The Z Garbage Collector

Low Latency GC for OpenJDK

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HotSpot Garbage Collection Team
Jfokus VM Tech Summit 2018

Safe Harbor Statement

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Agenda

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

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A Scalable Low Latency Garbage Collector

Goals

TB Multi-terabyte heaps

10ms Max GC pause time

Lay the foundation for future GC features

15% Max application throughput reduction

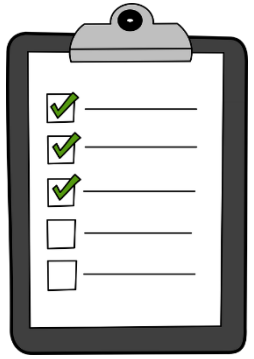
GC pause times **do not** increase with heap or live-set size

At a Glance

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

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

Current Status



- Design and implementation approaching mature and stable
- Main focus on **Linux/x86_64**
  - Other platforms can be added if there's enough demand
- Performance looks very good
  - Both in terms of latency and throughput

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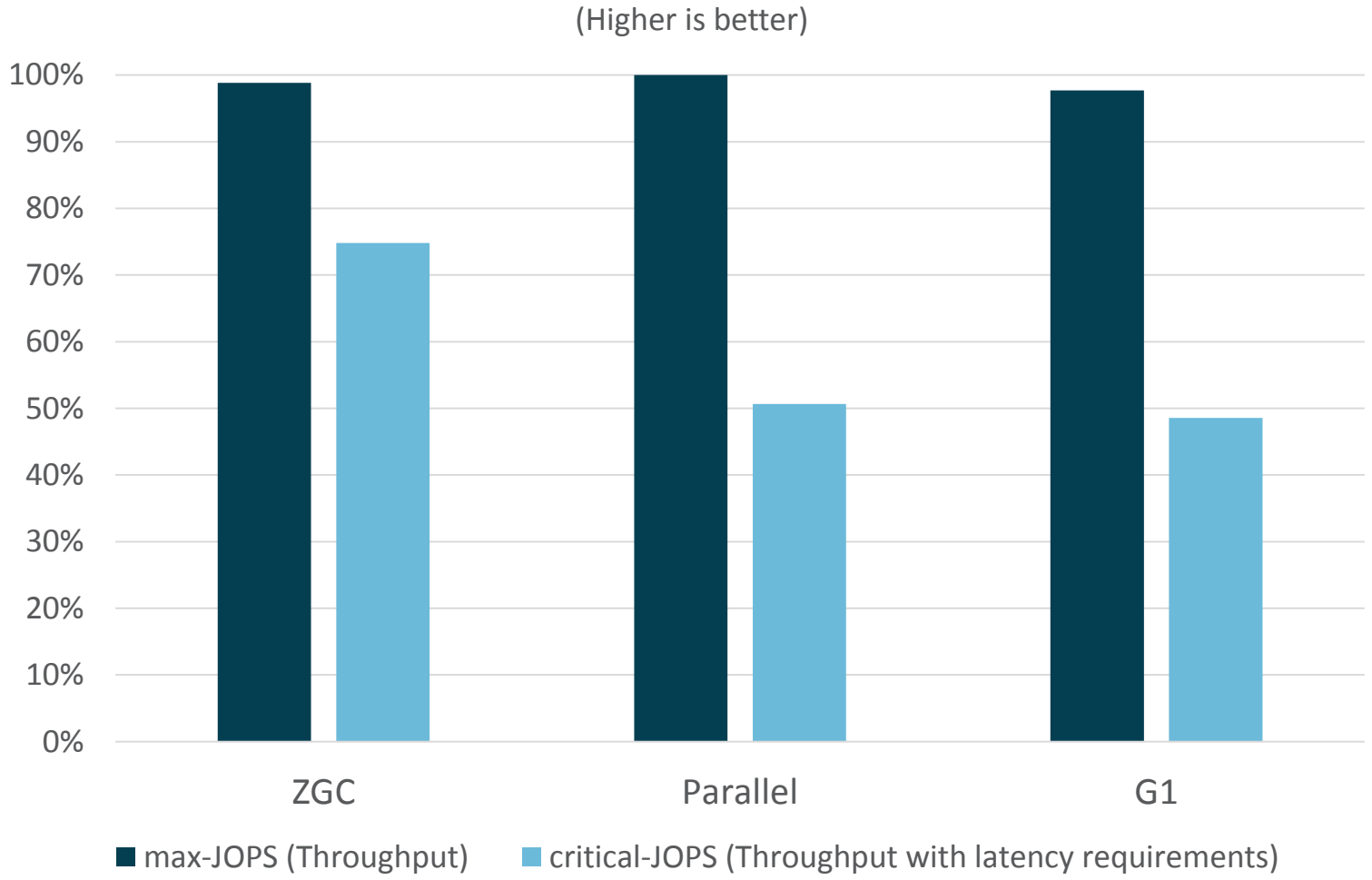
SPECjbb®2015 – Score



Mode: Composite

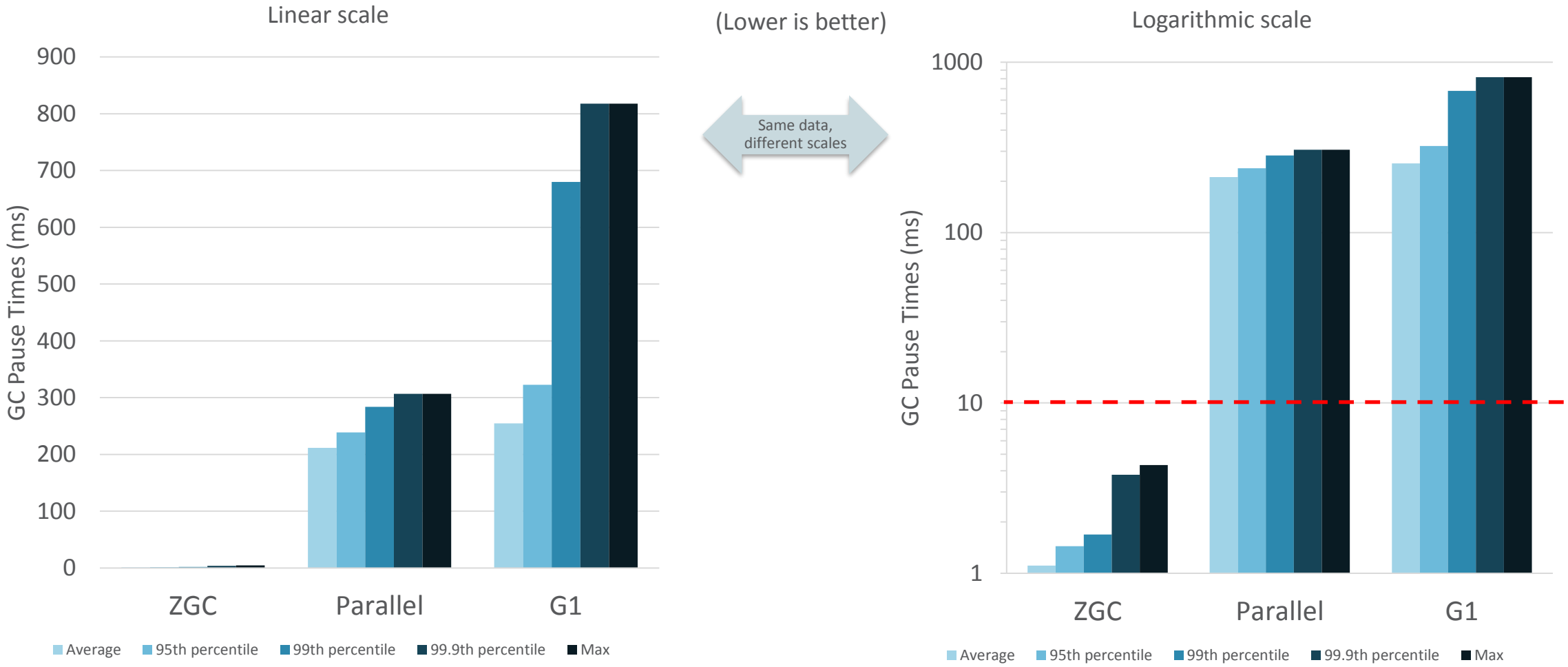
Heap Size: 128G

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.

SPECjbb®2015 – Pause Times



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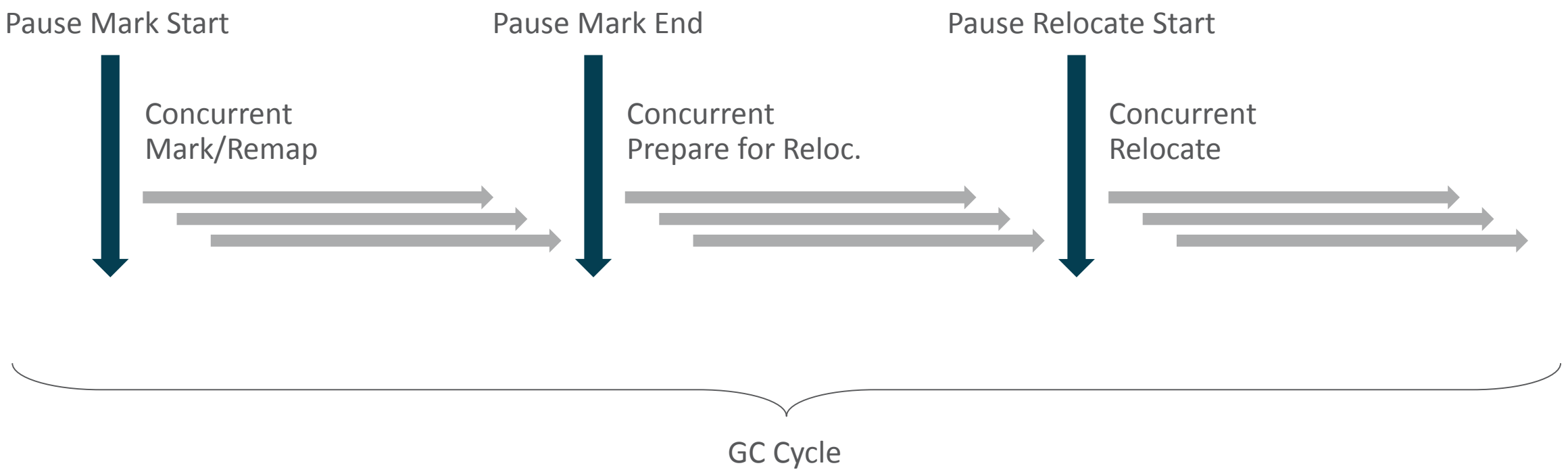
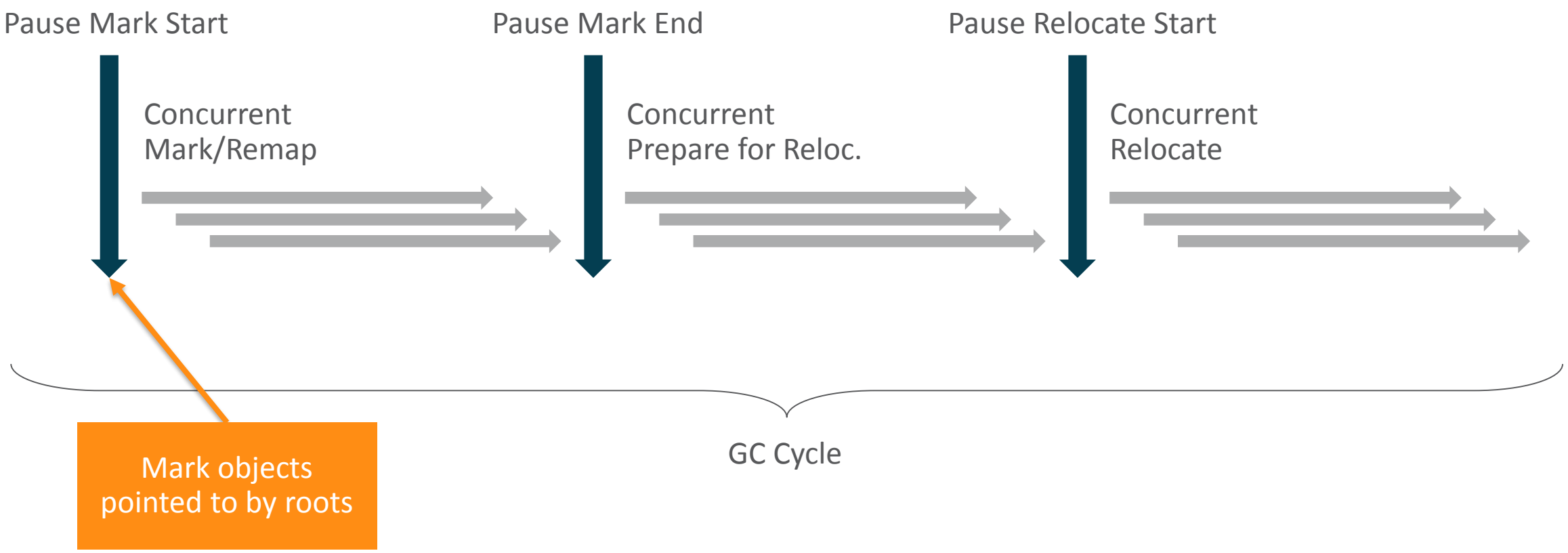
ZGC Phases



ZGC Phases



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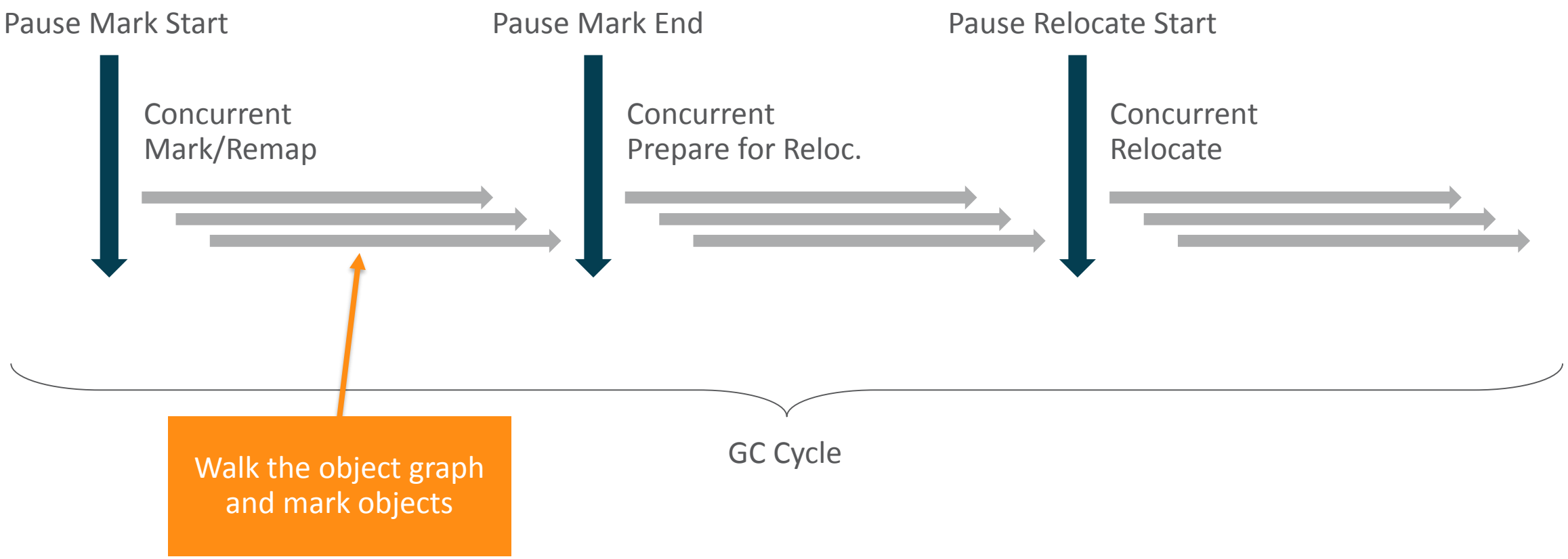

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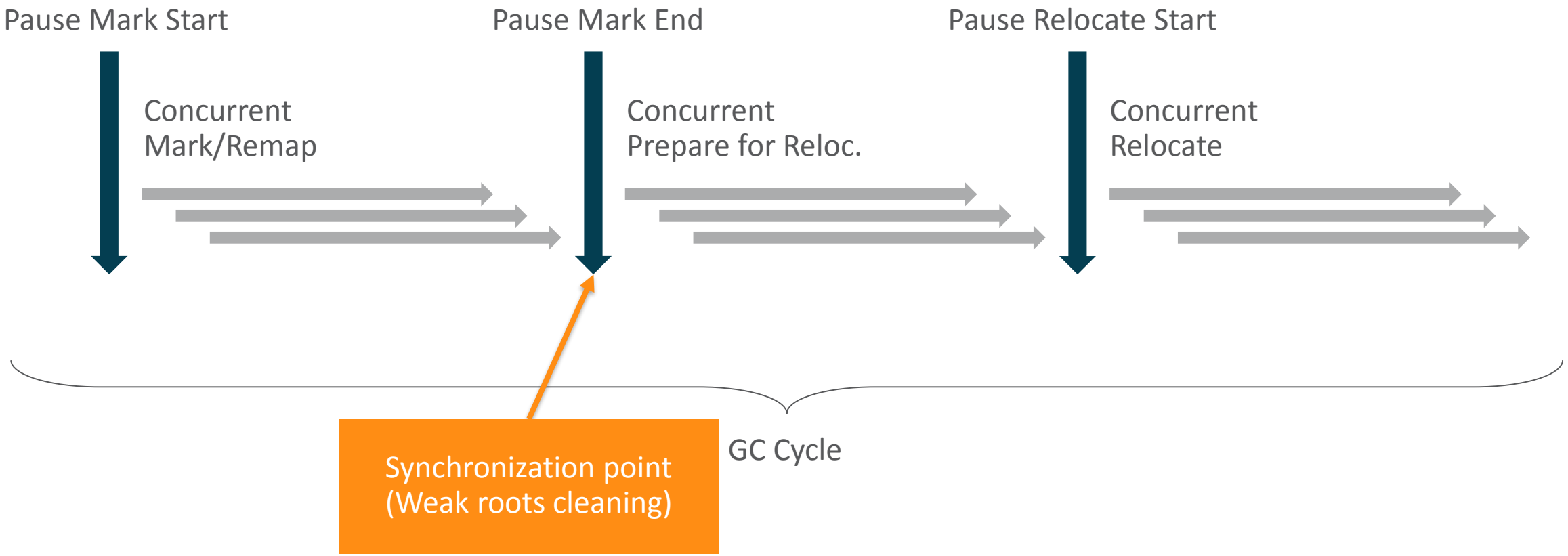

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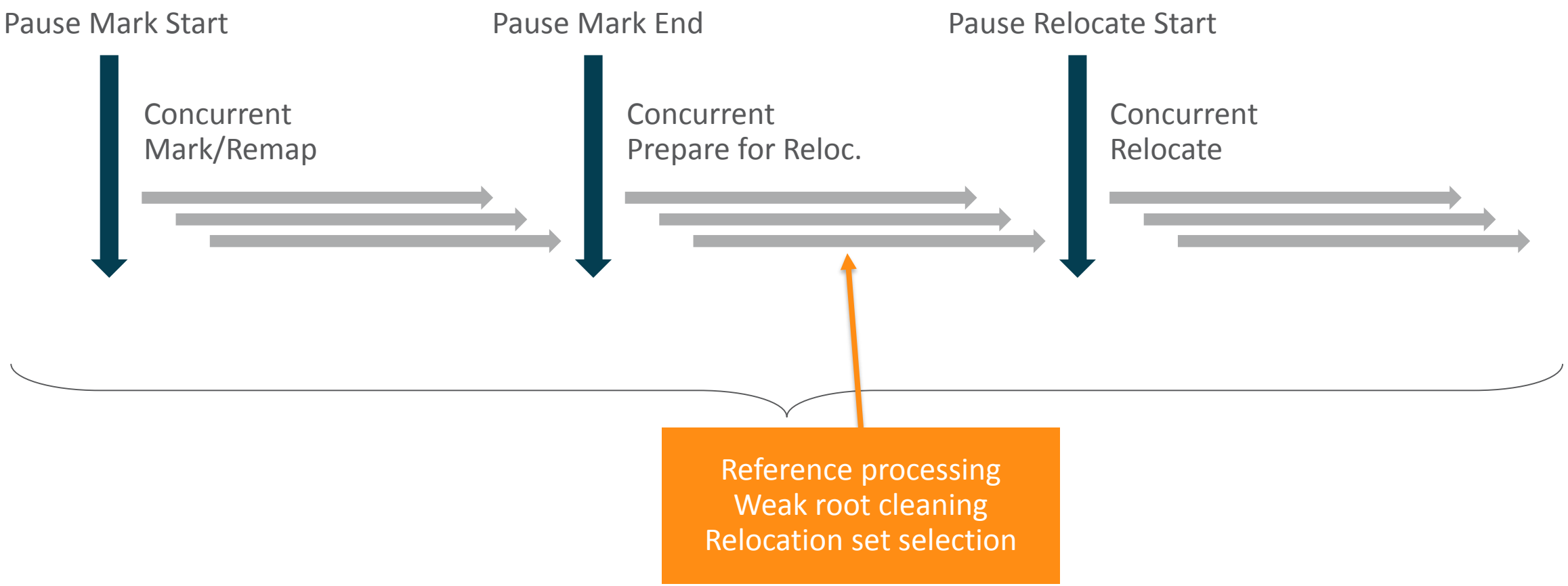

