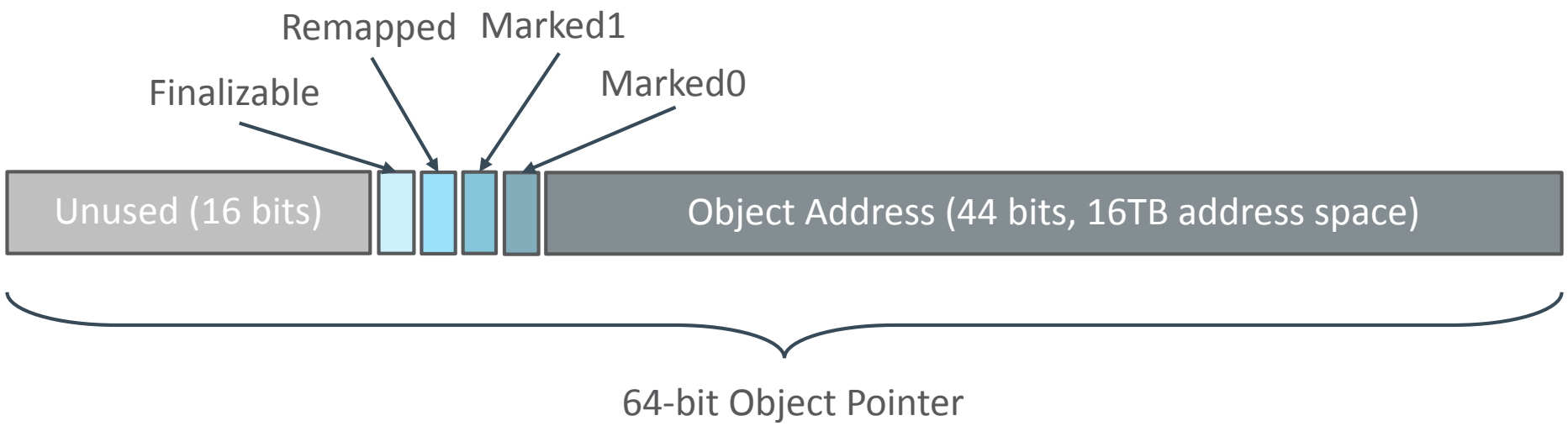

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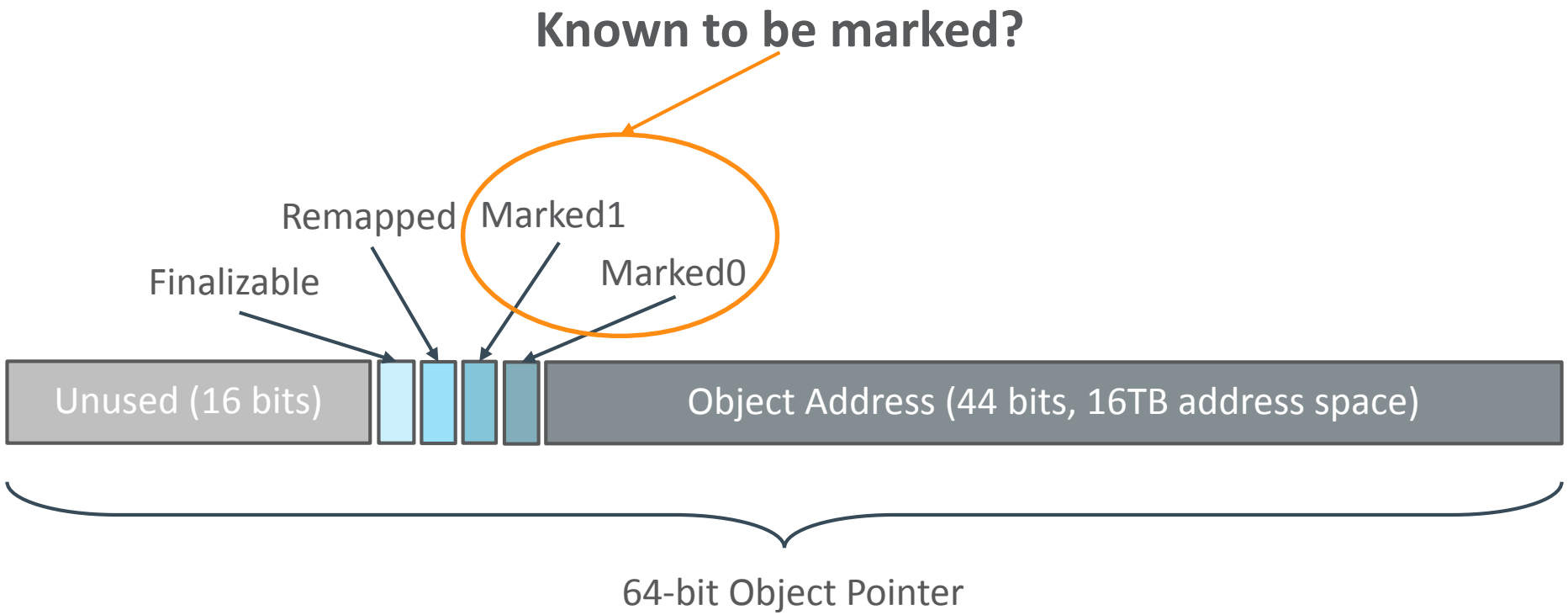

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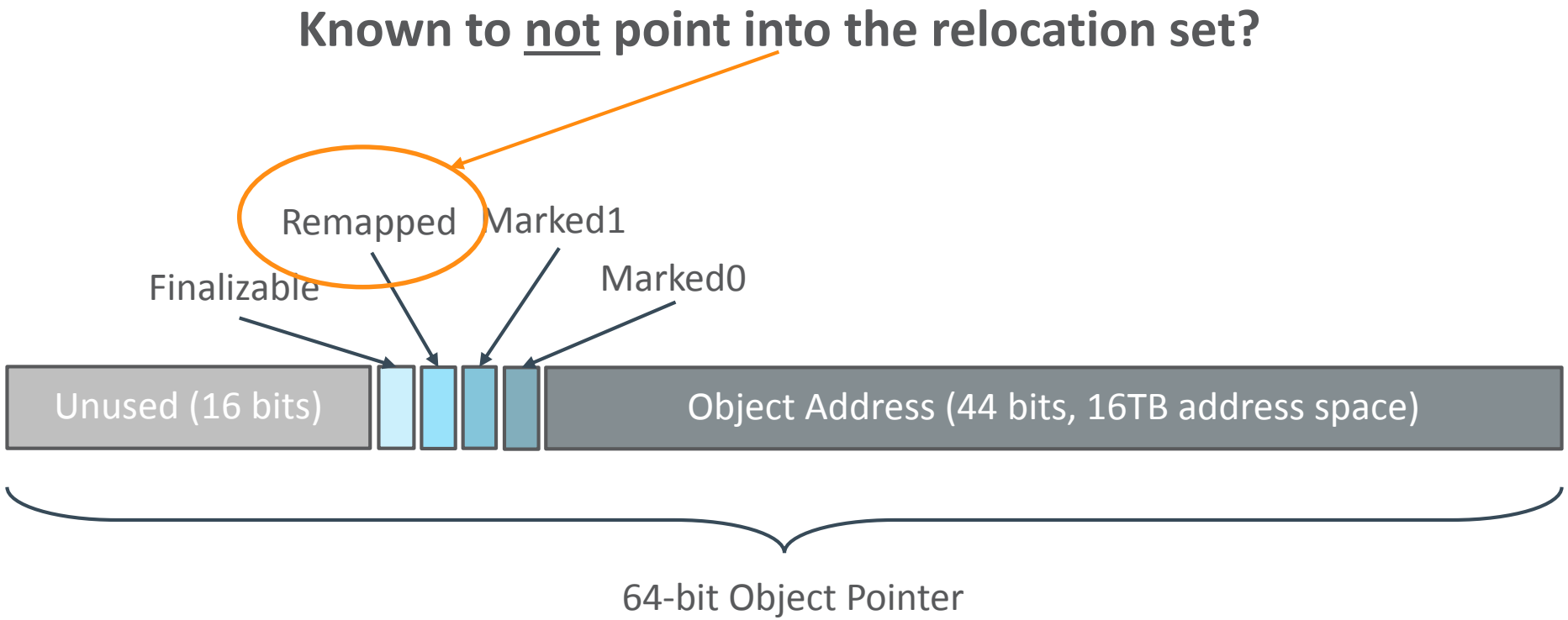

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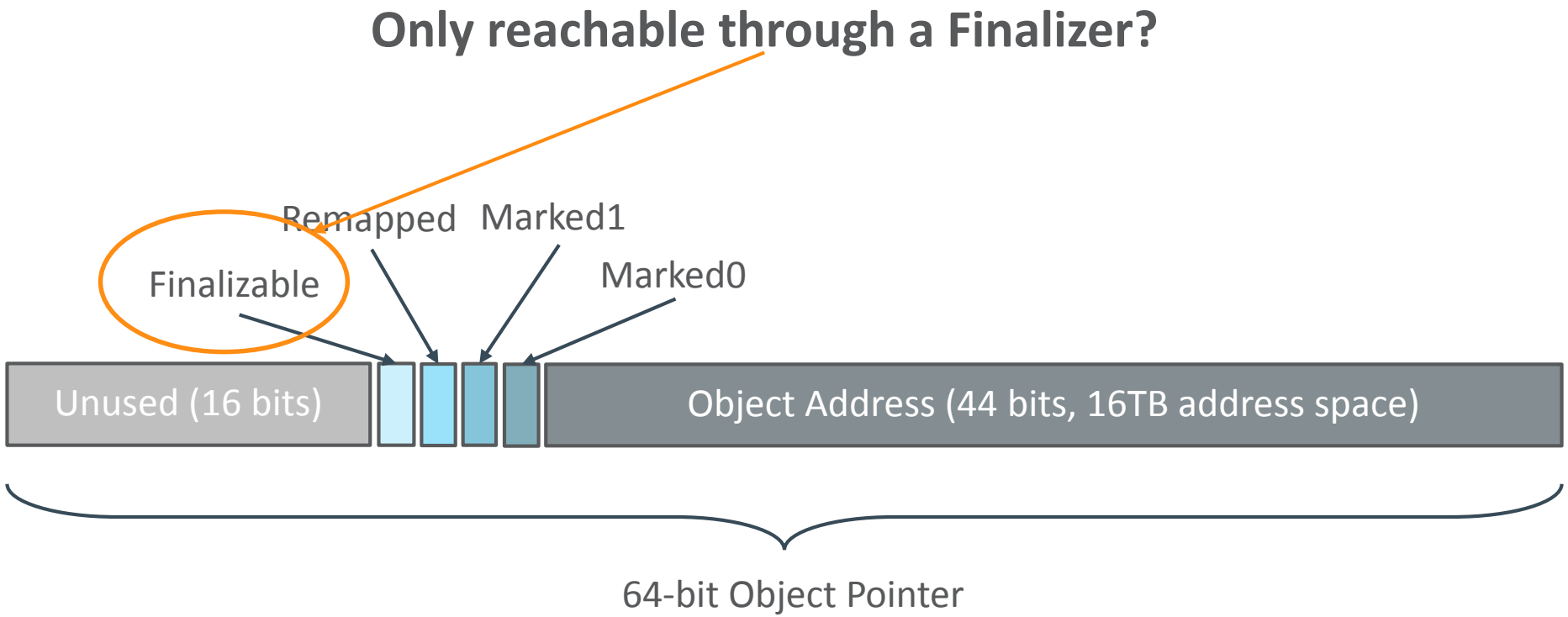

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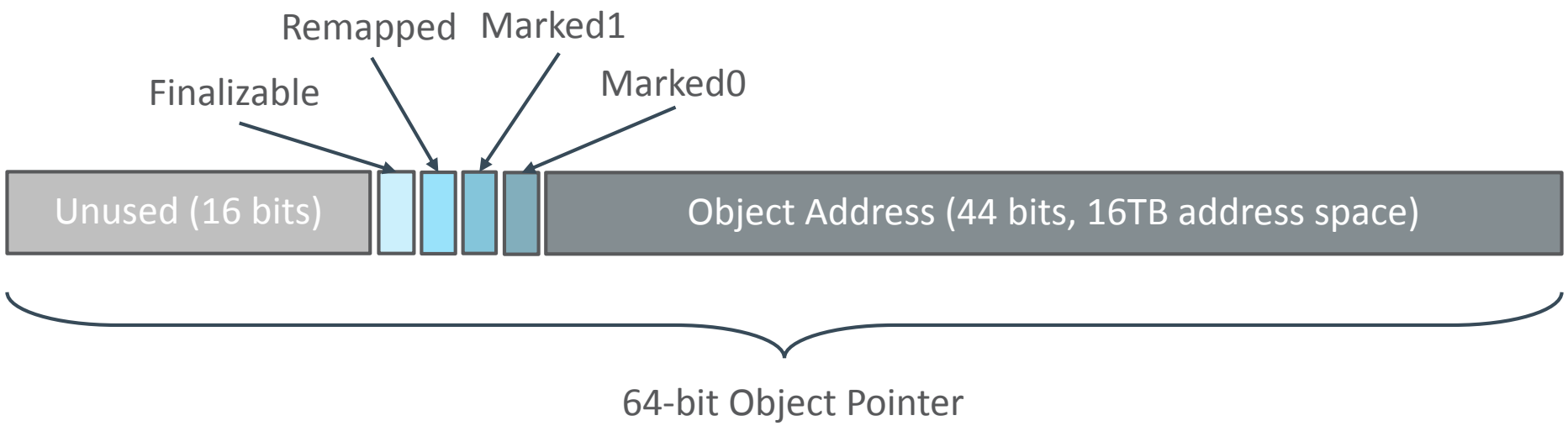


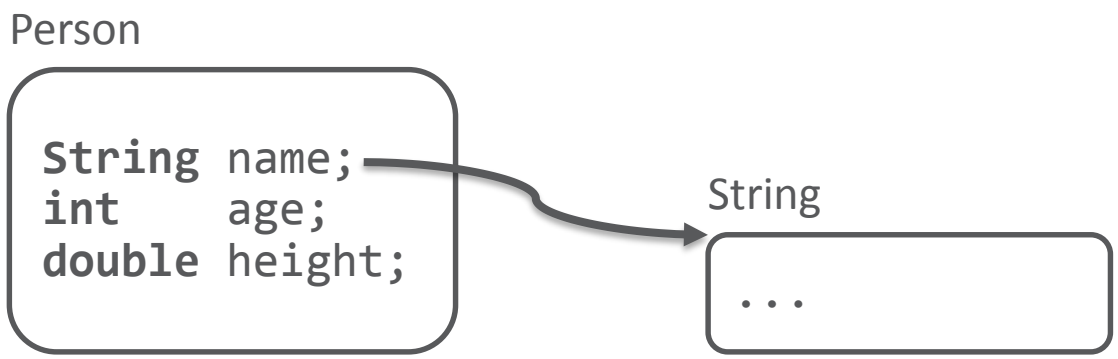
Load Barrier

- 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 **heal** it

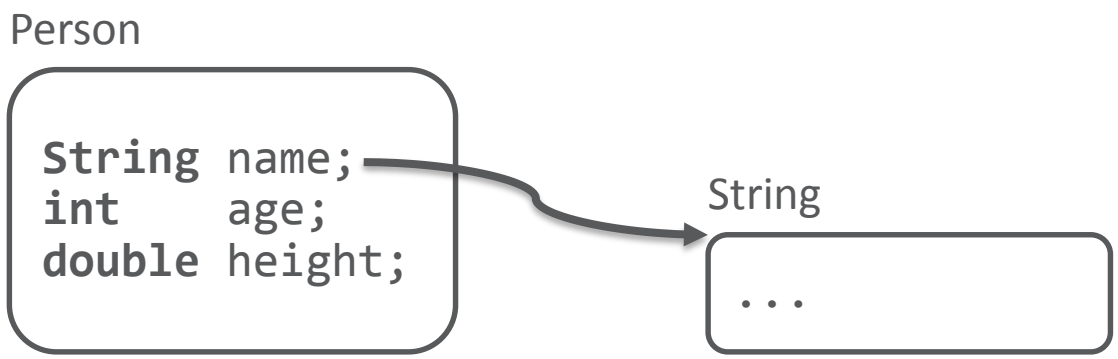
Load Barrier

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



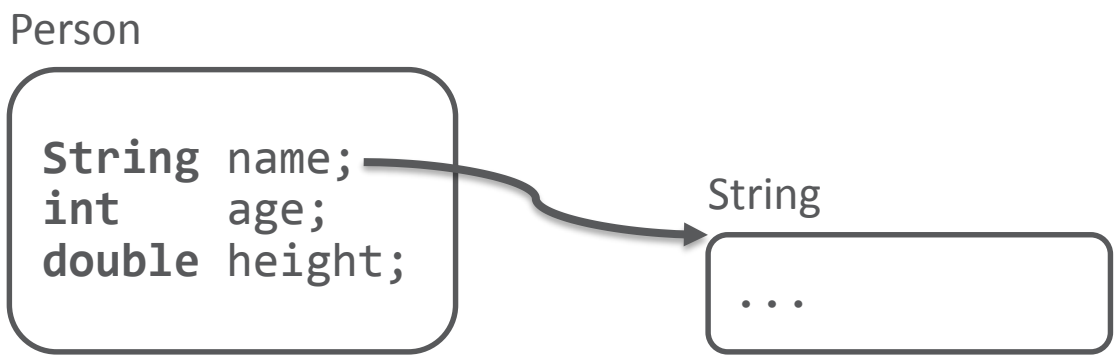
Load Barrier

```
