Concurrent GCs
ZGC & Shenandoah

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Simone Bordet

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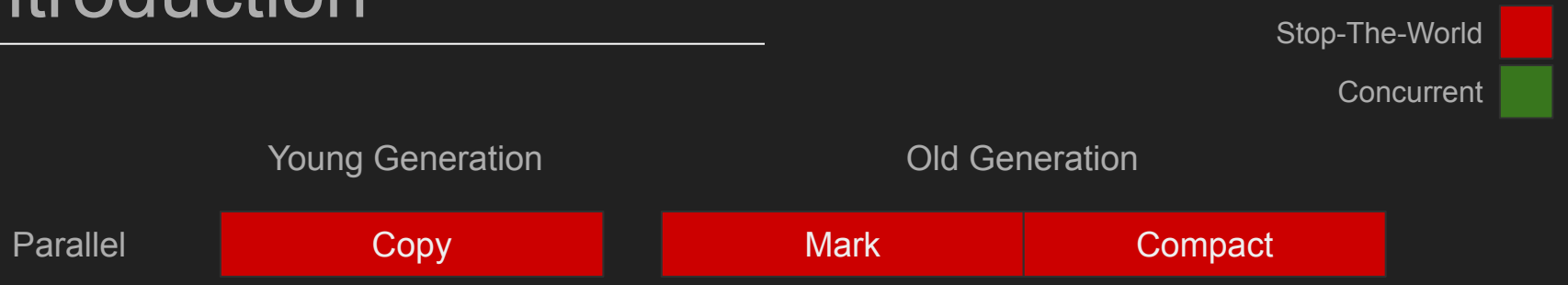
- Works @ Webtide
  - The company behind Jetty and CometD

- JVM Tuning Expert

Introduction

Introduction



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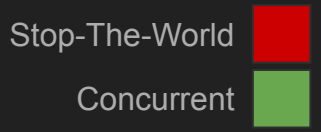
Introduction



	Young Generation	Old Generation	
Parallel	Copy	Mark	Compact
CMS	Copy	Conc Mark	Conc Sweep

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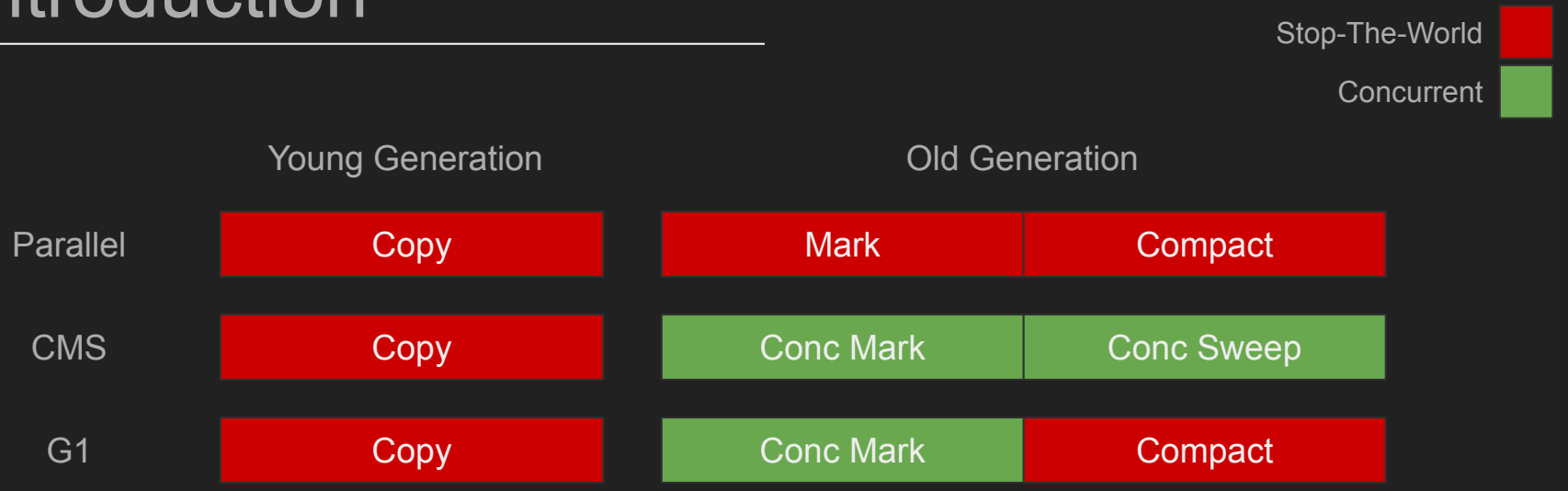
Introduction



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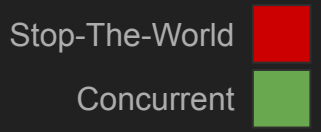
Introduction



	Young Generation	Old Generation	
Parallel	Copy	Mark	Compact
CMS	Copy	Conc Mark	Conc Sweep
G1	Copy	Conc Mark	Compact
ZGC		Conc Mark	Conc Compact
Shenandoah		Conc Mark	Conc Compact

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Introduction

- Concurrent GCs
  - GC runs concurrently with the application
- GC races with Application
  - Marking an object “alive”
  - Compacting / Moving objects

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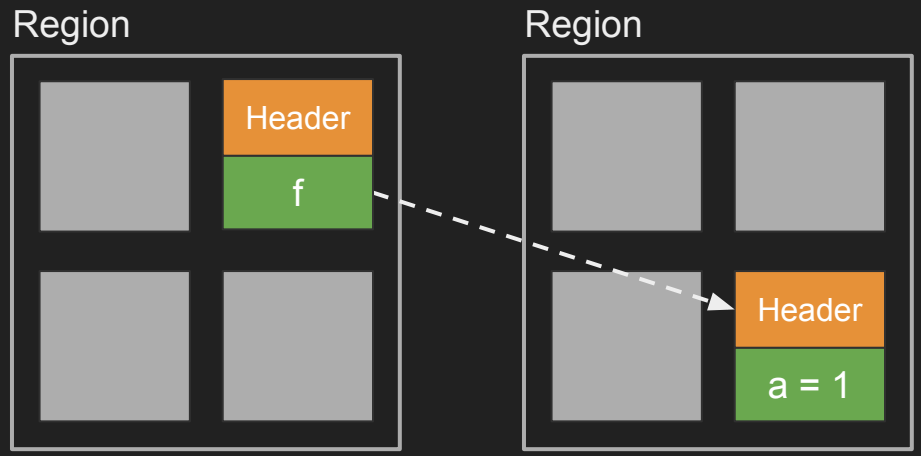
Introduction

- Concurrent copying example



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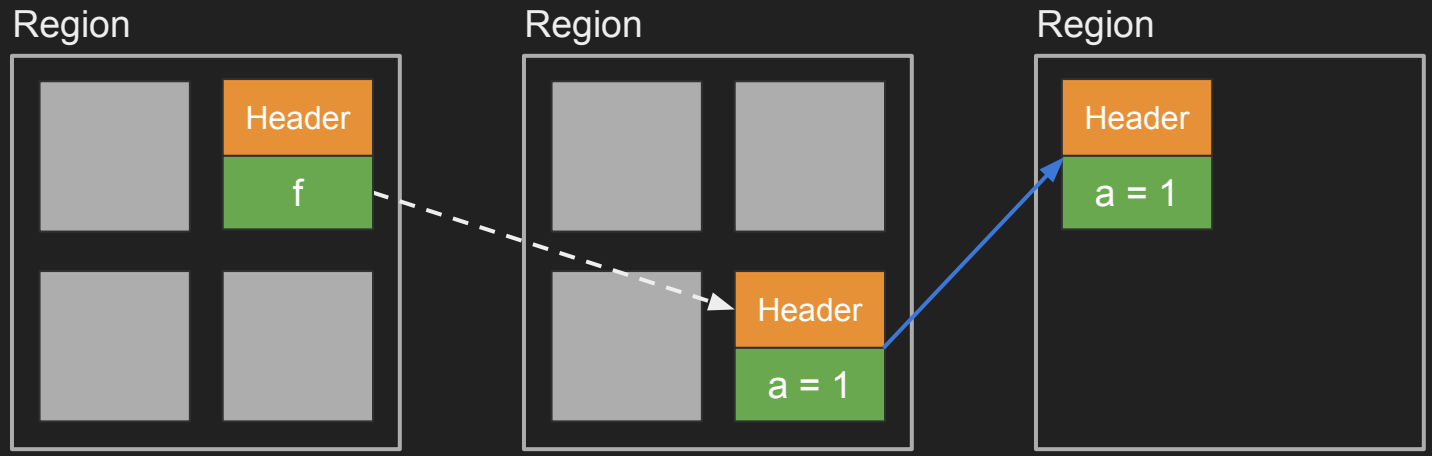
Introduction