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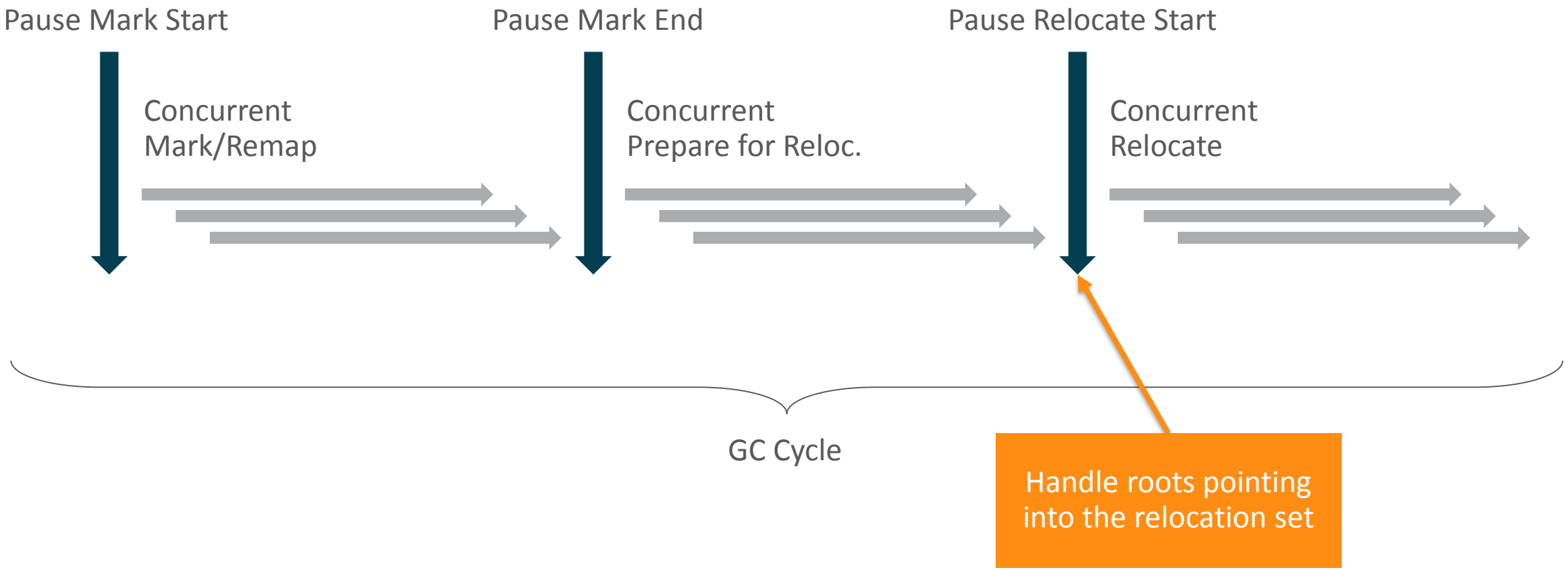

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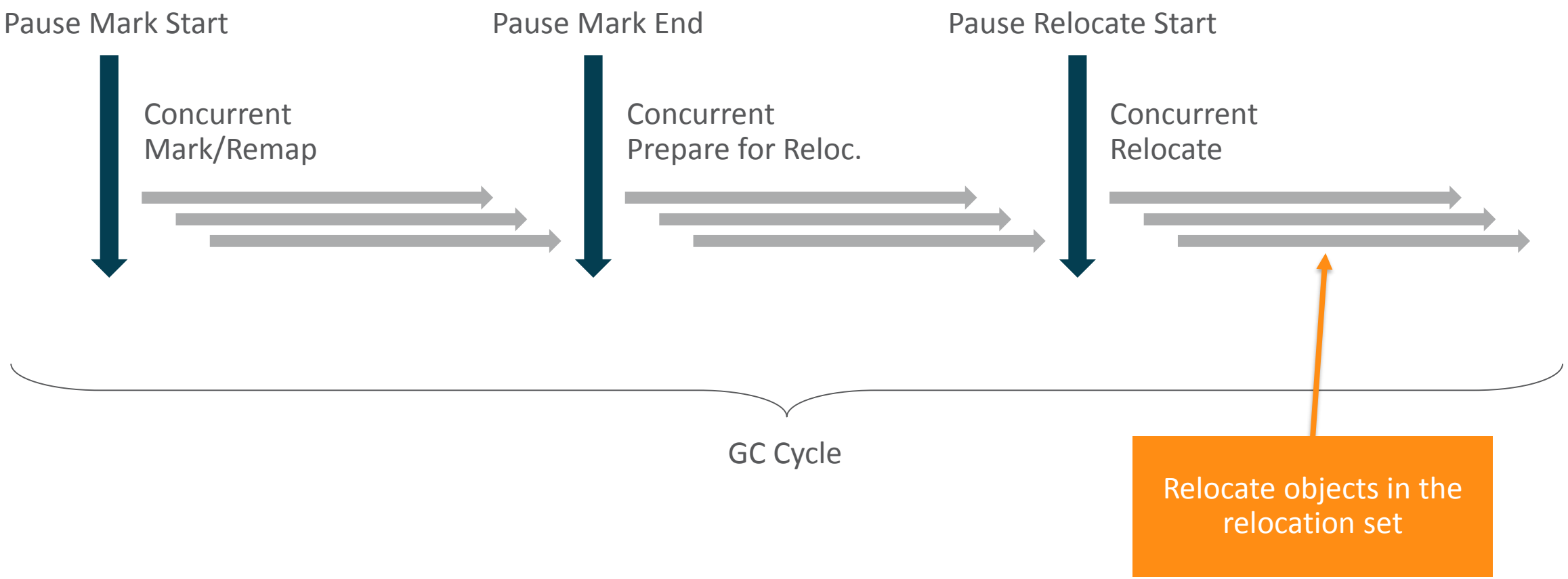

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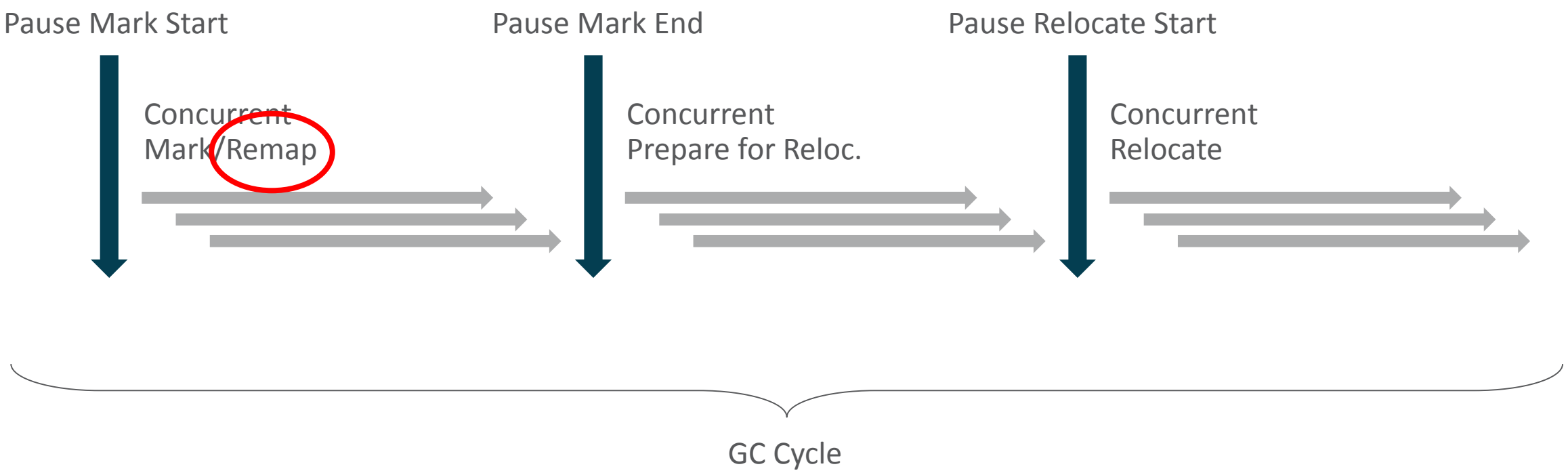

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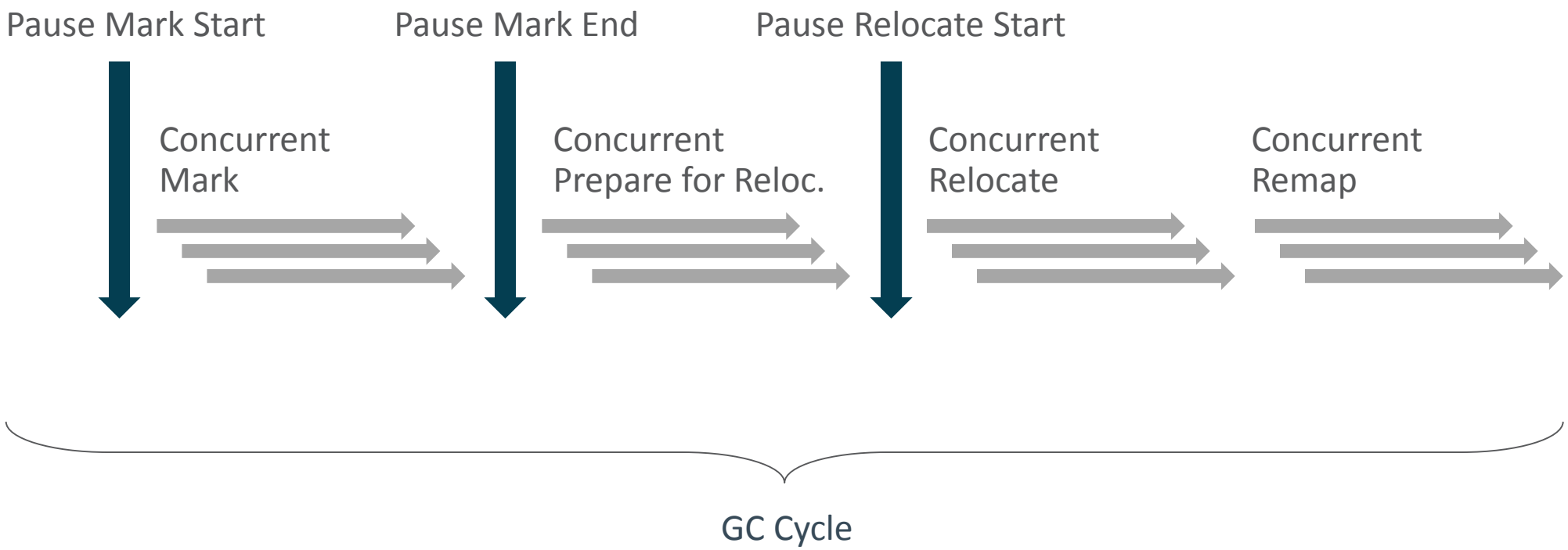

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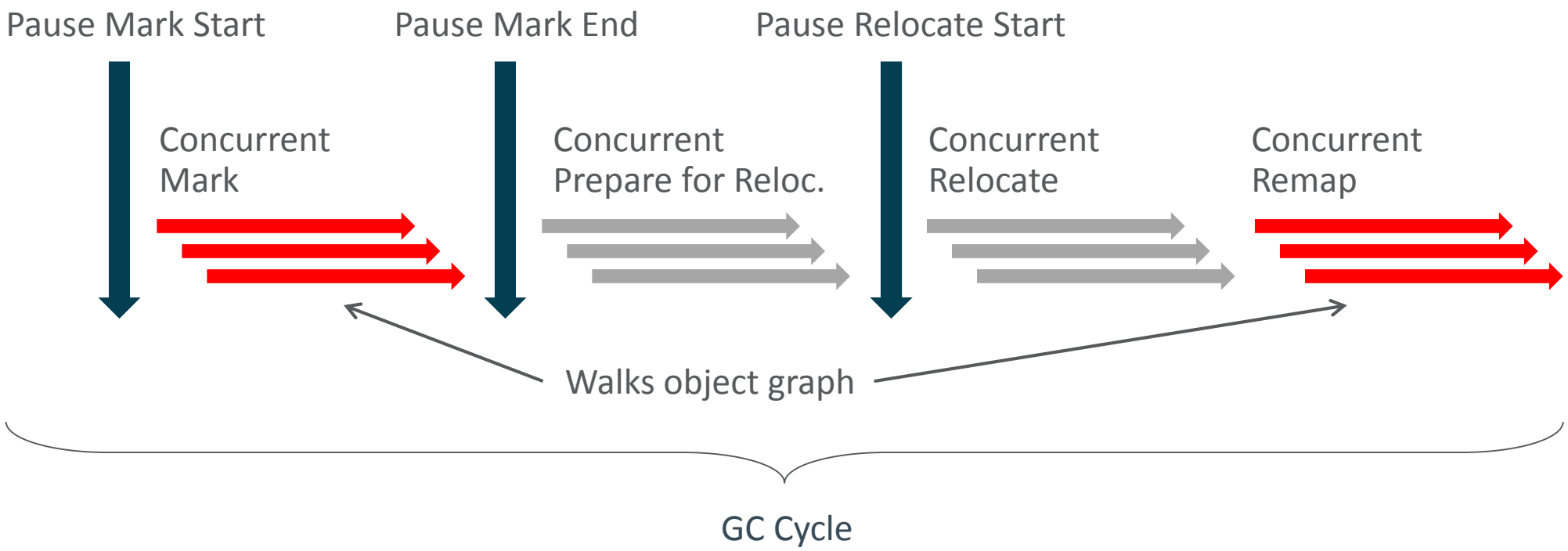

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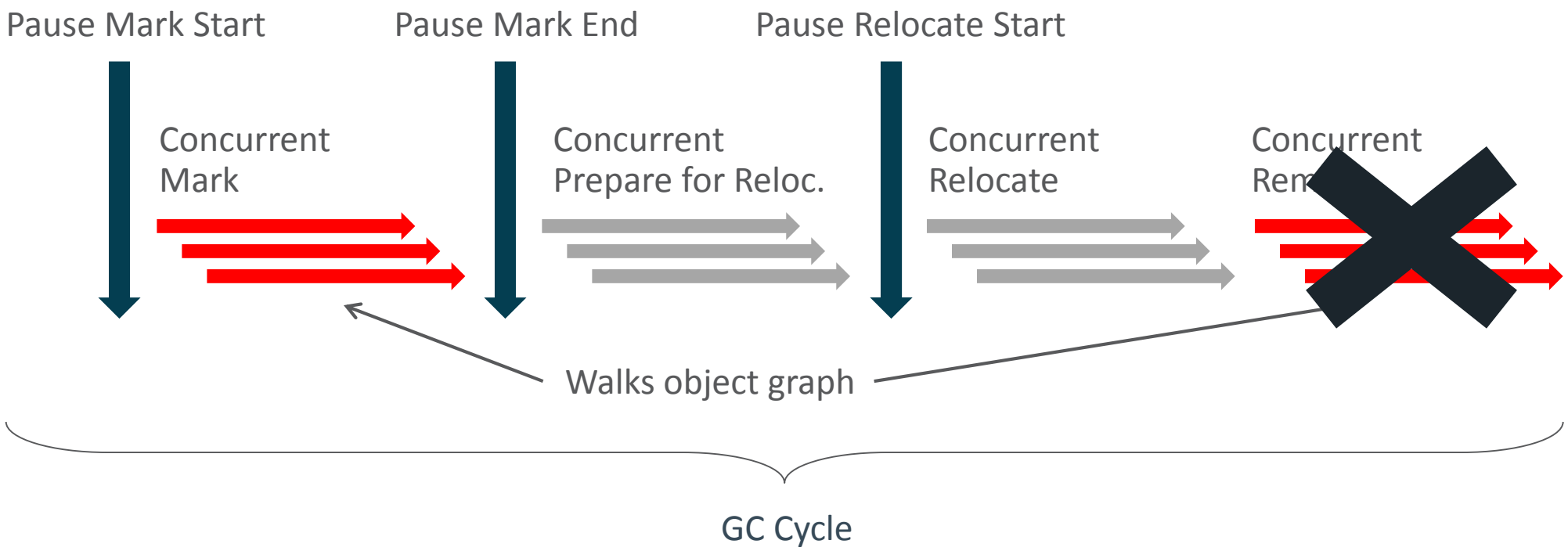

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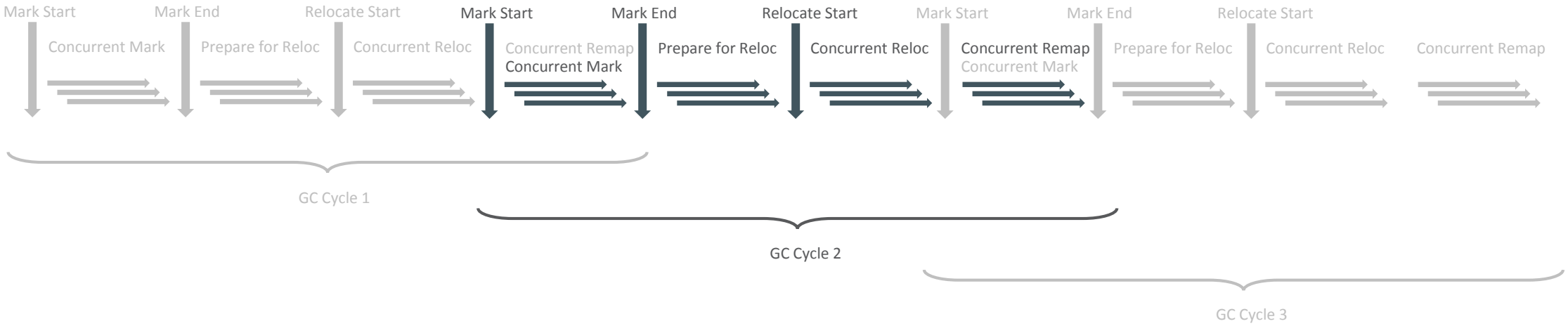
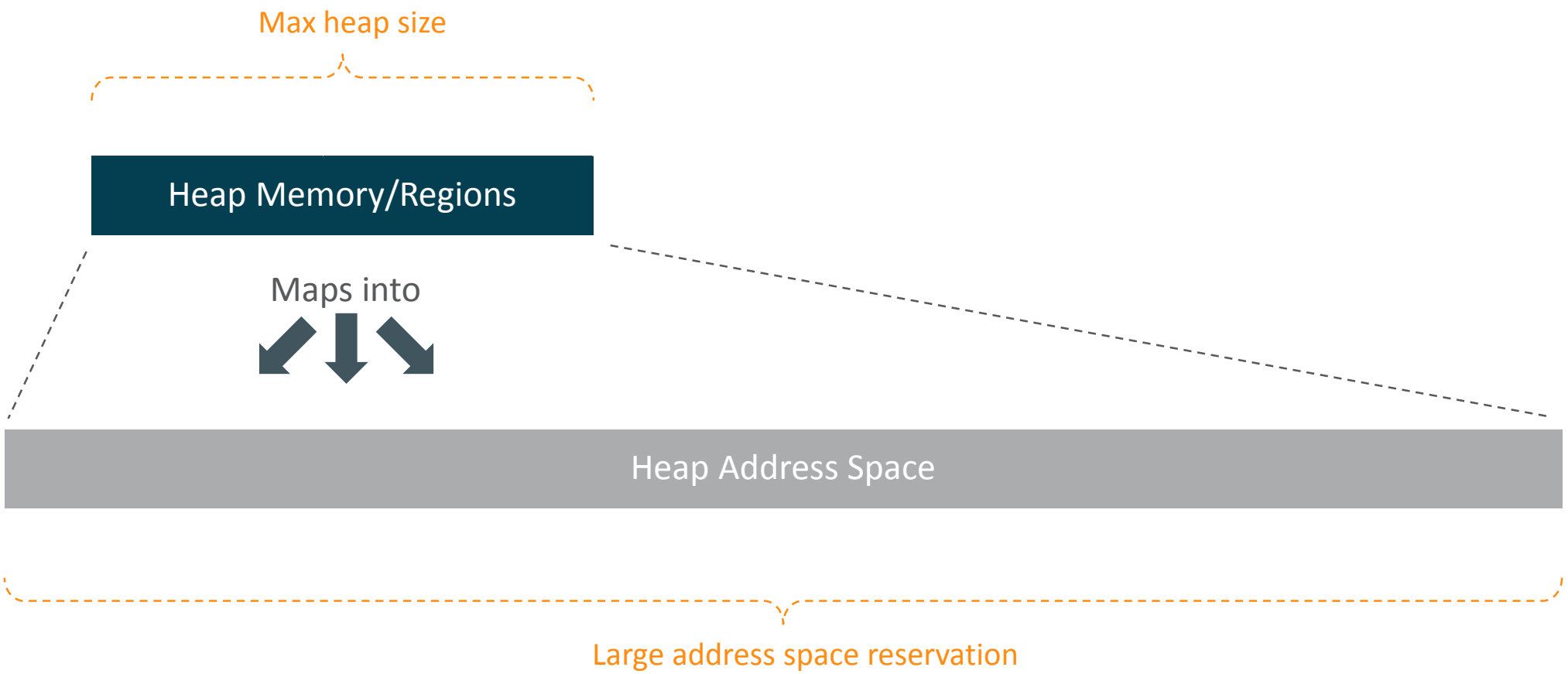


Heap Address Space



Heap Regions

Also known as ZPages

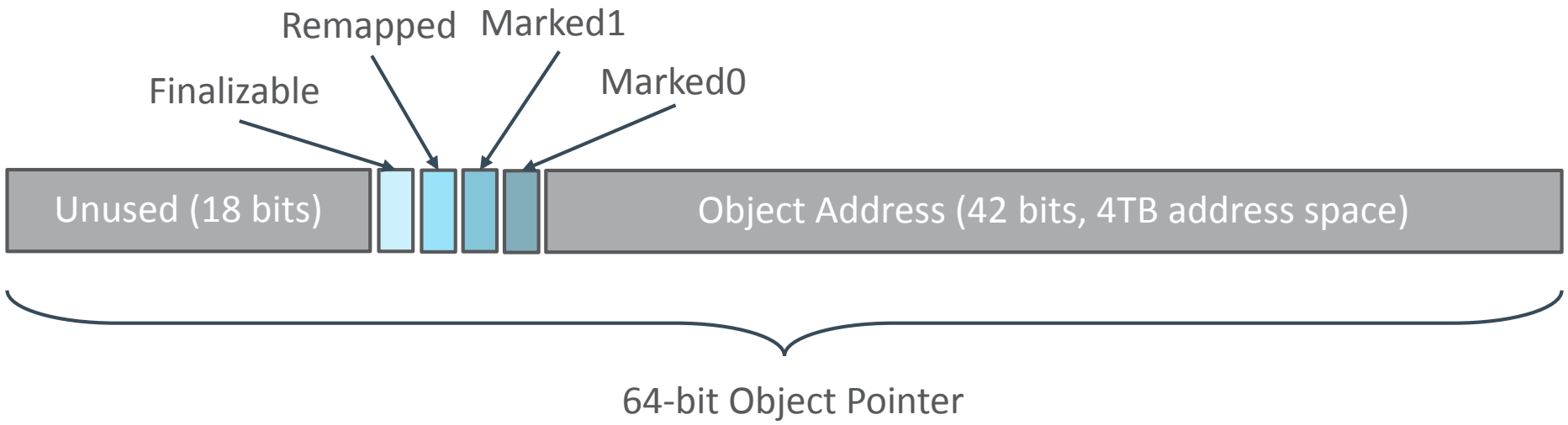
- Dynamically created/destroyed
- Dynamically sized
  - Multiple of **2MB** on **x86_64**
- Size groups
  - **Small** (2MB)
  - **Medium** (32MB)
  - **Large** (N x 2MB)