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>
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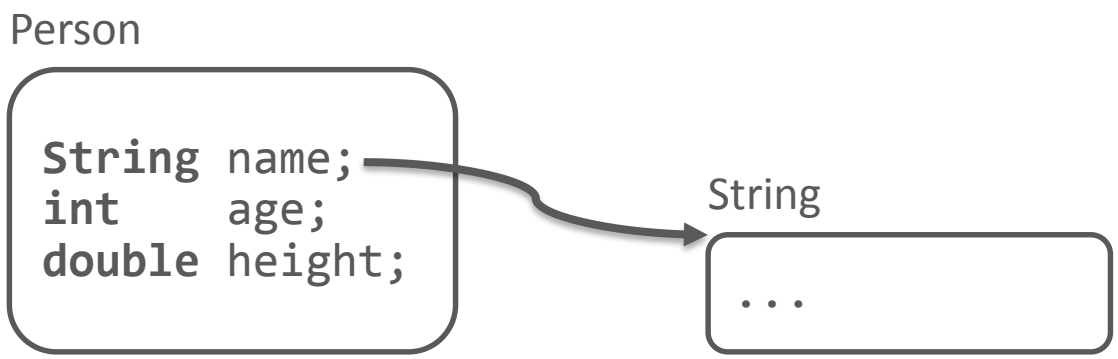
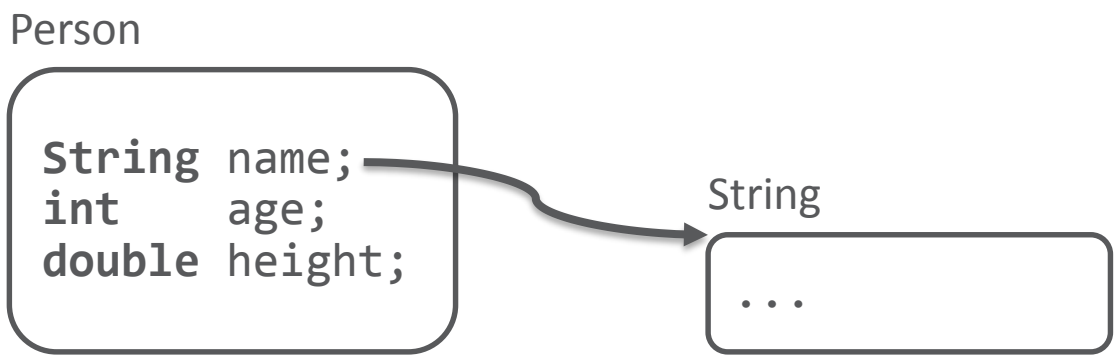


Load Barrier

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



Load Barrier

```
mov     0x10(%rax), %rbx
test    %rbx, 0x20(%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, 0x20(%r15)
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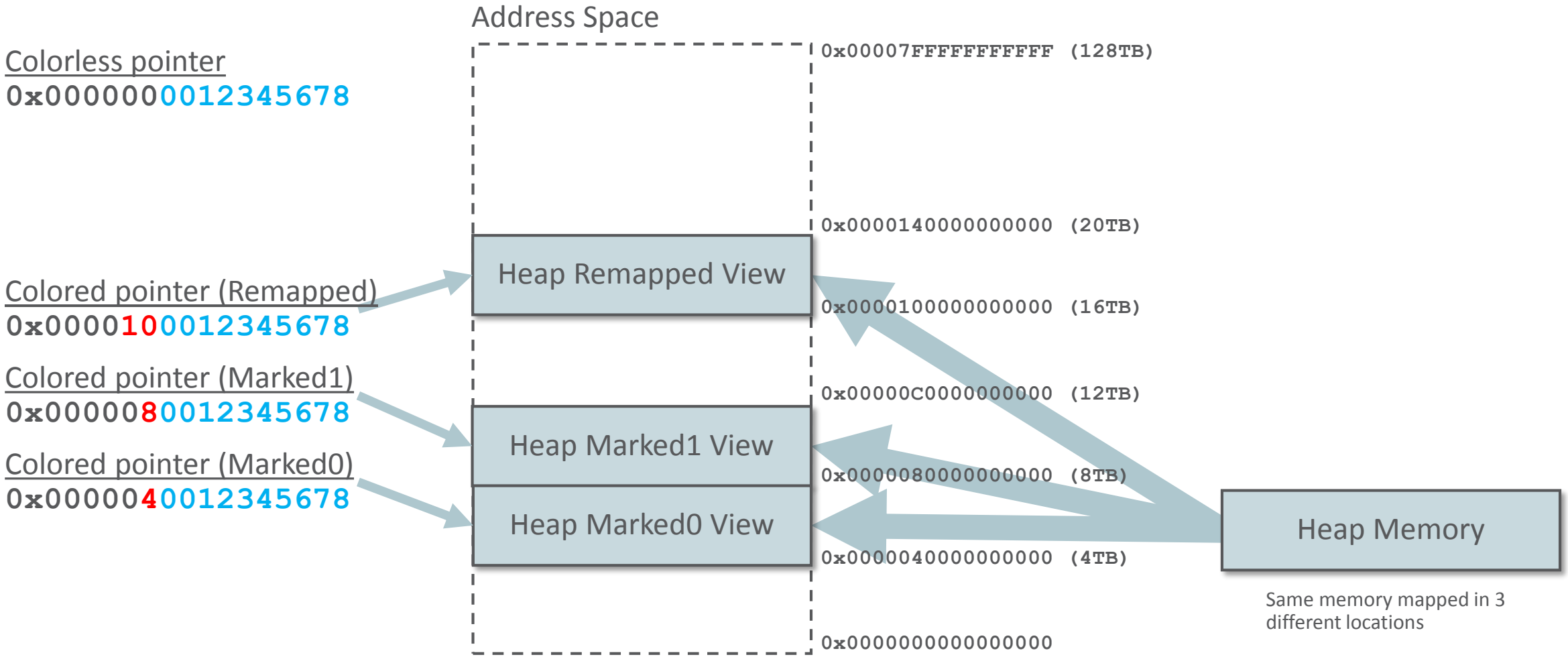
```

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

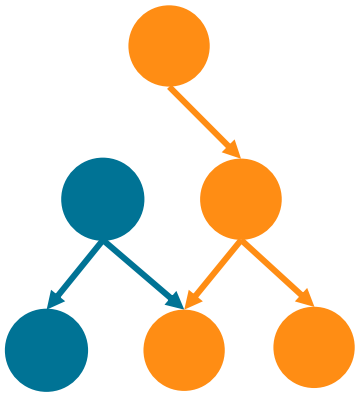
~4% execution overhead on **SPECjbb®2015**

Heap Multi-Mapping on **Linux/x86_64**

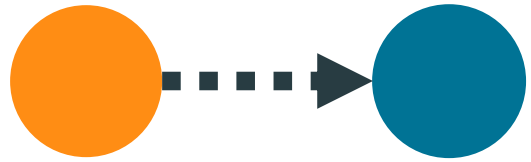


Mark

- Concurrent & Parallel
