TRASHTALK

EXPLORING THE MEMORY MANAGEMENT IN THE JVM

ABOUT ME.

Gerrit Grunwald | Developer Advocate | Azul

MEMORY MANAGEMENT

IN THE JVM...

azul

IS AUTOMATIC RIGHT...?

azul

SO...WHY CARE...?

azul

MEMORY MANAGEMENT

Why you should care...

- 🗑 Impact on application performance

MEMORY MANAGEMENT

Why you should care...

- 🗑 Impact on application performance
- 🗑 Impact on application responsiveness

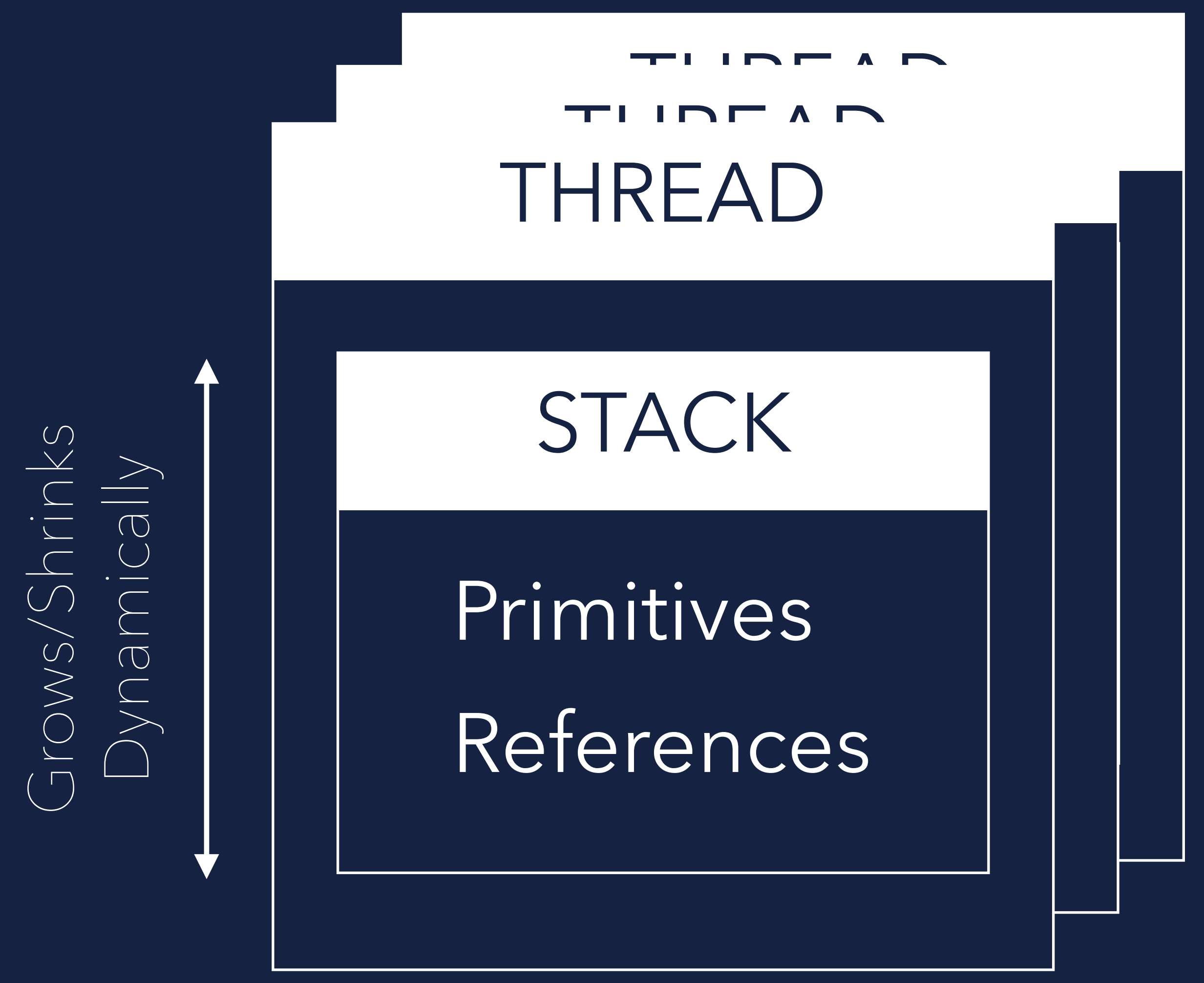
MEMORY MANAGEMENT

Why you should care...

- ♻ Impact on application performance
- ♻ Impact on application responsiveness
- ♻ Impact on system requirements

MEMORY MANAGEMENT

Stack, Heap and Metaspace



Local access -> thread safe

azul

MEMORY MANAGEMENT

Stack, Heap and Metaspace

Local access -> thread safe

Shared access -> Not thread safe

Needs Garbage Collection

azul

MEMORY MANAGEMENT

Stack, Heap and Metaspace

Local access -> thread safe

Shared access -> Not thread safe

Needs Garbage Collection

Contains info needed for JVM to work with classes

MEMORY MANAGEMENT

In the JVM...

```java
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

}
```

azul

MEMORY MANAGEMENT

In the JVM...

```java
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

}
```