Colored Pointers

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

Colored Pointers

Layout on x86_64



Colored Pointers

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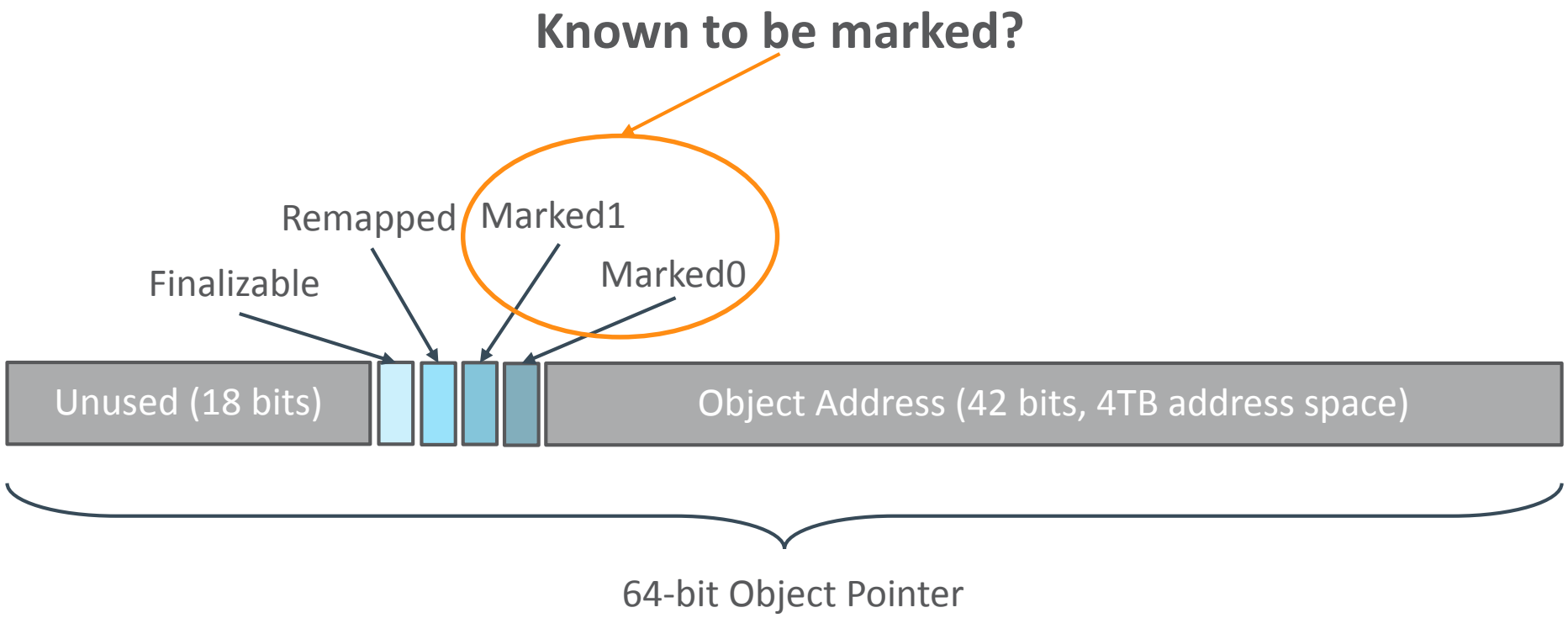
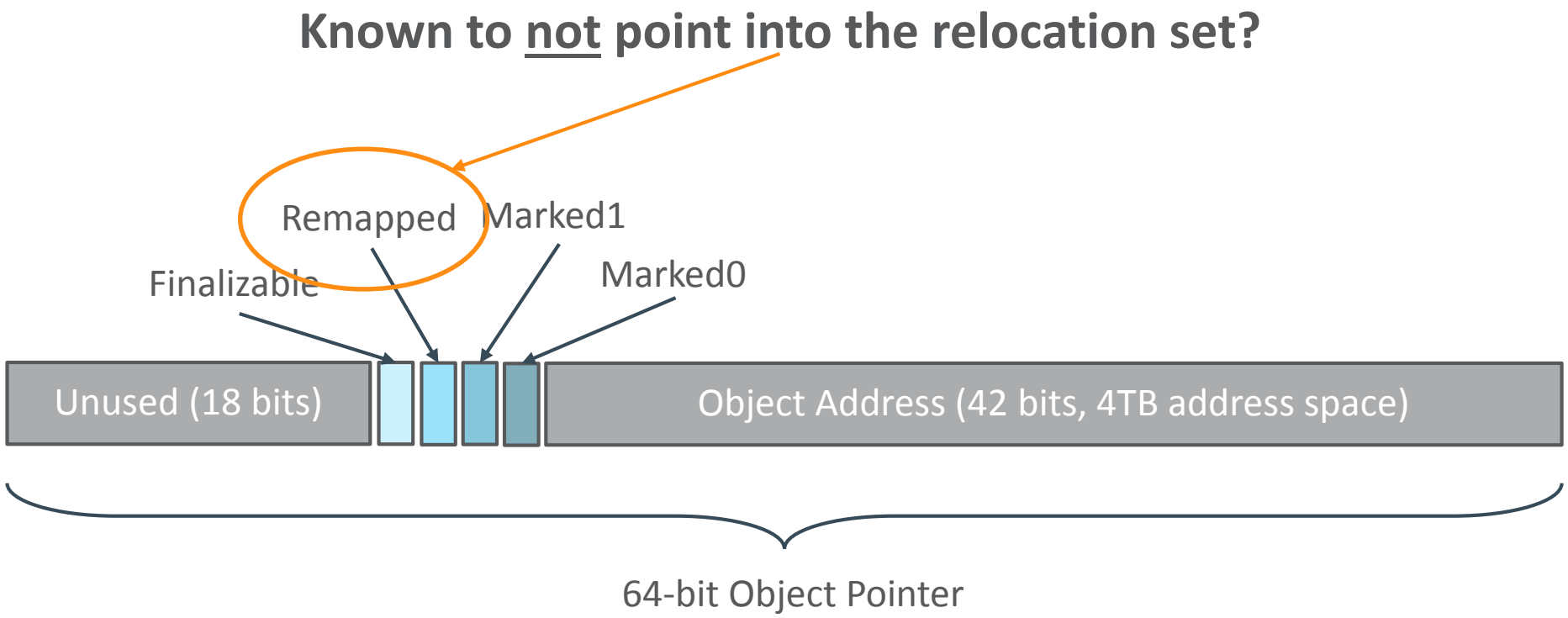


Colored Pointers

Layout on x86_64



Colored Pointers

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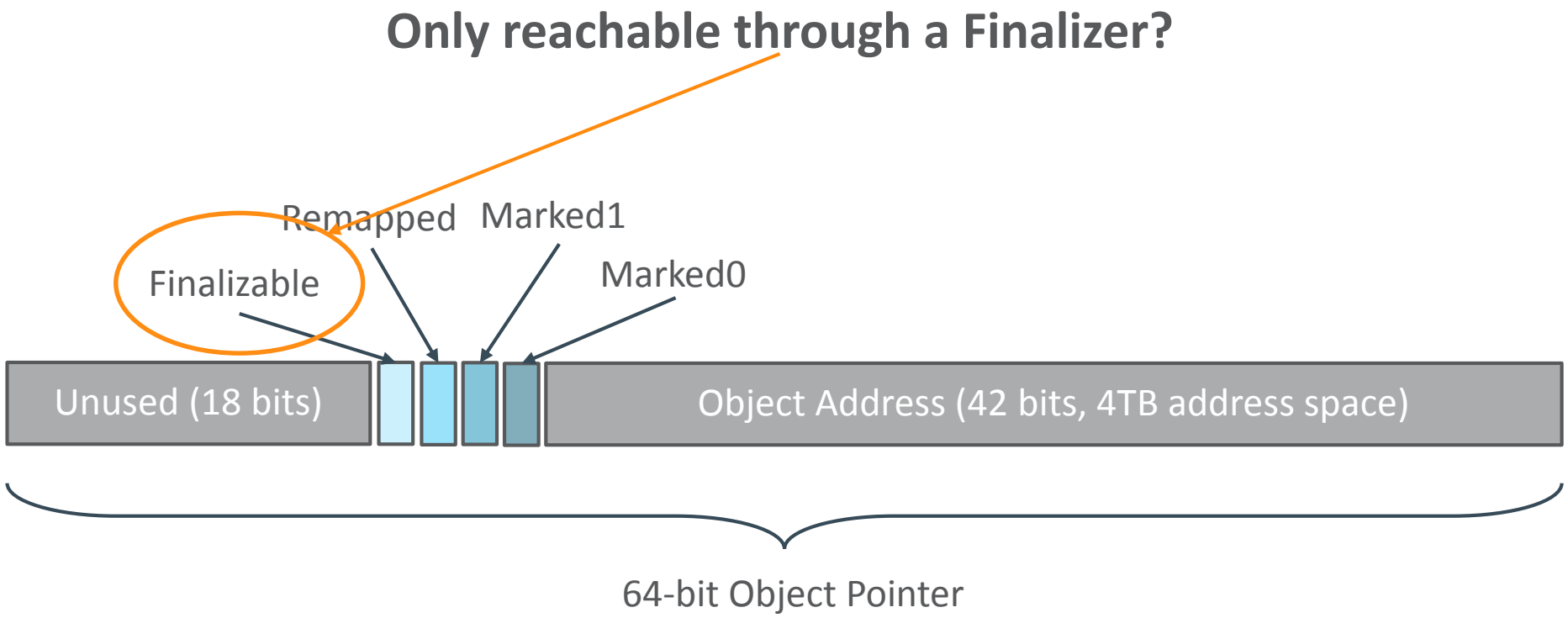
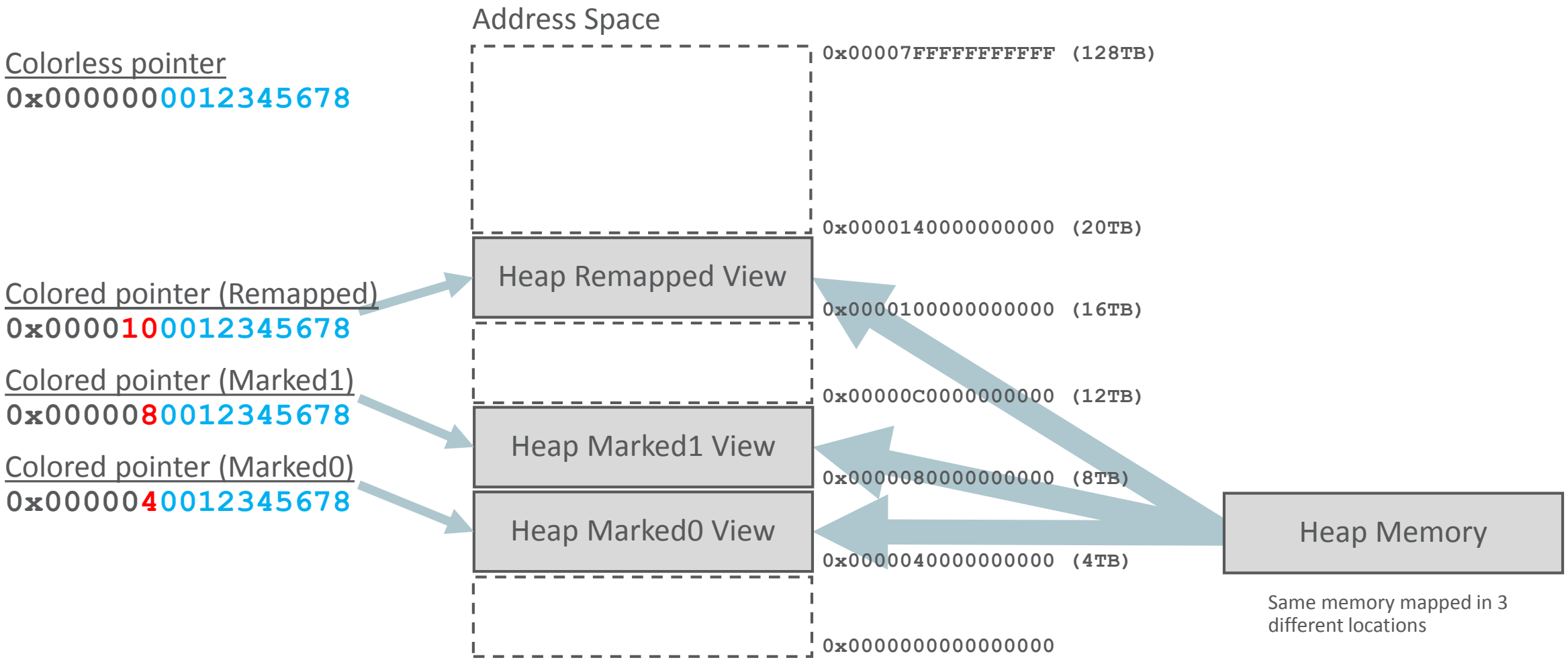
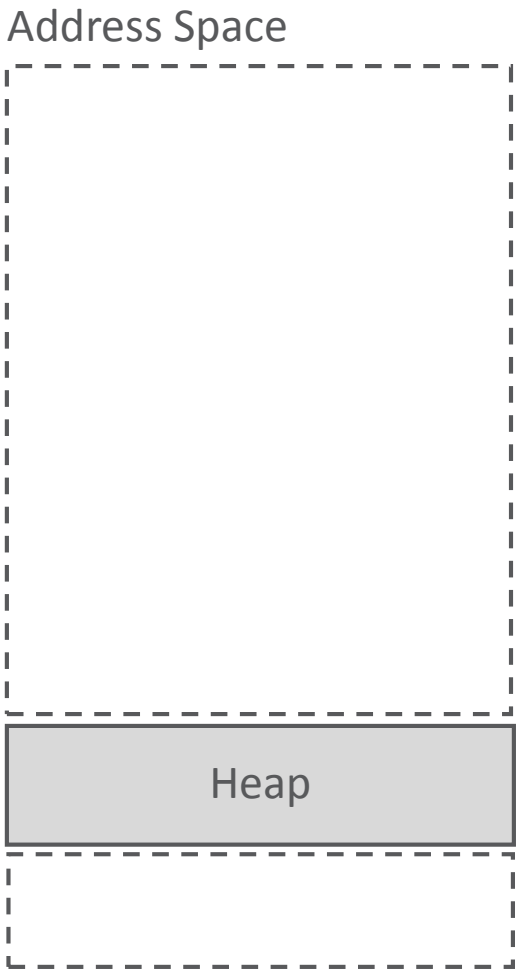


Heap Multi-Mapping on **Linux/x86_64**



Heap Mapping on **Solaris/SPARC**

- Single heap mapping
- Virtual address masking in hardware
- **Load** and **store** instructions mask out metadata bits



(ARM AArch64 also supports this)

Load Barrier

- Applied when **loading an object reference** from the heap
  - **Not** when later using that reference to access the object
  - Conceptually similar to the decoding of compressed oops

- Looks at the color of the pointer
  - Take action if the pointer has a "**bad**" color (mark/relocate/remap)
  - Change to the "**good**" color (repair/heal)

- Optimized for the common case
  - Most object references will have the "**good**" color

Load Barrier

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

Load Barrier

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

Load Barrier

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

Load Barrier

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

Load Barrier

```
Object o = obj.fieldA;          // Loading an object reference from heap
load_barrier(register_for(o), address_of(obj.fieldA));
```

Load Barrier

```
Object o = obj.fieldA;          // Loading an object reference from heap
if (!(o & good_bit_mask)) {
  if (o != null) {
    slow_path(register_for(o), address_of(obj.fieldA));
  }
}
```

Load Barrier

```
Object o = obj.fieldA;          // Loading an object reference from heap
if (o & bad_bit_mask) {
  slow_path(register_for(o), address_of(obj.fieldA));
}
```

Load Barrier

```
mov     0x20(%rax), %rbx
test    %rbx, (0x16)%r15
jnz     slow_path
```

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

Load Barrier

```
mov     0x20(%rax), %rbx
test    %rbx, (0x16)%r15
jnz     slow_path
```

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

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

Load Barrier (**r12 version**)

```
mov     0x20(%rax), %rbx
test    %rbx, %r12
jnz     slow_path
```

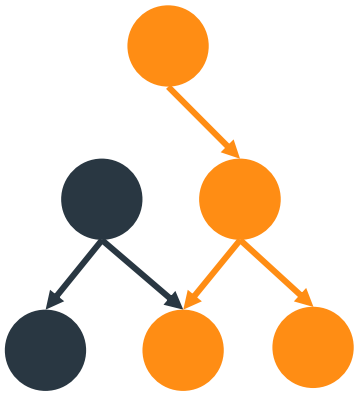
```
// Object o = obj.fieldA;
// Bad color?
// Yes -> Enter slow path and
// mark/relocate/remap, adjust
// 0x20(%rax) and %rbx
```

Always keep **bad_bit_mask** in **r12**

- Avoids a memory load, but reserves a register
- We don’t support compressed oops, so we can repurpose r12, the heap base register

Mark

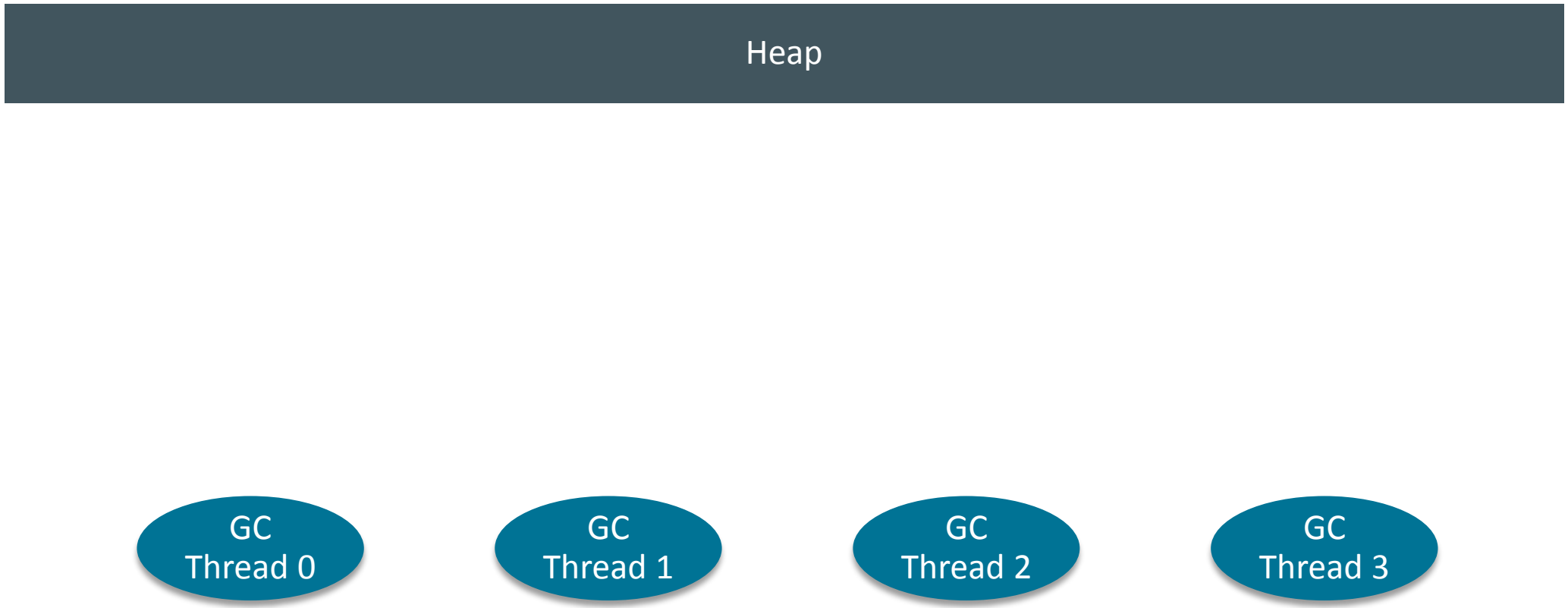
- Concurrent & Parallel
- Load barrier
  - Detects loads of non-marked object pointers
- Finalizable mark
  - Enabler for Concurrent Reference Processing
- Thread local handshakes
  - Used to synchronize end of concurrent mark
- Striped



Striped Mark

- Scalability
  - Heap divided into logical stripes
  - Isolate each GC thread to work on its own stripe
  - Minimized shared state
- **Edge** pushing vs. **Node** pushing
  - Potentially more work
  - … but lends itself better to parallel processing

Striped Mark



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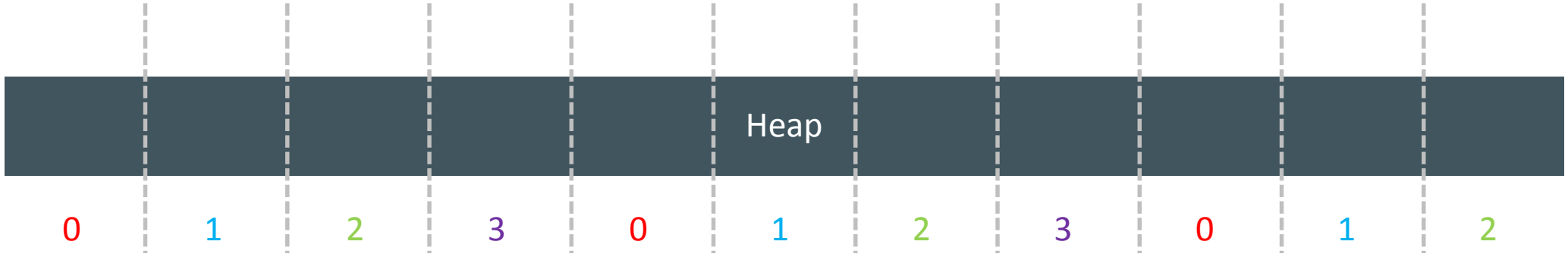