- Garbage Collector compacts object



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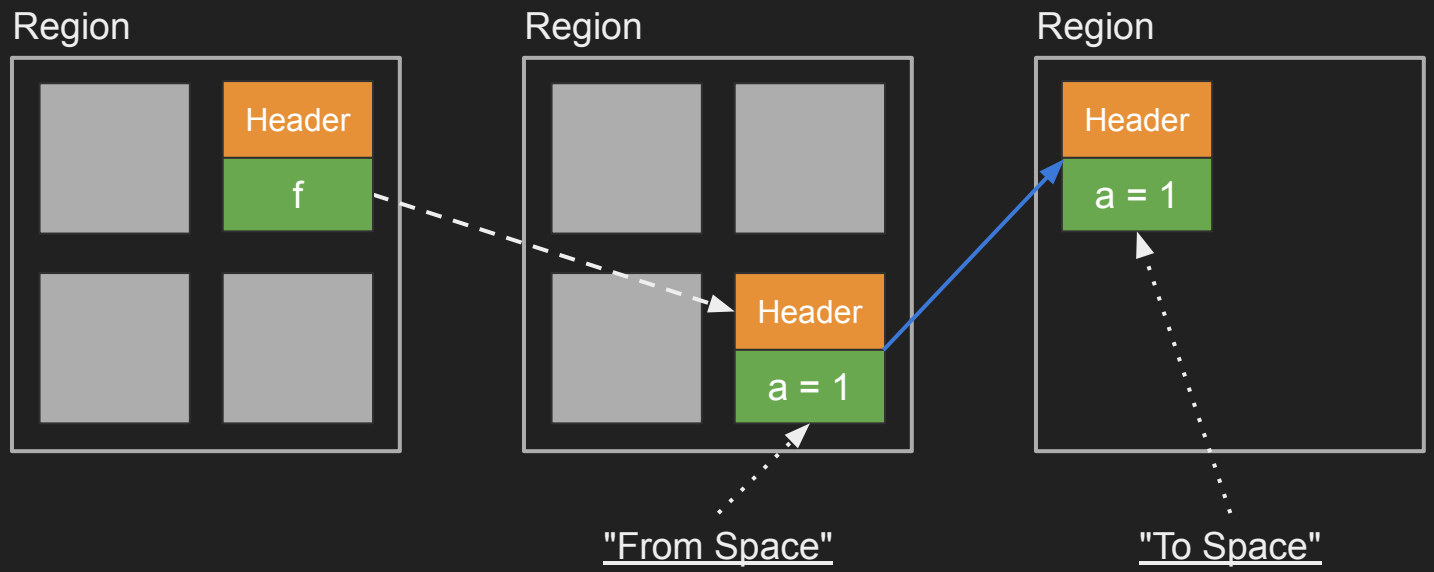
Introduction



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Introduction

- Application writes concurrently

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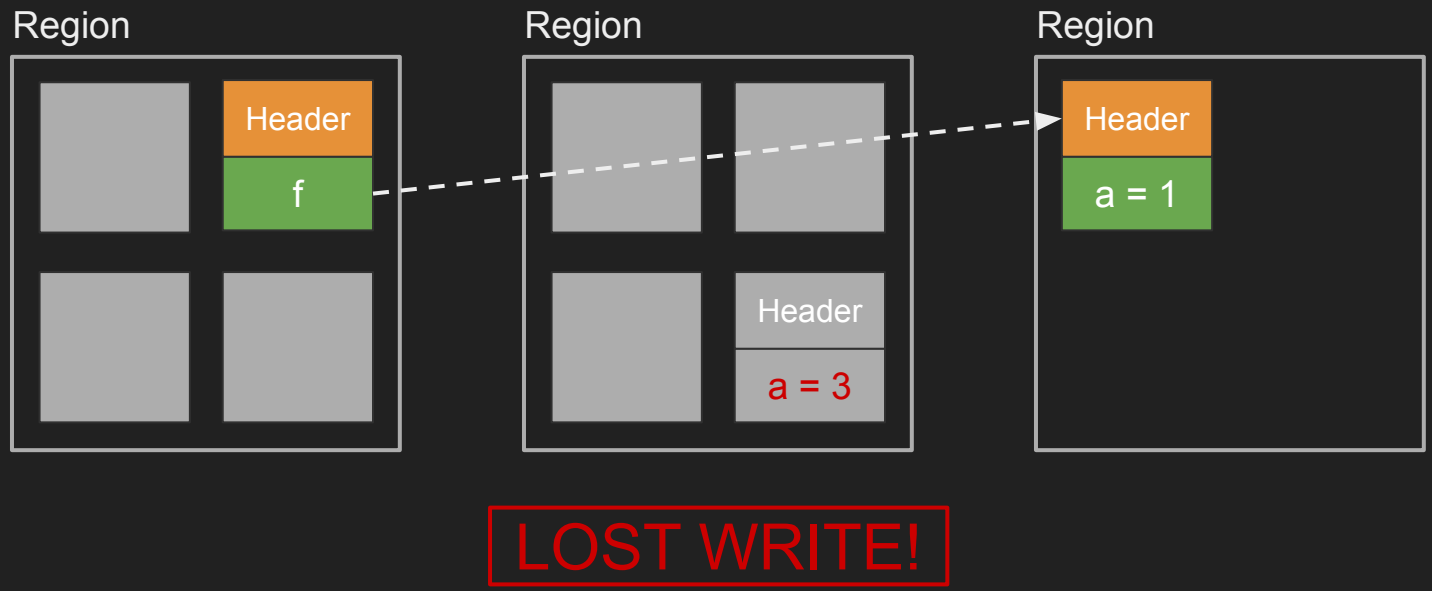
Introduction

- Garbage Collector updates references



Introduction

- Concurrent GCs store object metadata
  - E.g. whether an object has been marked
- Concurrent GCs require JIT support
- JIT injects code that helps the GC
  - GC barriers

ZGC

ZGC

- Present in OpenJDK 11+
  - Available in AdoptOpenJDK builds
  - Available in Oracle OpenJDK builds
    - From https://jdk.java.net
- Scalable Low Latency GC
- Concurrent Compaction, Single Generation

ZGC

- Only for Linux x86 64-bit
  - No compressed pointers
  - ARM port underway

- Region Based
  - ZPages - similar to G1 regions
    - Small (2 MiB - object size up to 256 KiB)
    - Medium (32 MiB - object size up to 4 MiB)
    - Large (4+ MiB - object size > 4 MiB)

ZGC

GC Thread
App Thread

STW
Mark Start

Scan threads stacks
Mark object roots

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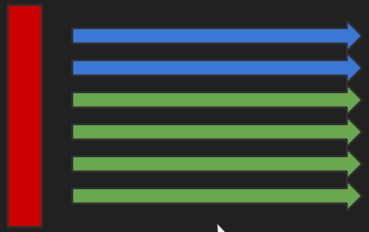
ZGC

GC Thread
App Thread

Concurrent
Marking



Mark object graph
Gather liveness information

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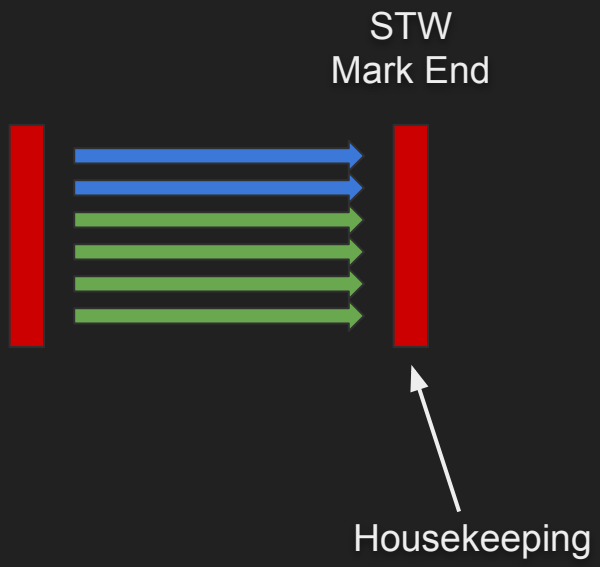
ZGC



GC Thread
App Thread

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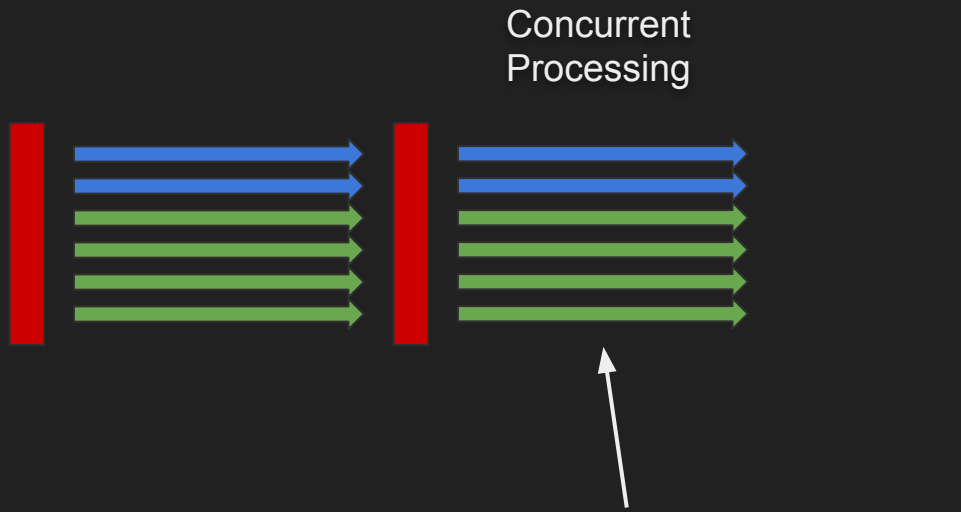
ZGC