Stack area for thread 1

Frame for main

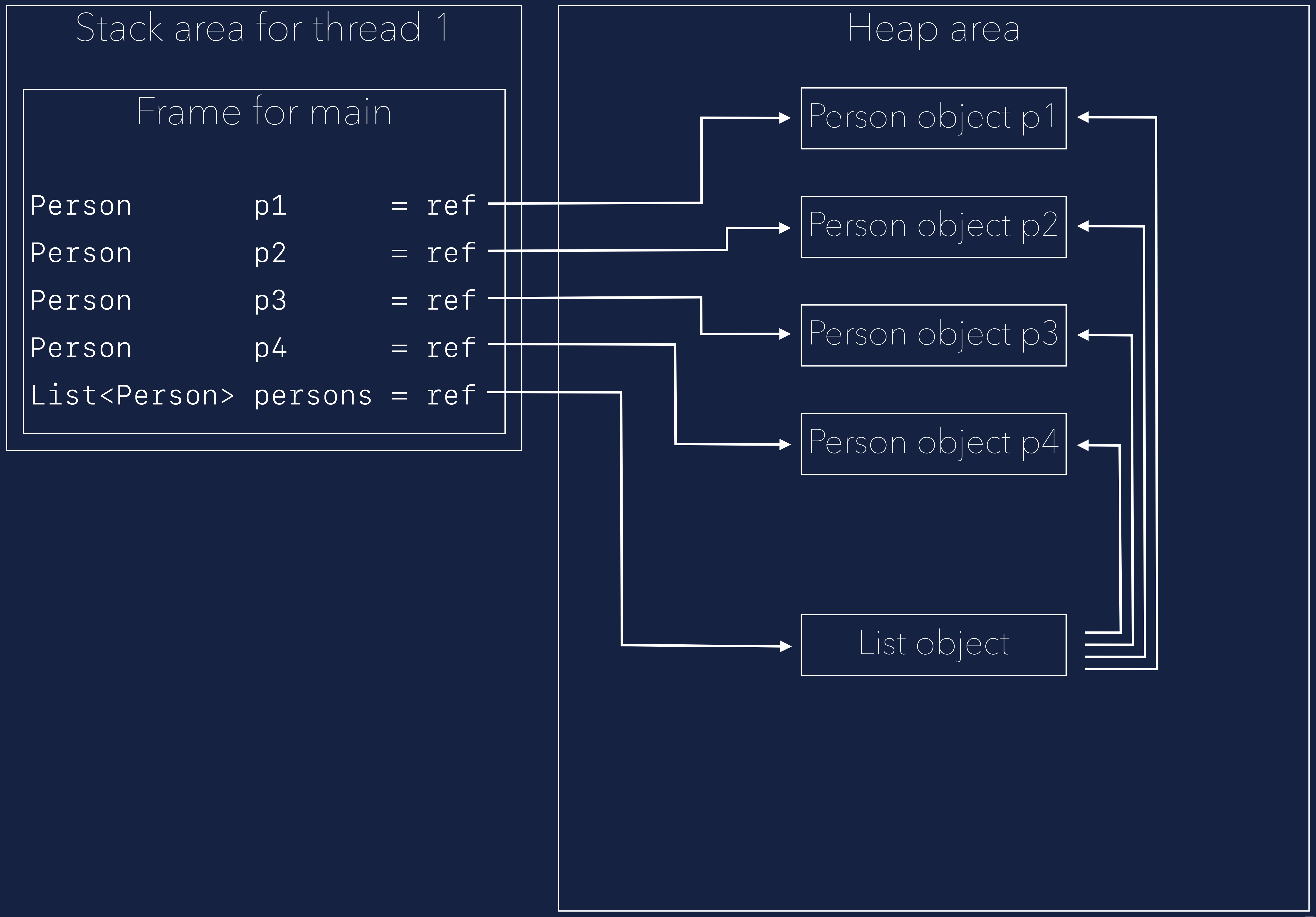
Person	p1	= ref
Person	p2	= ref
Person	p3	= ref
Person	p4	= ref
List<Person>	persons	= ref

azul

MEMORY MANAGEMENT

In the JVM…

```java
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

}
```