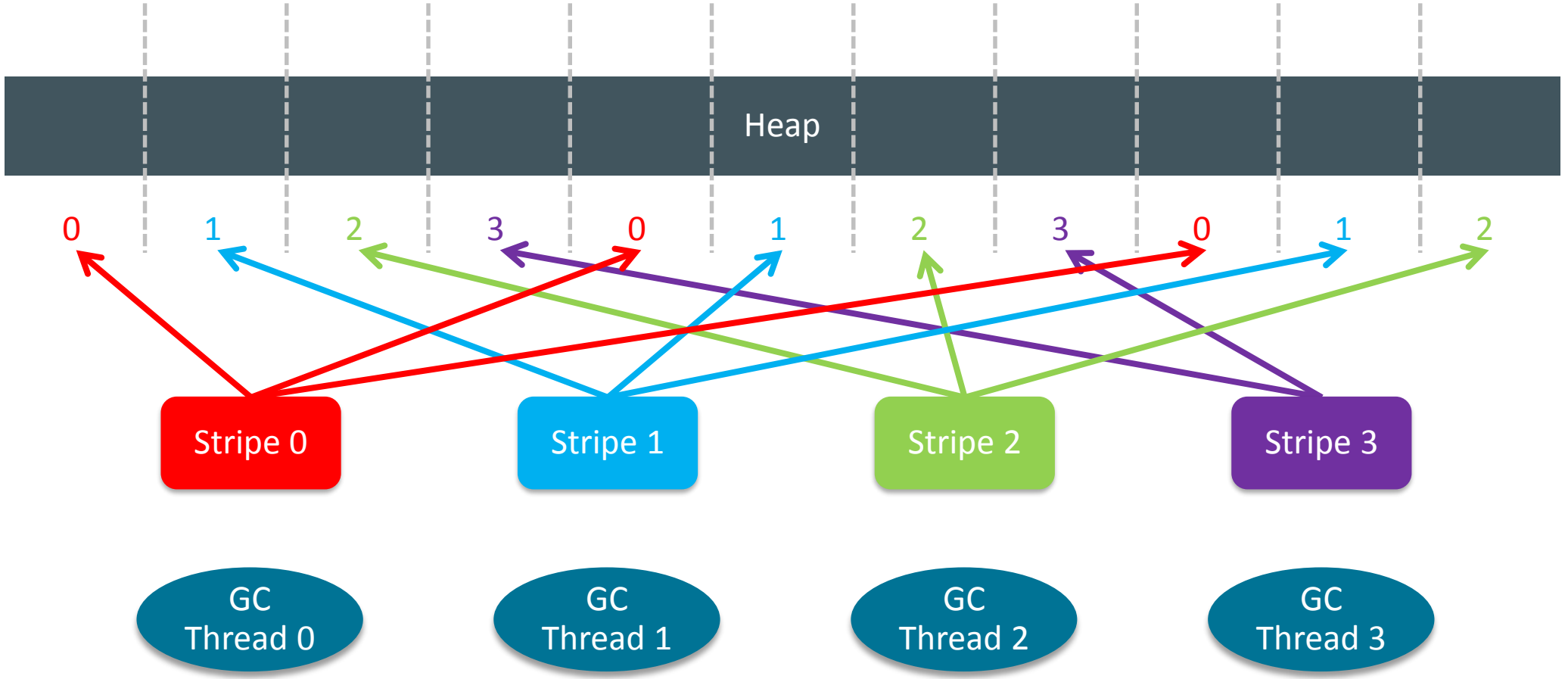
GC Thread 0

GC Thread 1

GC Thread 2

GC Thread 3

Striped Mark



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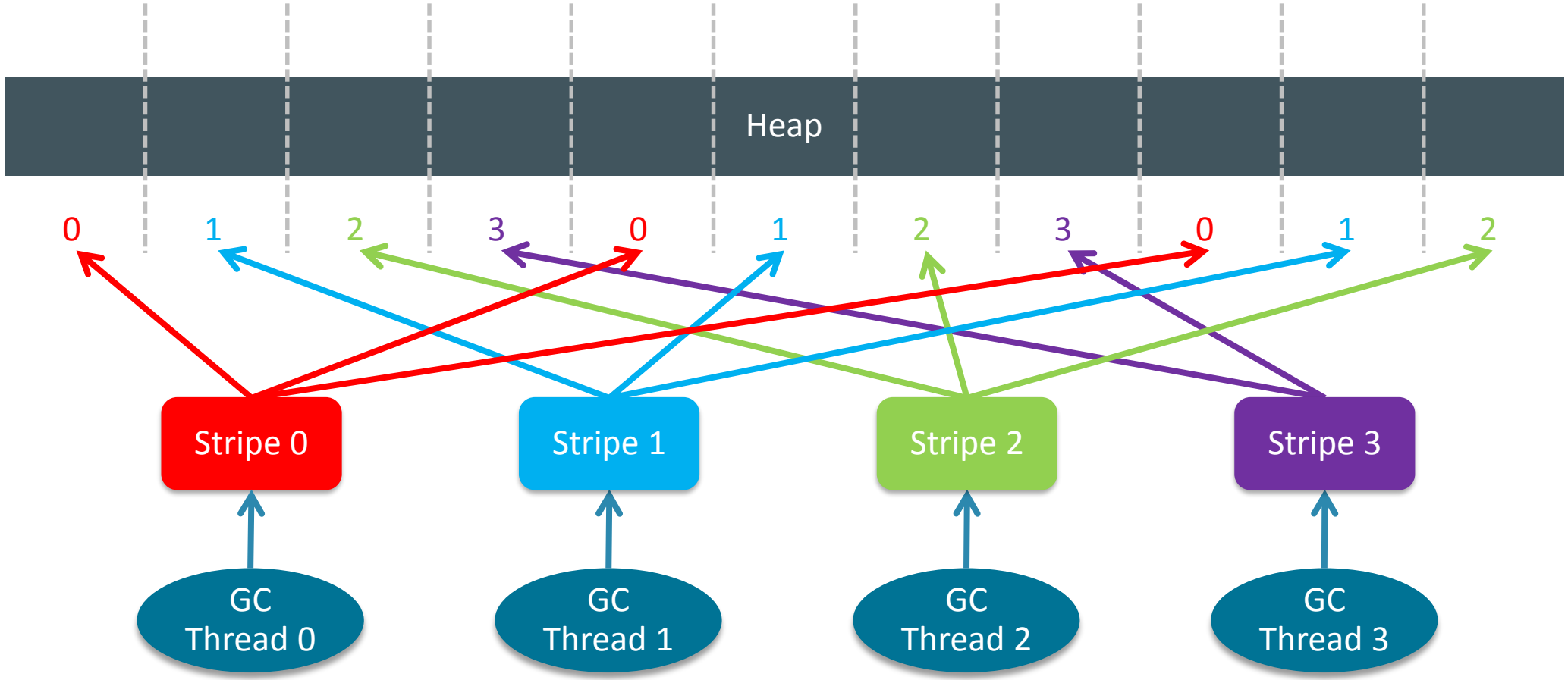

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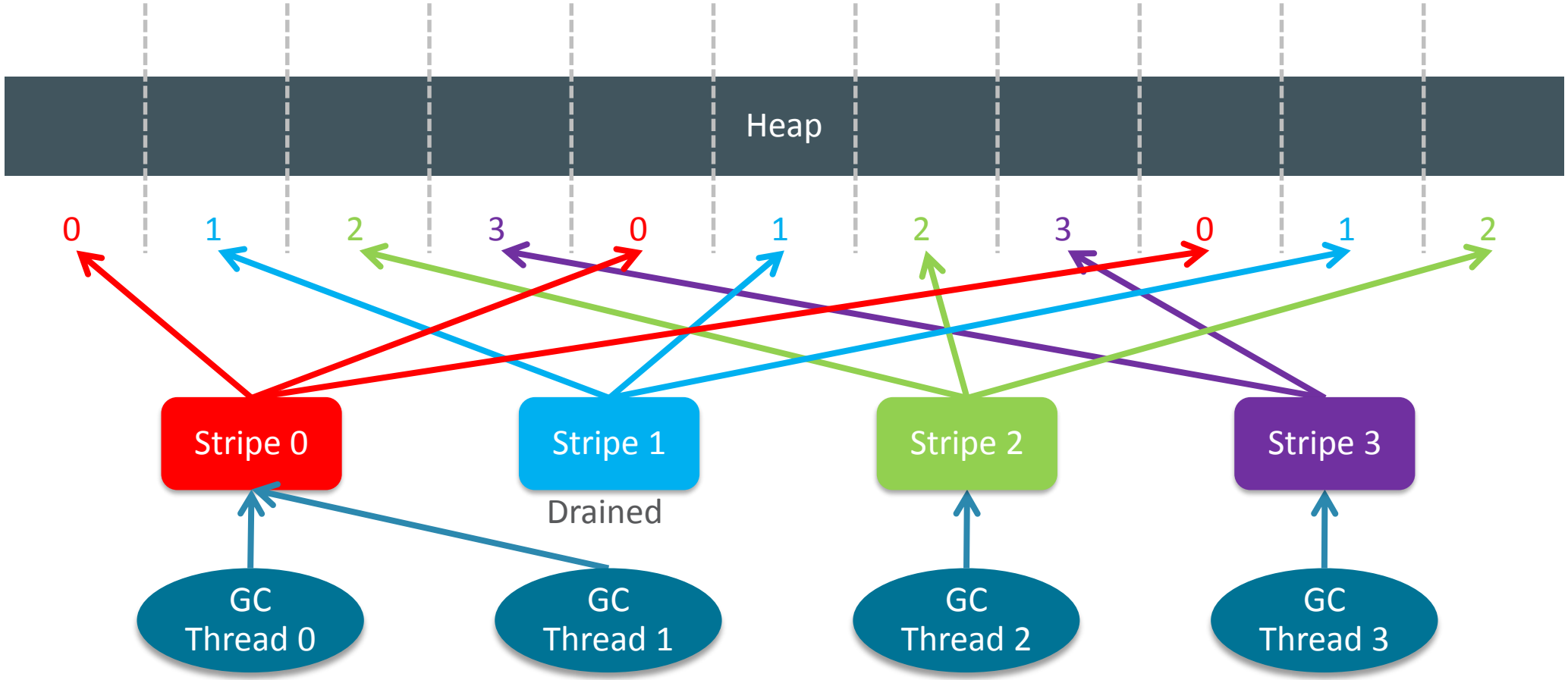
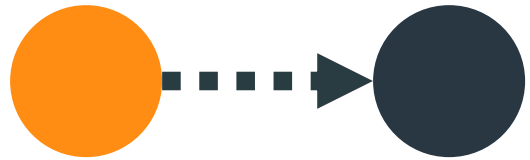


Reference Processing

Dealing with Soft/Weak/Final/PhantomReference

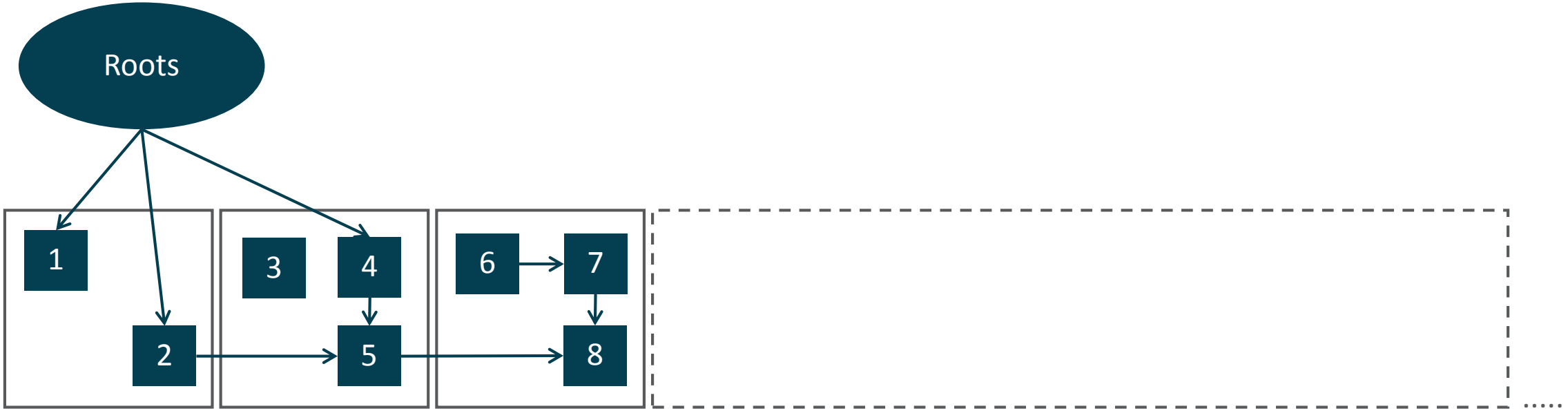
- Concurrent & Parallel
- Liveness/Reachability analysis
  - **Complete** after concurrent mark
  - Strongly reachable, Final reachable and Unreachable
- Processing/Enqueuing
  - **Single** pass
  - Load barrier **blocks** resurrection attempts (e.g. through **`Reference.get()`**)

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



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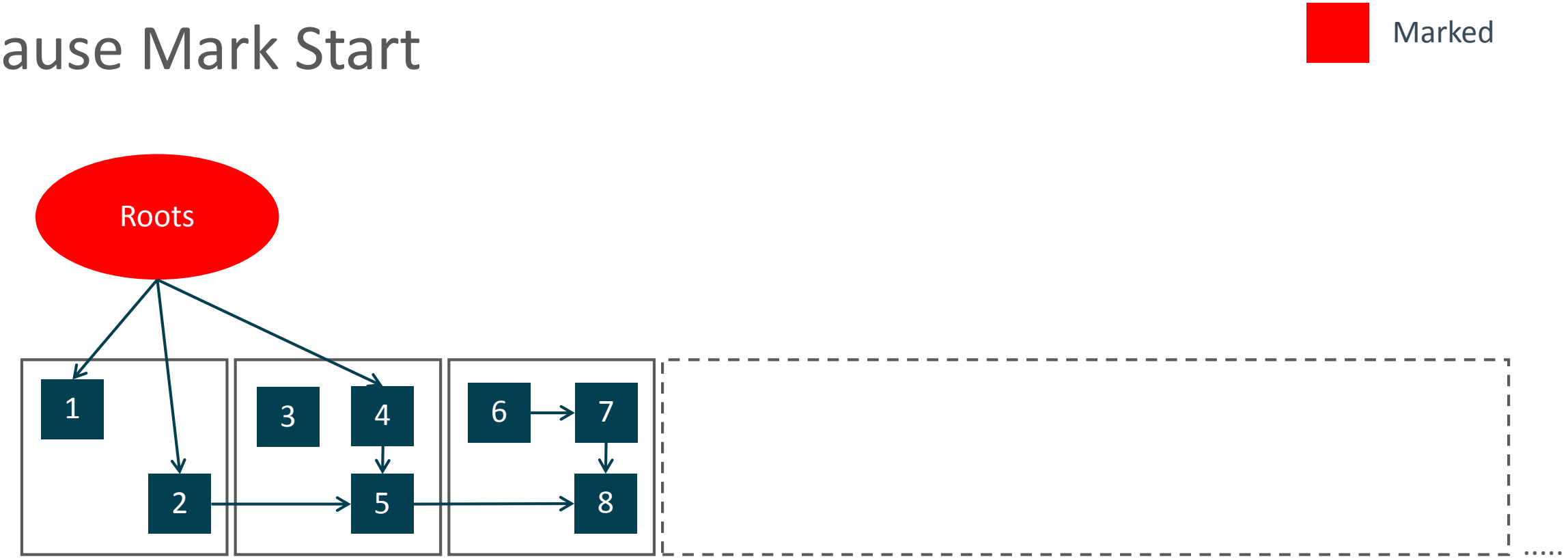

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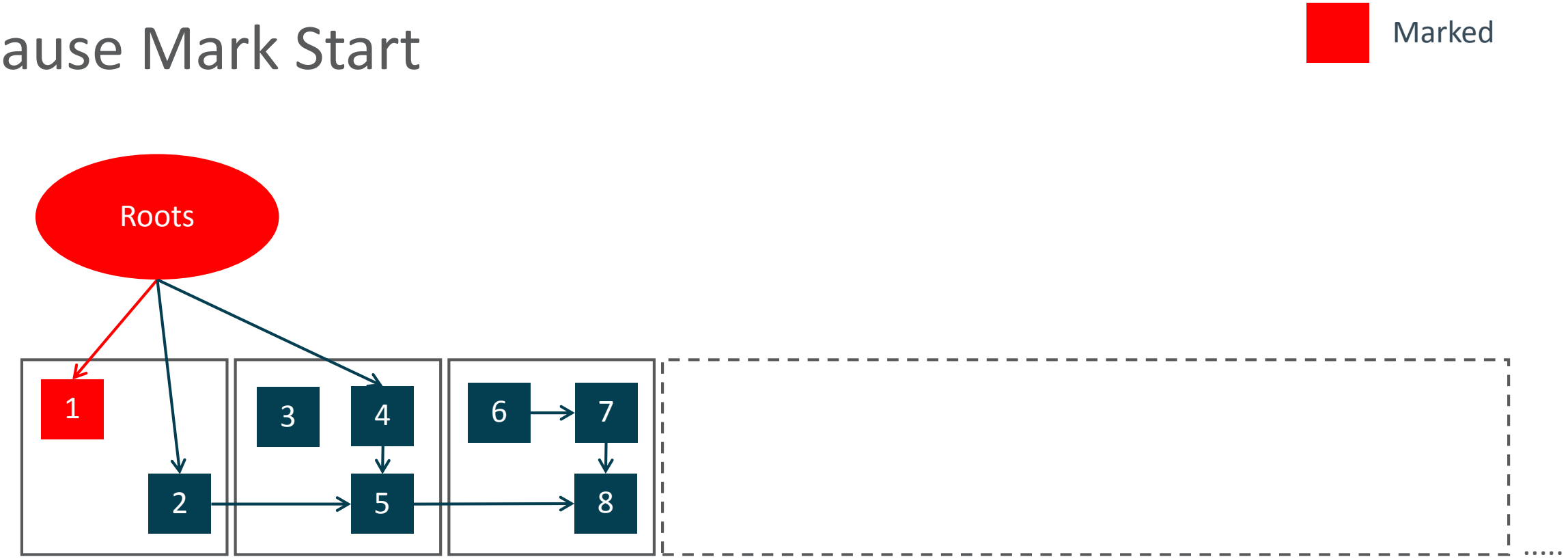

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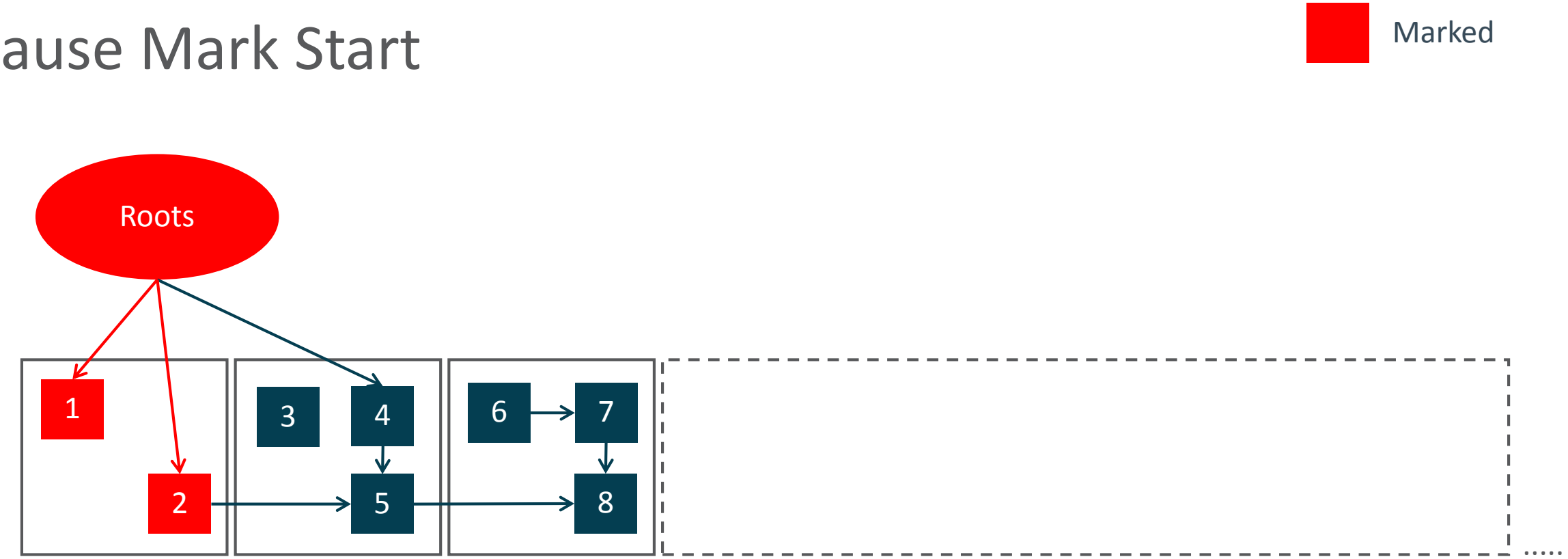

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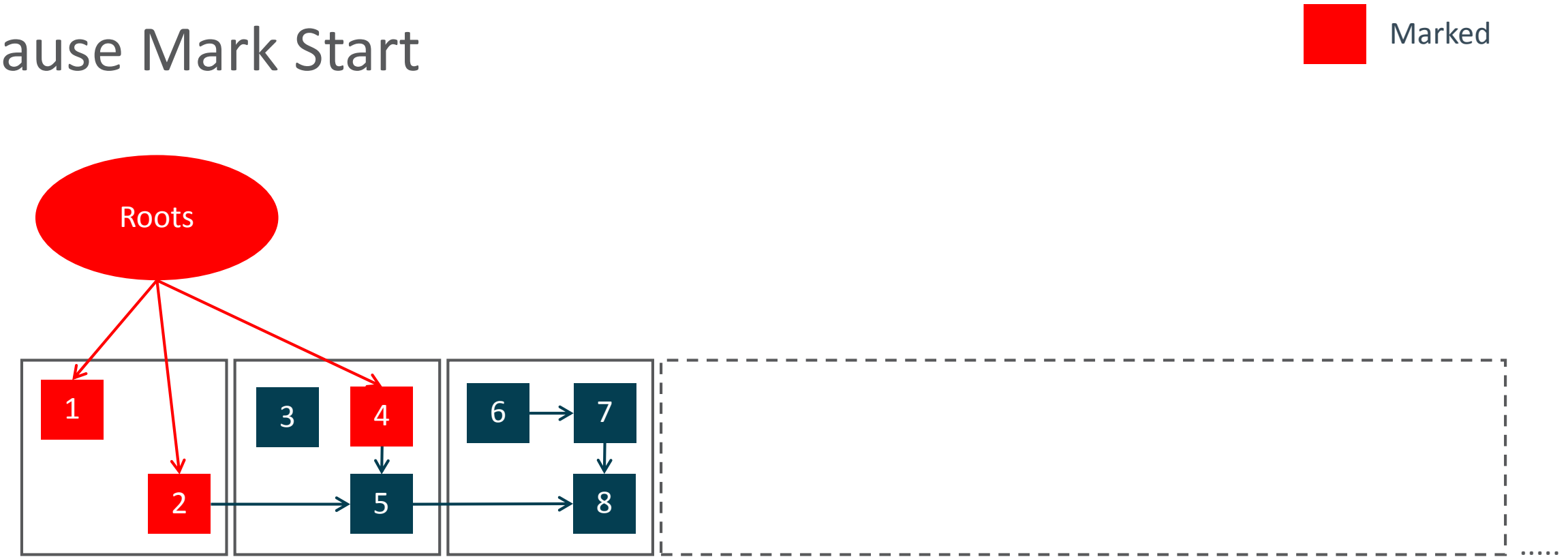
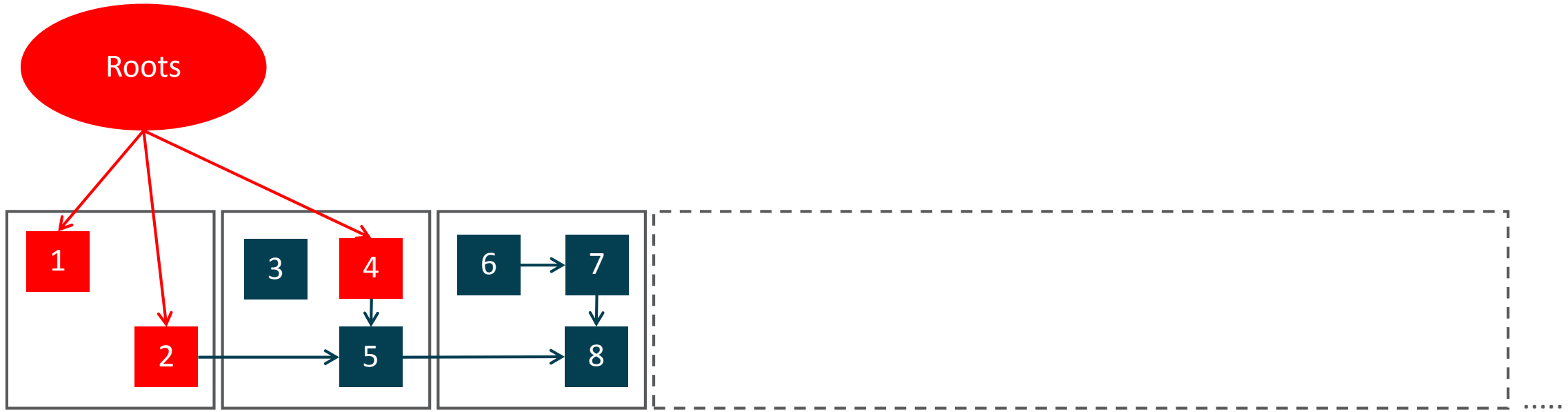
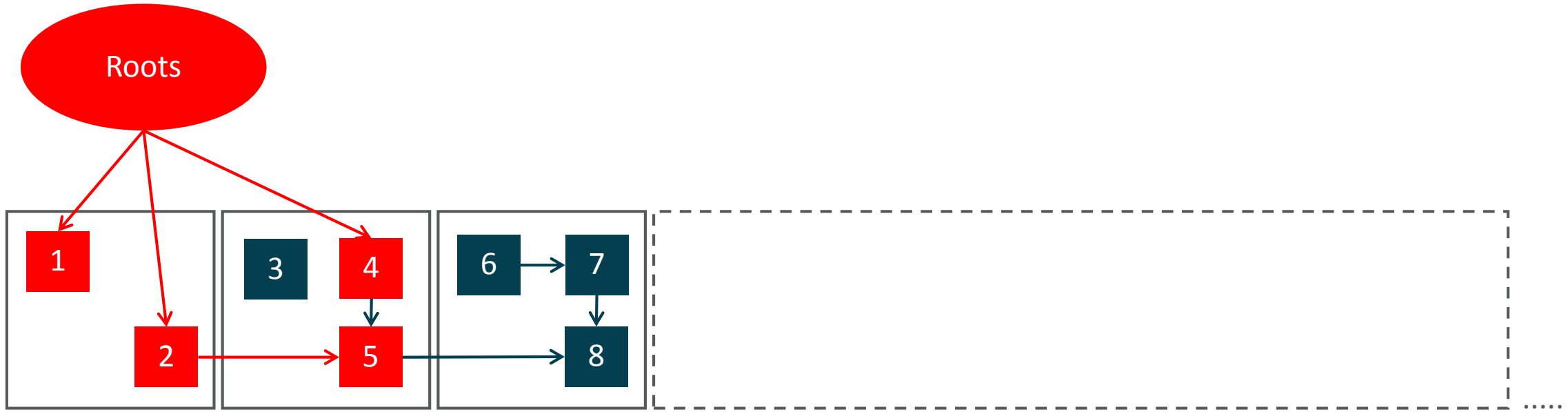