GC Thread
App Thread



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ZGC

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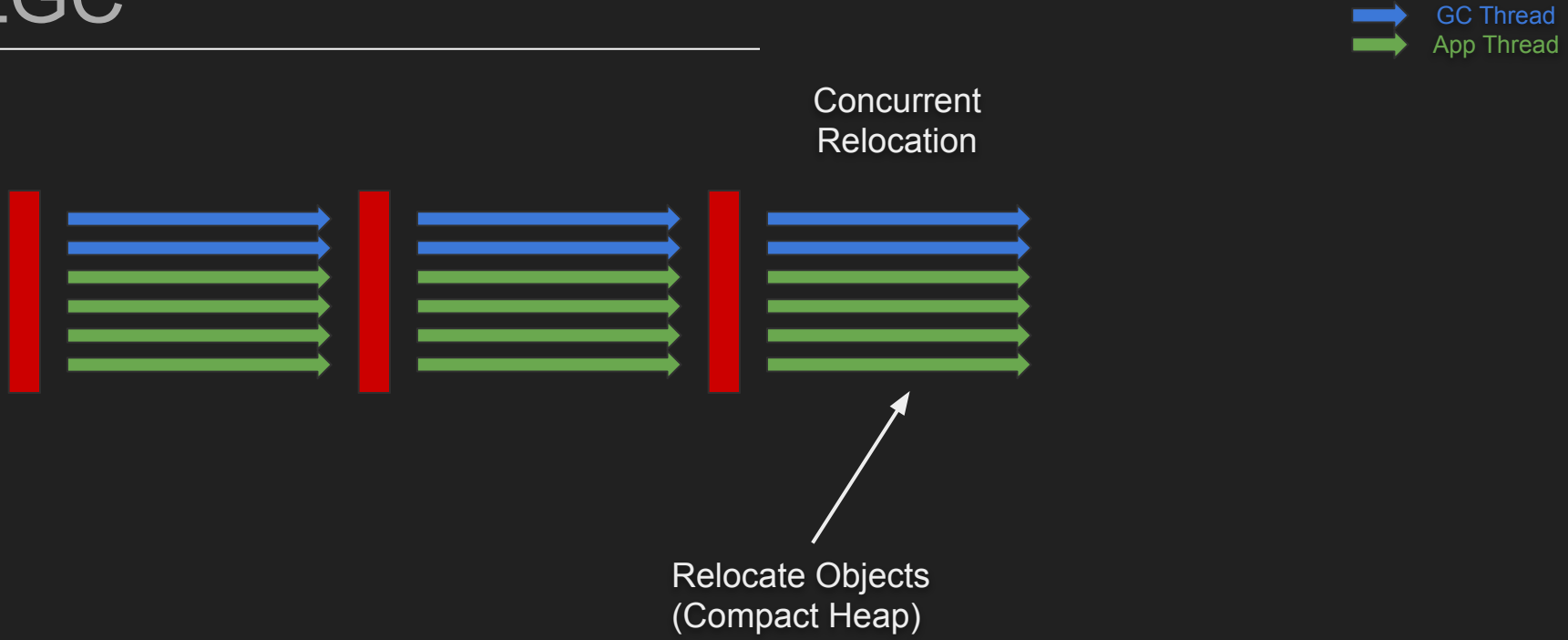
ZGC



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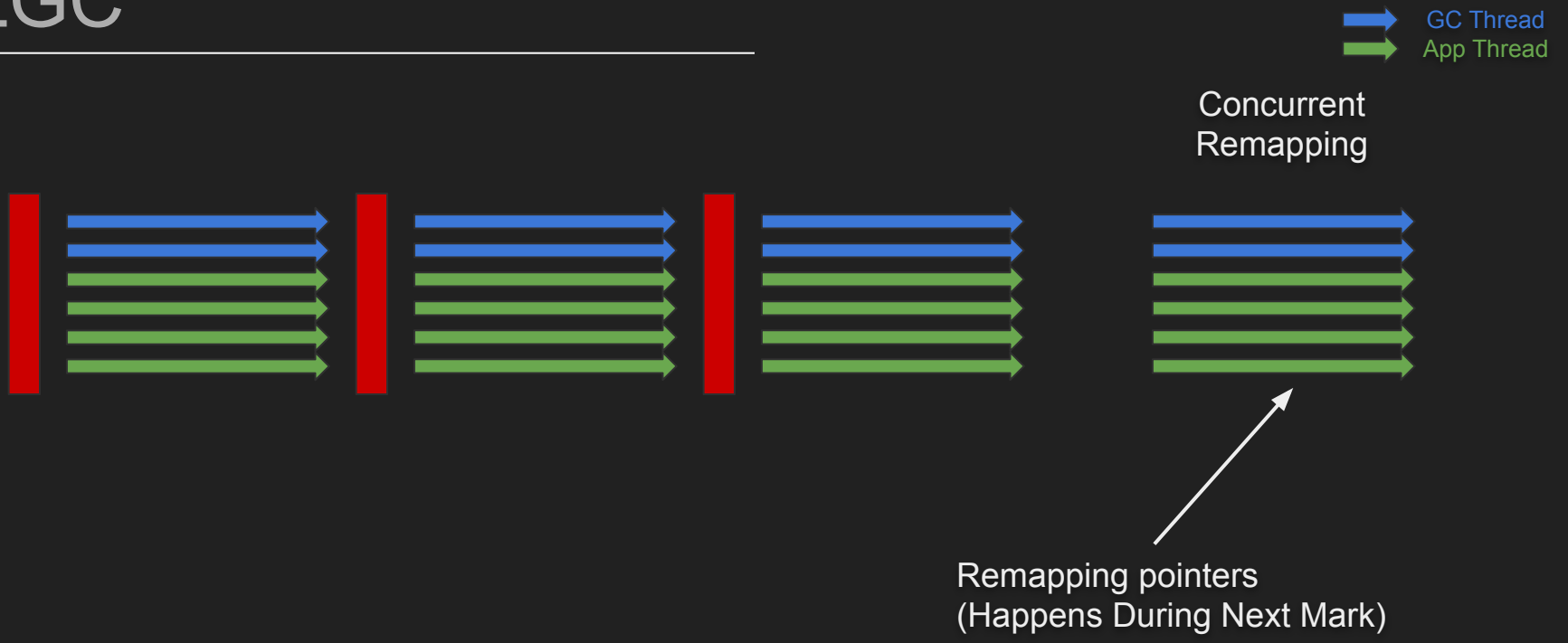
ZGC



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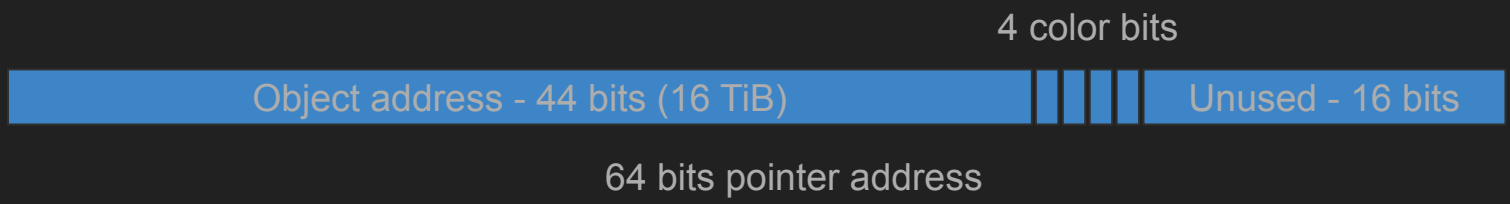
ZGC

- ZGC solution
  - To avoid races with the application
- Colored Pointers
- Load GC barrier

ZGC

- ZGC colored pointers
  - Color indicates GC metadata



- Check pointer color against GC phase
  - Wrong color => take action

ZGC

- ZGC load GC barrier

```
Object f = obj.field;
<load_barrier>
```

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ZGC

- ZGC load GC barrier

```
Object f = obj.field;
if (addr_of(f) & wrong_gc_color) {
  slow_path()
}
```

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ZGC

- ZGC load GC barrier

```
Object f = obj.field;
<load_barrier>

mov 0x10(%rdi), %rsi
test %rsi, 0x20(%r15)
jne slow_path
```

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ZGC

- ZGC load GC barrier tests for the right color
- Wrong color -> take `slow_path`
  - Fix color & Run some action - atomically
- The action depends on the GC phase