- Load barrier
  - Detects loads of non-marked object pointers
- Striped
  - Heap divided into logical stripes
  - Isolate each GC thread to work on its own stripe
  - Minimized shared state

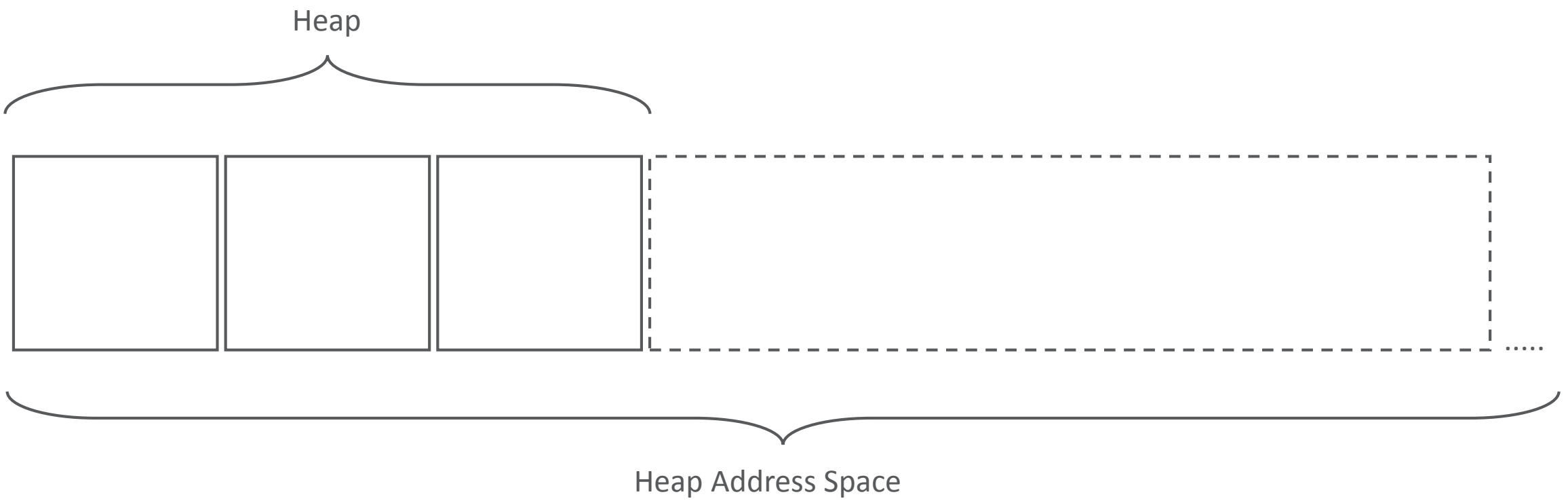


Relocation

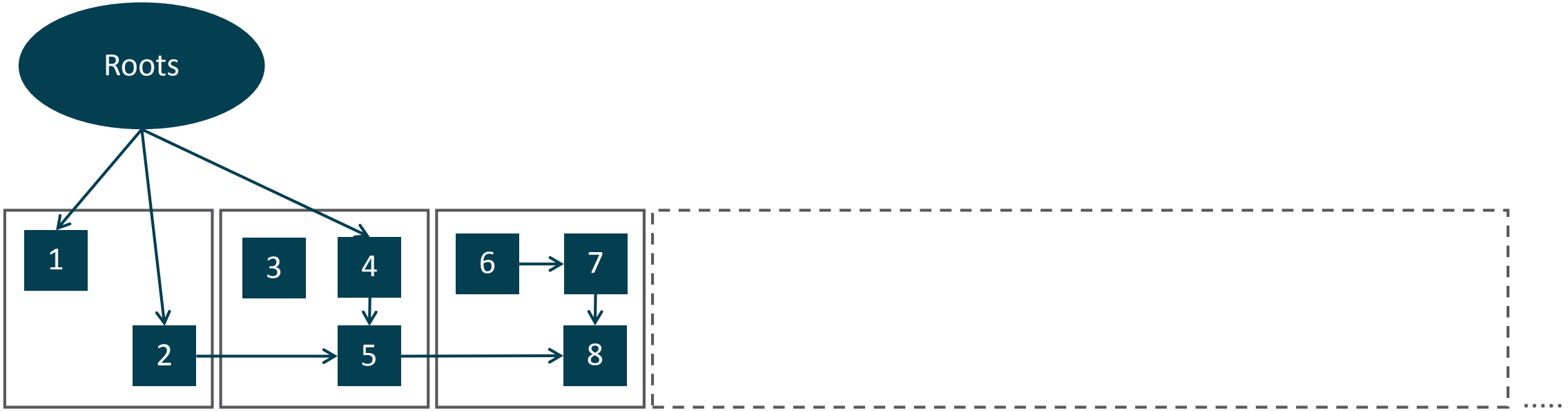


- Concurrent & Parallel
- Load barrier
  - Detects loads of object pointers pointing into the relocation set
  - Java threads help out with relocation if needed
- Off-heap forwarding tables
  - No forwarding information stored in old copies of objects
  - Important for immediate reuse of heap memory

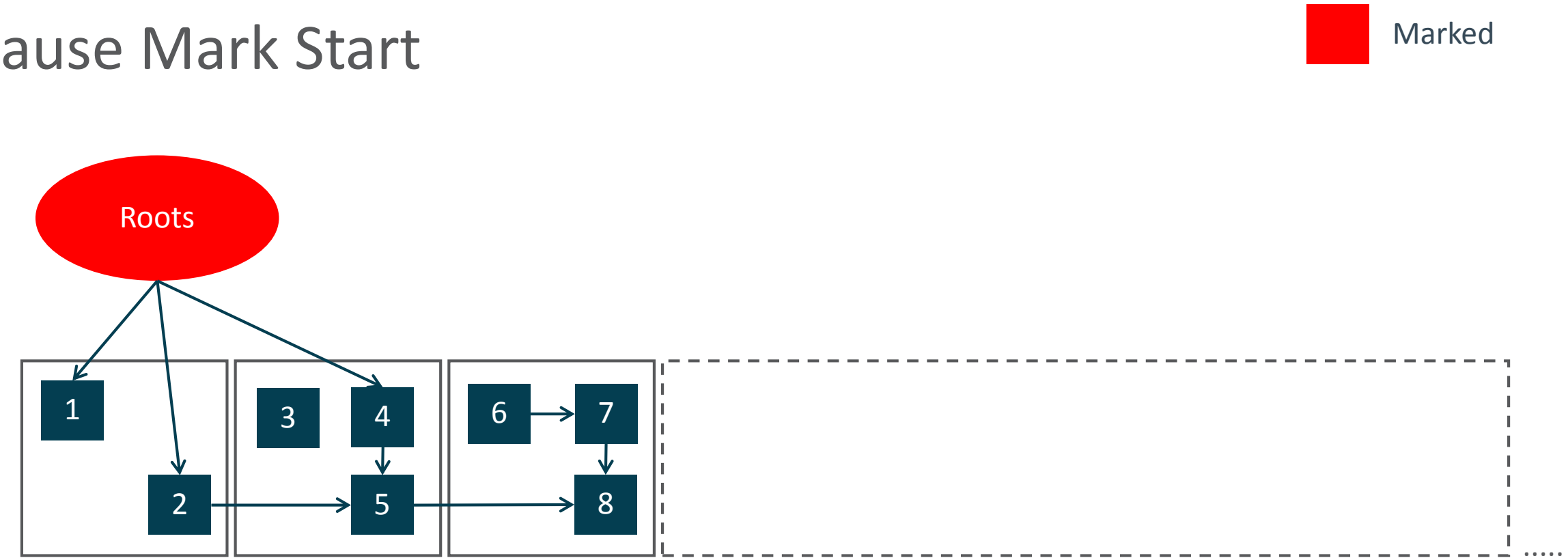
GC Cycle Example



GC Cycle Example



Pause Mark Start