Concurrent Mark



Concurrent Mark



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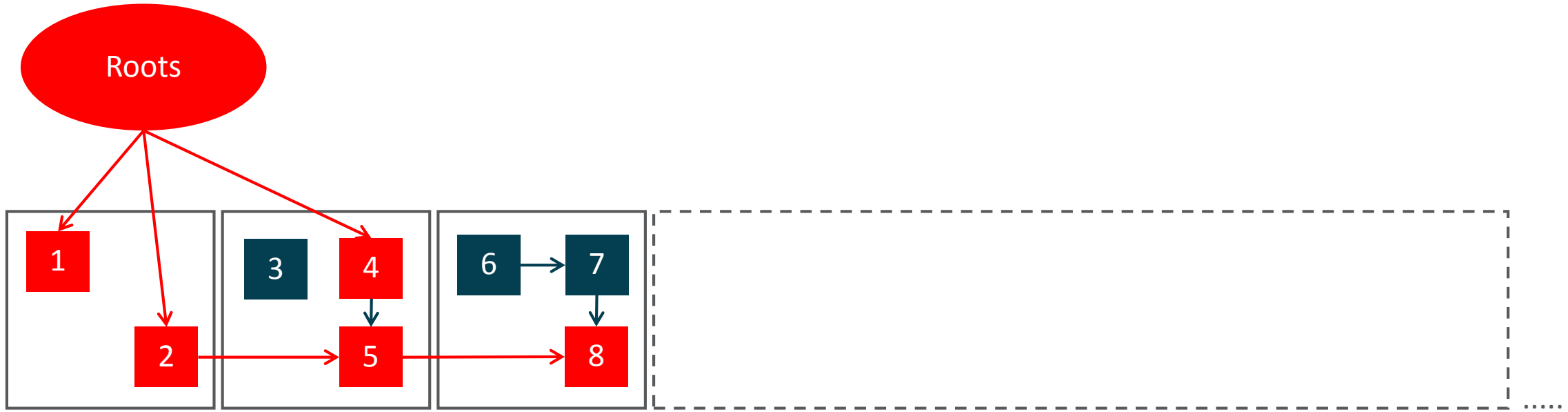

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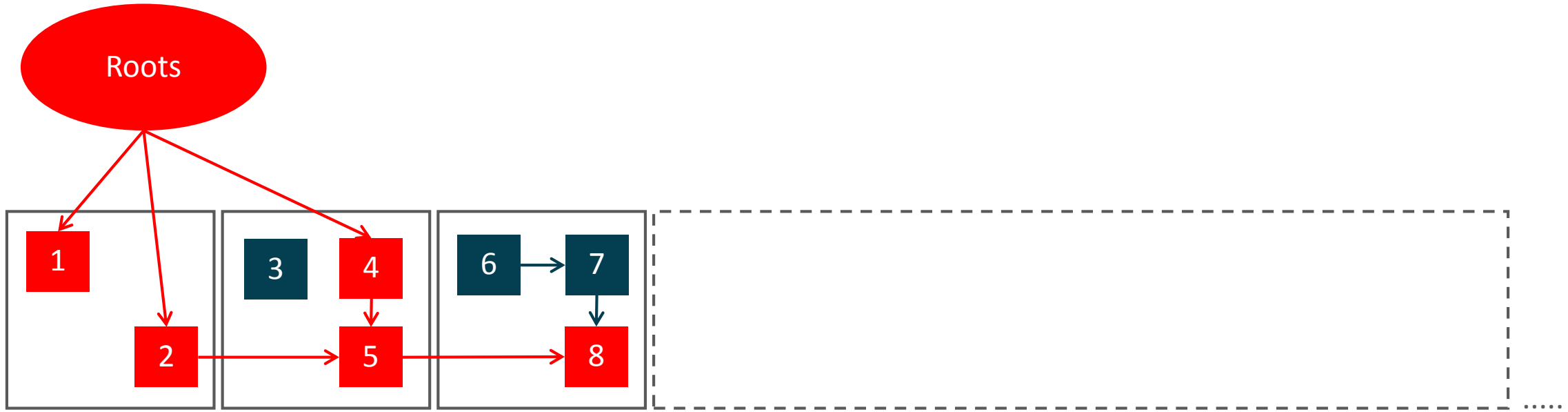

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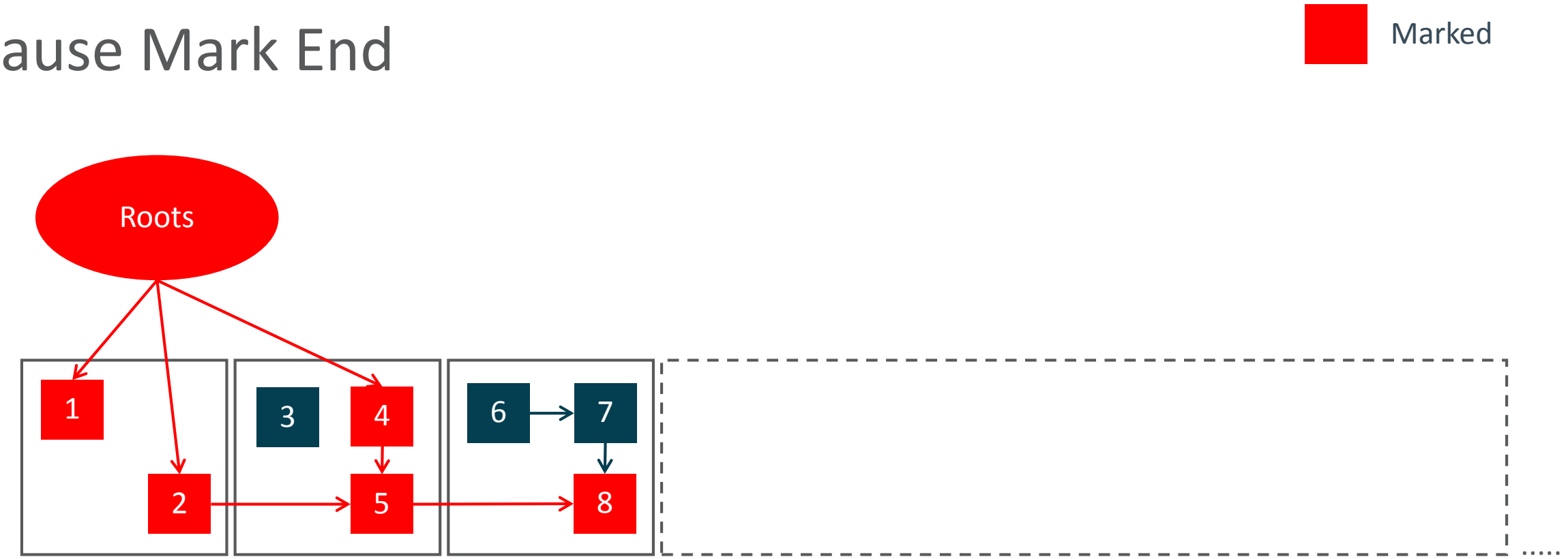
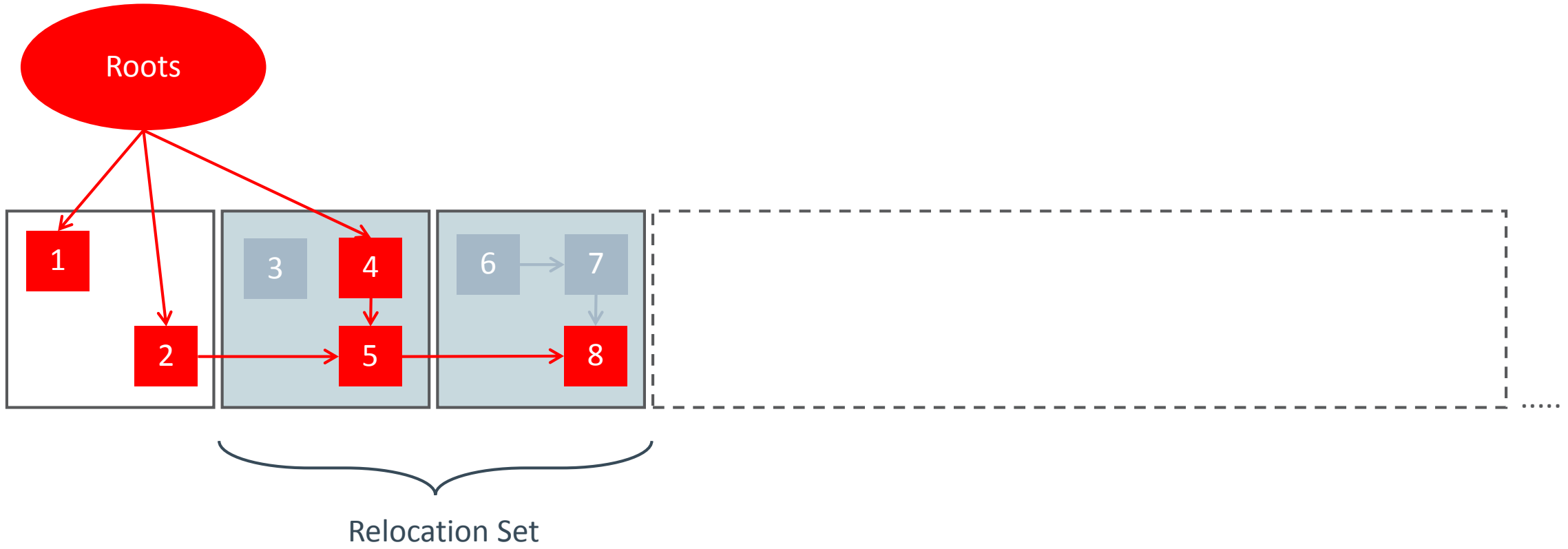
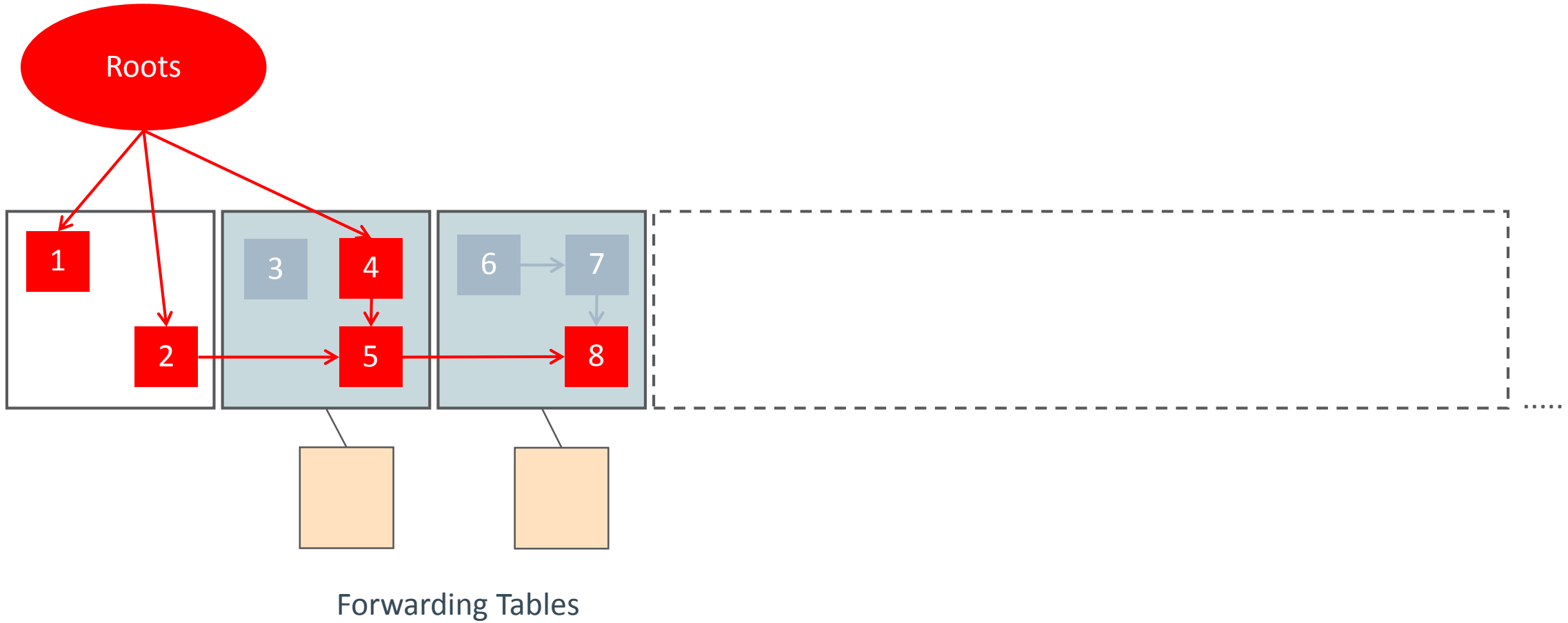


Concurrent Prepare for Relocate



Concurrent Prepare for Relocate



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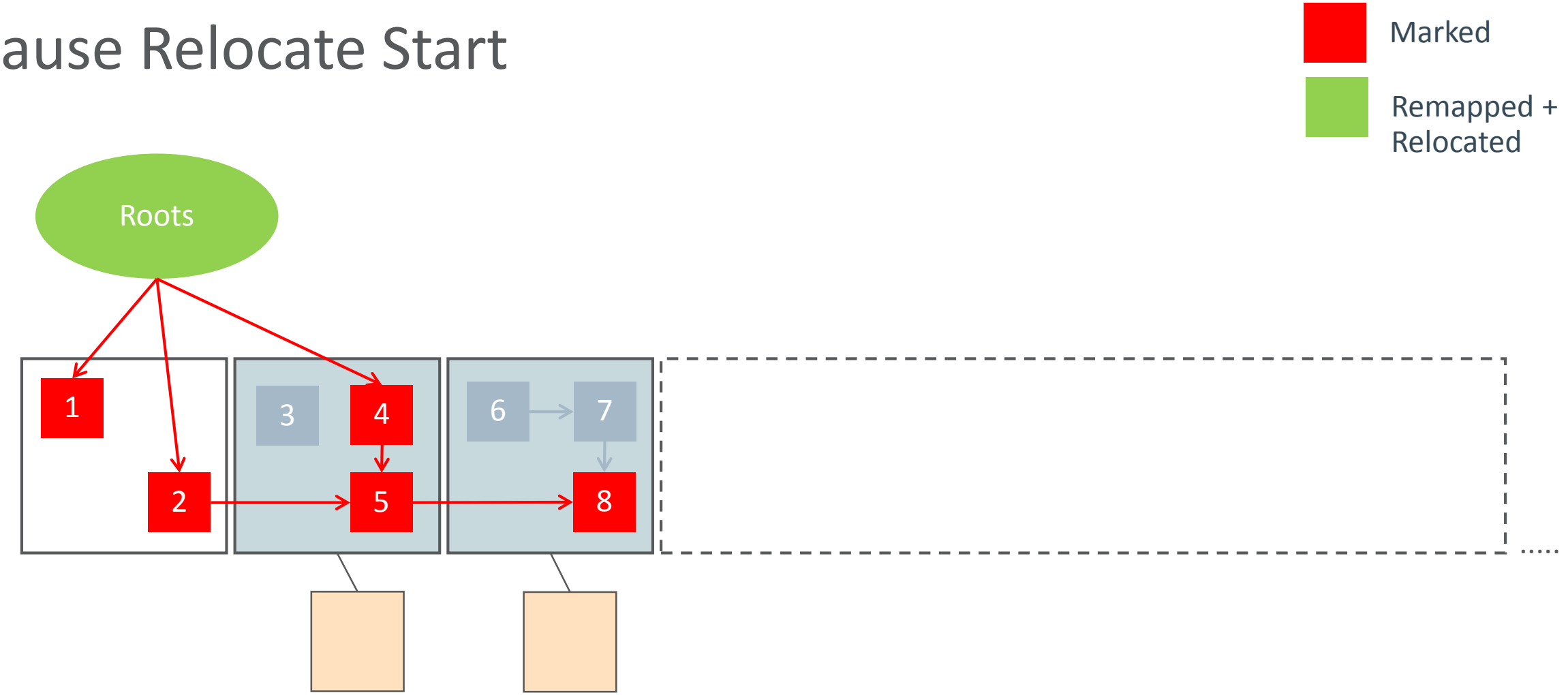

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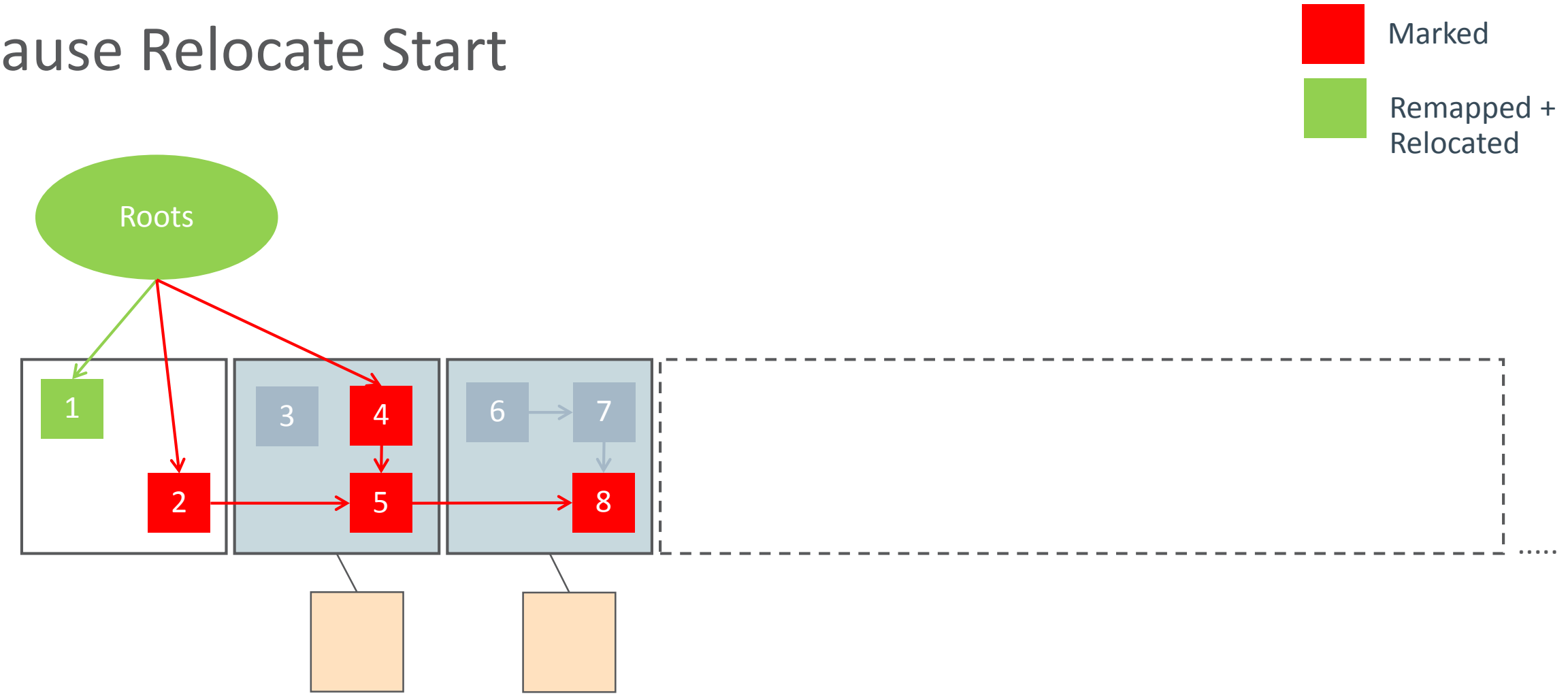