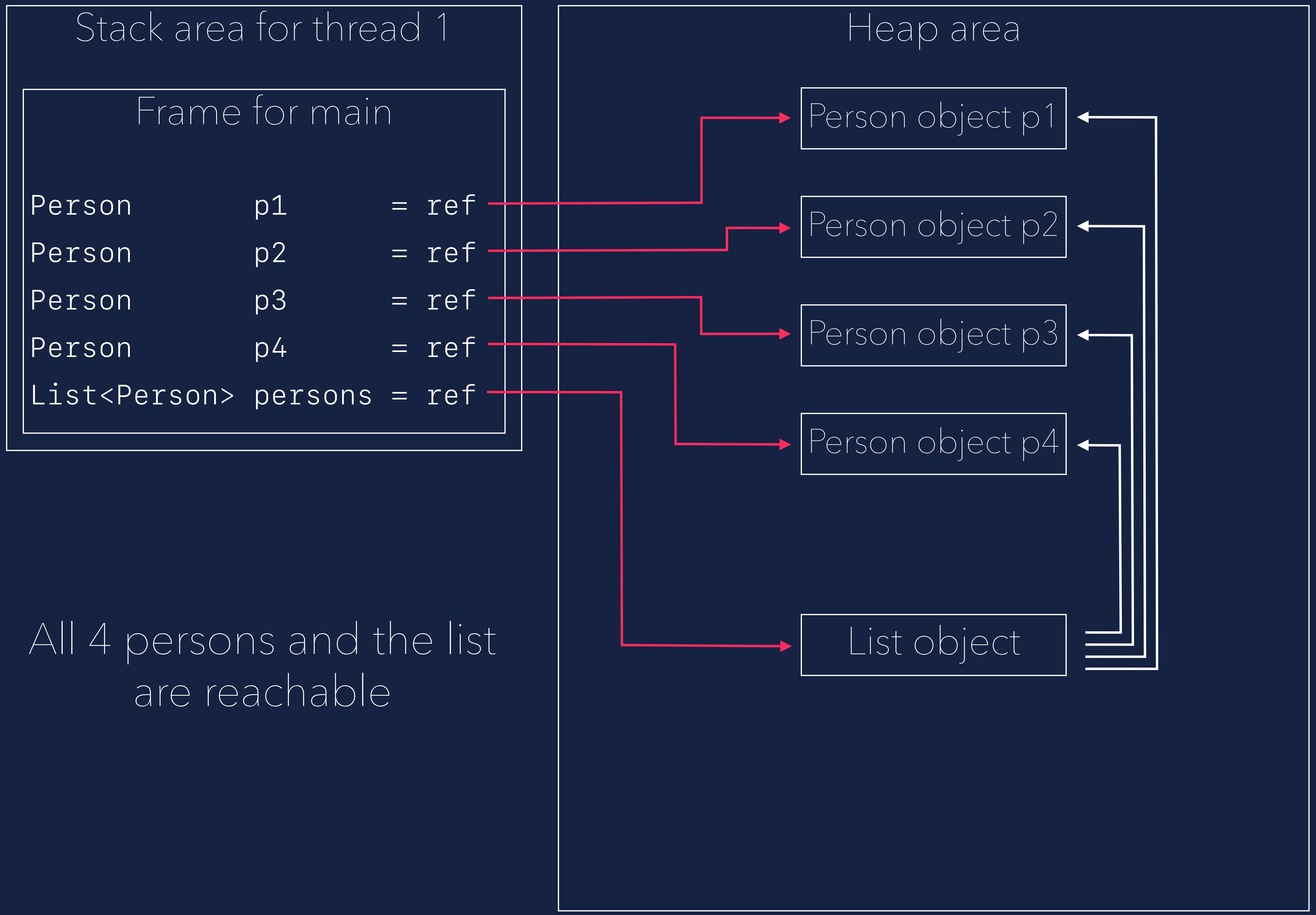


azul

MEMORY MANAGEMENT

In the JVM...

```
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

}
```

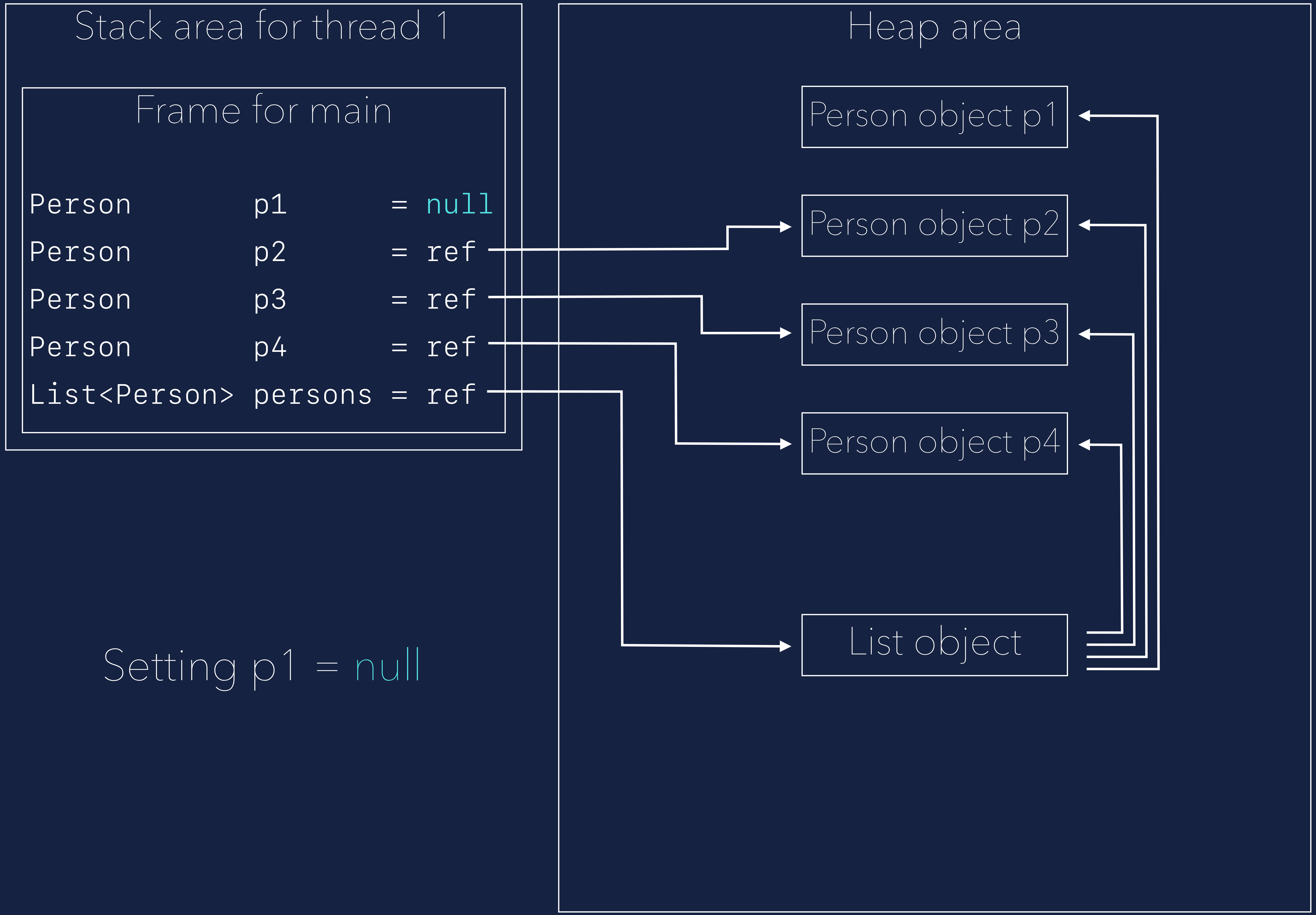


All 4 persons and the list are reachable

MEMORY MANAGEMENT

In the JVM...