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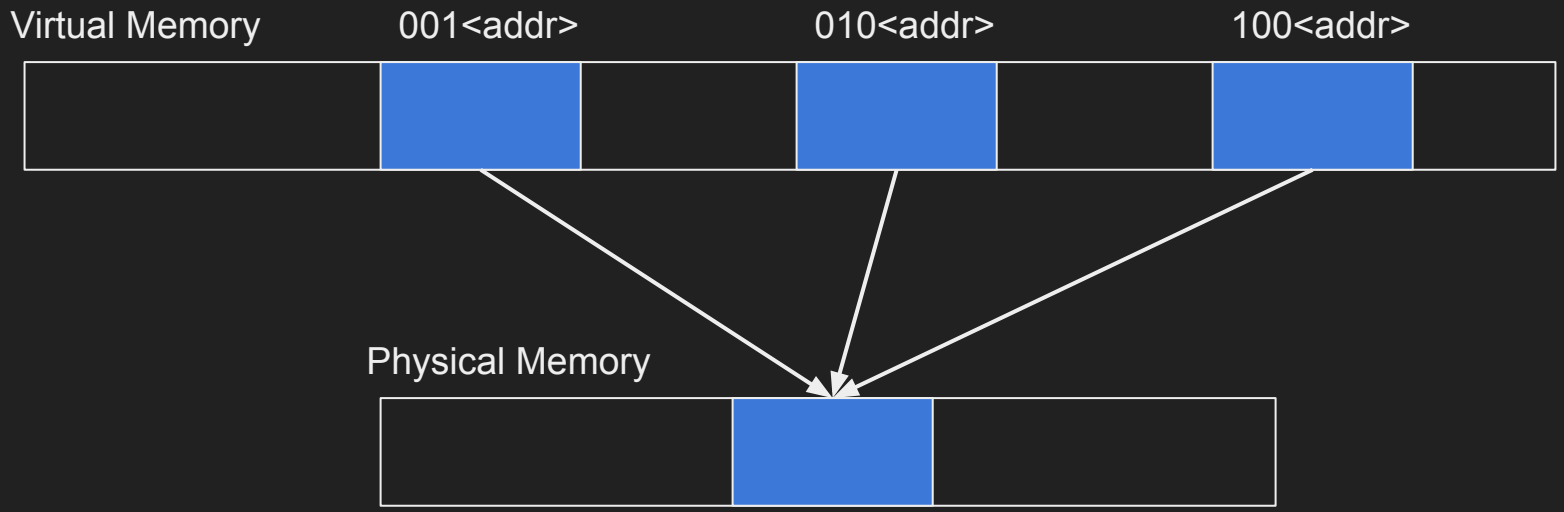
ZGC

- ZGC Multi-Mapping

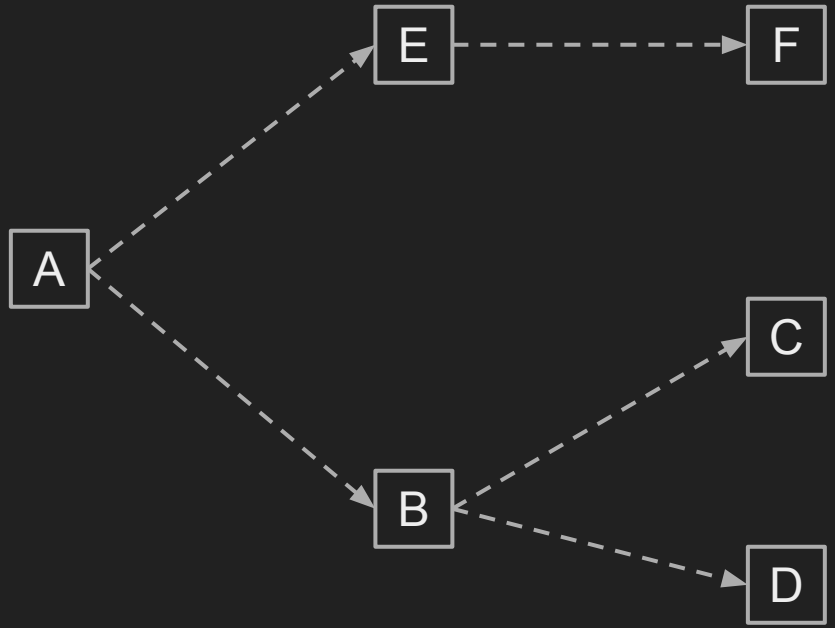


ZGC

- ZGC Multi-Mapping
- RSS shows 3x size
  - E.g. -Xmx=16G -> RSS~=50G
  - On Linux, use `smem` and track PSS
- Watch out for OOM Killers in clouds
  - E.g. AWS

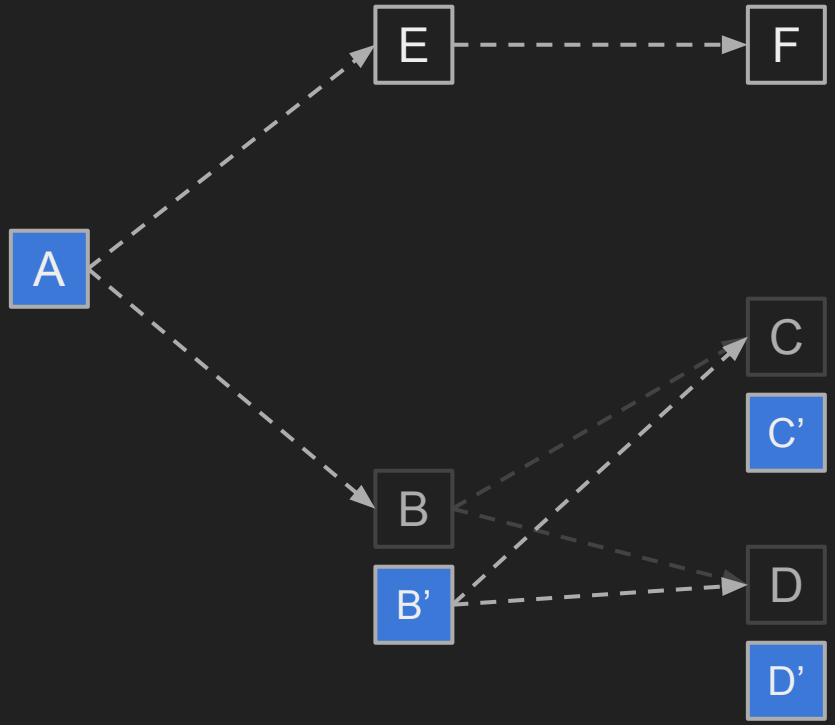
ZGC

- Relocation



ZGC

- Relocation



MetaData

B -> B'
C -> C'
D -> D'

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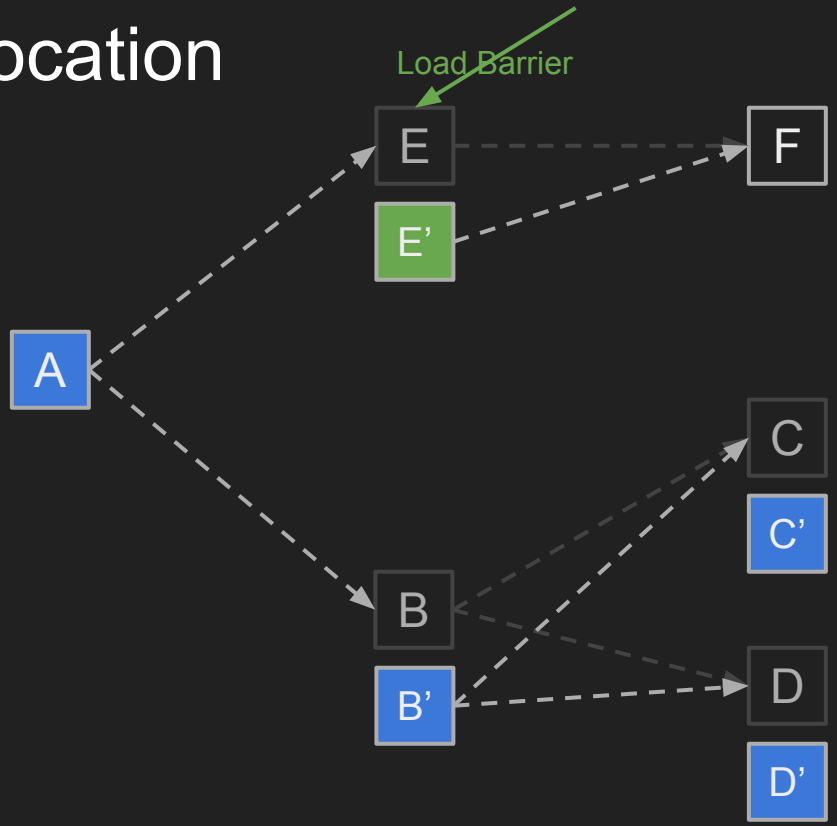
ZGC