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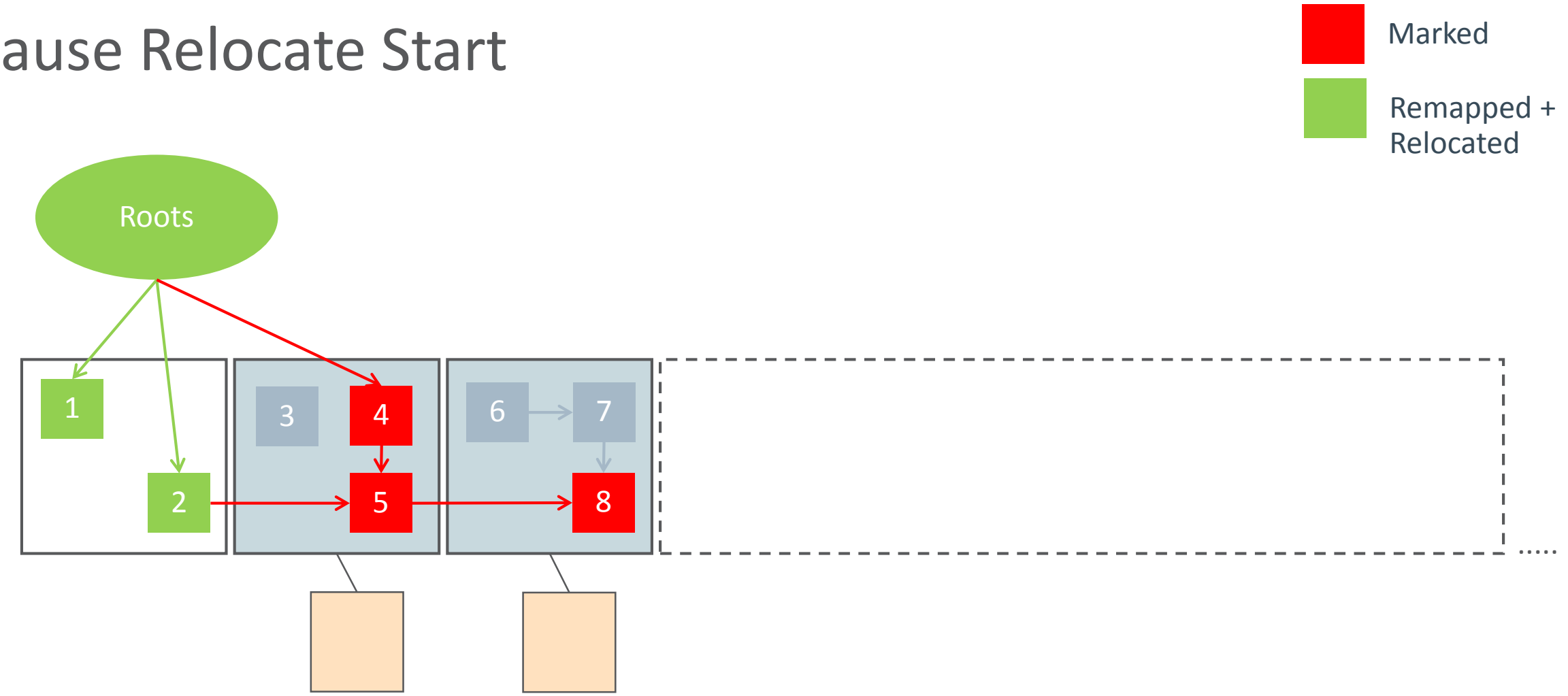
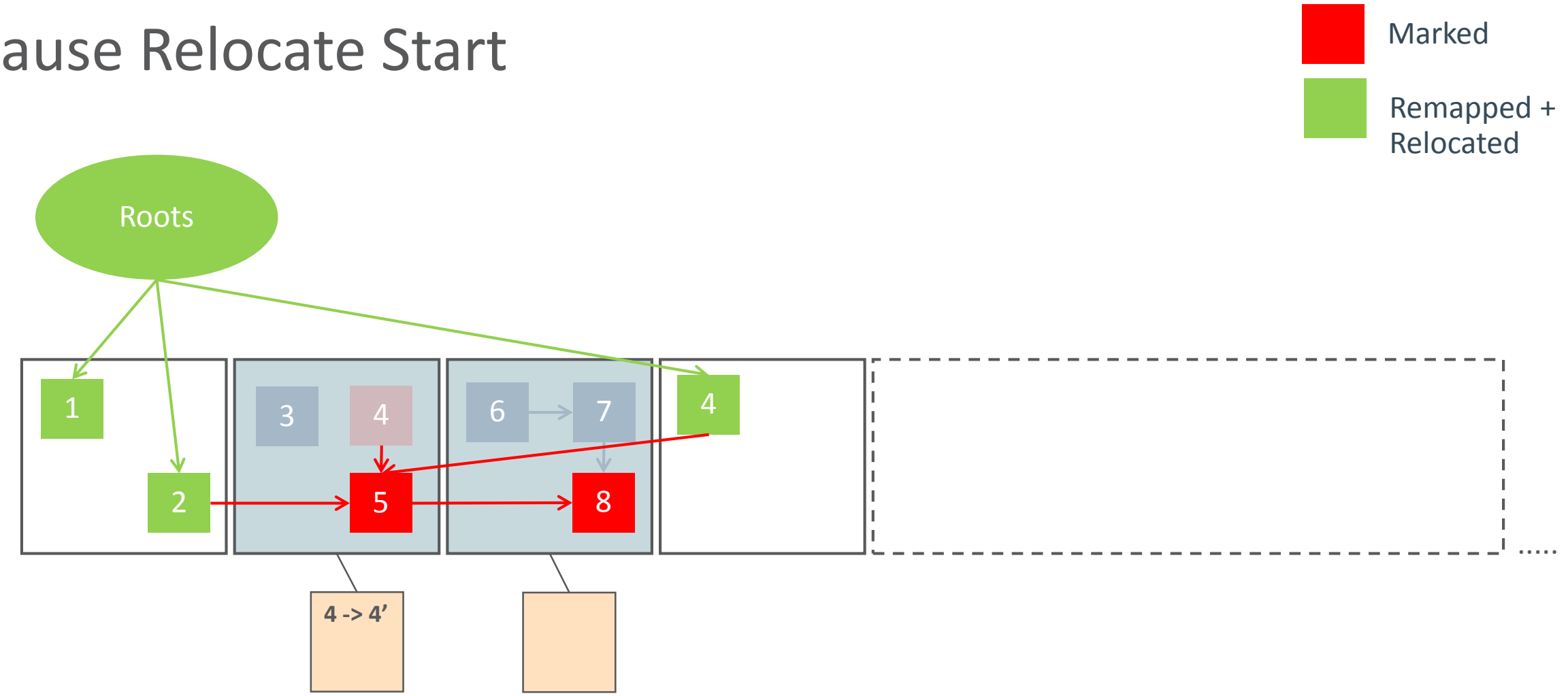
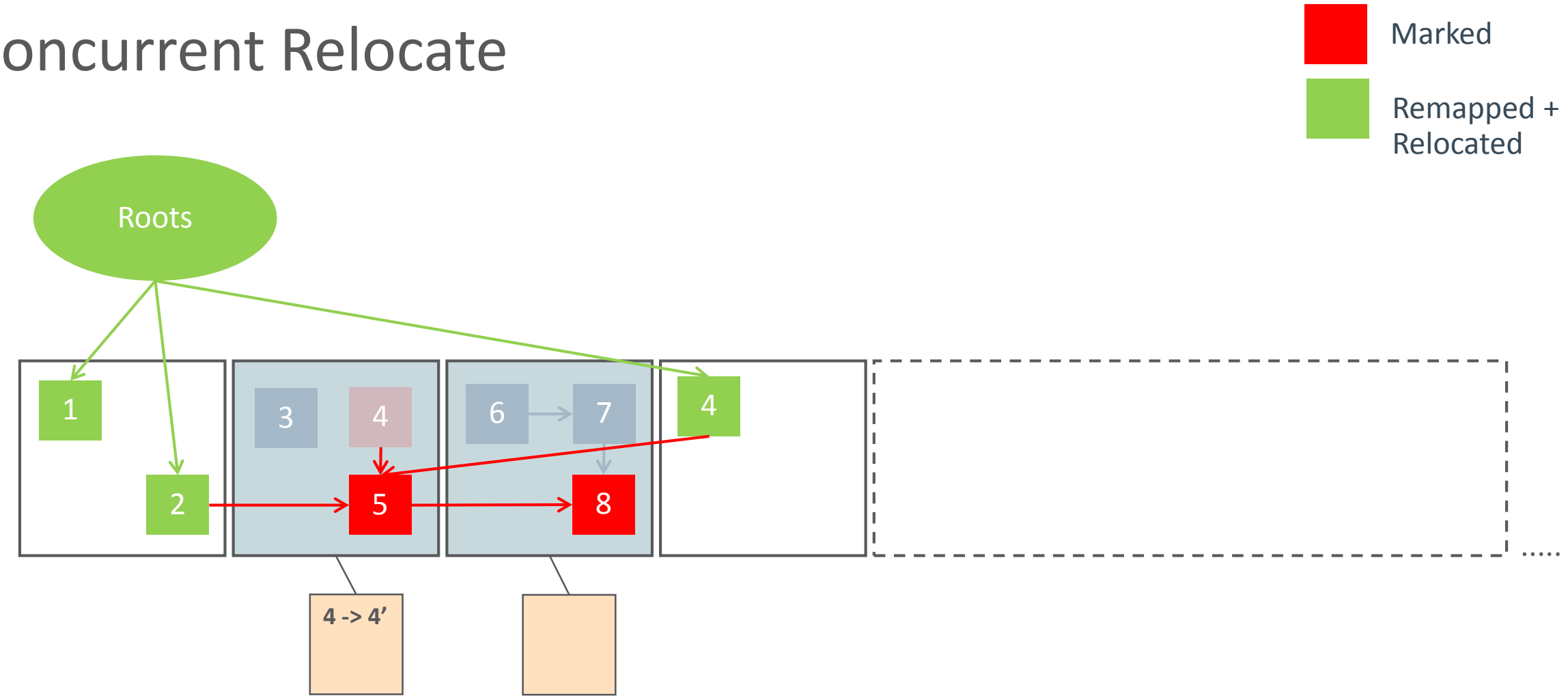


Pause Relocate Start



Concurrent Relocate



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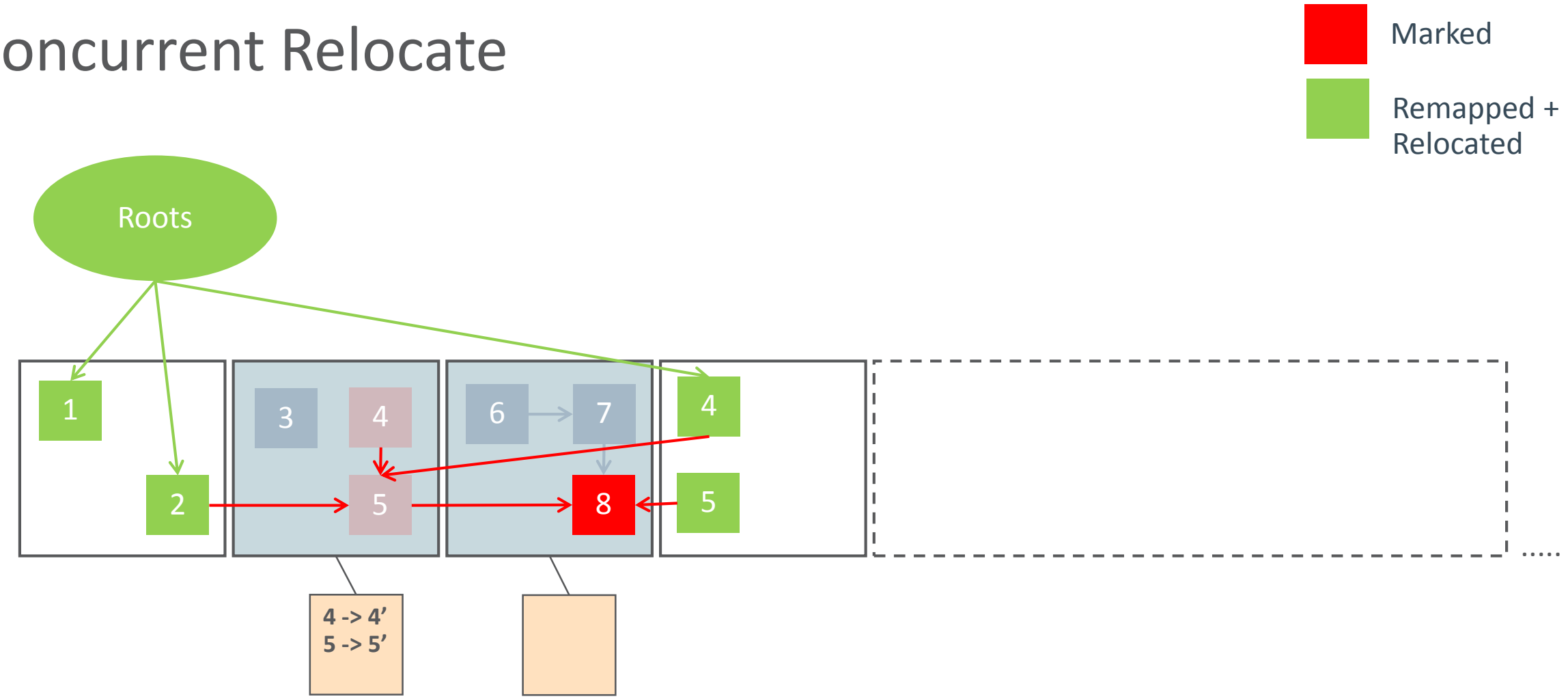

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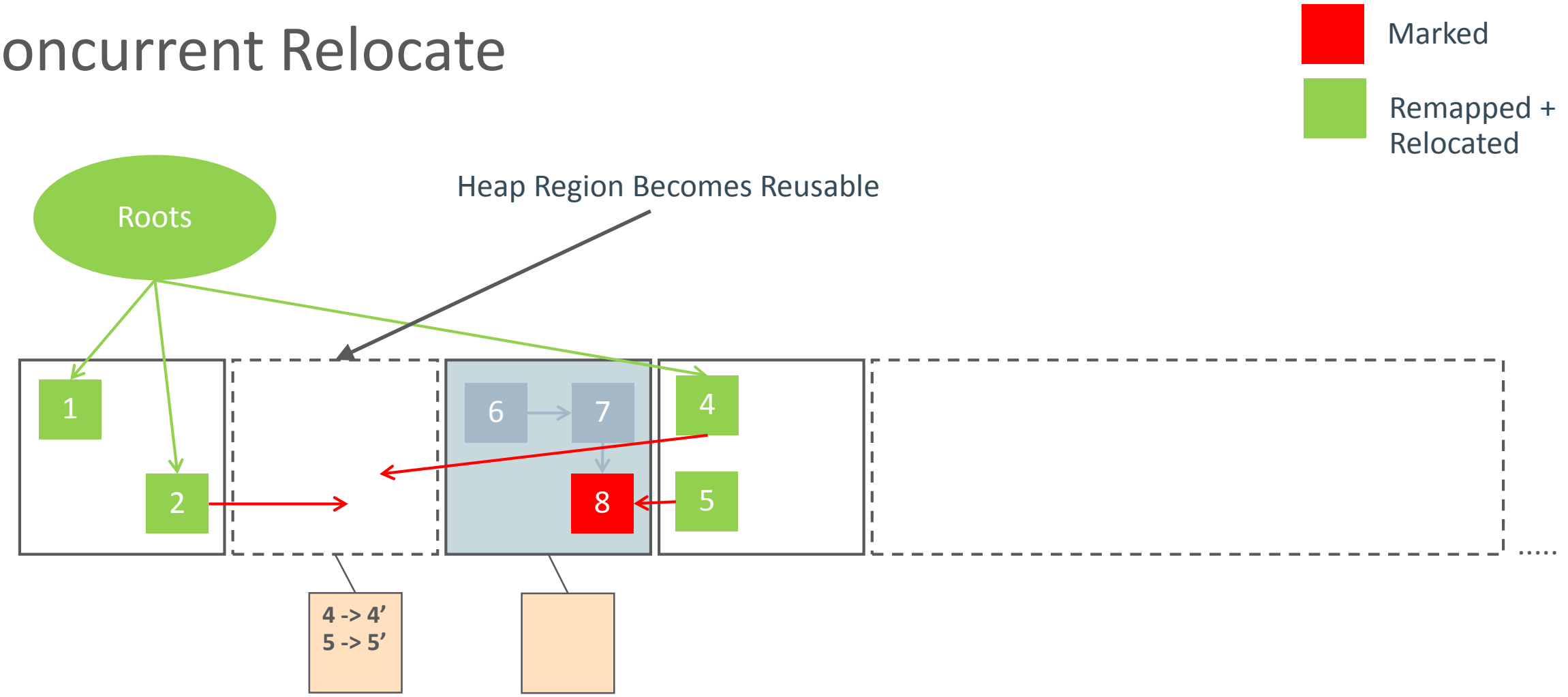

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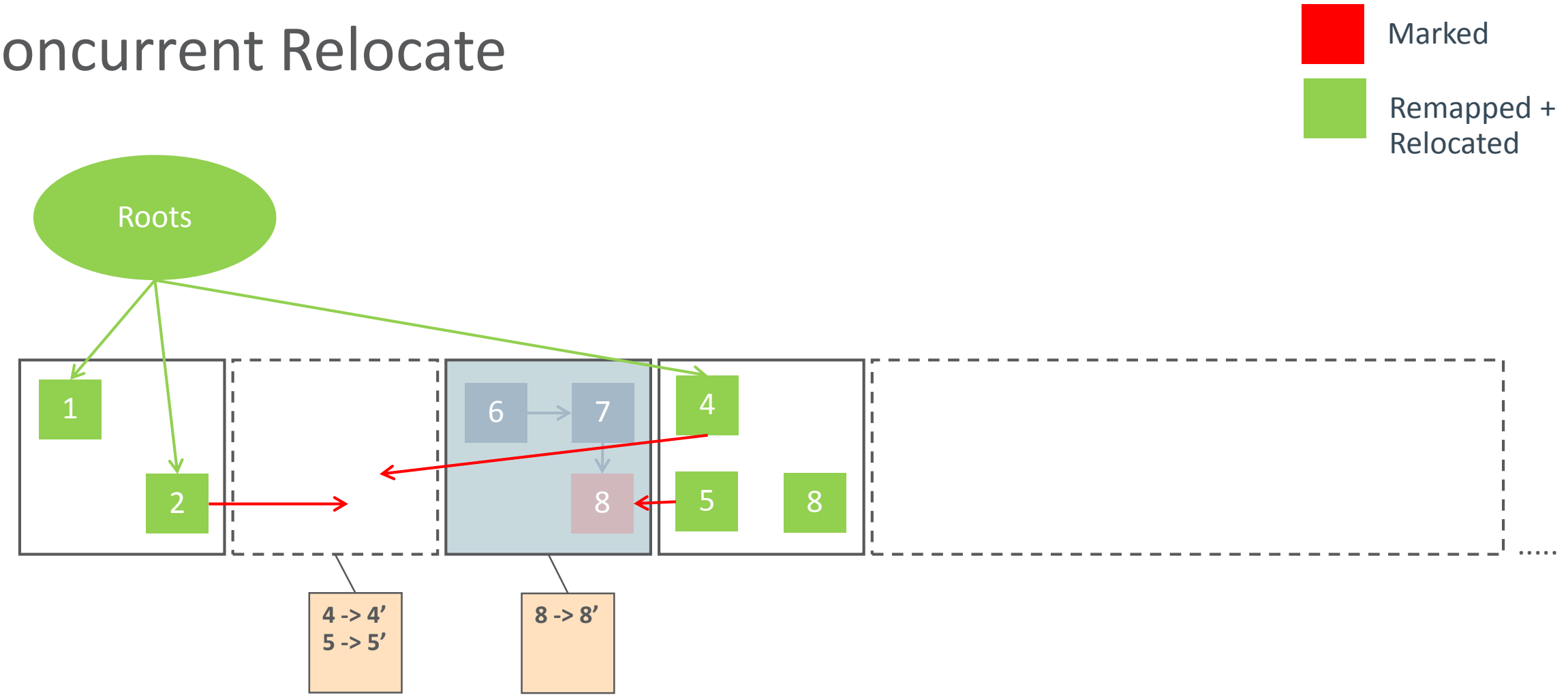
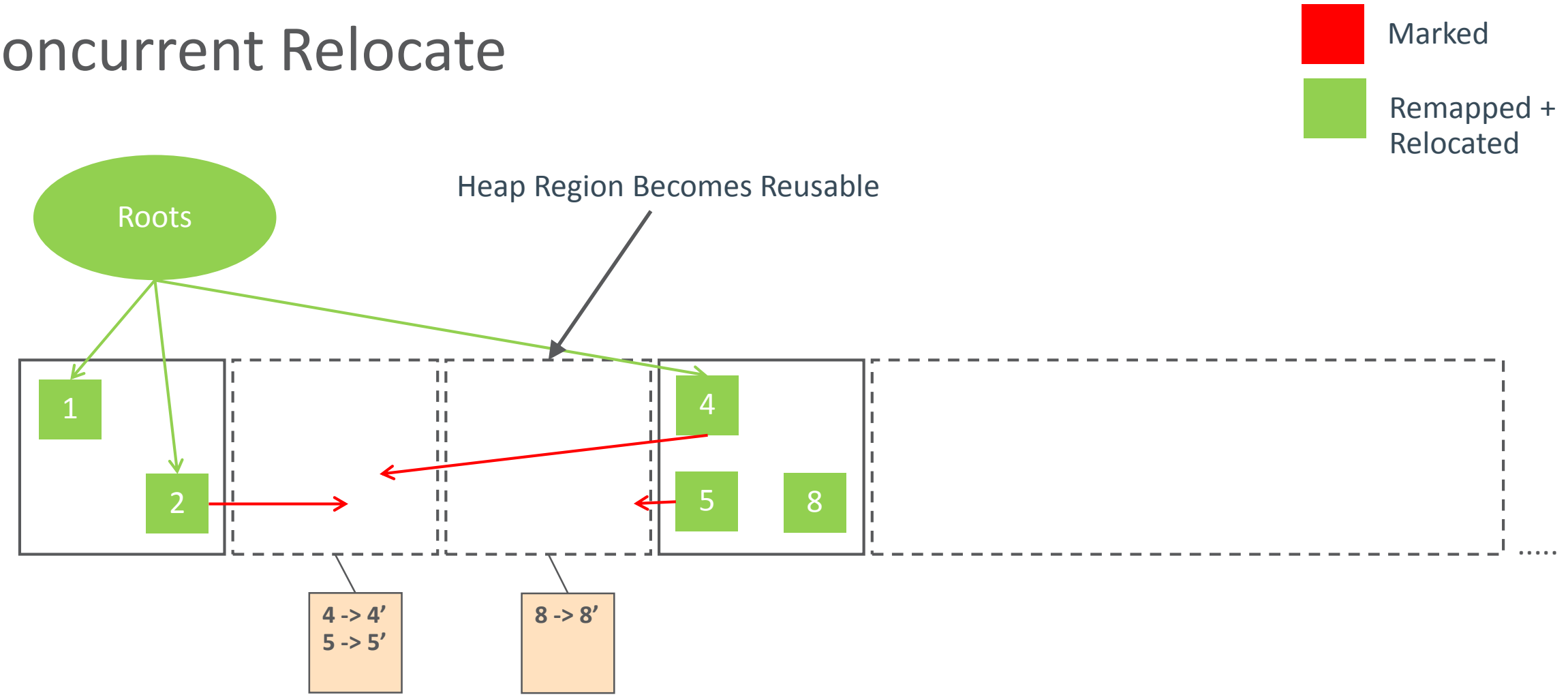
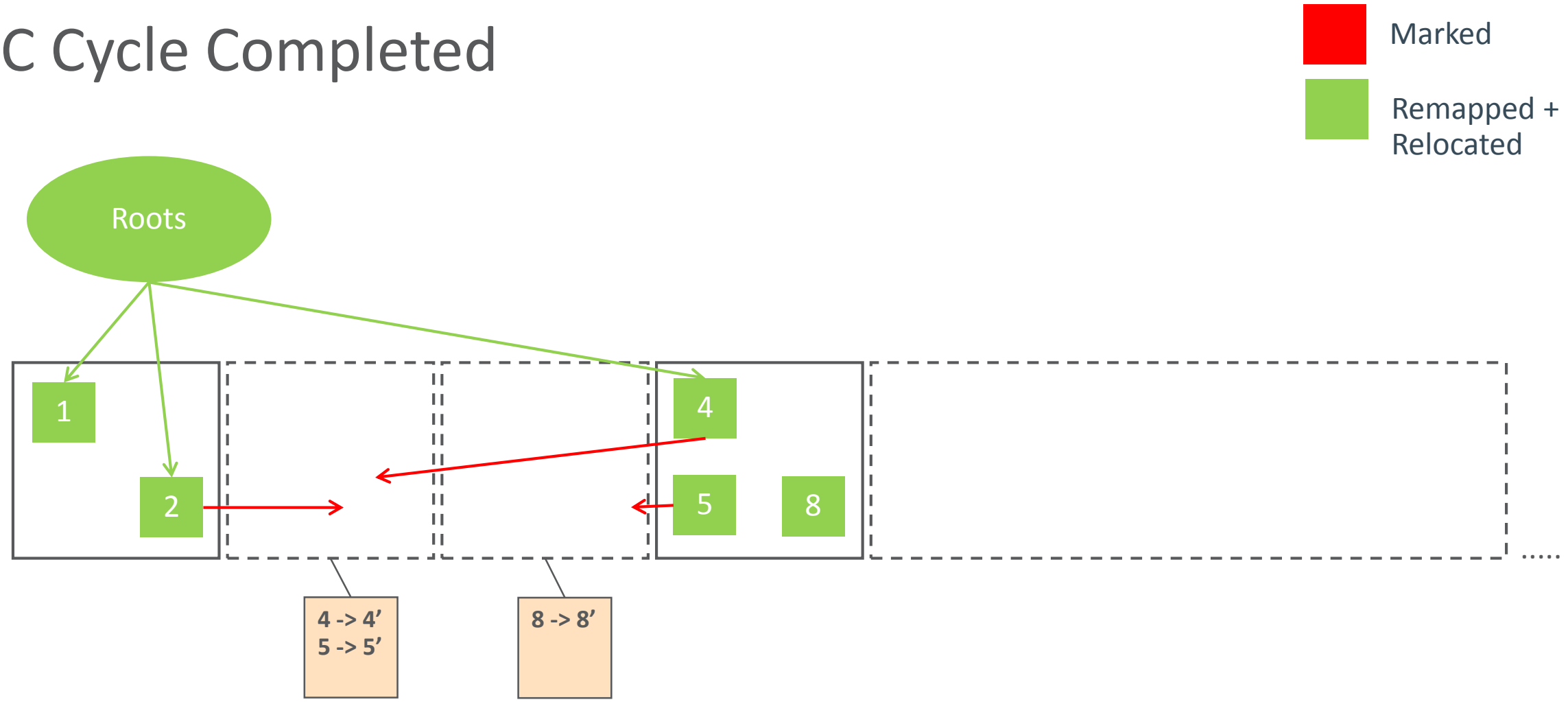