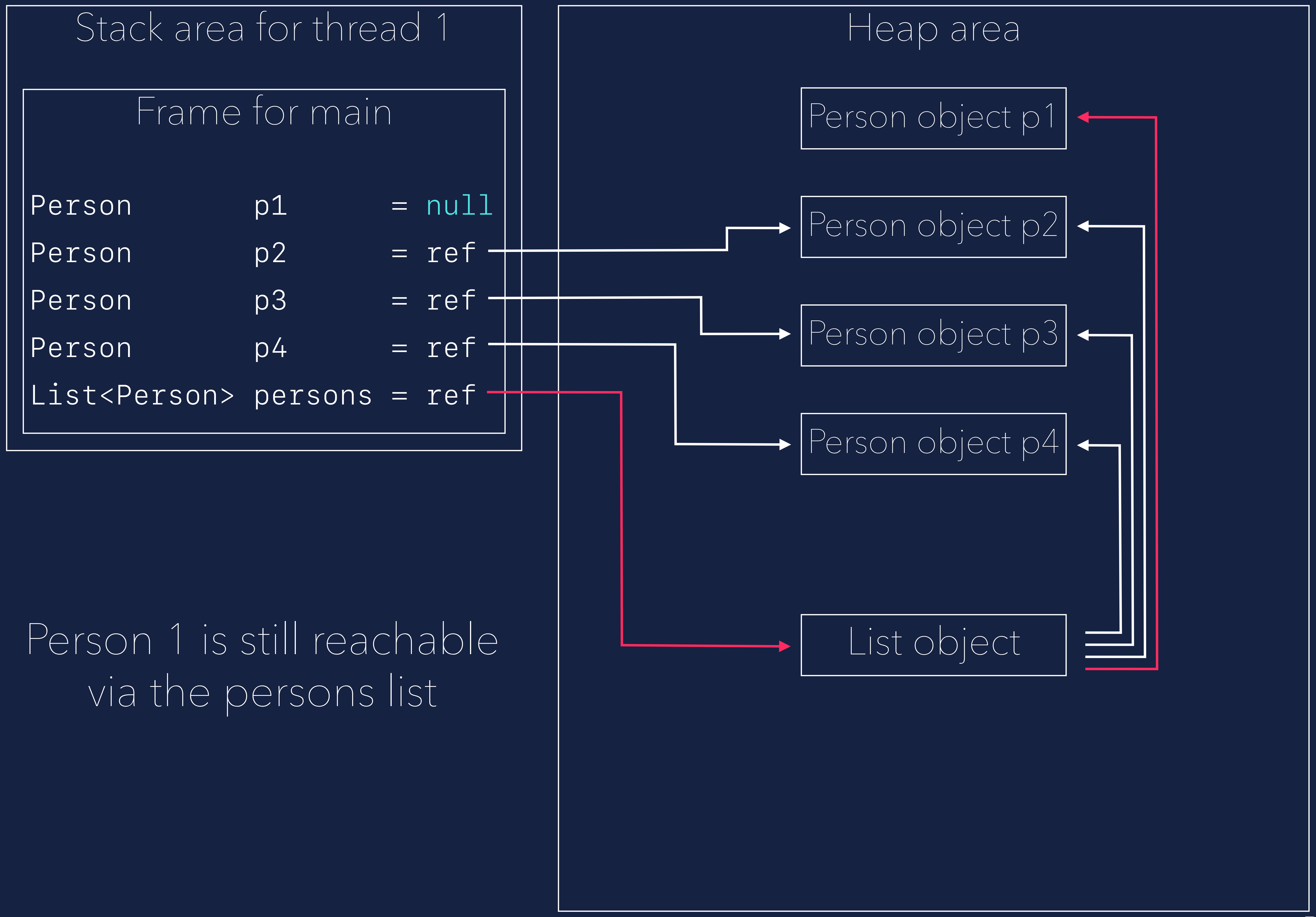
```java
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

    p1 = null;

}
```



MEMORY MANAGEMENT

In the JVM...

```java
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

    p1 = null;

    System.out.println(persons.get(0)); // -> Gerrit

}
```