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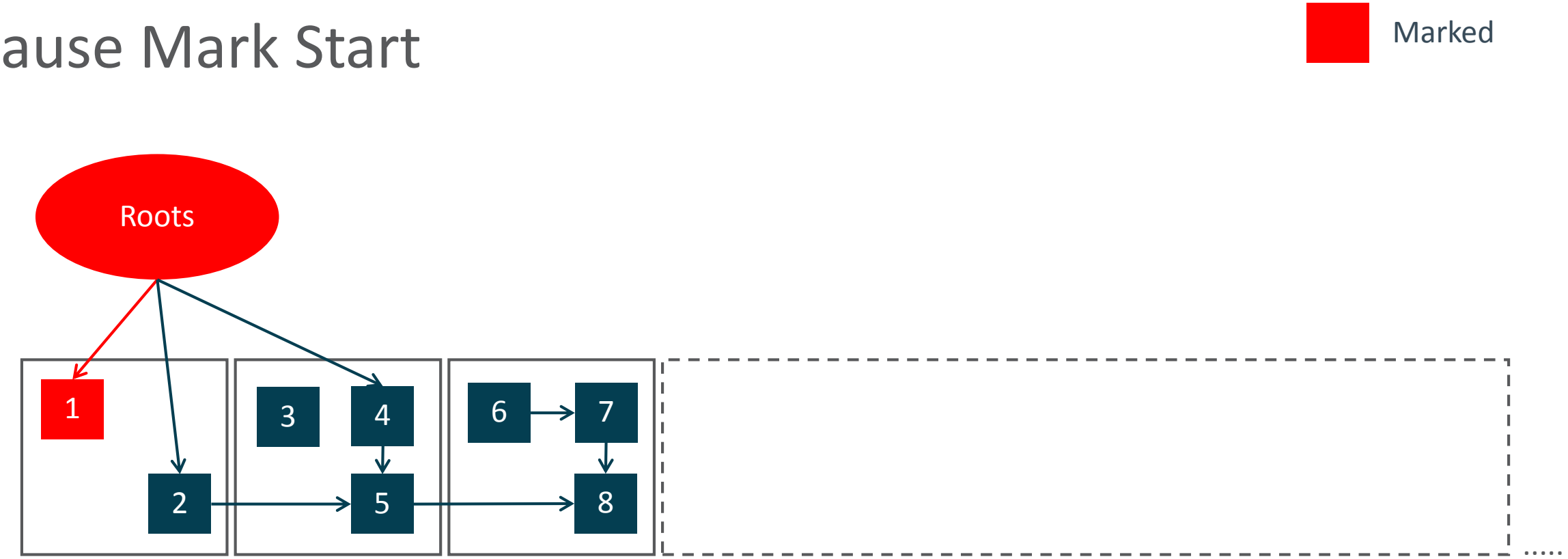

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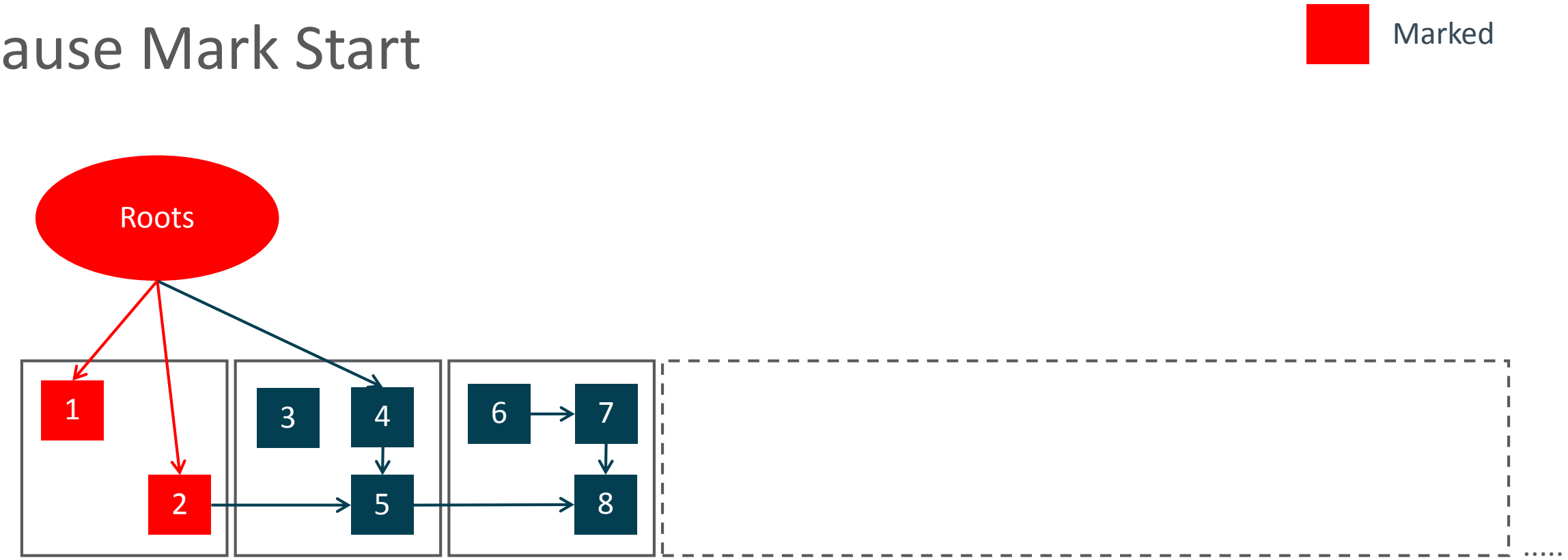

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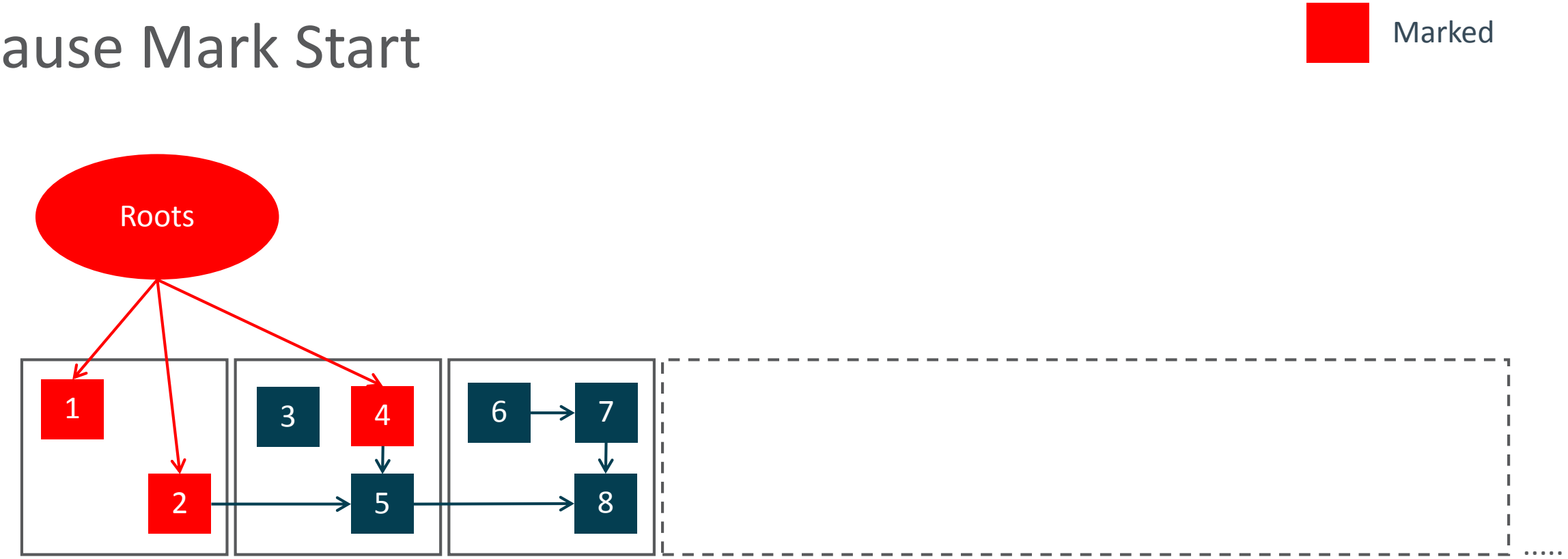
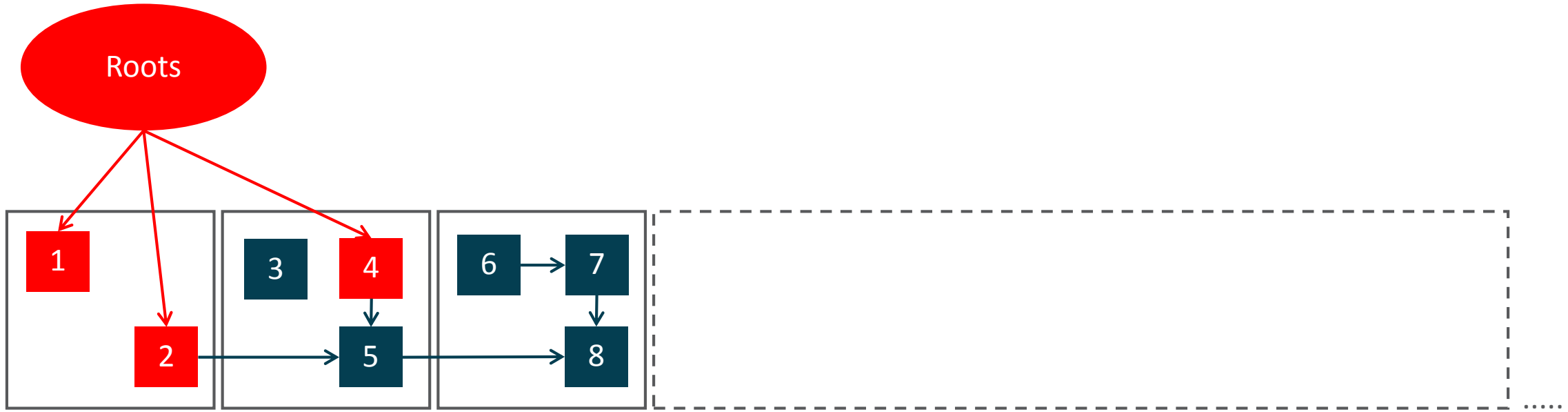


Concurrent Mark



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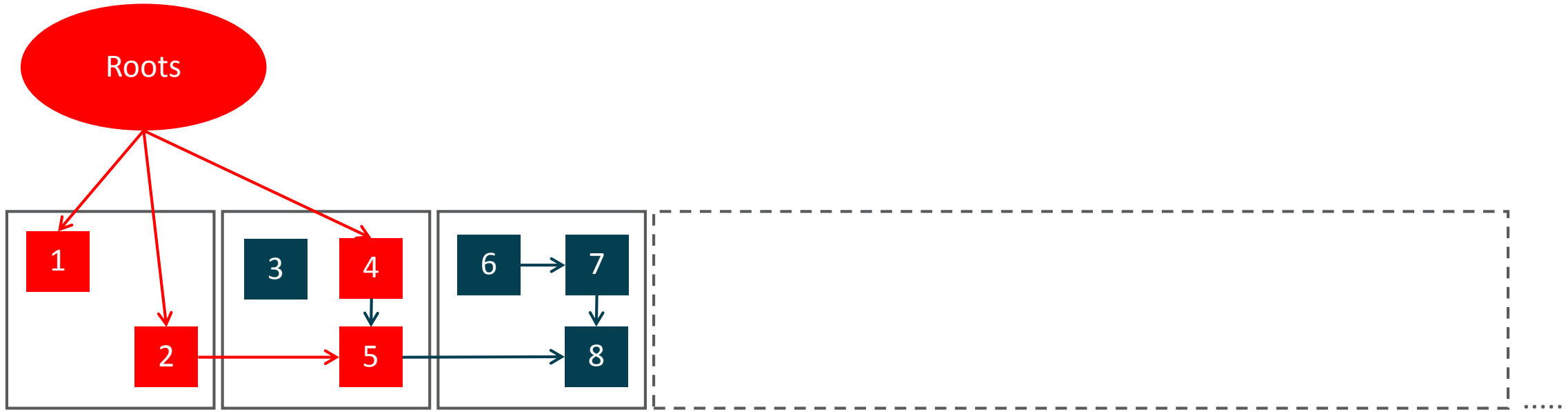

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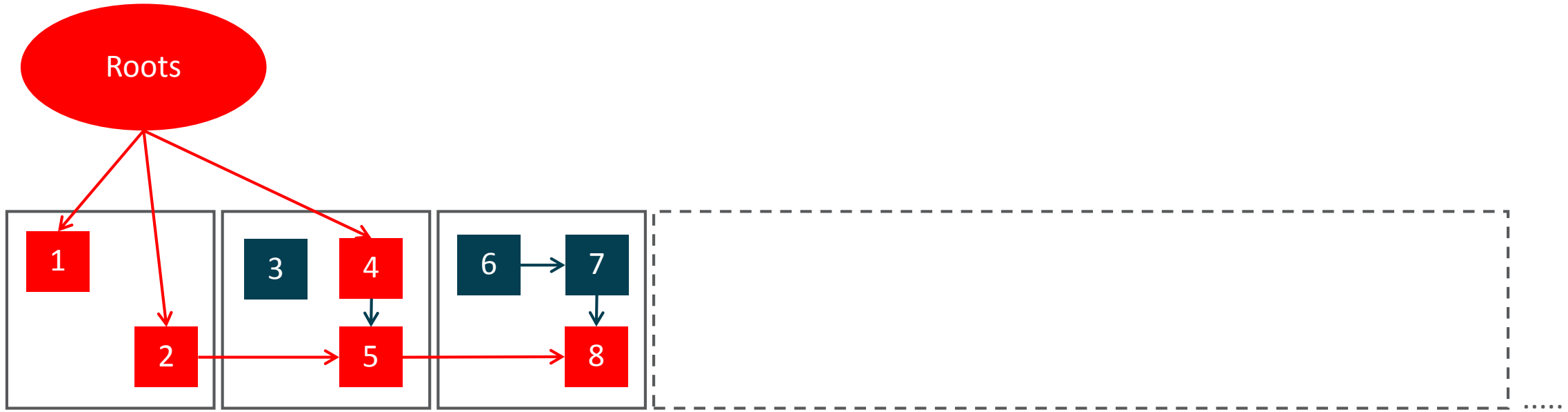

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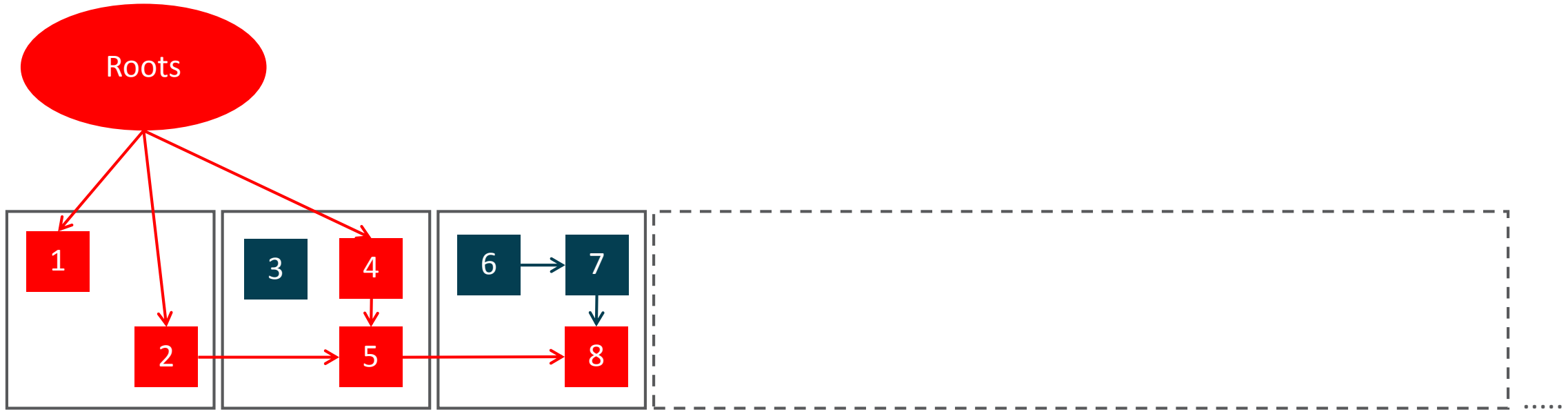
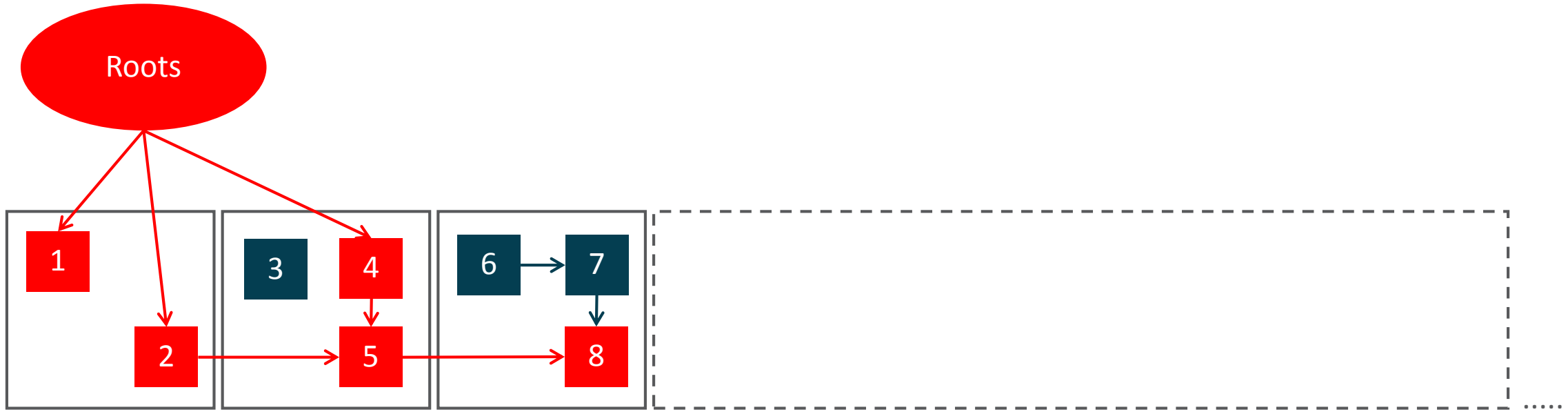
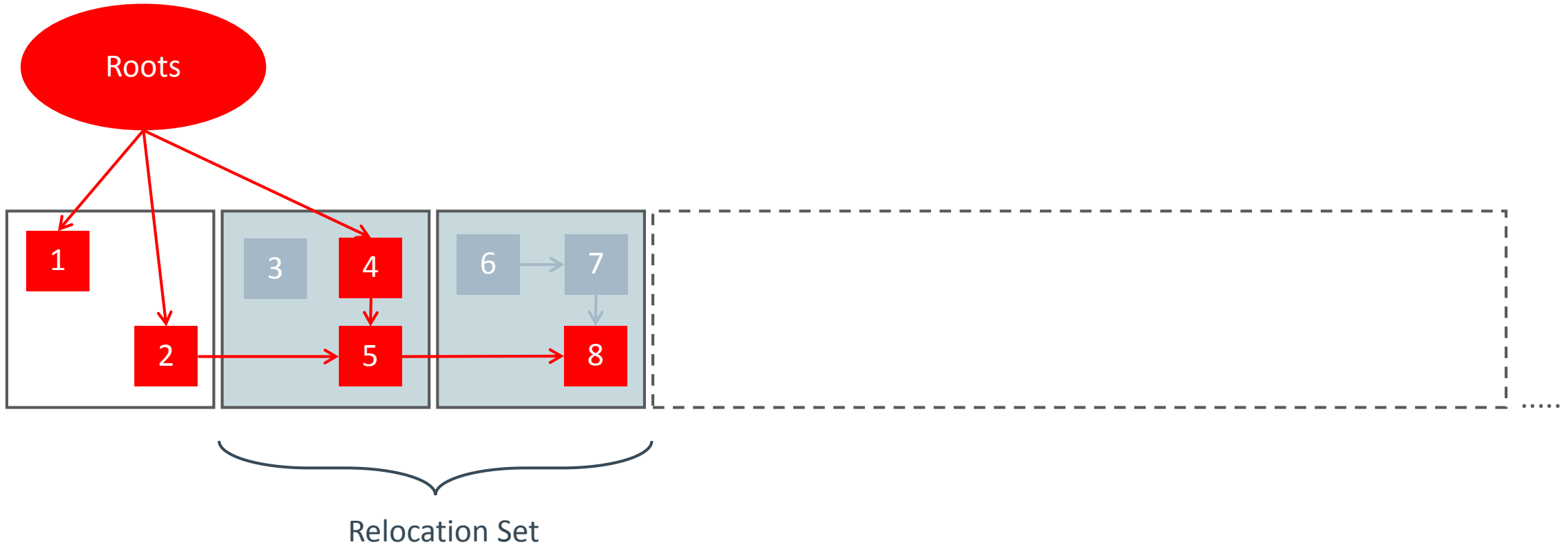


Pause Mark End



Concurrent Prepare for Relocate