- Relocation

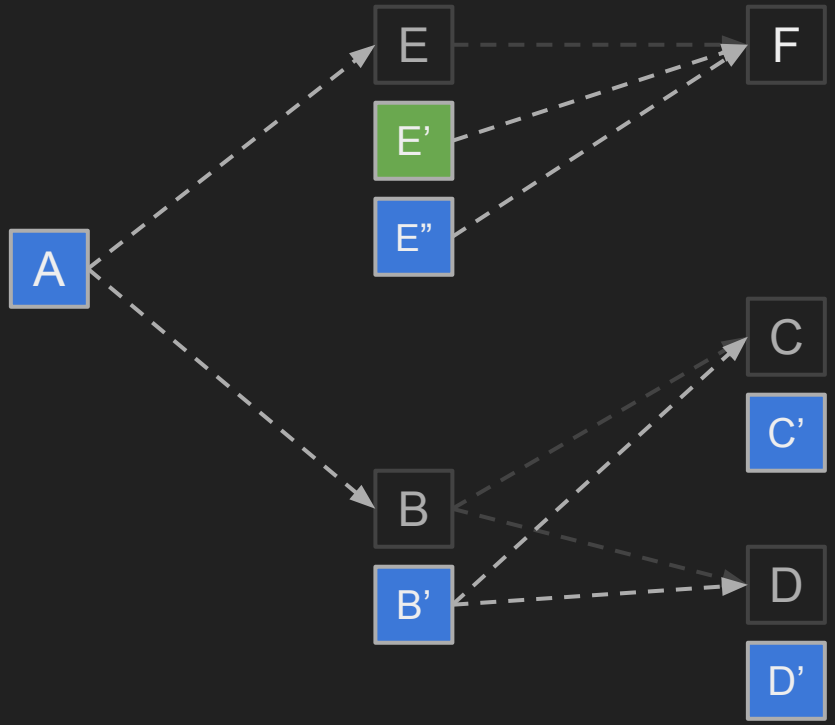


MetaData

B -> B'
C -> C'
D -> D'
E -> E'

ZGC

- Relocation



MetaData

B -> B'
C -> C'
D -> D'
E -> E'

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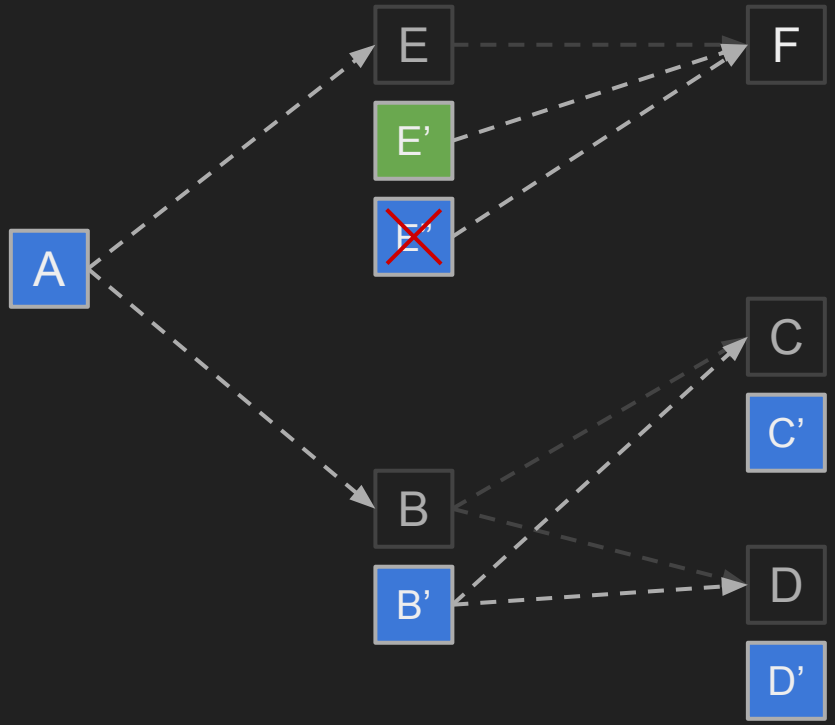
ZGC

- Relocation



MetaData

B -> B'
C -> C'
D -> D'
E -> E'
~~E -> E''~~

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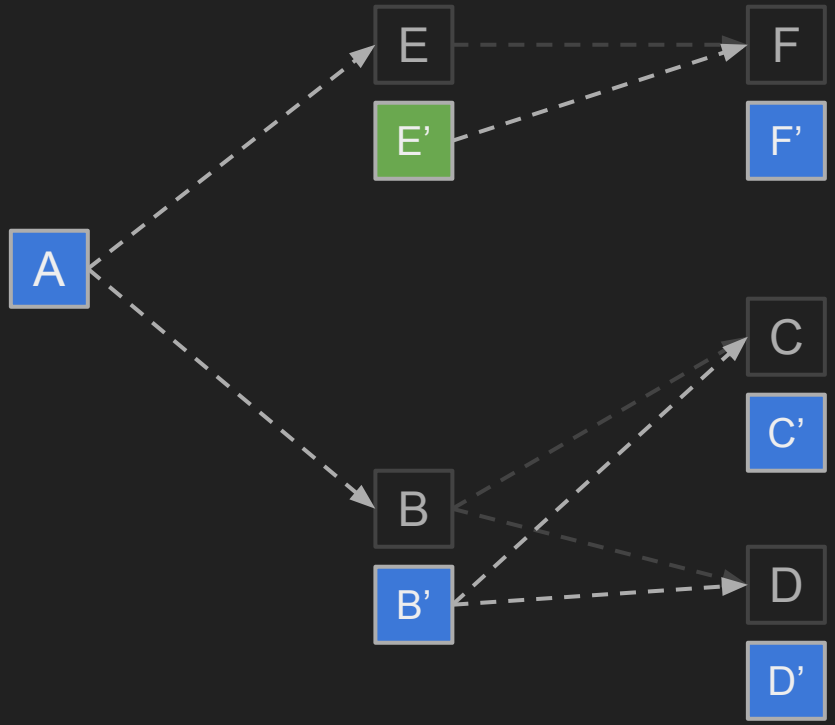
ZGC

- Relocation



MetaData

B -> B'
C -> C'
D -> D'
E -> E'
F -> F'

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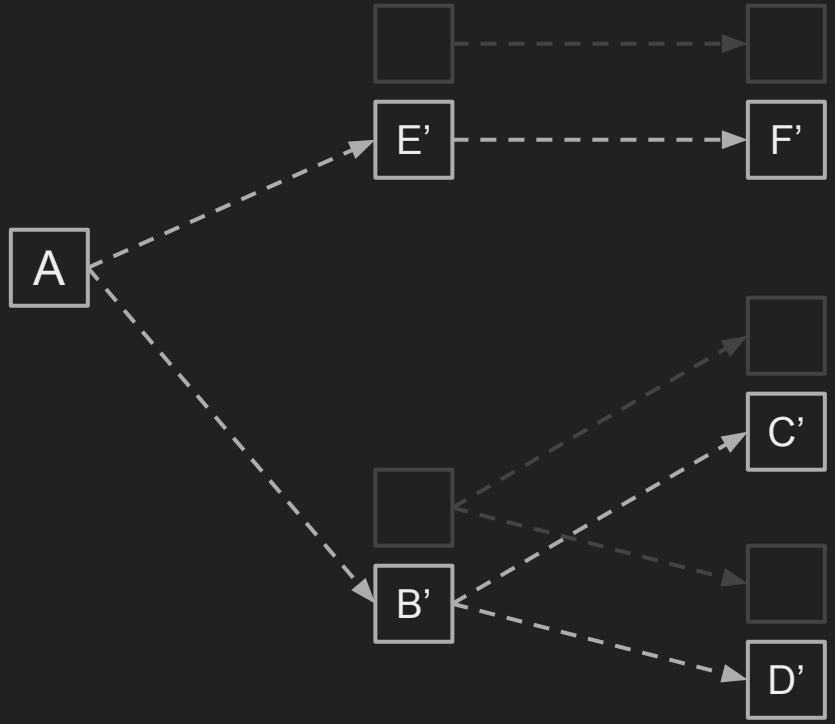
ZGC

- Remapping



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ZGC

- References
  - Per Lidén, Erik Österlund et al.
    - https://www.youtube.com/watch?v=7cWiwu7kYkE
    - https://www.youtube.com/watch?v=kF_r3GE3zOo
  - Project Wiki
    - https://wiki.openjdk.java.net/display/zgc/Main
  - Mailing List
    - zgc-dev@openjdk.java.net

ShenandoahGC

ShenandoahGC

- Present in OpenJDK 12+ repository
  - Available in AdoptOpenJDK builds
  - NOT available in Oracle's OpenJDK builds
  - Present in RedHat OpenJDK 8, 11+
- Scalable low latency GC
- Concurrent Compaction, Single Generation

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ShenandoahGC

- Available for x86 32-bit and 64-bit
  - ARM ports available
- Linux, MacOS, Windows
  - JDK 8, 11 & Latest
- Region Based
  - Derived from G1