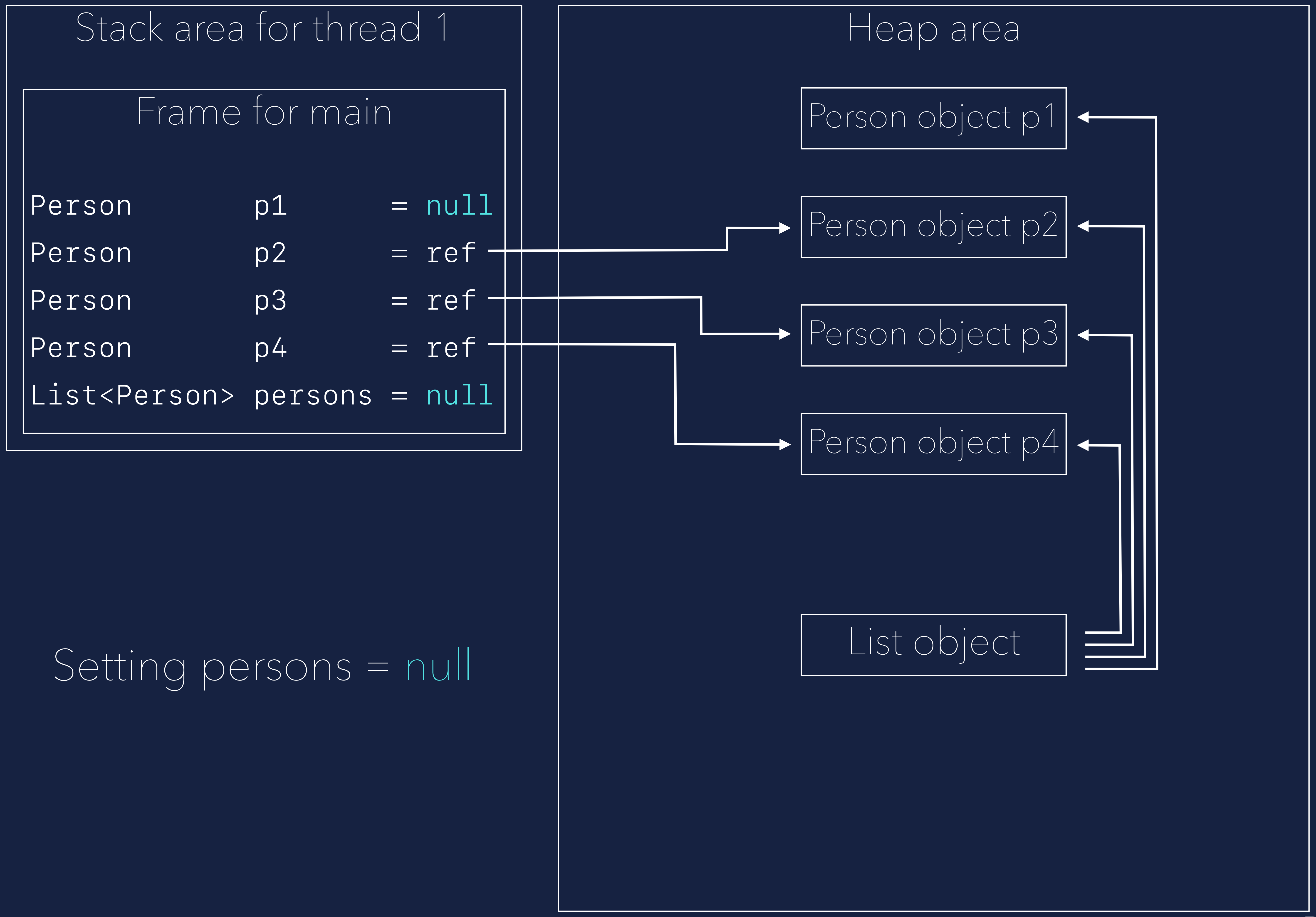


Person 1 is still reachable via the persons list

MEMORY MANAGEMENT

In the JVM...

```
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

    p1 = null;

    System.out.println(persons.get(0)); // -> Gerrit

    persons = null;
}
```

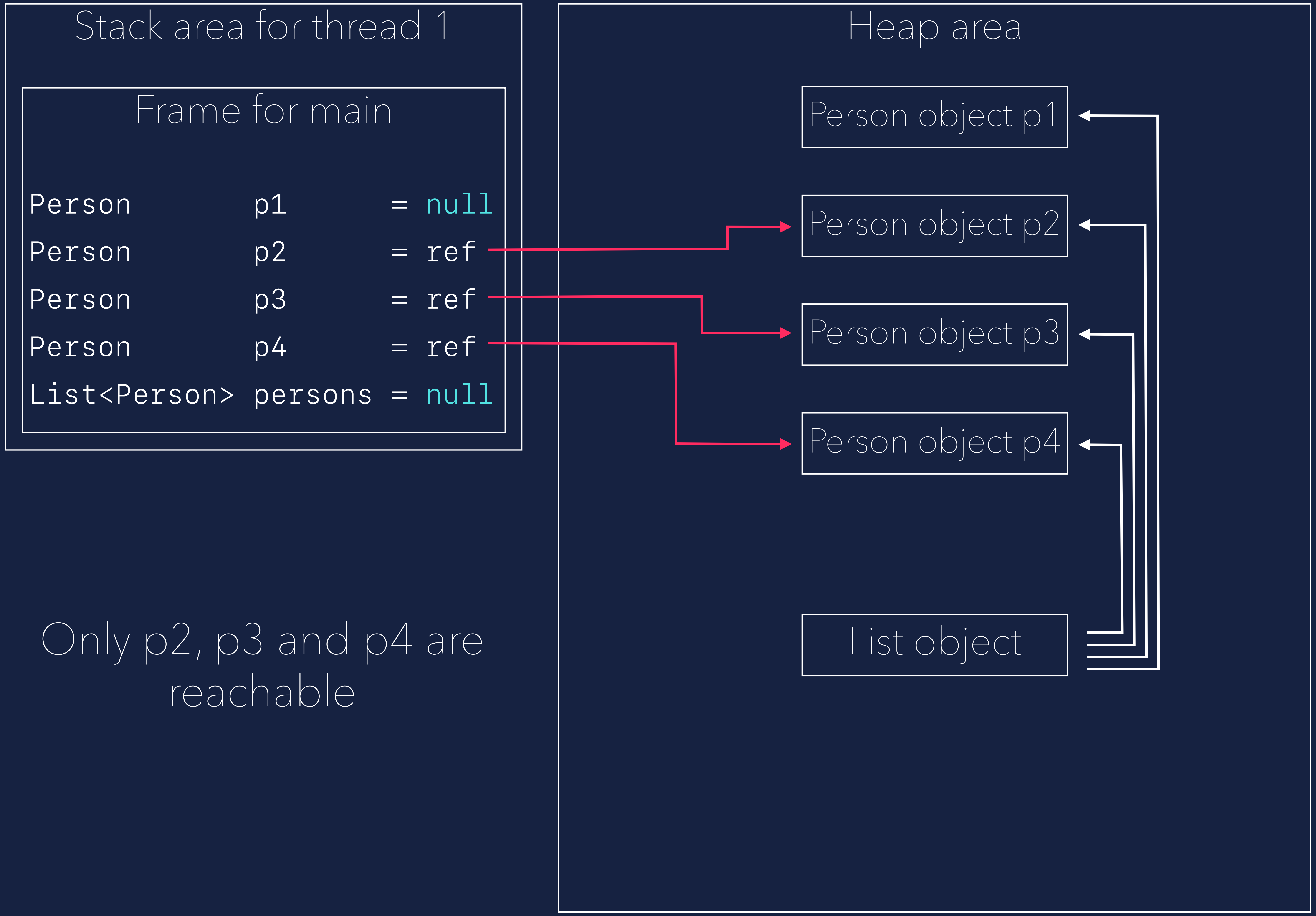


Setting persons = null

MEMORY MANAGEMENT

In the JVM...

```
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

    p1 = null;

    System.out.println(persons.get(0)); // -> Gerrit

    persons = null;
}
```