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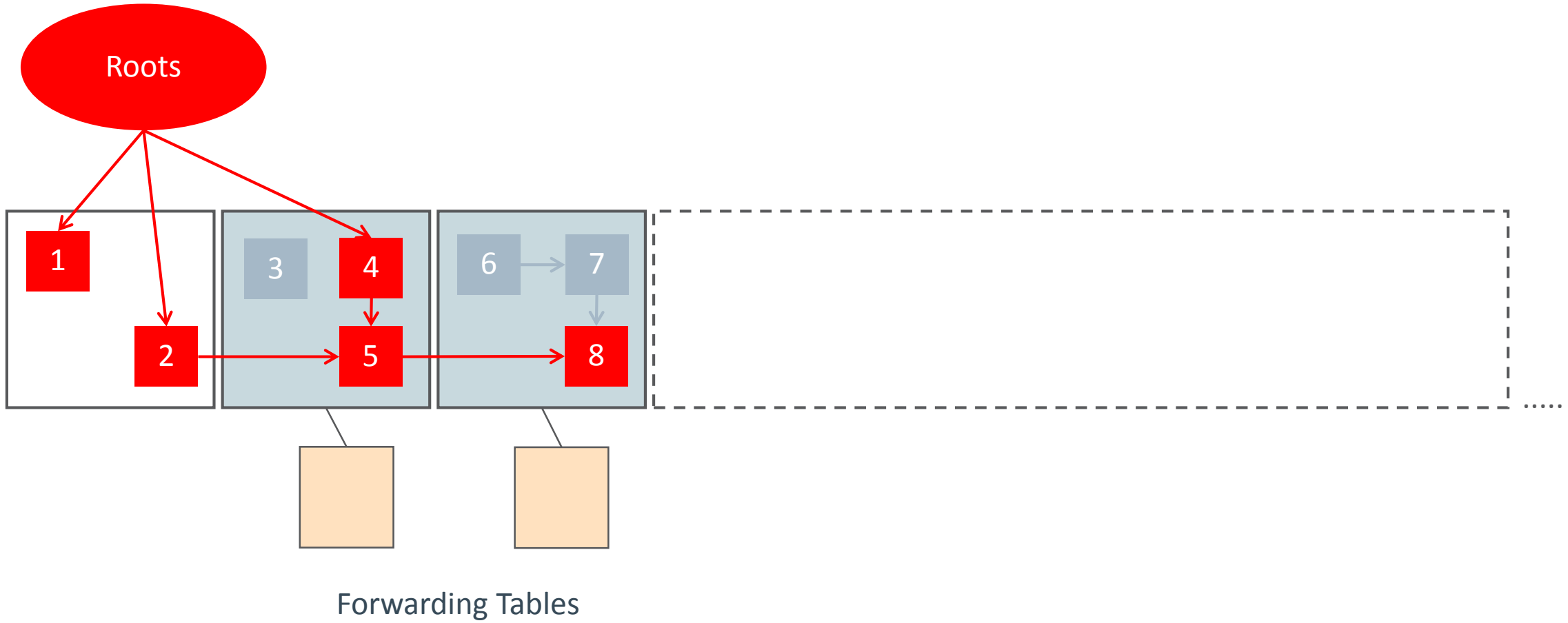
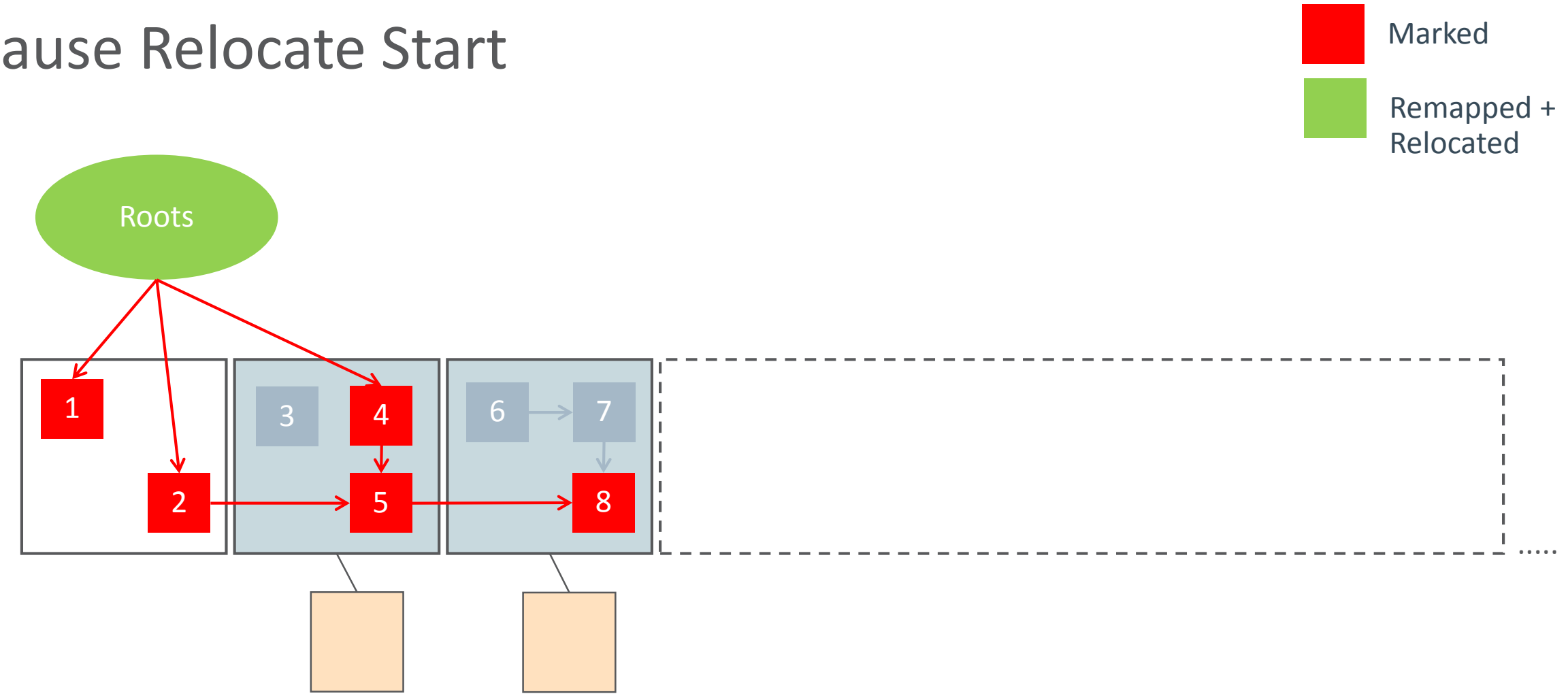


Pause Relocate Start



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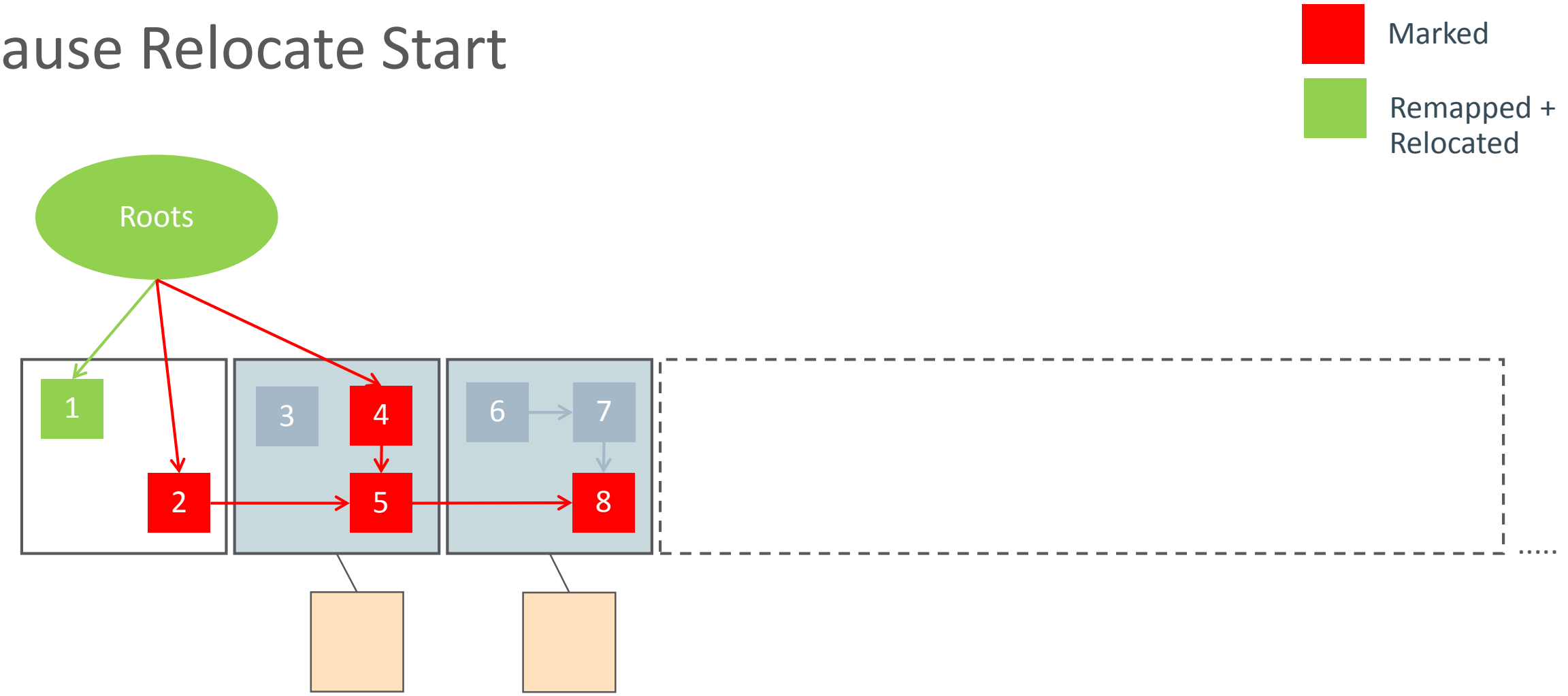

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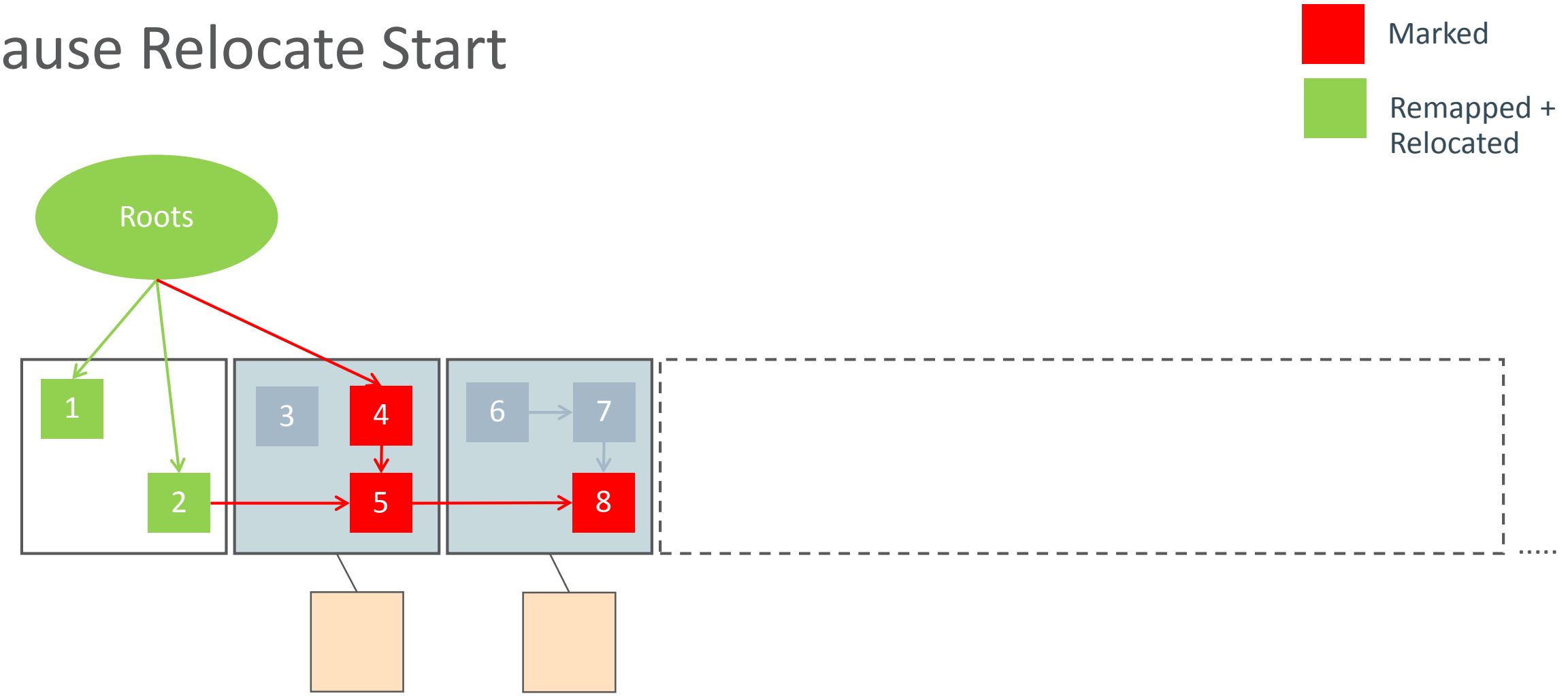

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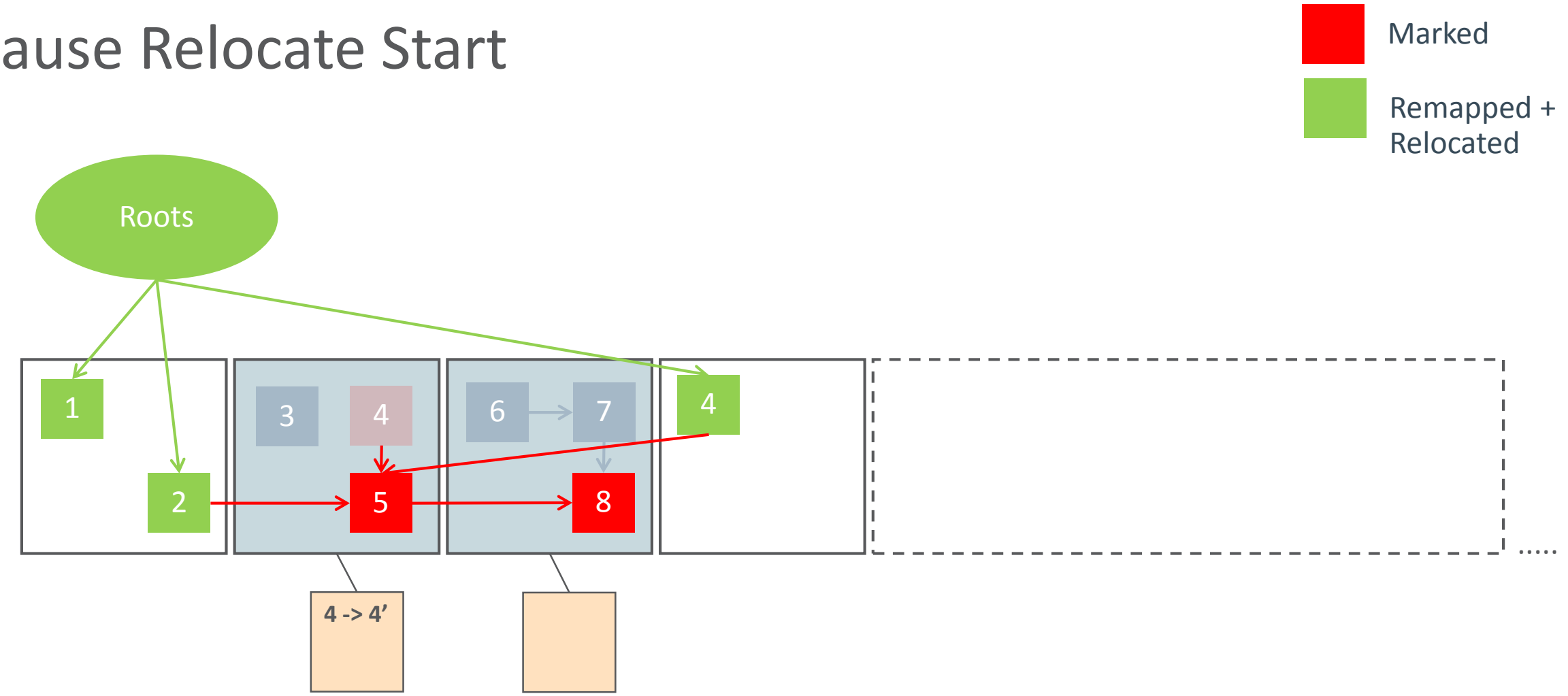

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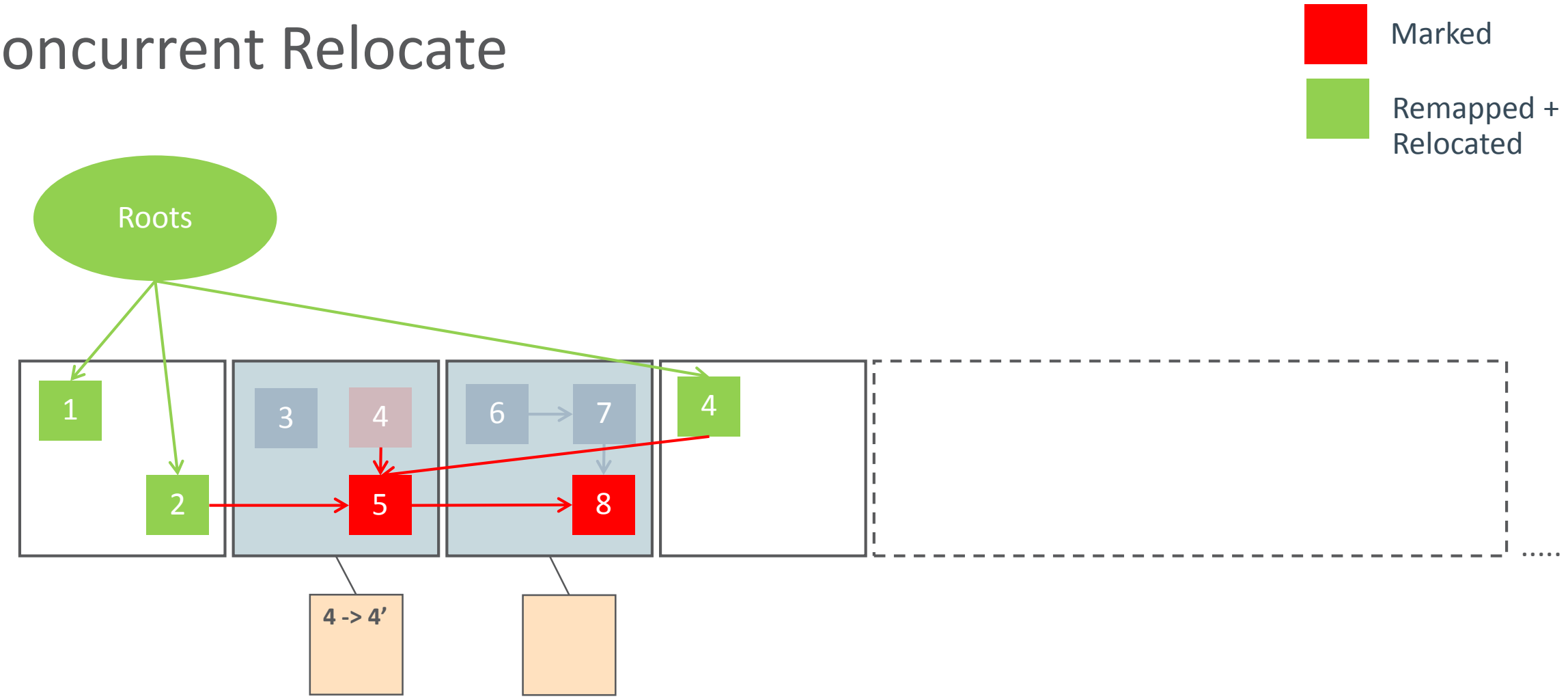

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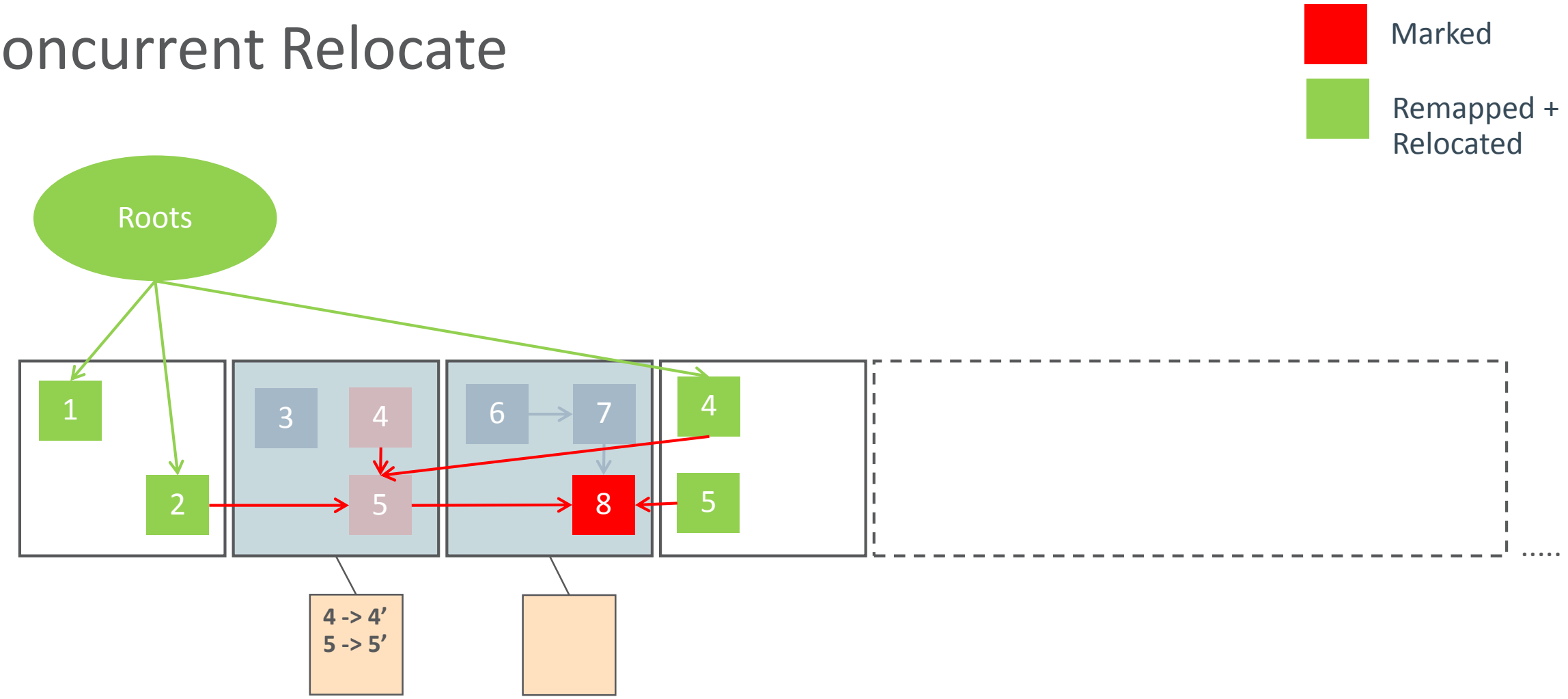

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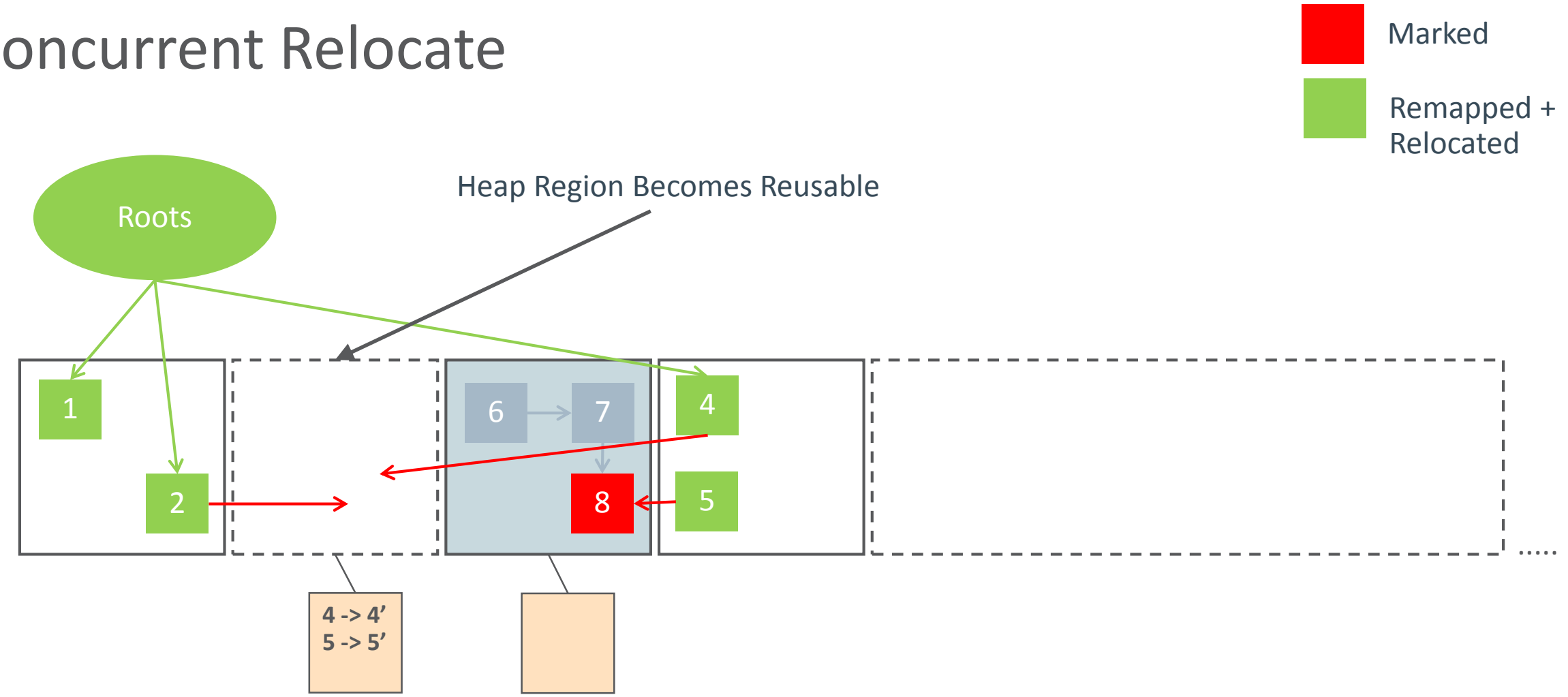