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ShenandoahGC

GC Thread
App Thread

STW
Mark Start

Scan threads stacks
Mark object roots

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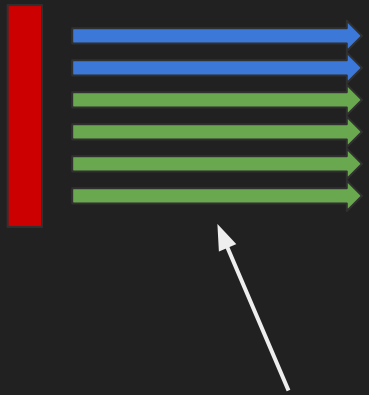
ShenandoahGC

GC Thread
App Thread

Concurrent
Marking



Mark object graph
Gather liveness information

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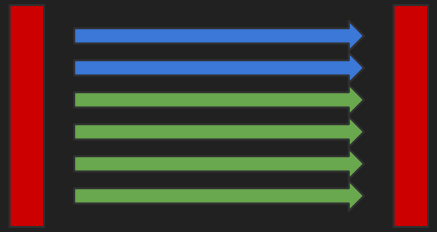
ShenandoahGC

GC Thread
App Thread

STW
Mark End



Weak Reference Processing
Unload Classes
Evacuate Roots
Housekeeping

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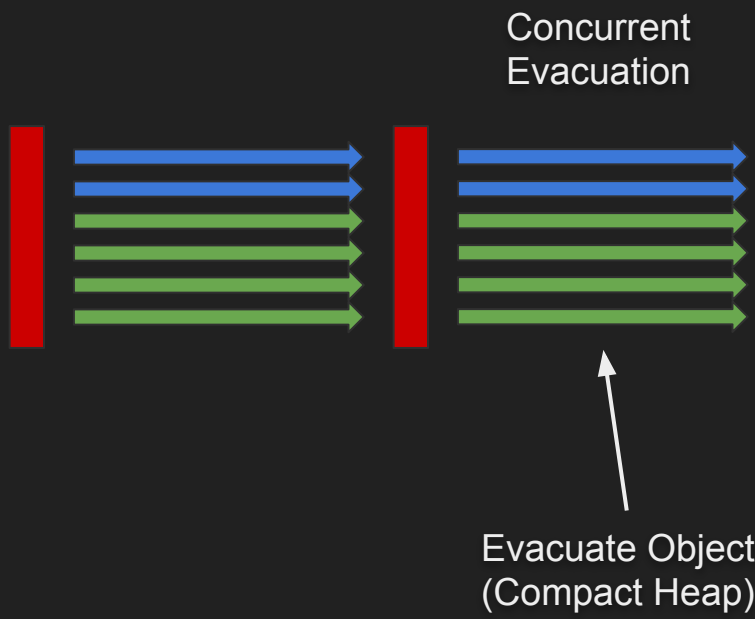
ShenandoahGC



GC Thread
App Thread

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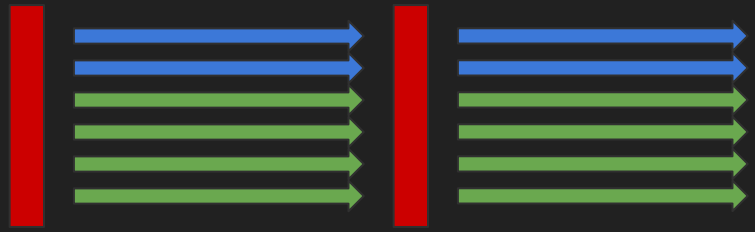
ShenandoahGC

GC Thread
App Thread



Concurrent
Update References

Remapping pointers
(Happens During Next Mark)

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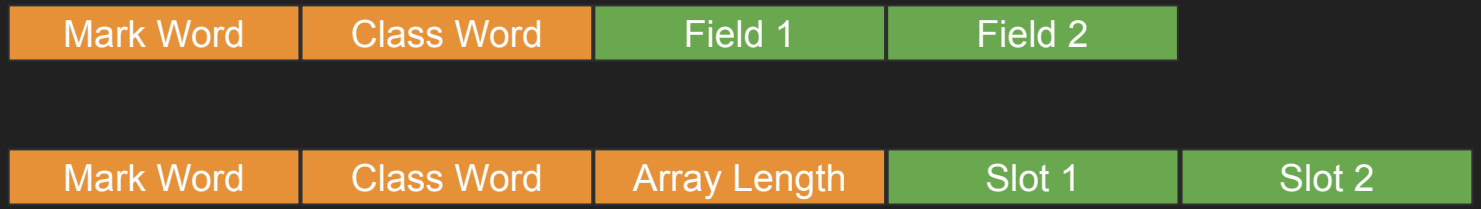
ShenandoahGC

- ShenandoahGC solution
  - To avoid races with the application
- Brooks (Forward) Pointers
- Load & Store GC Barriers

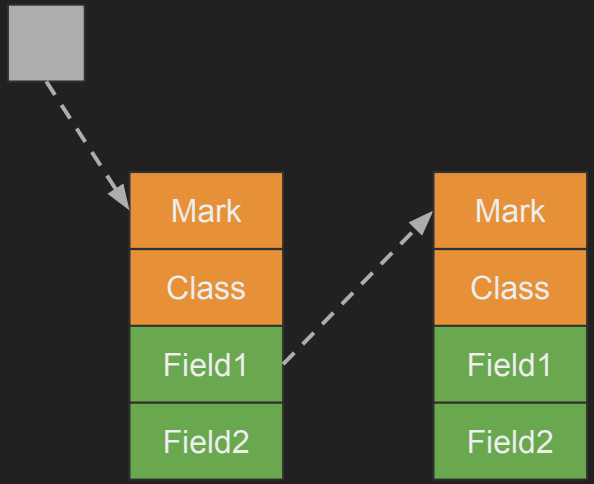
ShenandoahGC

- HotSpot Object Header
  - "Word" == 32 bits on i386; 64 bits on x86-64



ShenandoahGC 1.0

- ShenandoahGC 1.0



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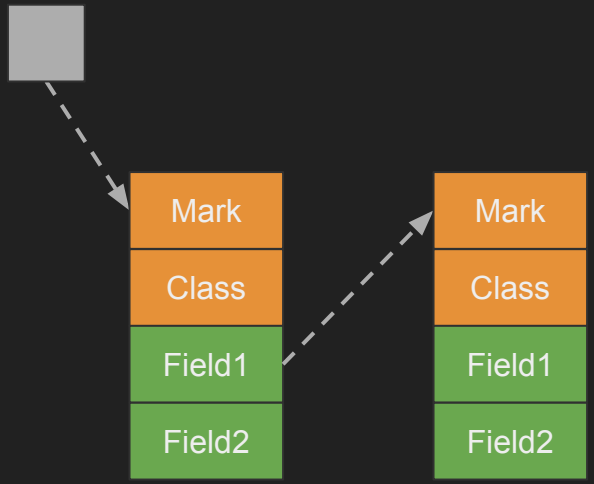
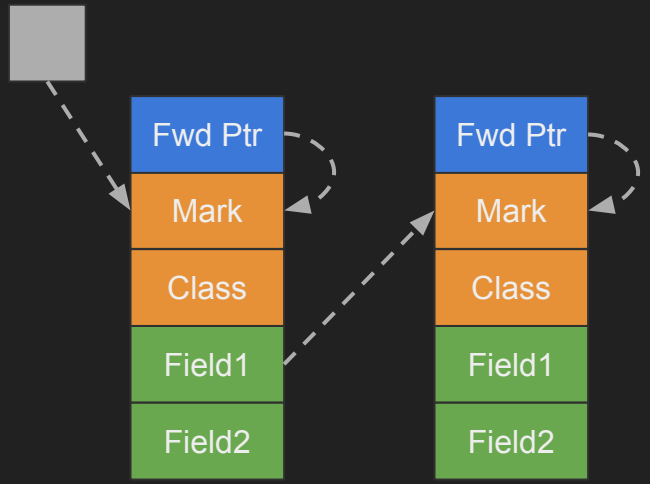
ShenandoahGC 1.0

- ShenandoahGC 1.0





ShenandoahGC 1.0

- ShenandoahGC 1.0

- Maintains weak to-space invariant
  - Reads from both from-space to-space copies
  - Writes only to to-space copy

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ShenandoahGC 1.0

- Load GC barrier: dereference forward pointer

```
Object f = obj.field;
<load_barrier>
```

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ShenandoahGC

- Load GC barrier: dereference forward pointer

```
Object f = obj.field;
f = deref(addr_of(f) - 8);
```

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ShenandoahGC 1.0

- Load GC barrier: dereference forward pointer

```
Object f = obj.field;
<load_barrier>

mov 0x10(%rdi), %rsi
mov -0x08(%rsi), %rsi
```

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ShenandoahGC

- Store GC barrier
  - Runs some action depending on GC phase

```
obj.f = o;
<store_barrier>
```

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ShenandoahGC

- Store GC barrier
  - Runs some action depending on GC phase

```
obj.f = o;
if (in_evac_phase &&
    in_collection_set(obj) &&
    !is_forwarded(obj))
  slow_path();
```

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ShenandoahGC

- Store GC barrier
  - Runs some action depending on GC phase

```
obj.f = o;
mov 0x3d8(%r15), %r11
test %r11, %r11
...
jne <slow_path>
```