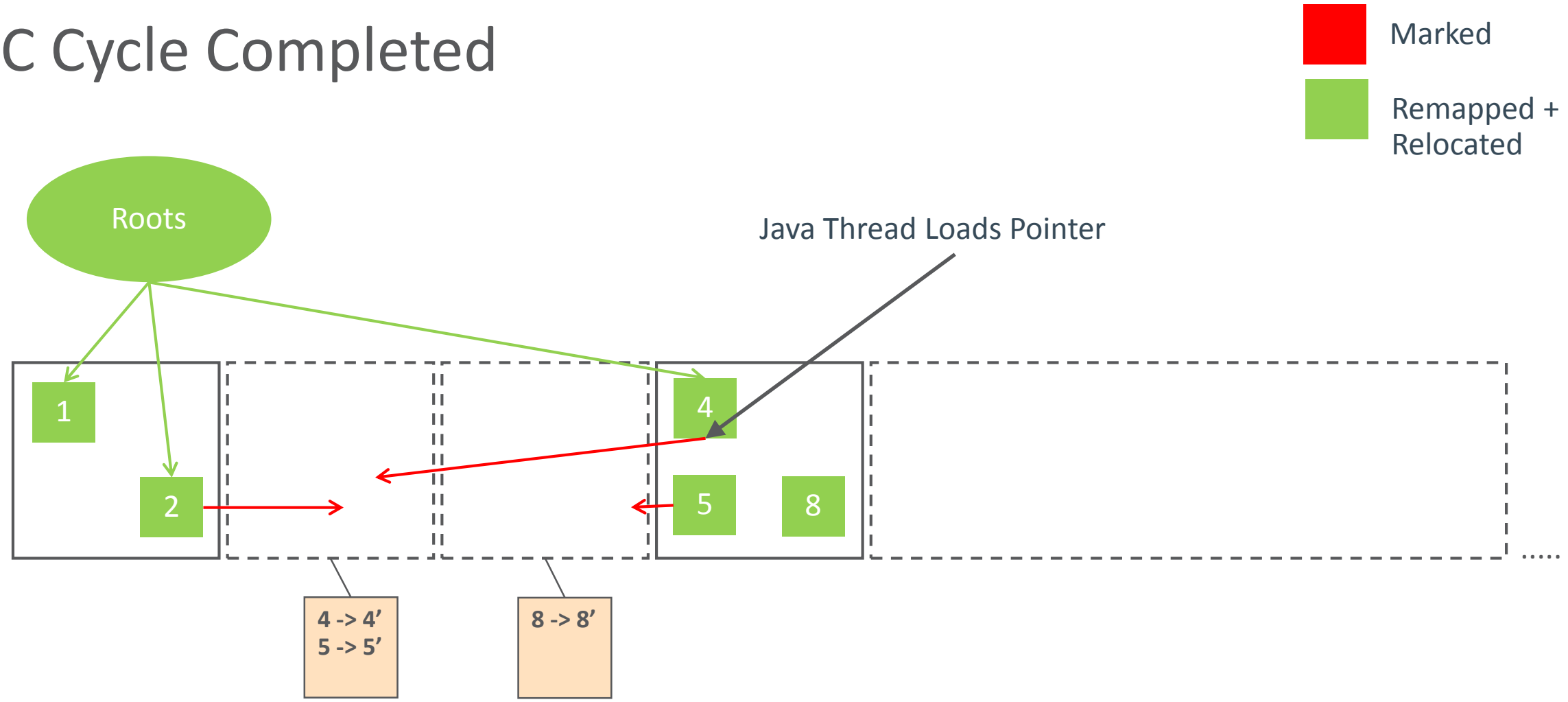
Concurrent Relocate



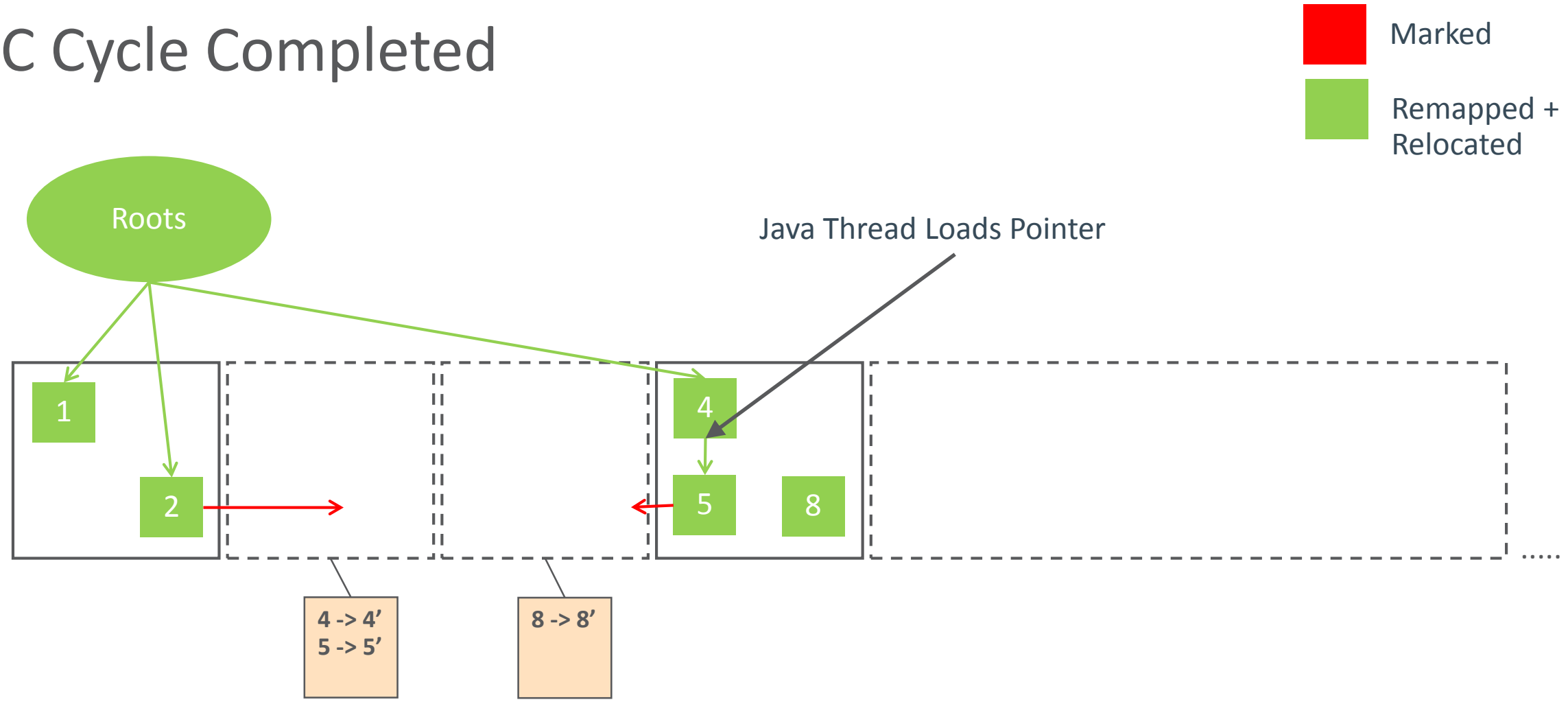
GC Cycle Completed



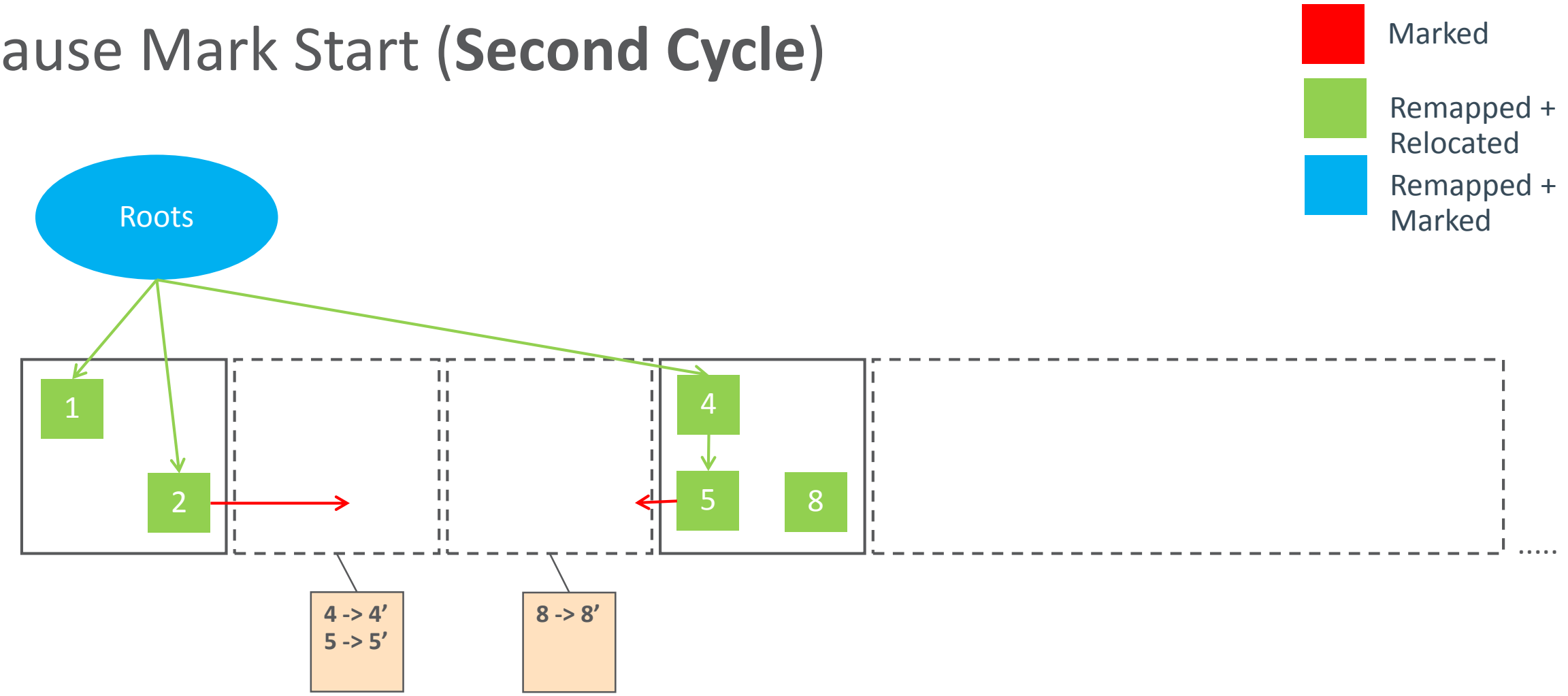
GC Cycle Completed



GC Cycle Completed



Pause Mark Start (**Second Cycle**)



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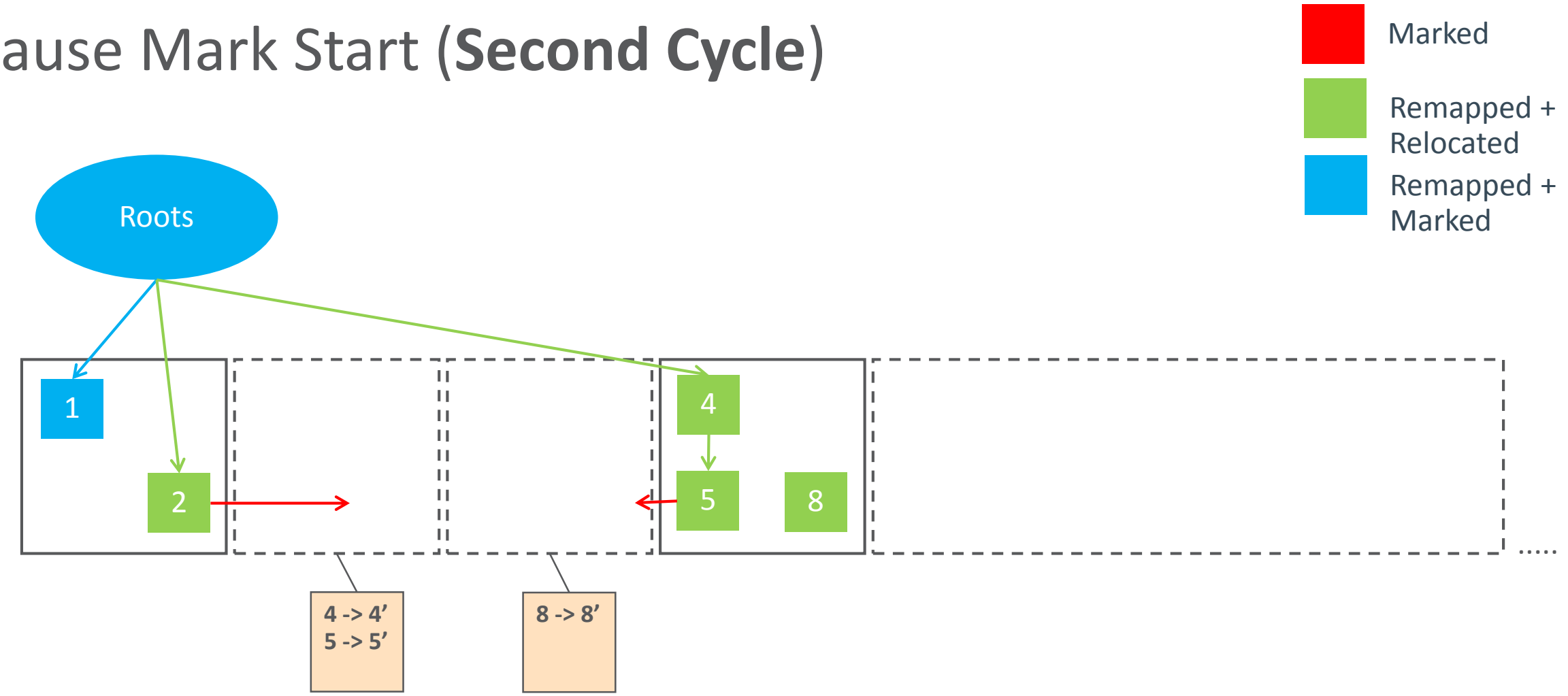

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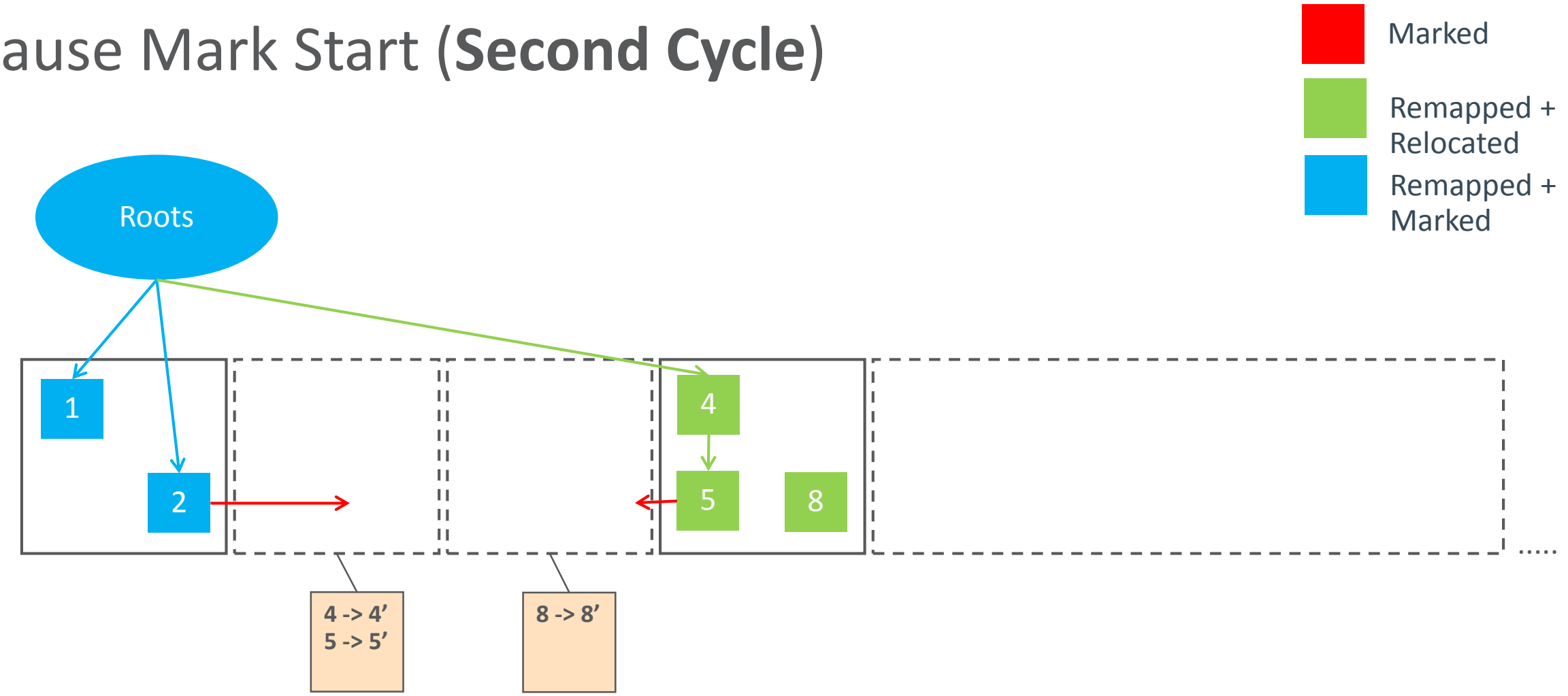