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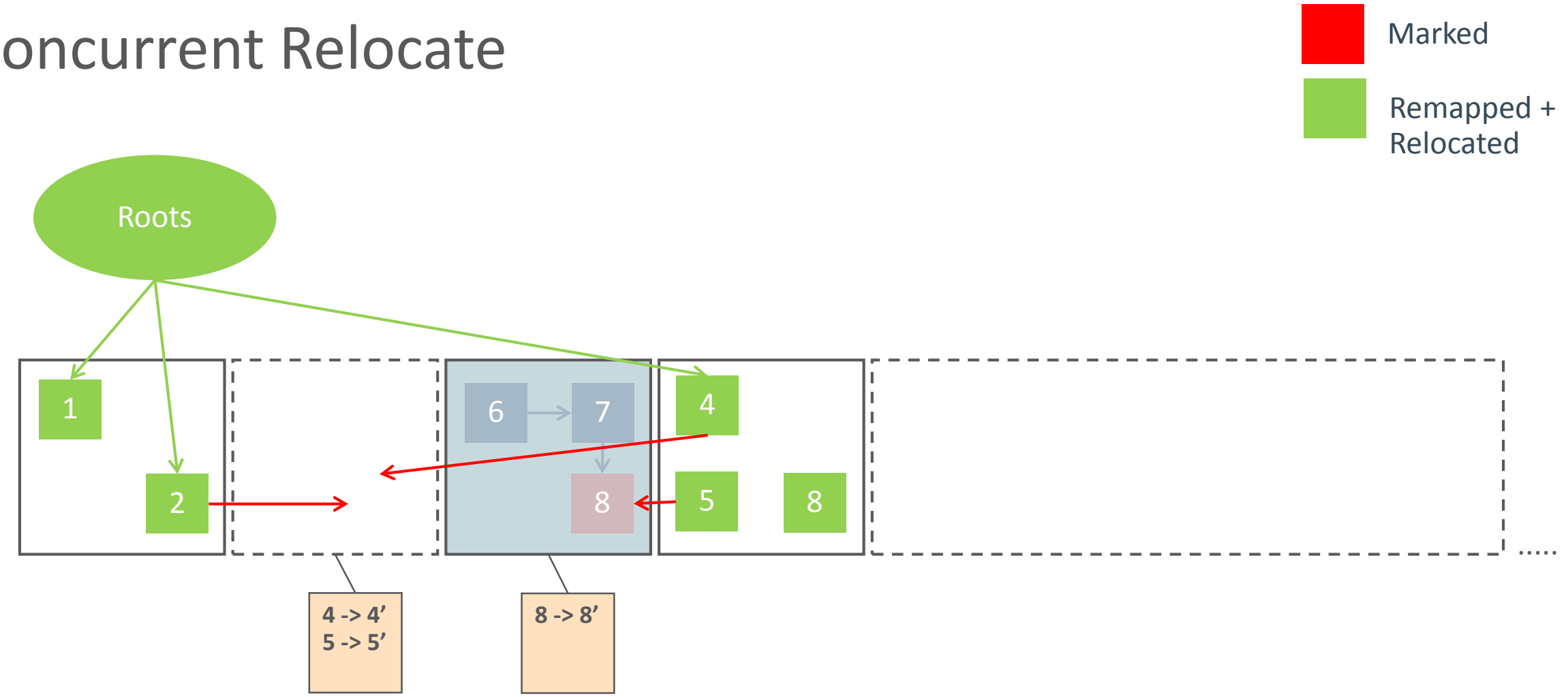

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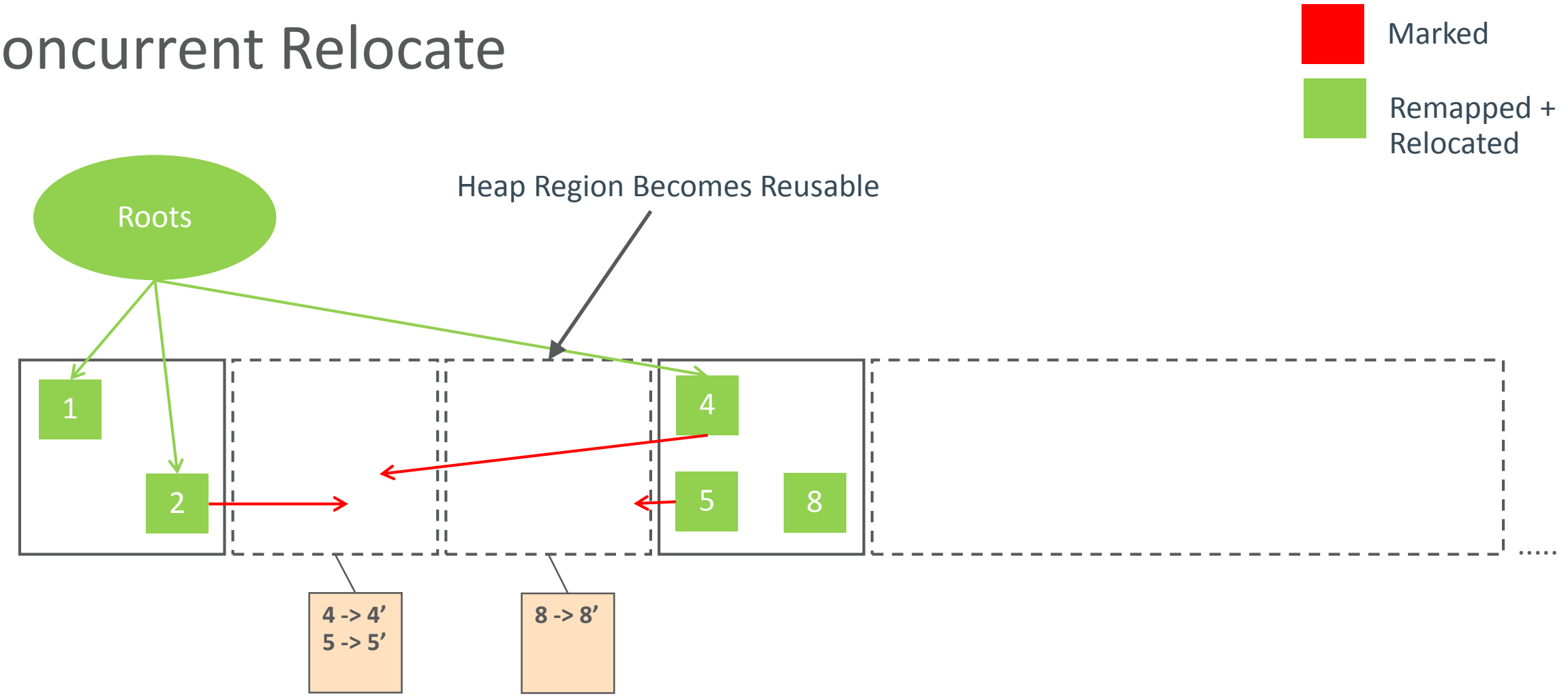
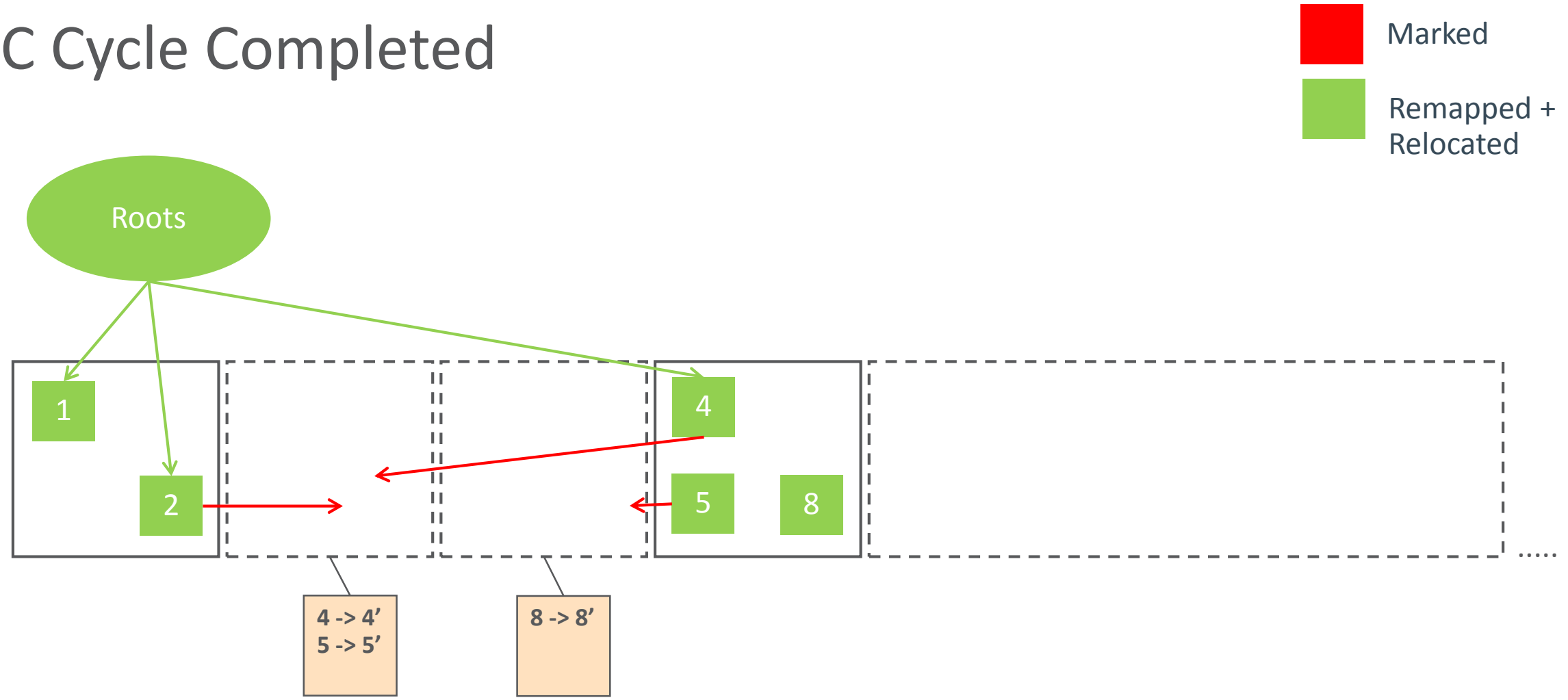


GC Cycle Completed



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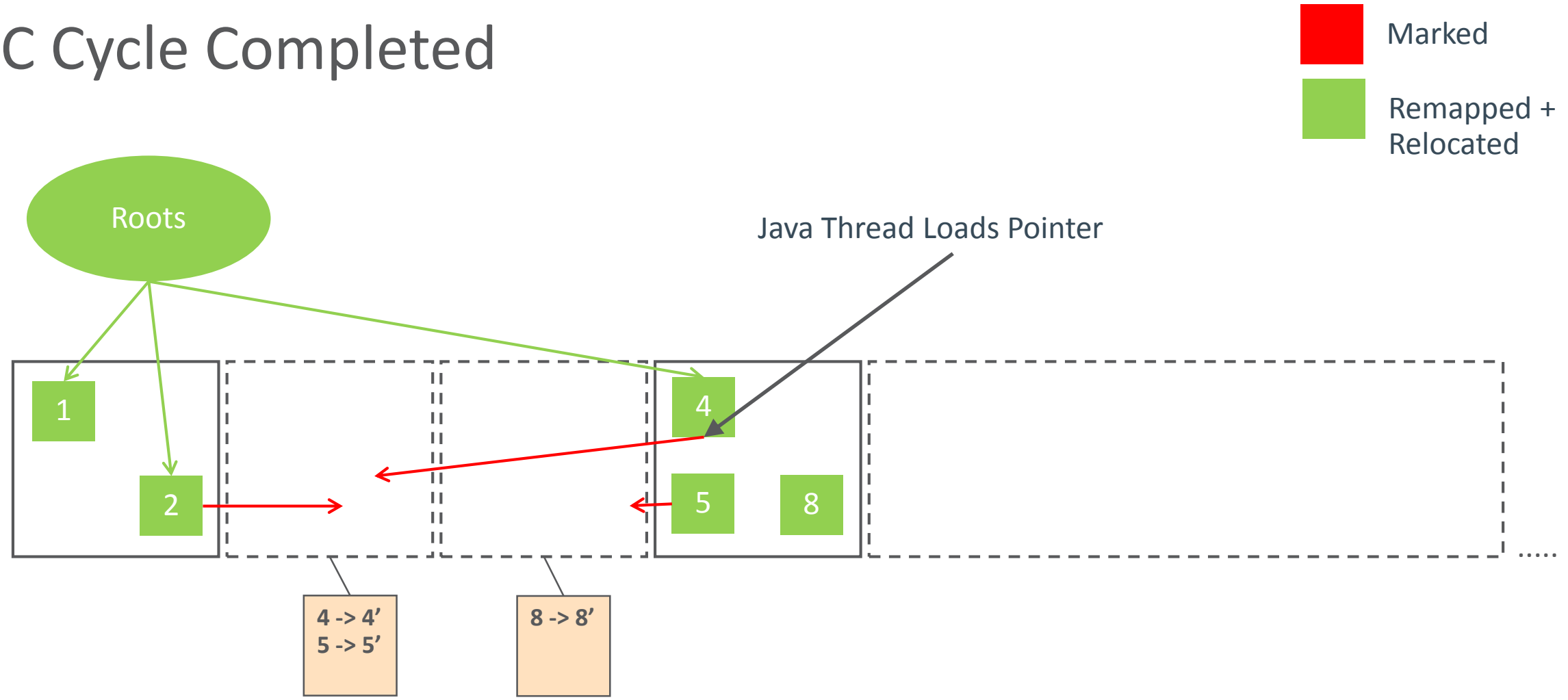
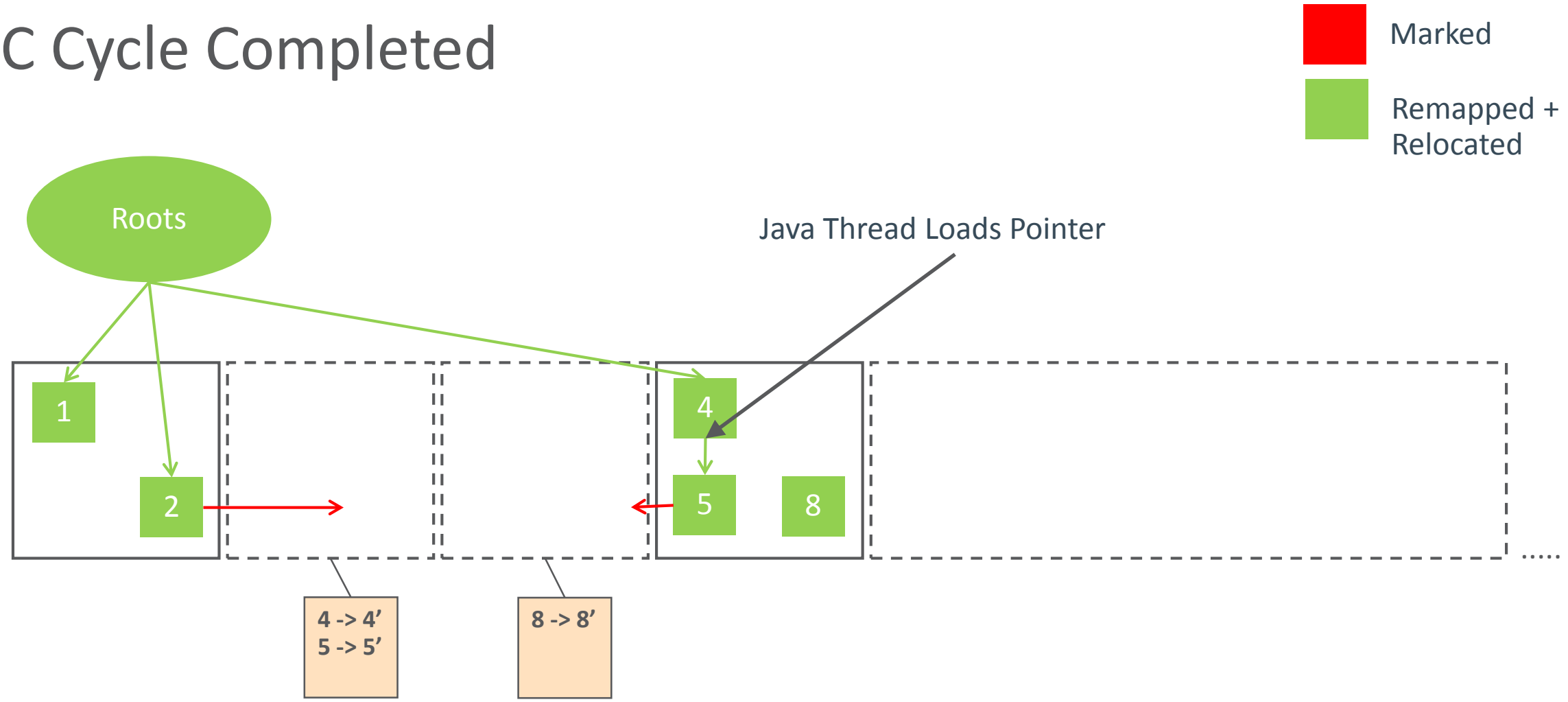
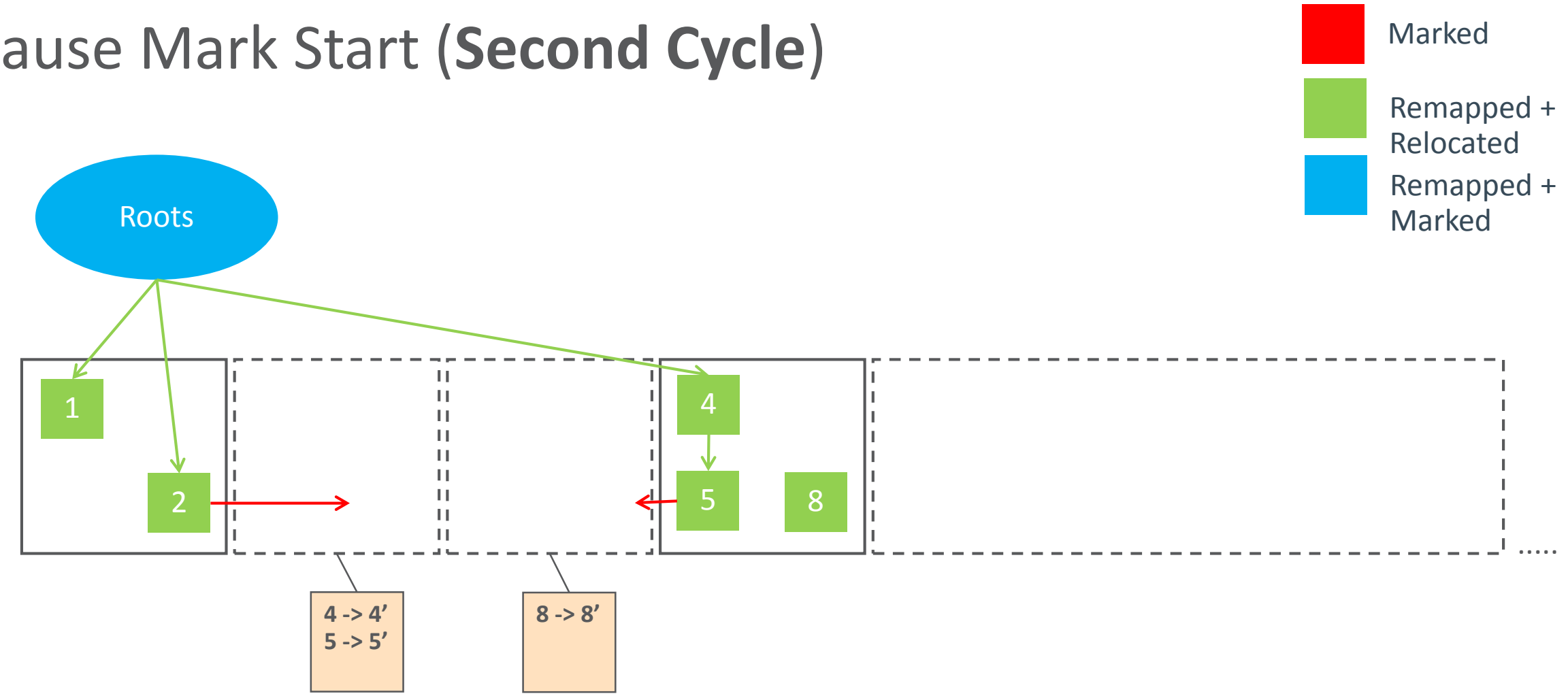


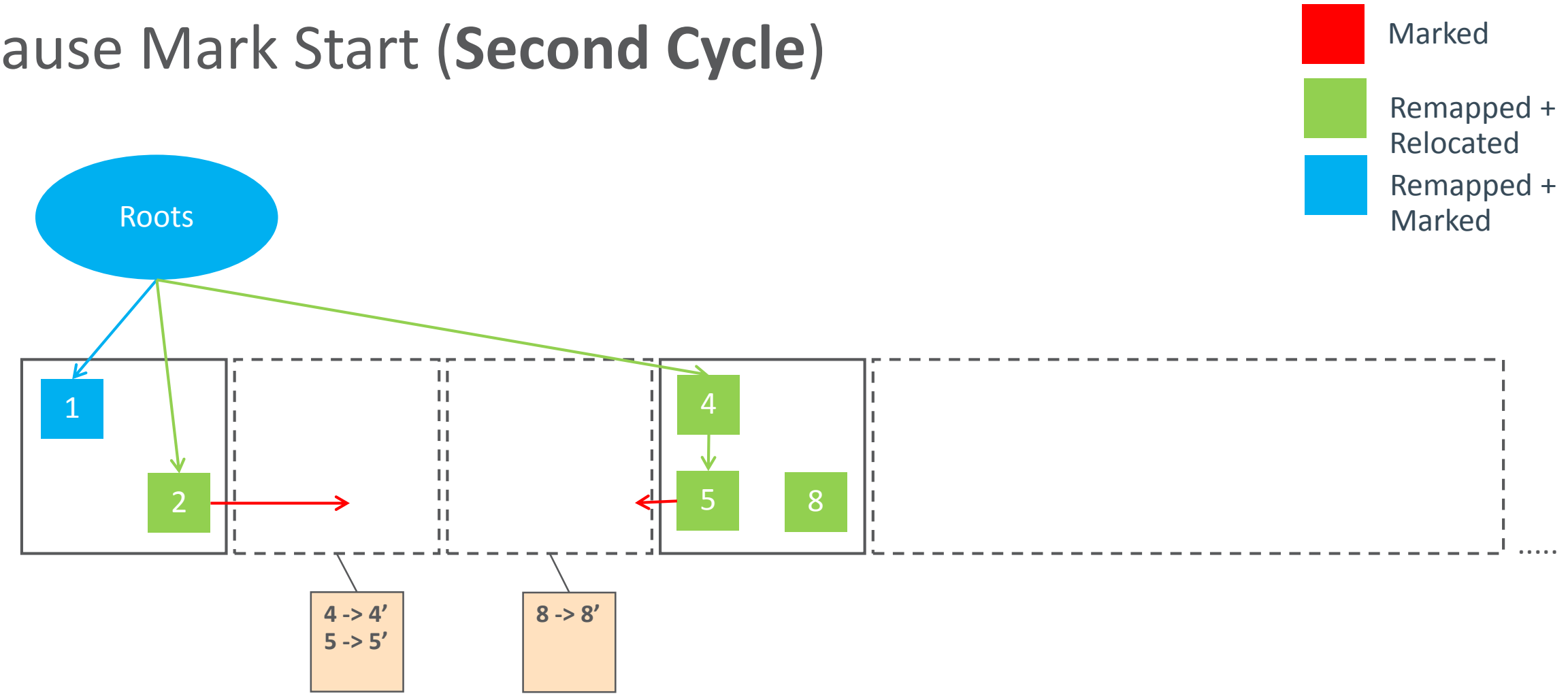
GC Cycle Completed



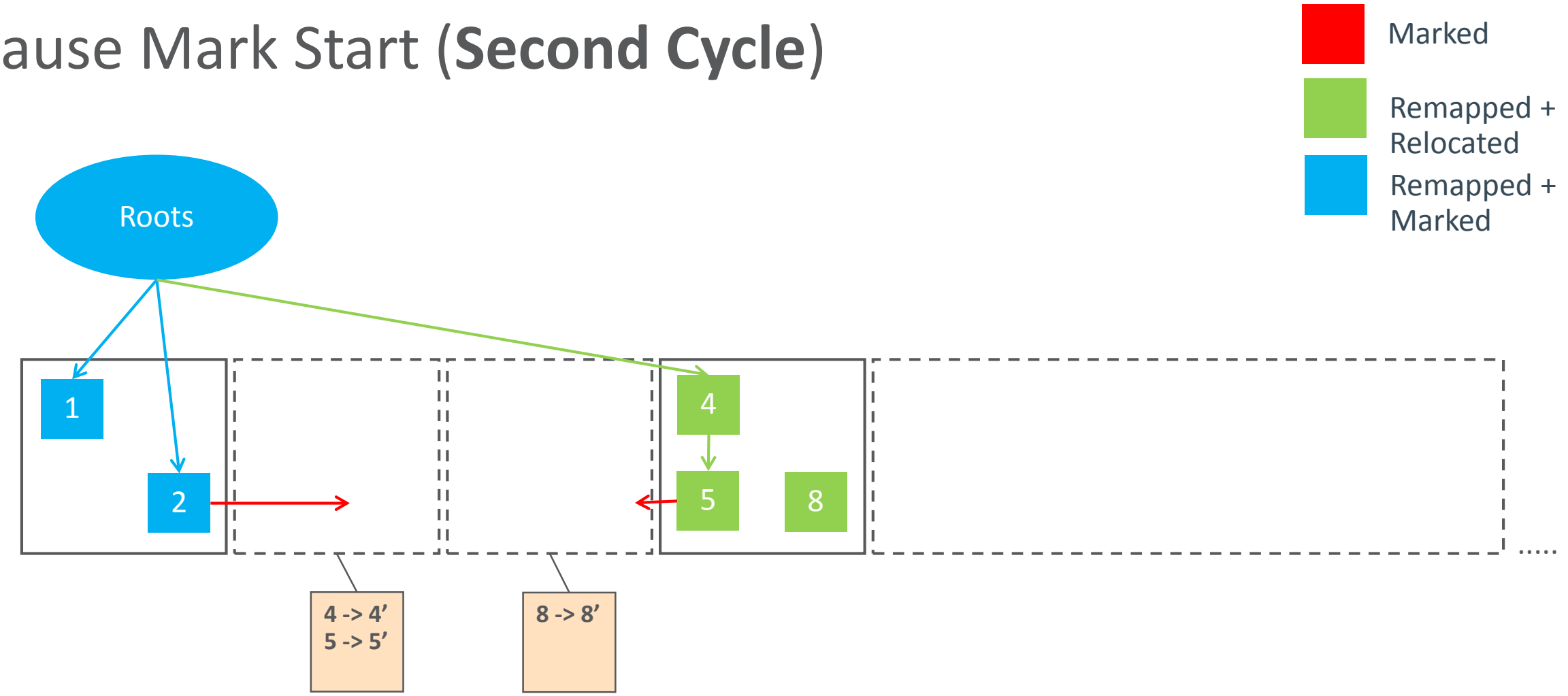
Pause Mark Start (**Second Cycle**)



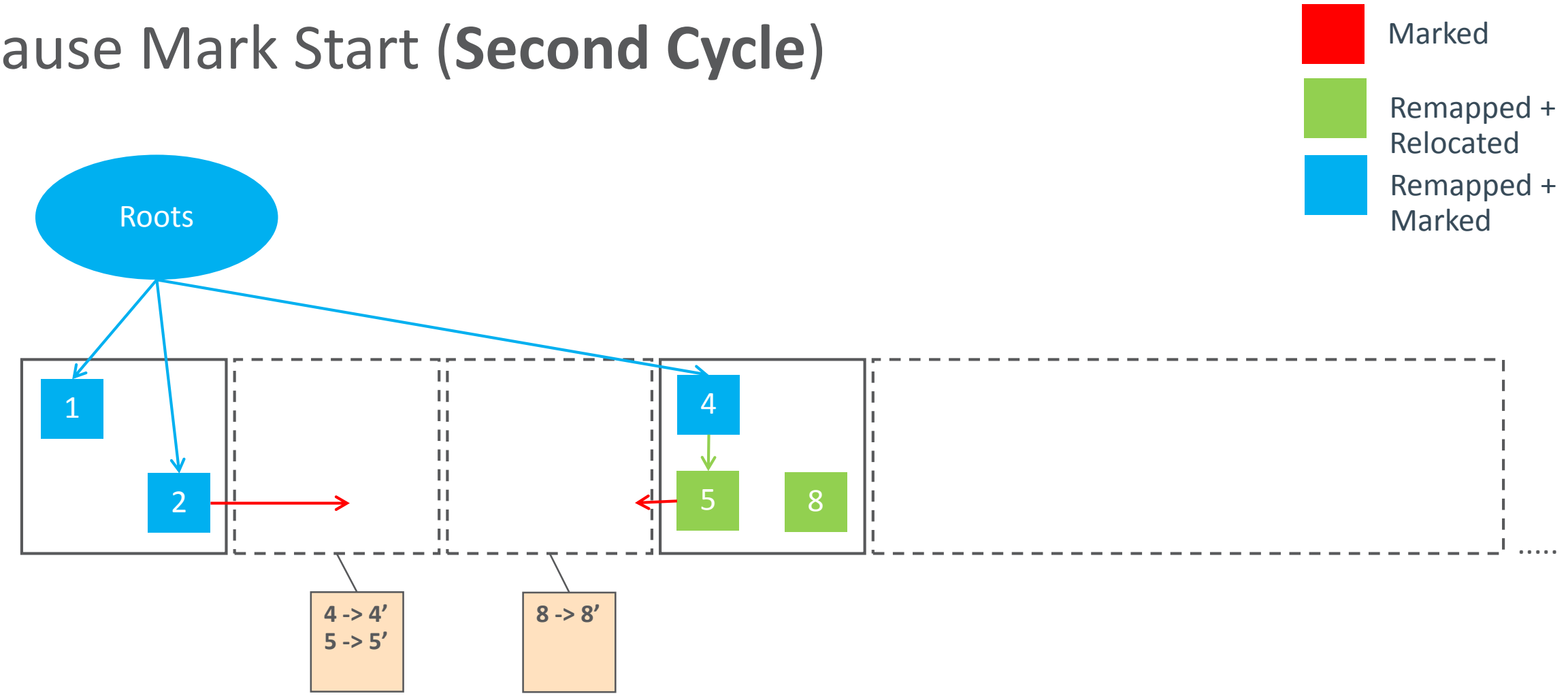
Pause Mark Start (**Second Cycle**)



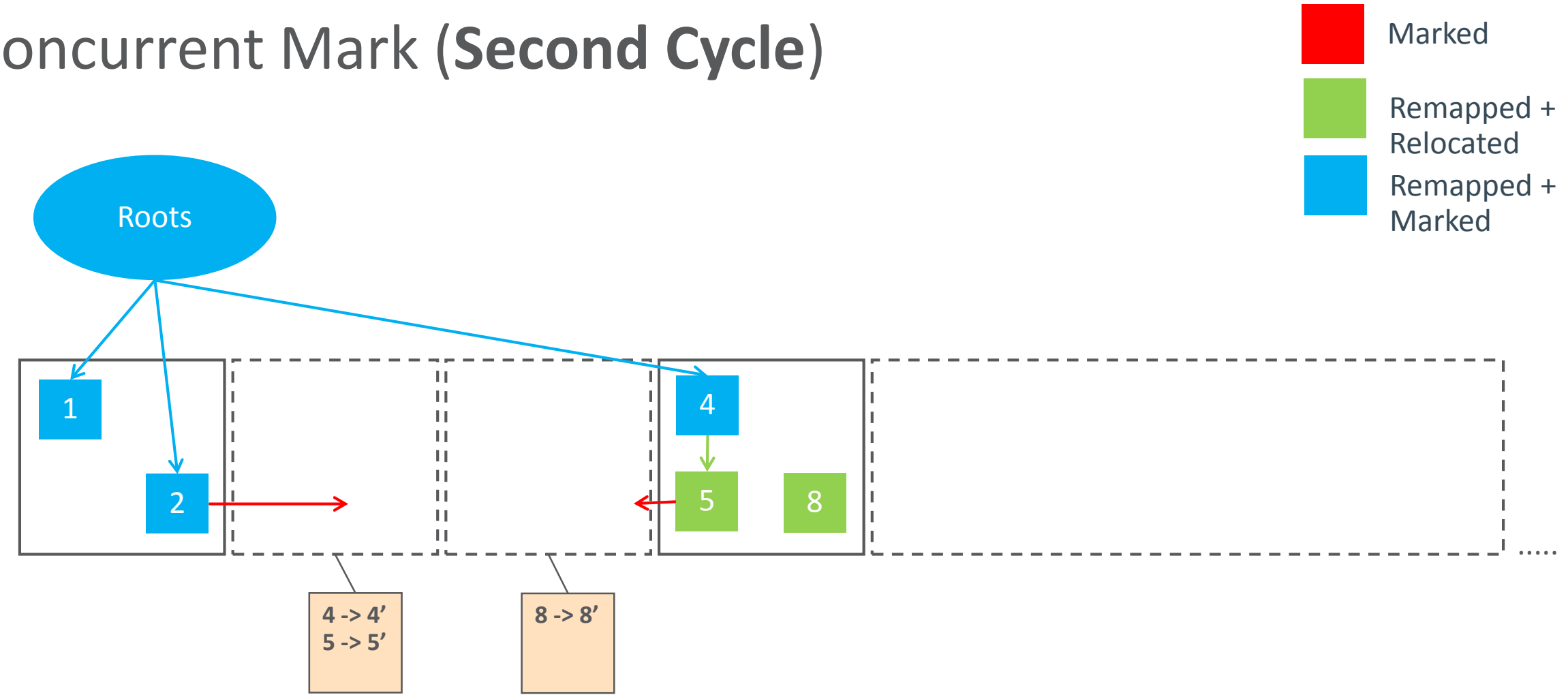
Pause Mark Start (**Second Cycle**)