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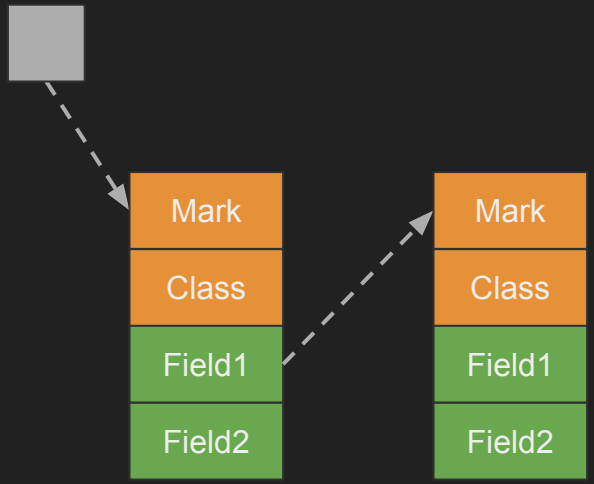
ShenandoahGC

- ShenandoahGC 1.0 Problems
- More memory needed (due to the forward pointer)
  - Worst case 50%, common case 5-10%
- Complicated (exotic) GC barriers
  - Load & Store GC barriers to maintain invariants

ShenandoahGC

- ShenandoahGC 2.0



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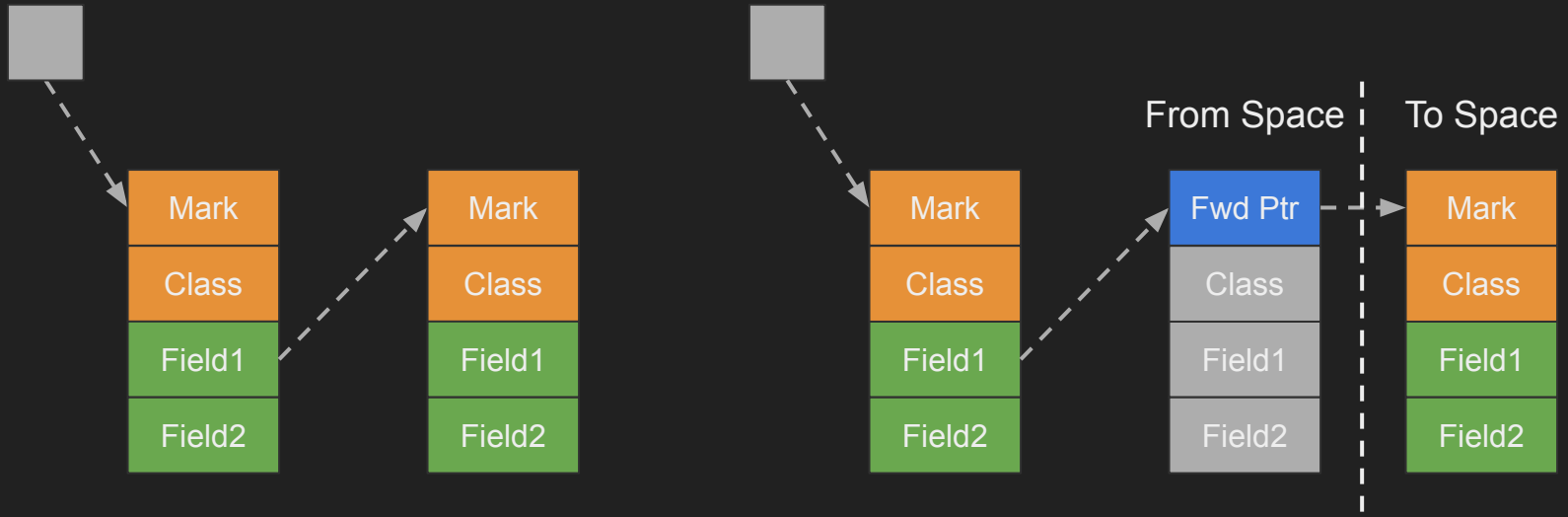
ShenandoahGC

- ShenandoahGC 2.0



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ShenandoahGC

- ShenandoahGC 2.0

- Maintains a strong to-space invariant
  - Reads only possible from to-space copy
  - Writes only possible from to-space copy

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ShenandoahGC 2.0

- Load Barrier (LRB - Load Reference Barrier)
  - Checks whether there may be forwarded objects
    - And whether in c-set and whether is forwarded

```
Object f = obj.f;
<load_barrier>
```

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ShenandoahGC 2.0

- Load Barrier (LRB - Load Reference Barrier)

```
Object f = obj.f;
if (in_evac_phase &&
    in_collection_set(obj) &&
    !is_forwarded(obj))
  slow_path();
```

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ShenandoahGC 2.0

- Load Barrier (LRB - Load Reference Barrier)

```
Object f = obj.f;
test  $0x1,0x20(%r15)
...
jne <slow_path>
```

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ShenandoahGC 2.0

- Shenandoah 2.0

- Load and Store GC barrier are the same!
  - Big codebase simplification
  - Improved performance

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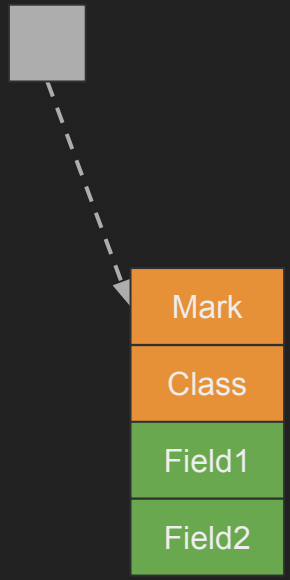
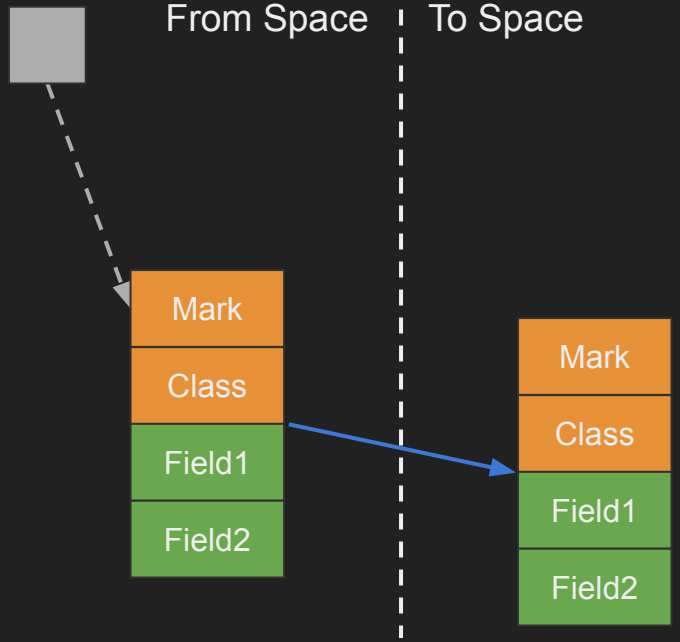
ShenandoahGC

- Evacuation



ShenandoahGC

- Evacuation (GC Copy)



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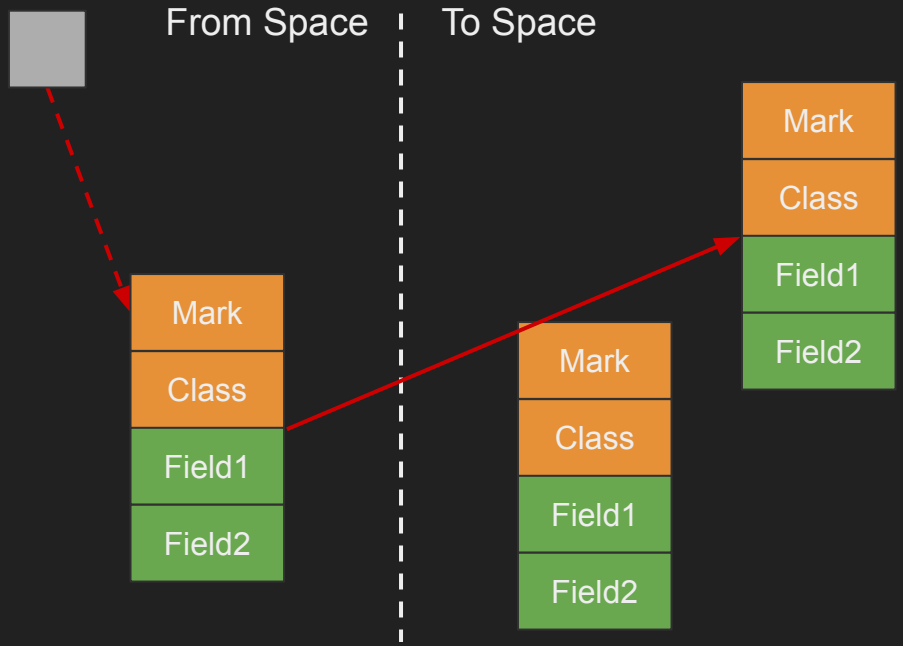
ShenandoahGC

- Evacuation (Application triggers LRB)