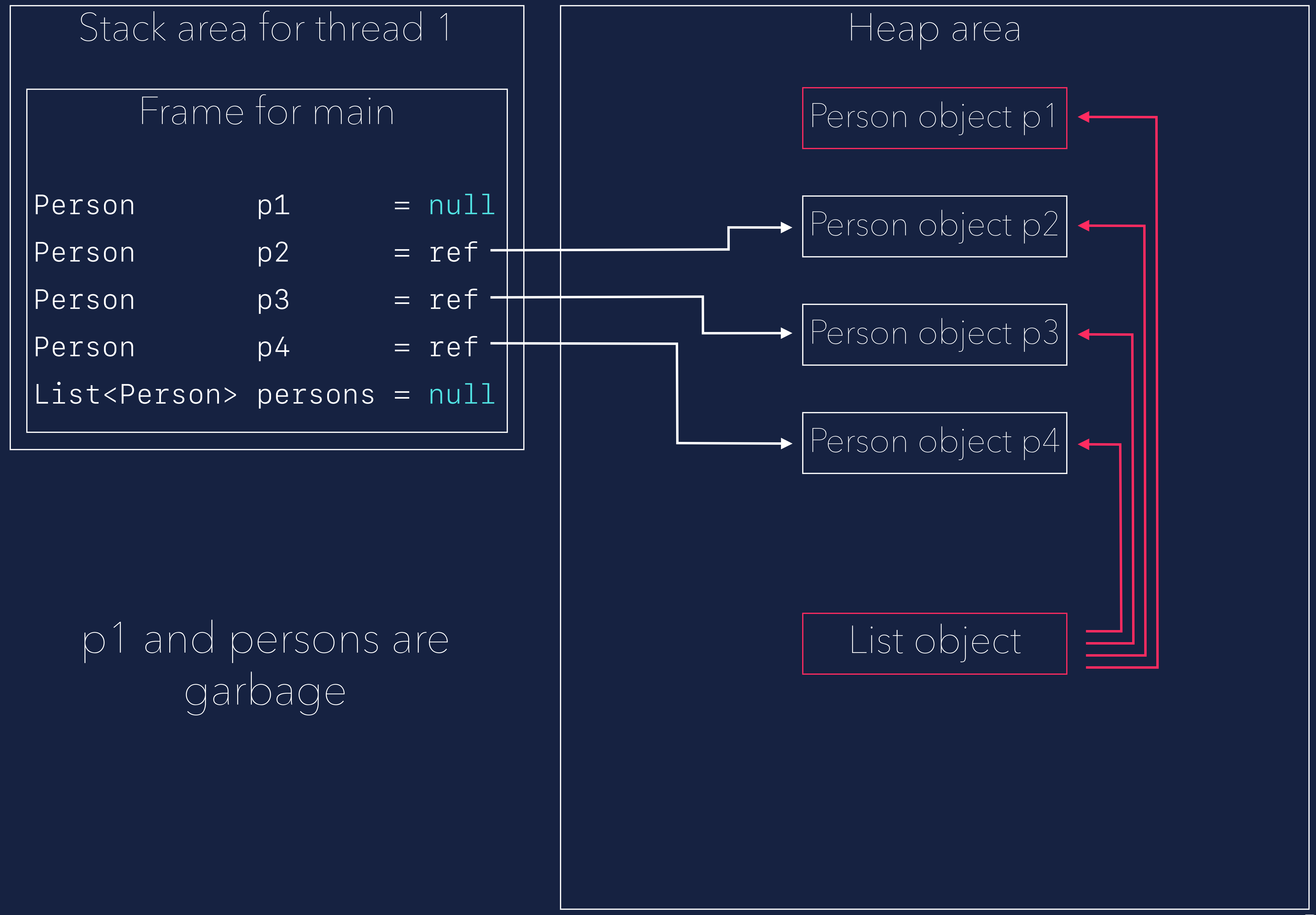


Only p2, p3 and p4 are reachable

MEMORY MANAGEMENT

In the JVM...

```java
public static void main(String[] args) {

    record Person(String name) {
        @Override public String toString() { return name(); }
    }

    Person p1 = new Person("Gerrit");
    Person p2 = new Person("Sandra");
    Person p3 = new Person("Lilli");
    Person p4 = new Person("Anton");

    List<Person> persons = Arrays.asList(p1, p2, p3, p4);

    System.out.println(p1); // -> Gerrit

    p1 = null;

    System.out.println(persons.get(0)); // -> Gerrit

    persons = null;
}
```



p1 and persons are garbage

HOW TO GET RID OF IT...?

azul

GARBAGE COLLECTION

azul

GARBAGE COLLECTION

What is it...

- 🗑 Form of automatic memory management

GARBAGE COLLECTION

What is it...

- 🗑 Form of automatic memory management
- 🗑 Identifies and reclaims no longer used memory

GARBAGE COLLECTION

What is it...

- Form of automatic memory management
- Identifies and reclaims no longer used memory
- Ensures efficient memory utilisation