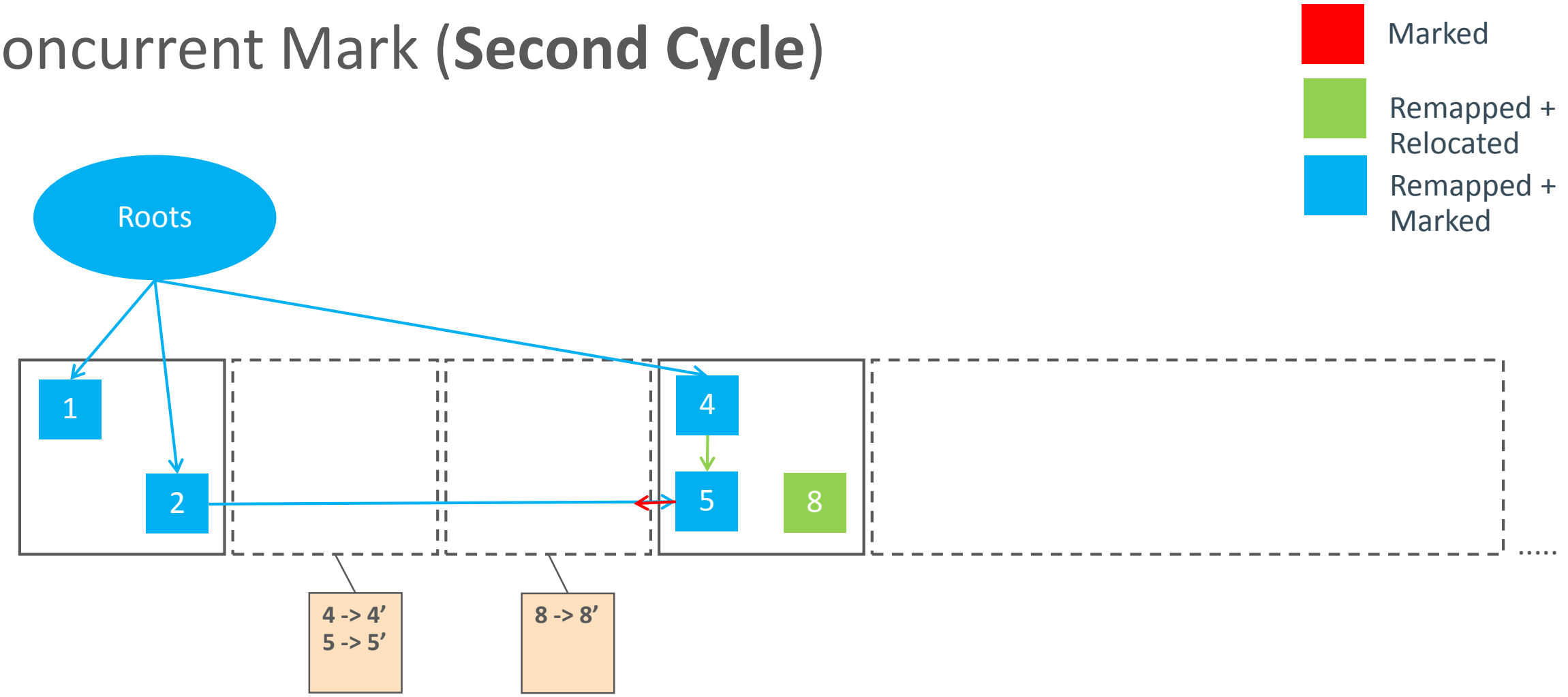
Pause Mark Start (**Second Cycle**)



Concurrent Mark (**Second Cycle**)



Concurrent Mark (**Second Cycle**)



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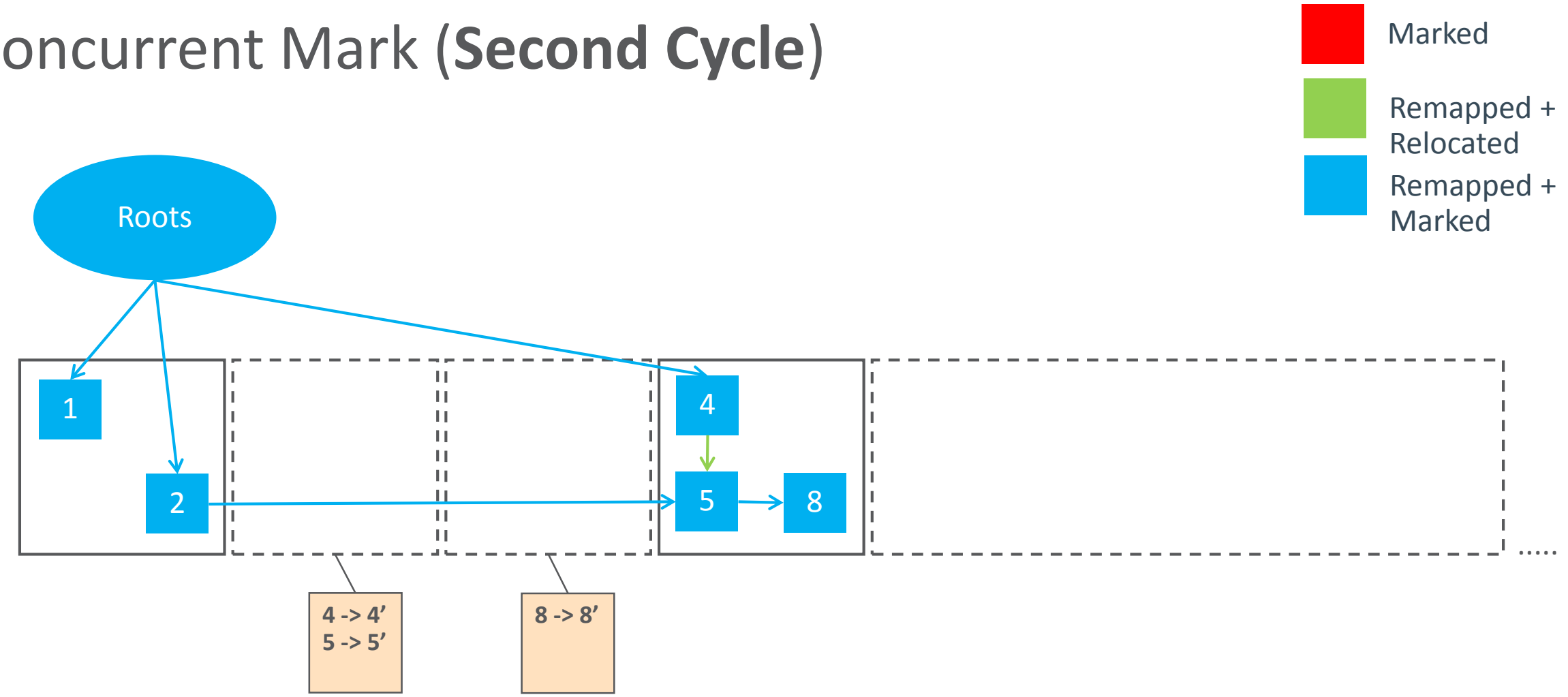
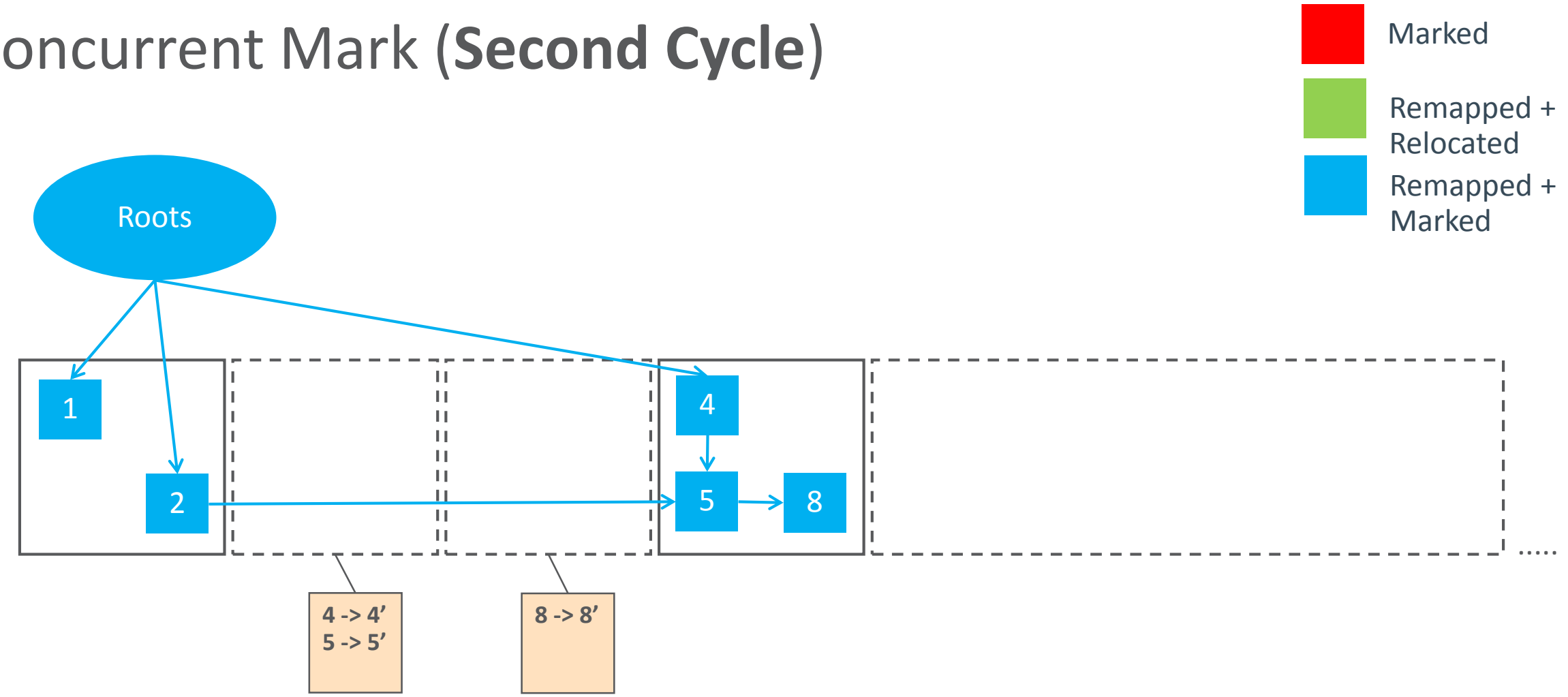
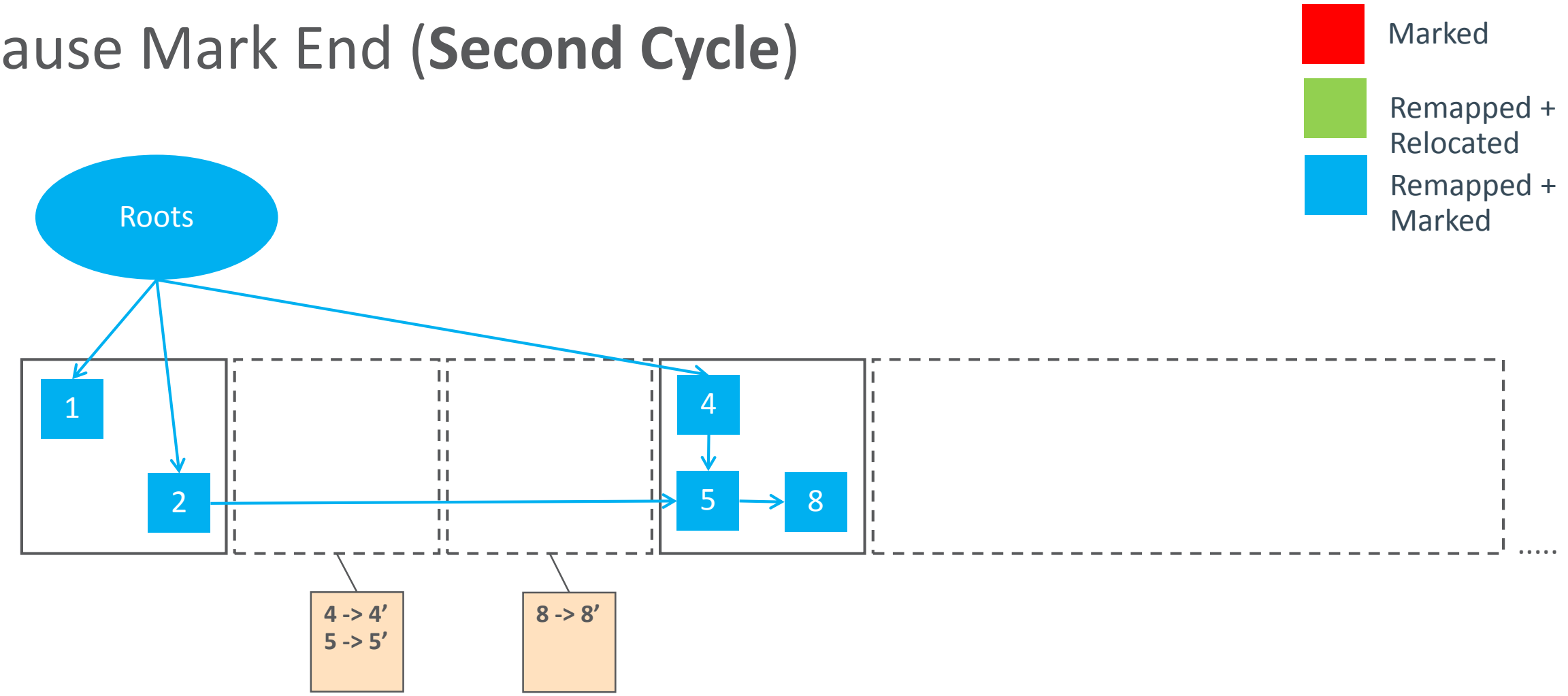


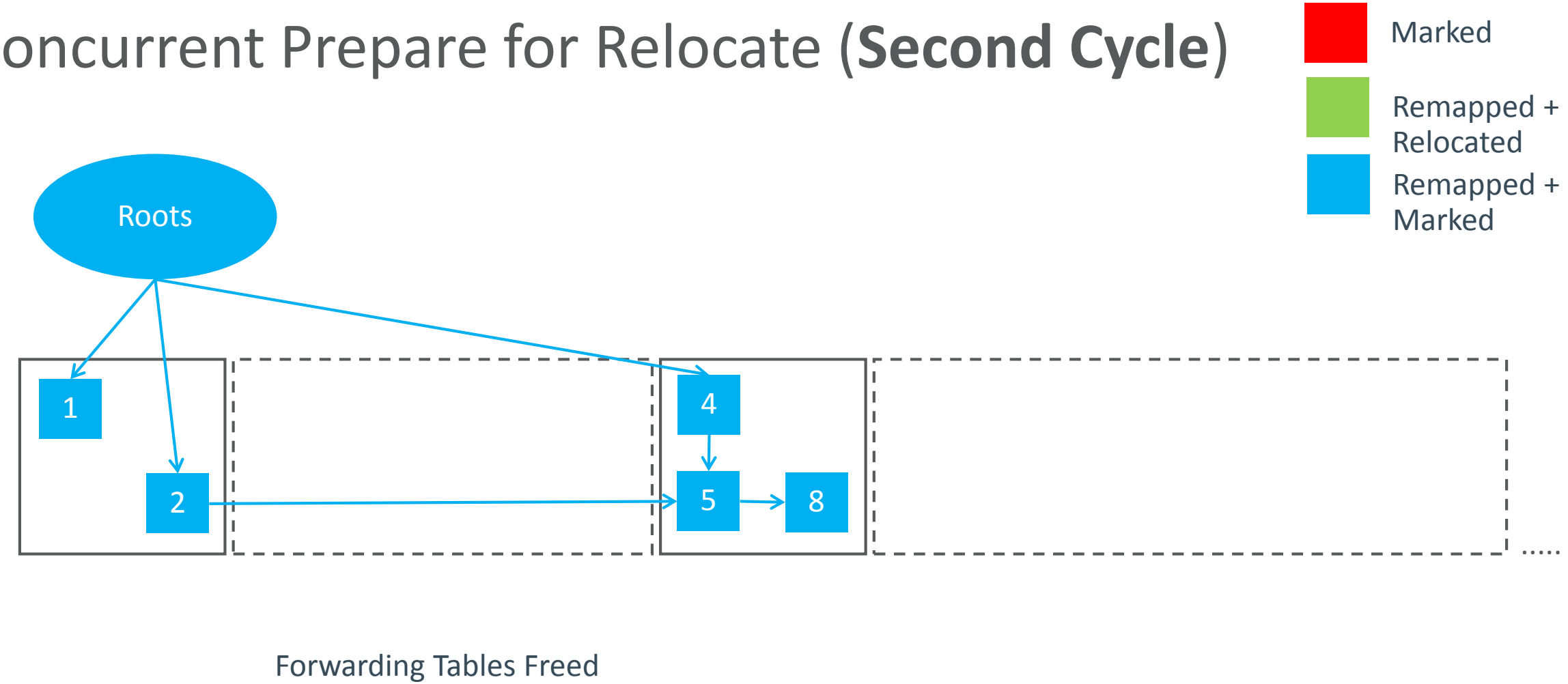
Concurrent Mark (**Second Cycle**)



Pause Mark End (**Second Cycle**)

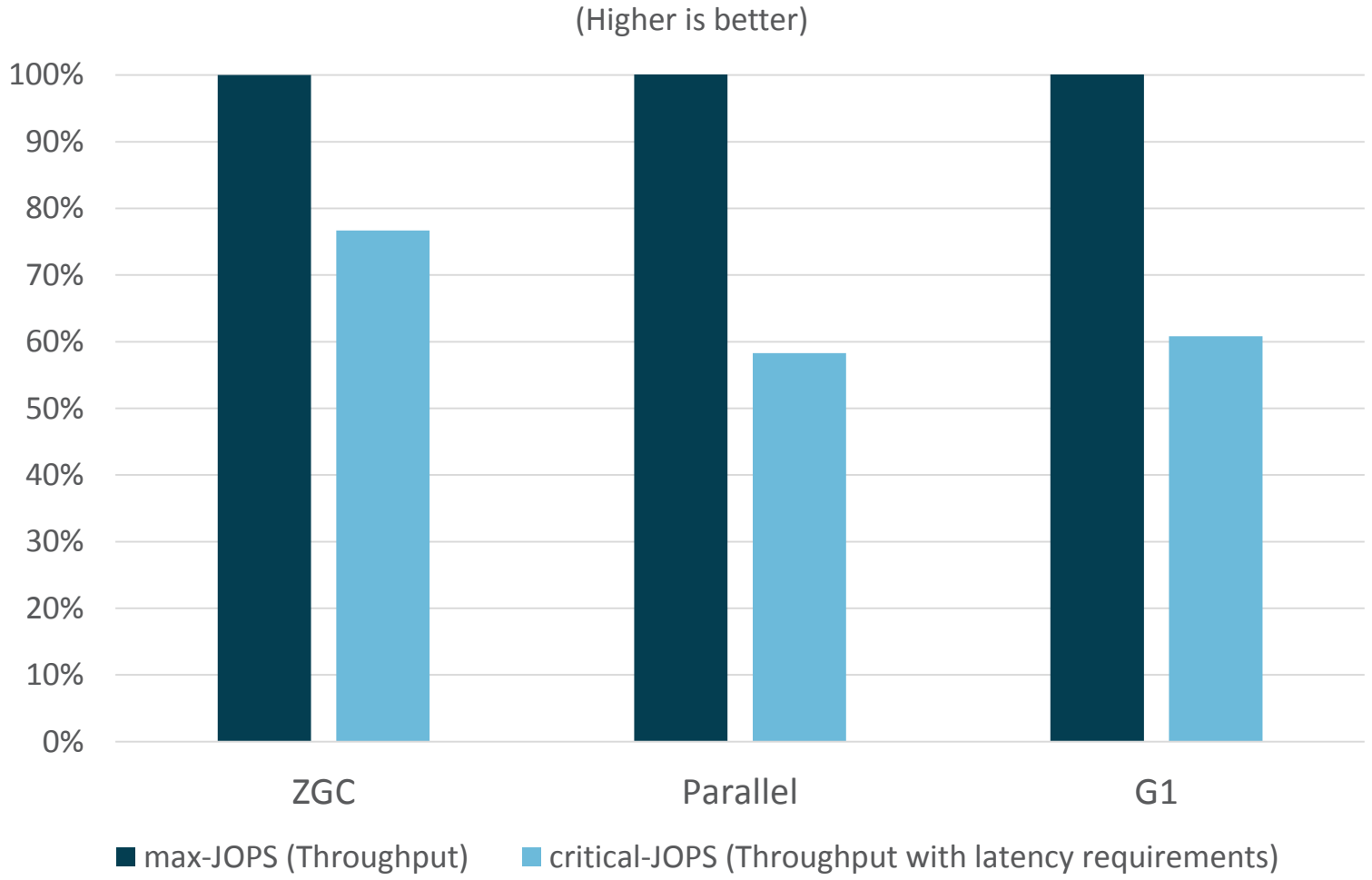


Concurrent Prepare for Relocate (**Second Cycle**)



Performance

SPECjbb®2015 – Score



Mode: Composite

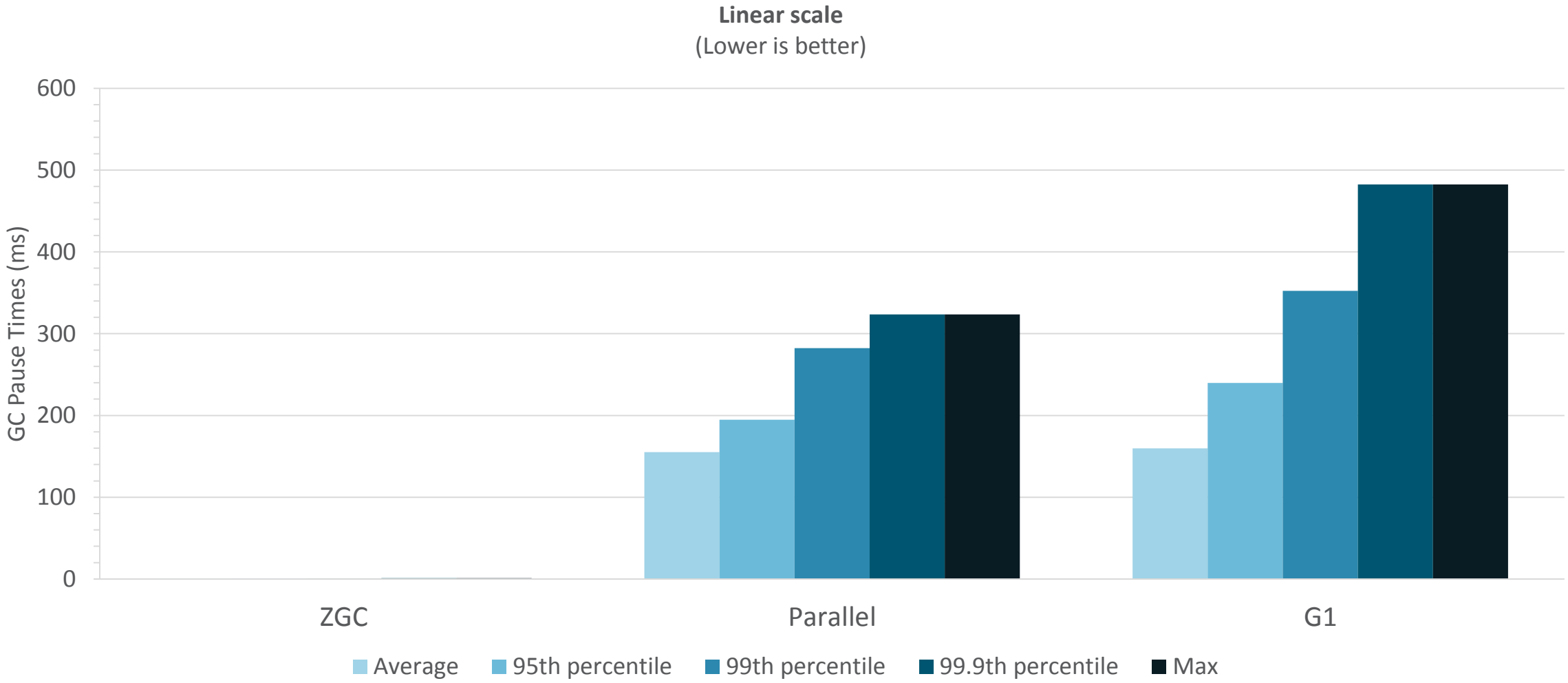
Heap Size: 128G

OS: Oracle Linux 7.5

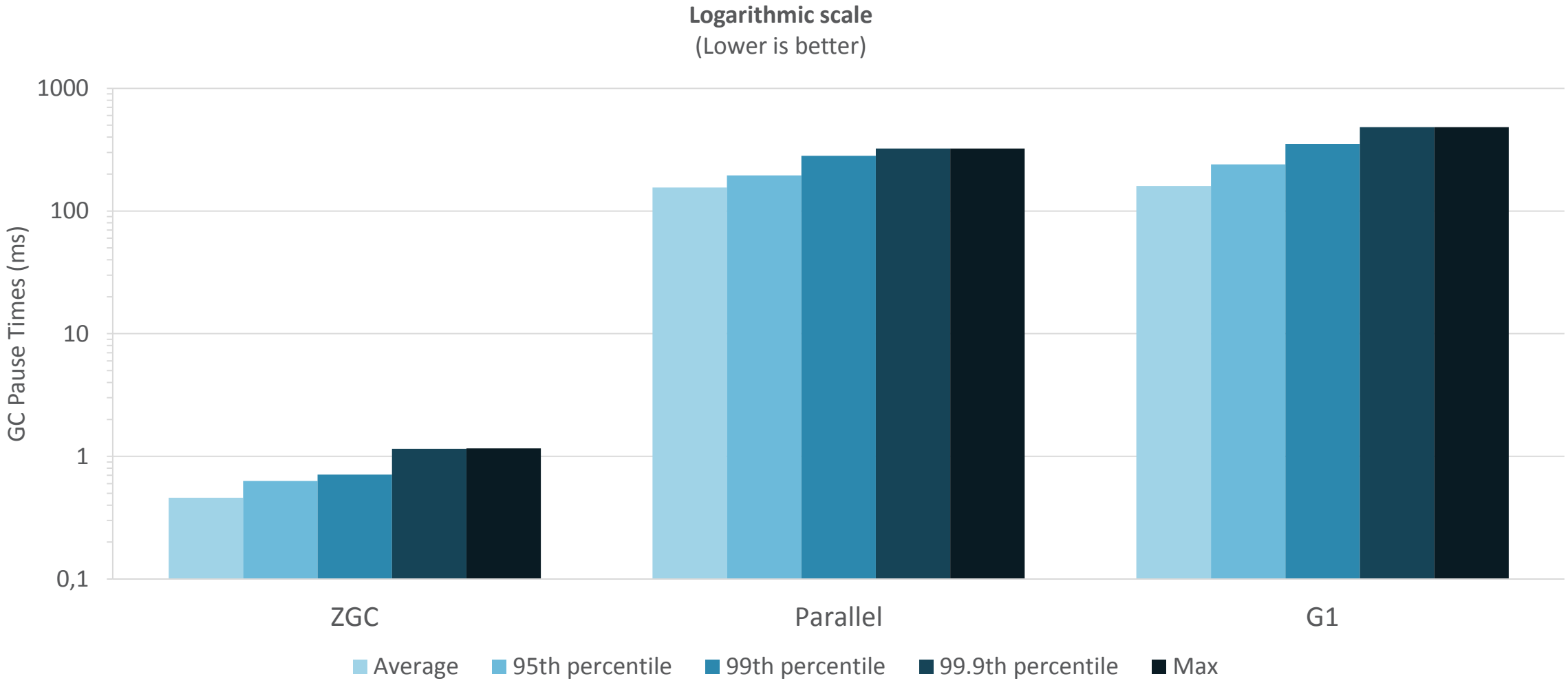
HW: Intel Xeon E5-2690 2.9GHz