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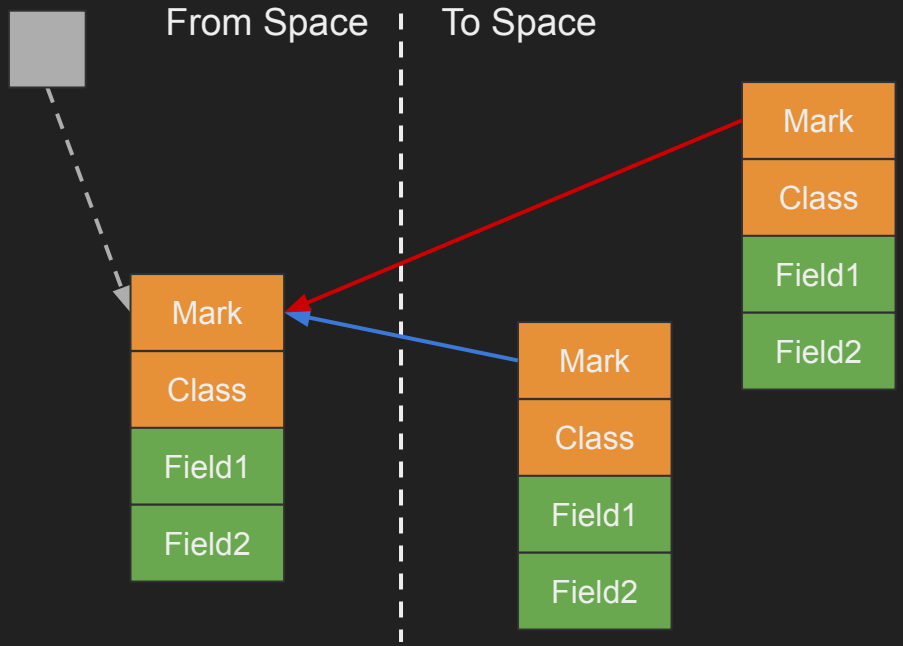
ShenandoahGC

- Evacuation (Atomic Fwd Ptr Update)



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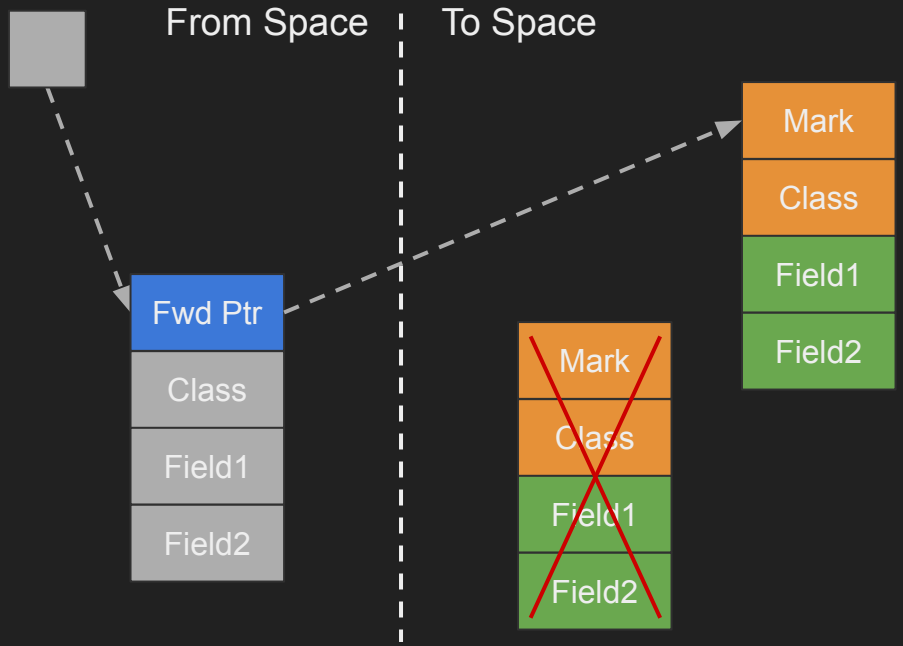
ShenandoahGC

- Evacuation (Application Wins)



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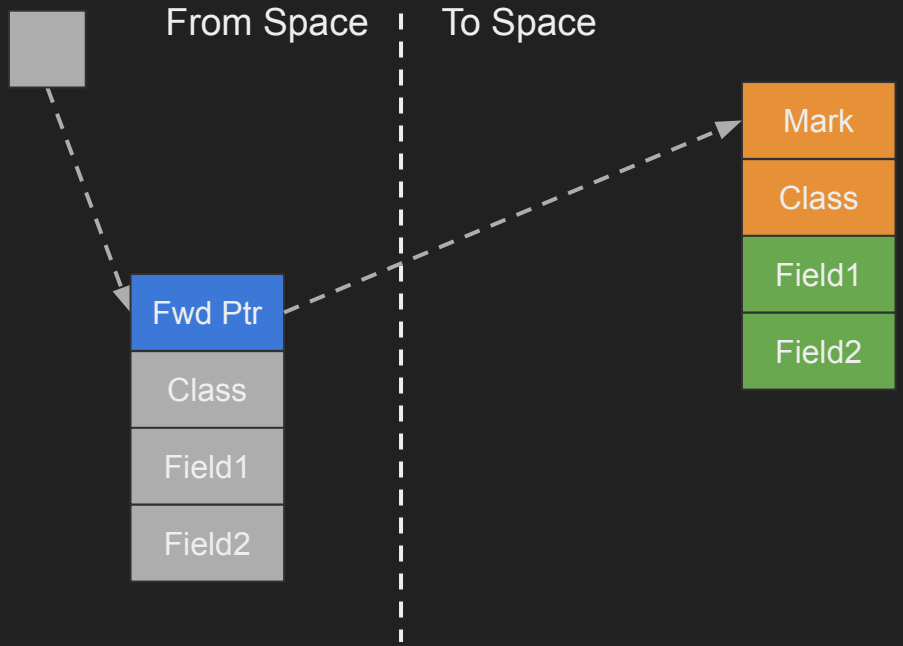
ShenandoahGC

- Evacuation (Application Read/Write)



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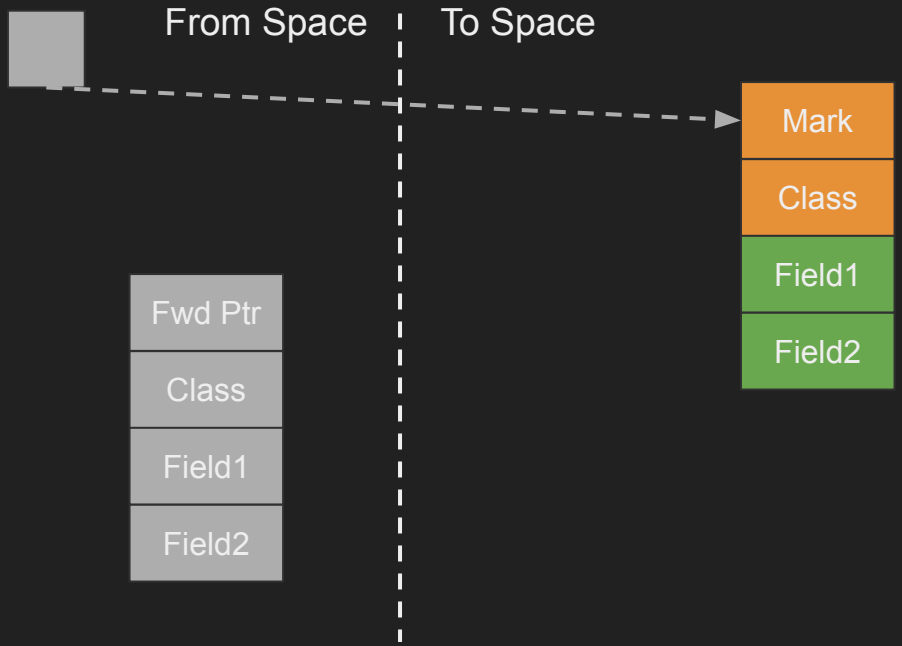
ShenandoahGC

- Update References



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ShenandoahGC

- Shenandoah Heuristics
  - Adaptive (default)
    - Maintains free heap amount
  - Static
    - Starts GC when tripping thresholds
  - Compact
    - Small footprint
  - Aggressive
    - Back to back GCs
  - Passive
    - Non concurrent, only Full GCs
  - Traversal

ShenandoahGC

- References
  - Project Wiki
    - https://wiki.openjdk.java.net/display/shenandoah/Main
  - Aleksey Shipilëv, Roman Kennke et al.
    - https://www.youtube.com/watch?v=VCeHkcwfF9Q
    - https://www.youtube.com/watch?v=E1M3hNlhQCg
  - Mailing List
    - shenandoah-dev@openjdk.java.net

Shenandoah Questions?

Conclusions

Conclusions

- Give Concurrent GCs a go

- Stuck with JDK 8?
  - Use Shenandoah

Already using JDK 11+?
  - ZGC or Shenandoah

- Report your feedback!

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