GARBAGE COLLECTION

What is it…

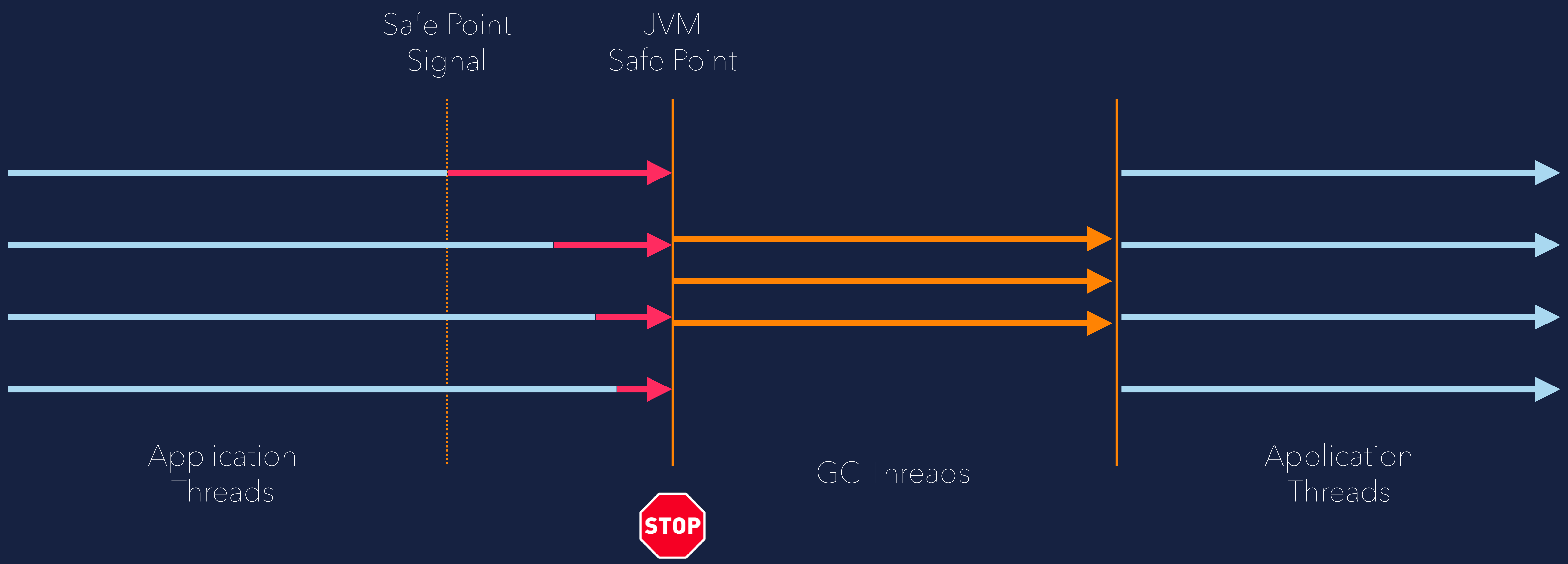
- Form of automatic memory management
- Identifies and reclaims no longer used memory
- Ensures efficient memory utilisation
- Frees user from managing the memory manually

STOPPING THE WRLD

azul

STOPPING THE W STOP RLD

Halt of all application threads



azul

CONSERVATIVE AND PRECISE

azul

GARBAGE COLLECTION

Conservative and Precise

- Conservative does not fully identify all object references
  (assumes any bit pattern in memory could be a reference, lead to more false positives)

azul

GARBAGE COLLECTION

Conservative and Precise

- Conservative does not fully identify all object references
  (assumes any bit pattern in memory could be a reference, lead to more false positives)
- Precise correctly identifies all references in an object
  (needed in order to move objects)

PHASES

(precise collectors)

azul

TRACING

Identify live objects in the heap

TRACING

Principle

- 🗑 Traverse graph starting from roots
  (only live objects)

TRACING

Principle

- Traverse graph starting from roots
  (only live objects)
- Mark all reachable objects

FREEING

Reclaim resources held by dead objects

azul

FREEING

Principle

- 🗑 Traverse whole heap space
  (not only live objects)

FREEING

Principle

- Traverse whole heap space
  (not only live objects)
- Clear unmarked objects

FREEING

Principle

- Traverse whole heap space
  (not only live objects)
- Clear unmarked objects
- Remove marked bits from marked objects

COMPACTION

Periodically relocate live objects

azul

PHASES

Two ways of compaction

🗑 Moving

Move all live objects to the beginning of the same area (e.g. heap)

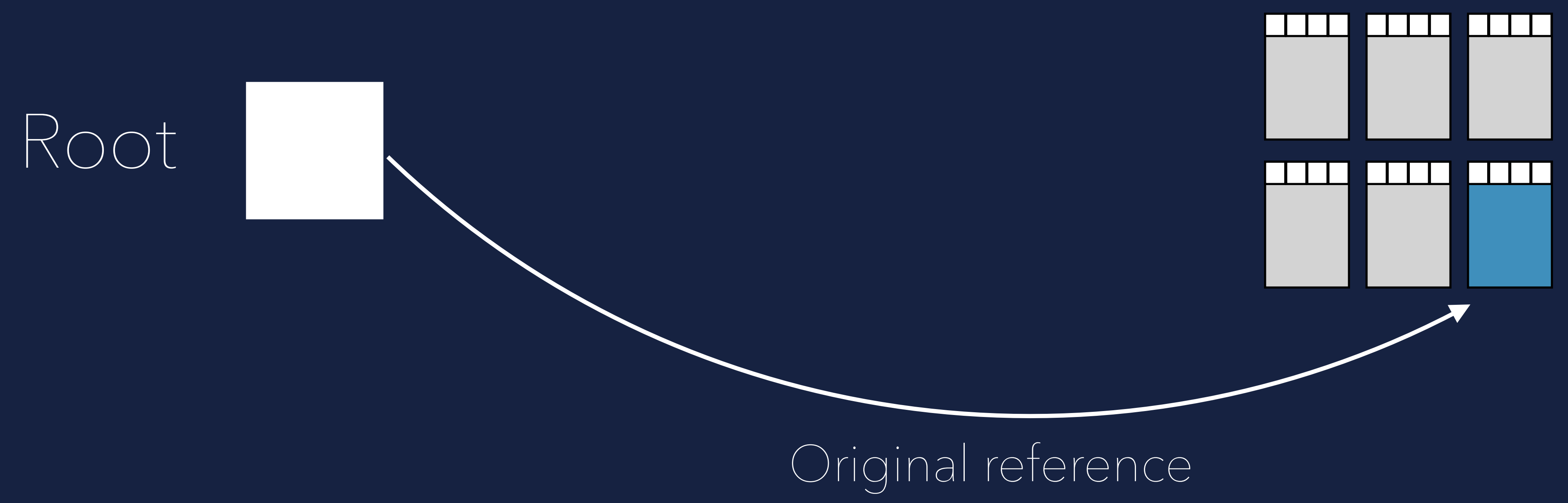
PHASES

Two ways of compaction

- Moving
  Move all live objects to the beginning of the same area (e.g. heap)
- Copying
  Move all live objects to another area, the former area only contains garbage and can be freed