2 sockets, 16 cores (32 hw-threads)

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.

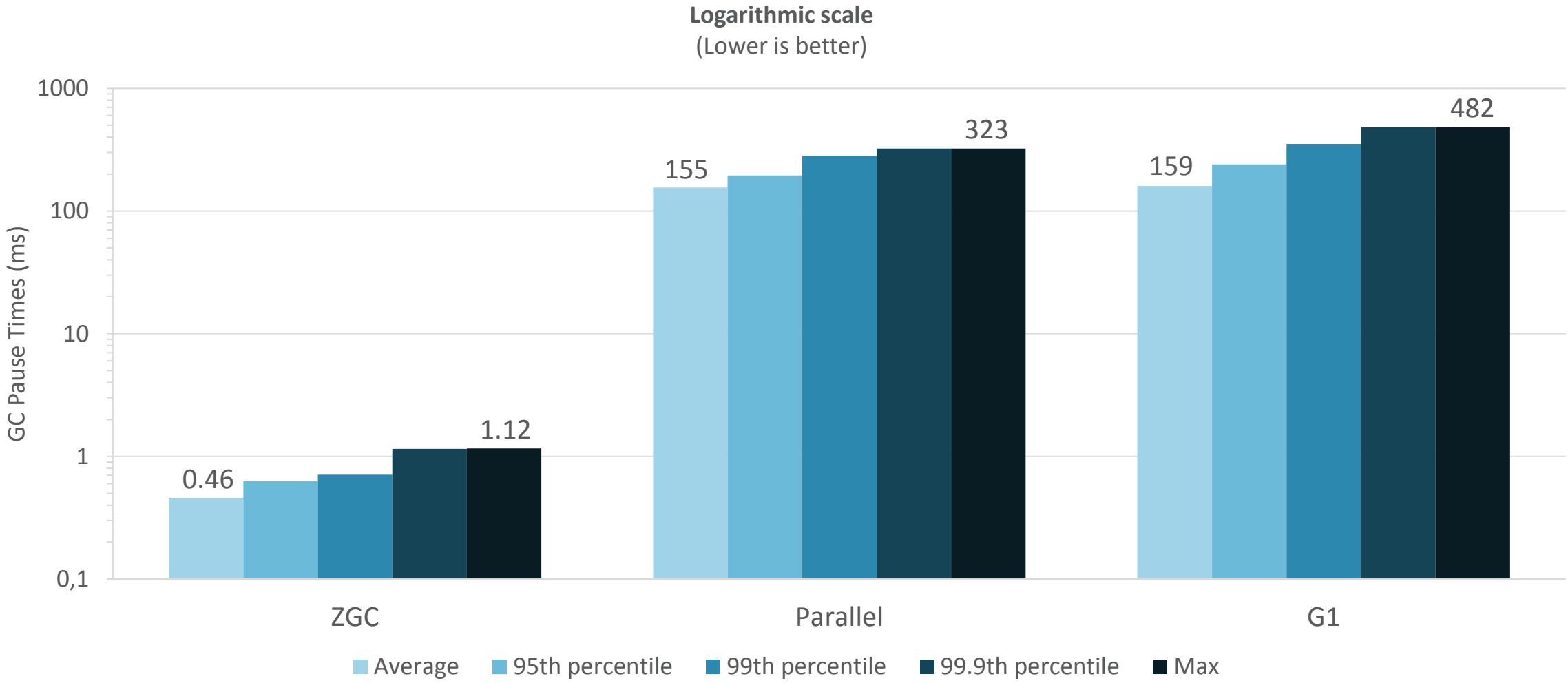
SPECjbb®2015 – GC Pause Times



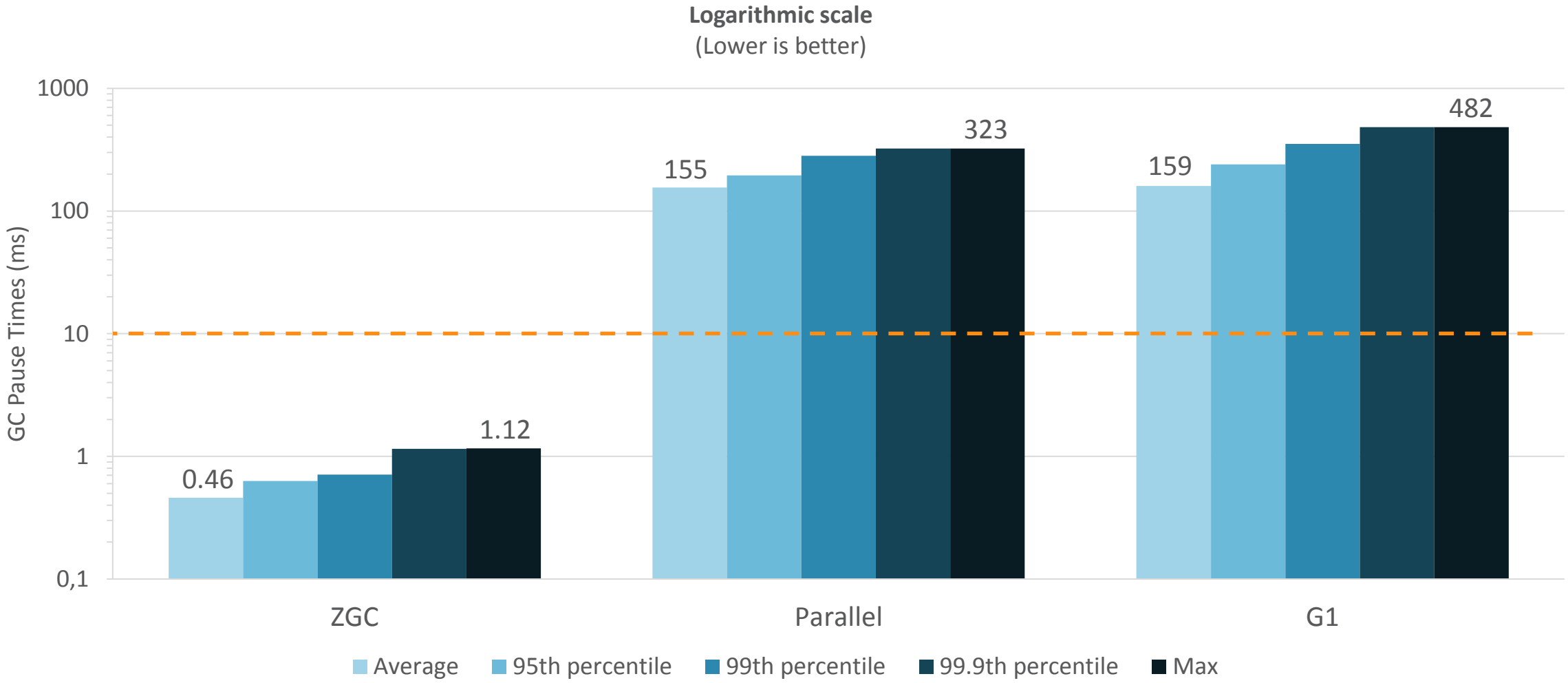
SPECjbb®2015 – GC Pause Times



SPECjbb®2015 – GC Pause Times



SPECjbb®2015 – GC Pause Times



Going Forward

- Generational
- Sub-millisecond *max* pause times
- Support additional platforms
- Graal JIT support

ZGC Project

OpenJDK

Mailing lists

hotspot-gc-dev@openjdk.java.net
zgc-dev@openjdk.java.net

Wiki

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

Source

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

Java™ ORACLE

Thanks!

Questions?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