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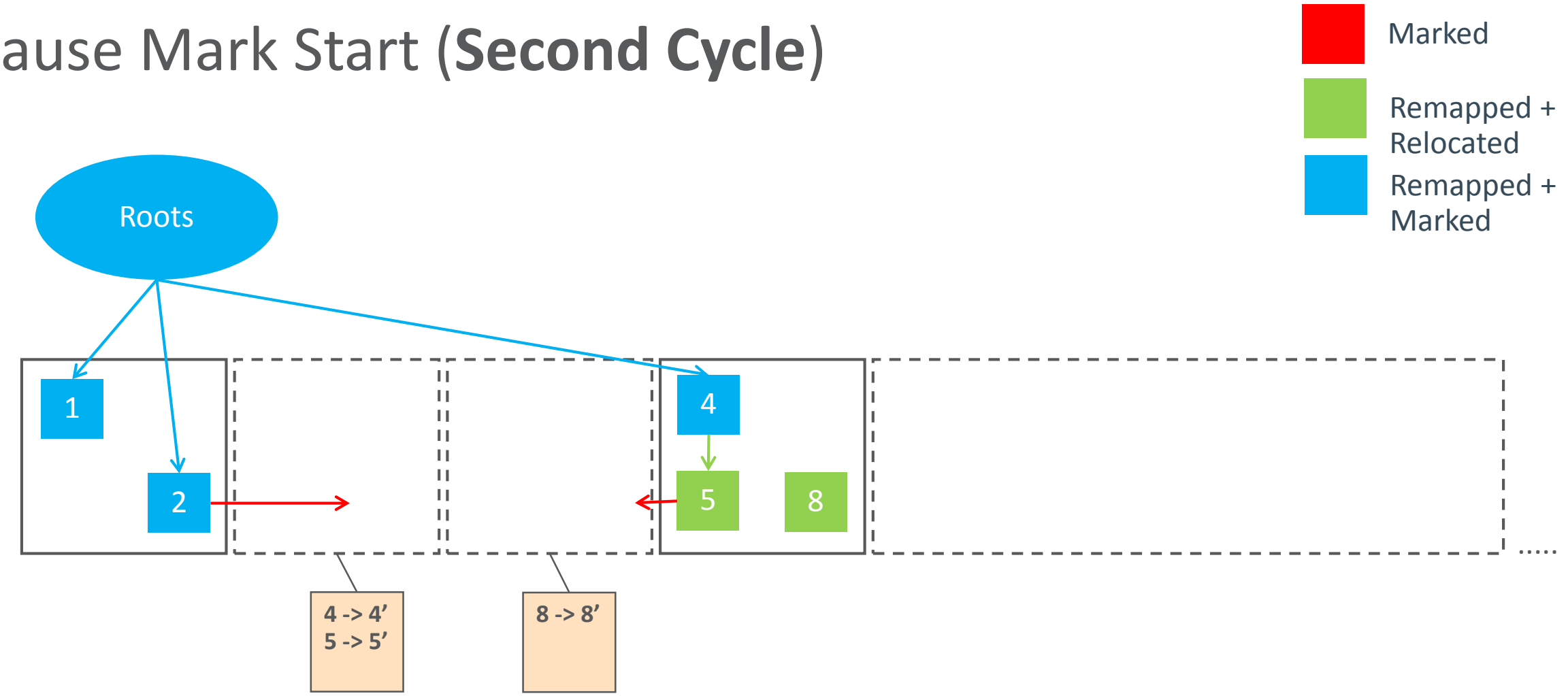

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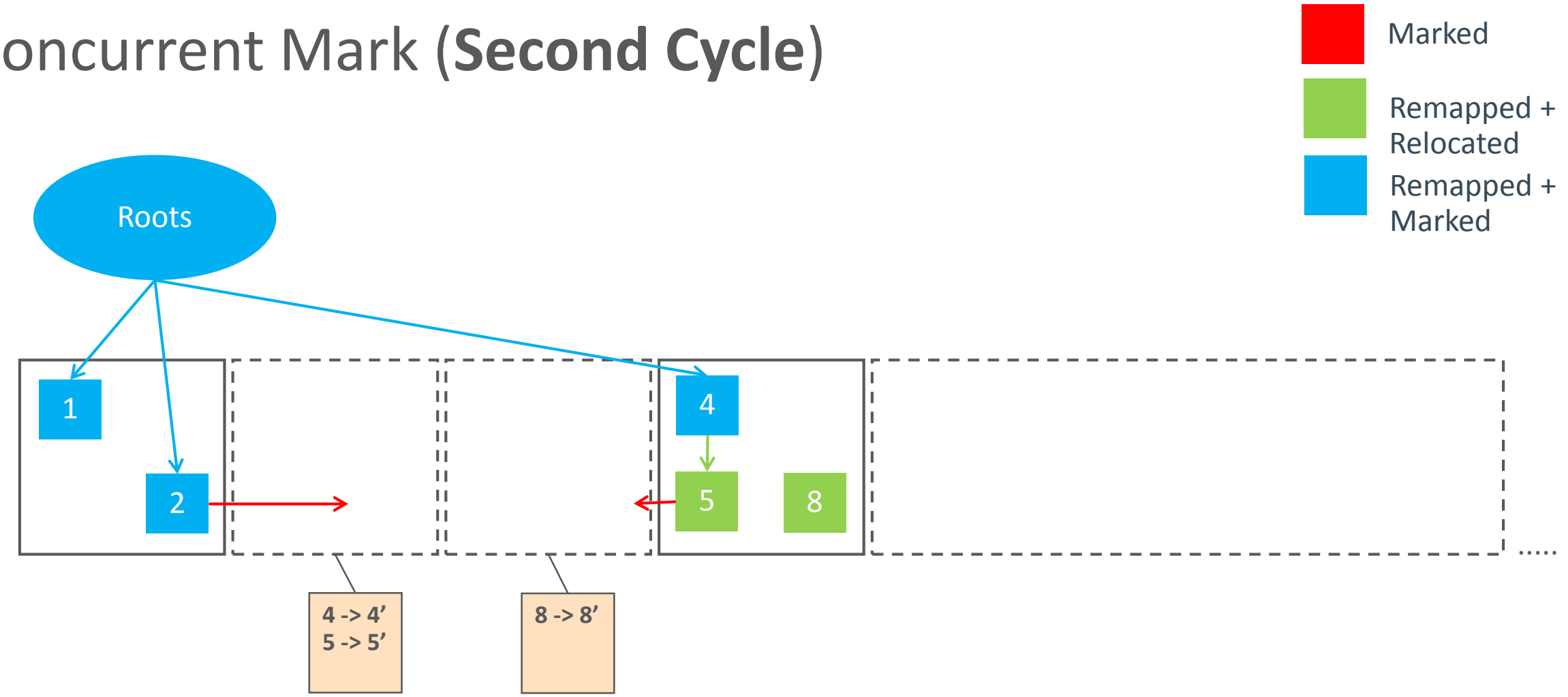

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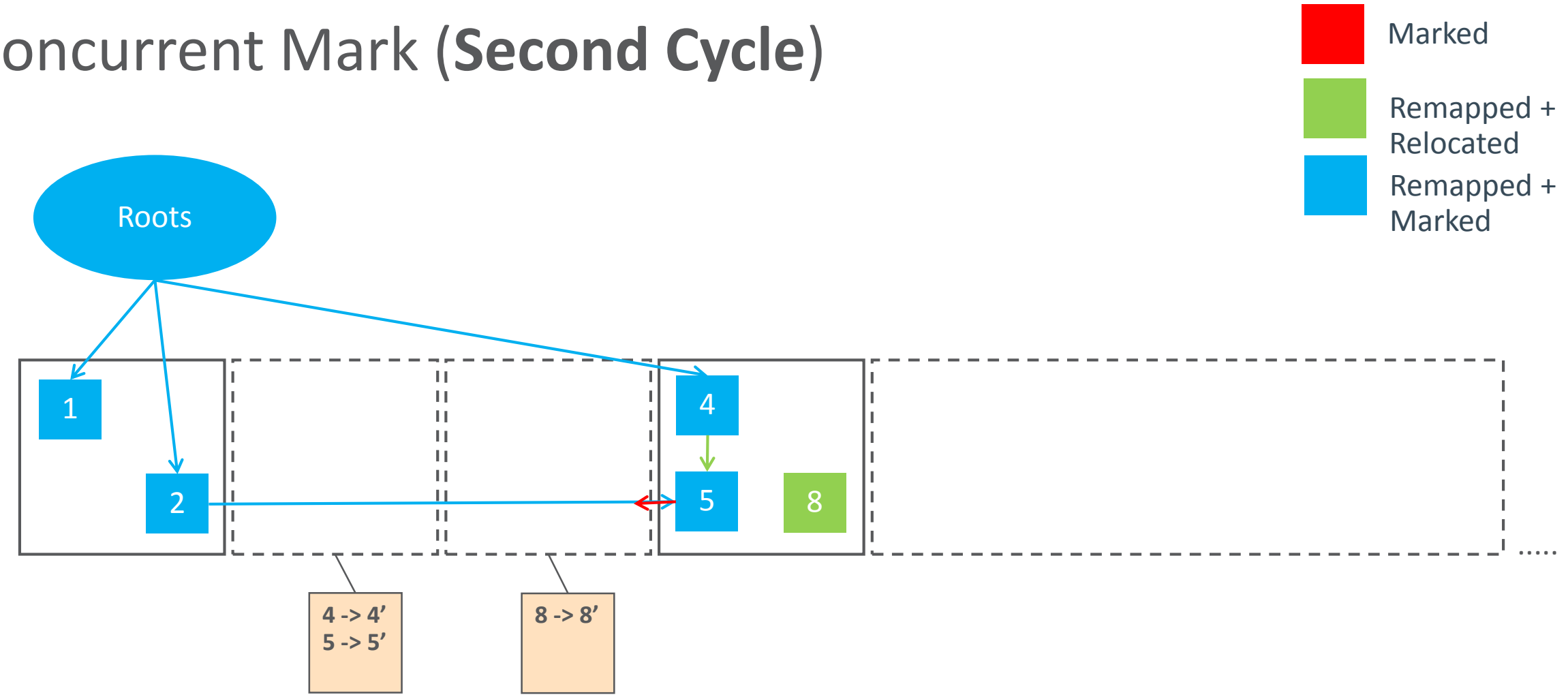

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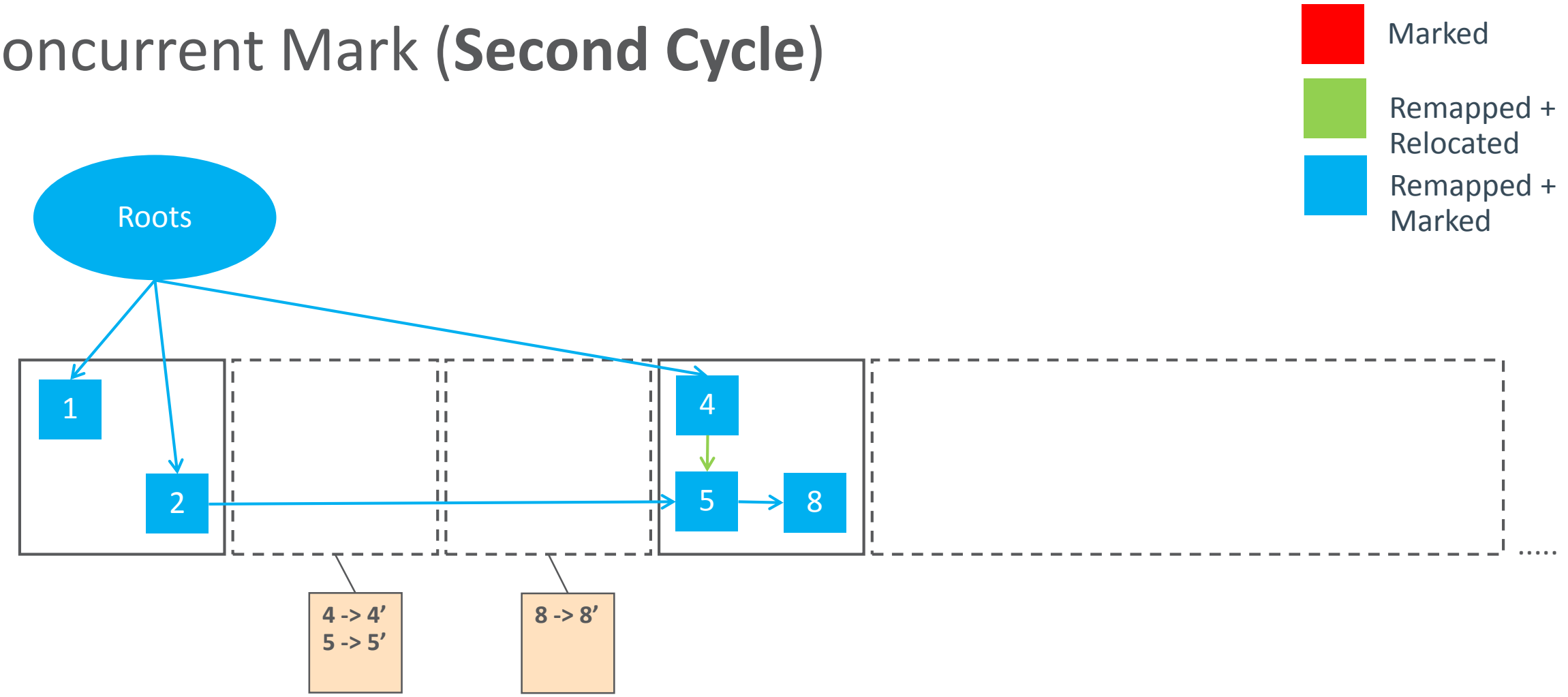
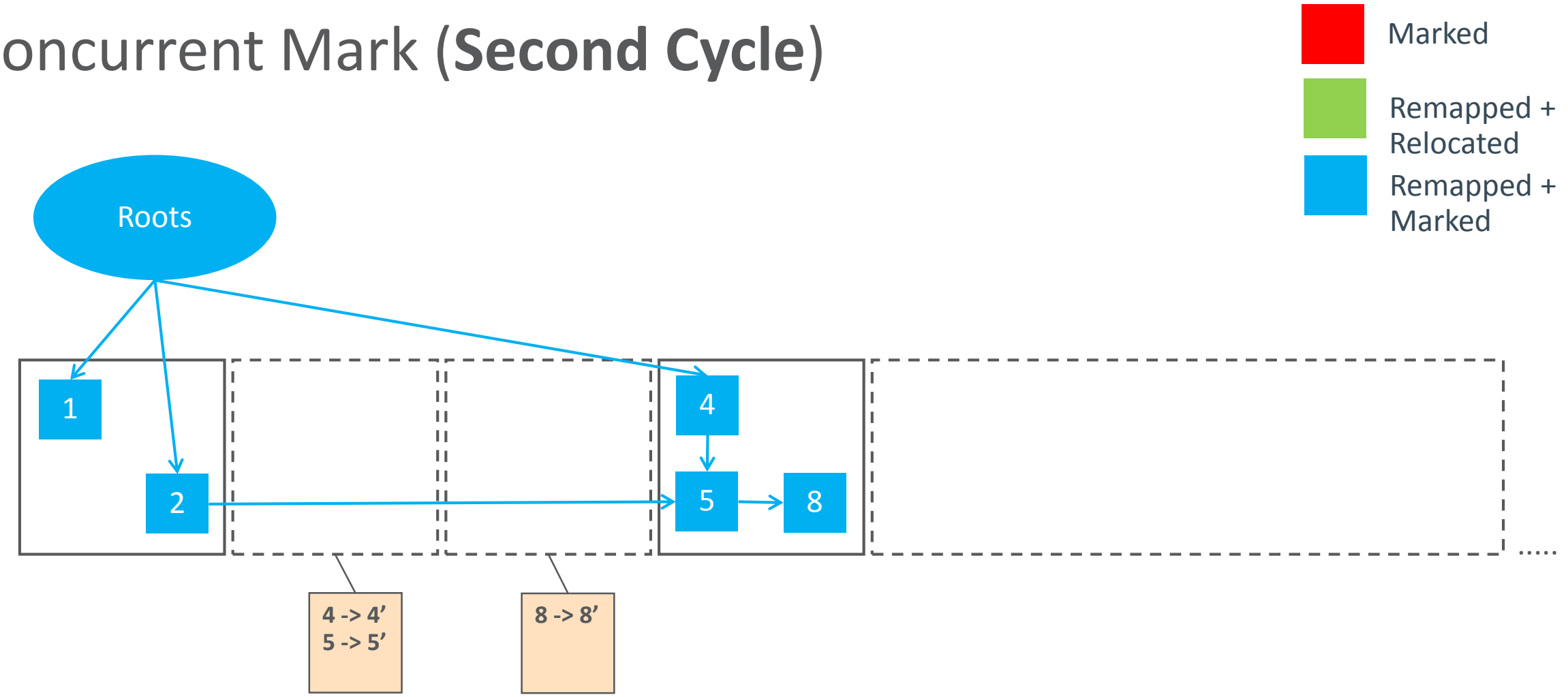
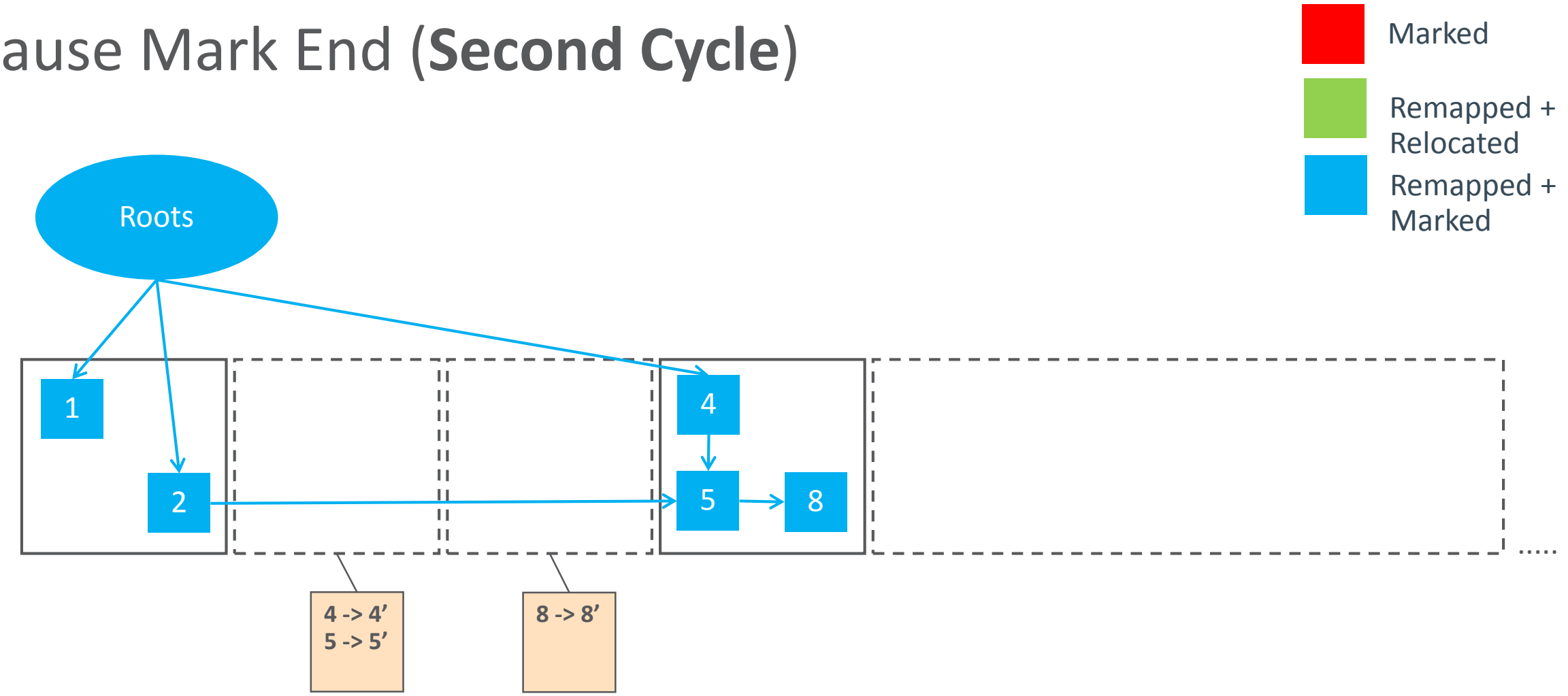


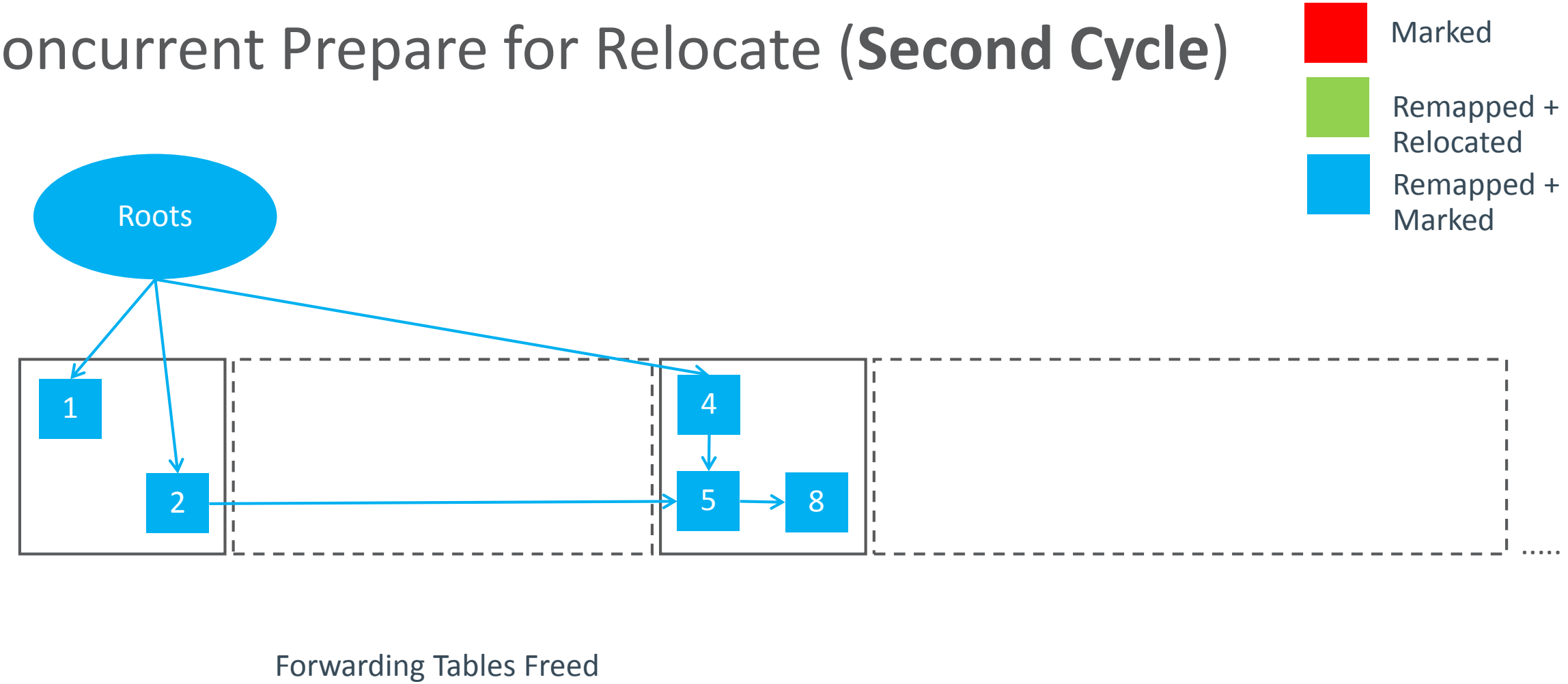
Concurrent Mark (**Second Cycle**)



Pause Mark End (**Second Cycle**)



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



Agenda

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

In The Works

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

Foundation for Future GC Features

Colored Pointers + Load Barriers

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

Agenda

1. What is ZGC?
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How To Get Started

Download

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

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

- Run

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

How To Get Started

JVM Options

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

Feedback Welcome!

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


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