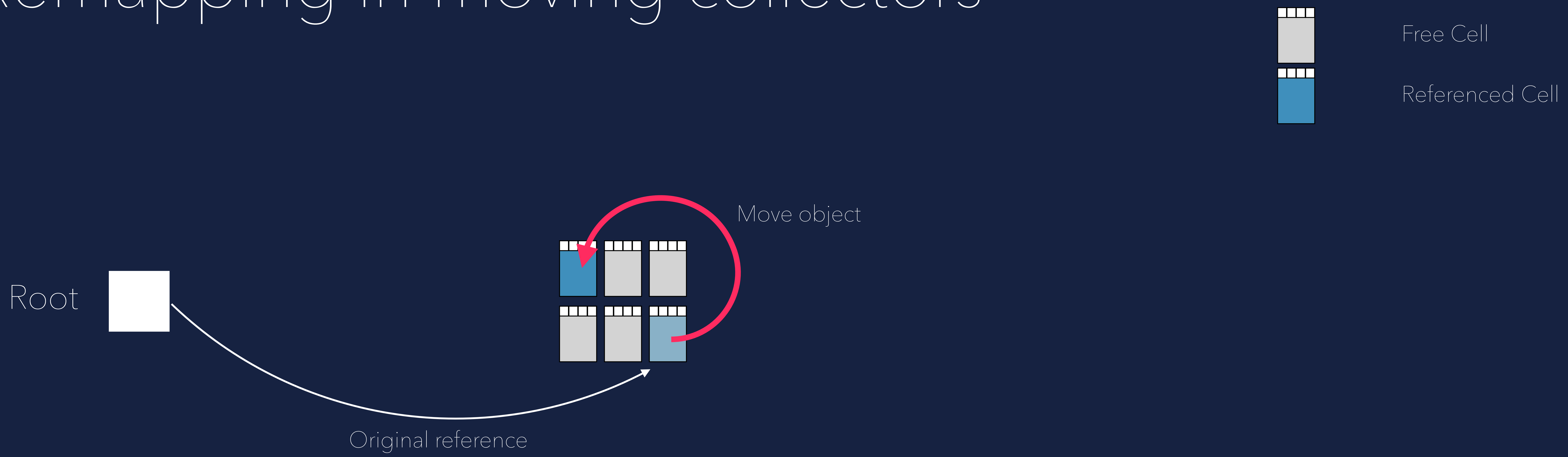
PHASES

Remapping in moving collectors



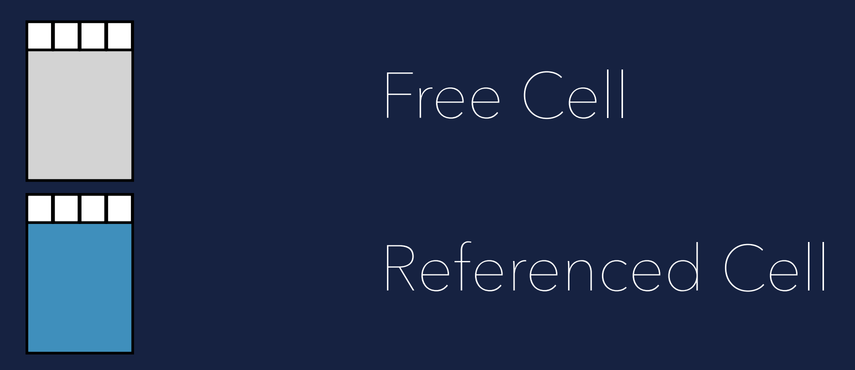
PHASES

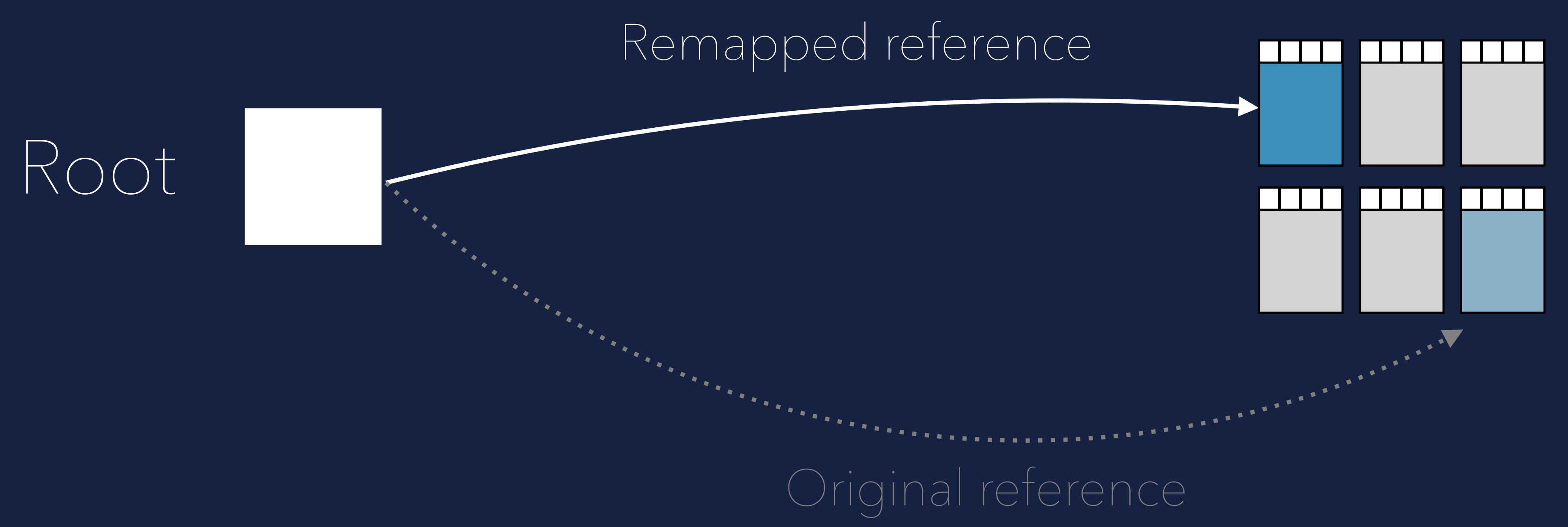
Remapping in moving collectors



PHASES

Remapping in moving collectors





COLLECTORS

azul

NON MOVING COLLECTOR

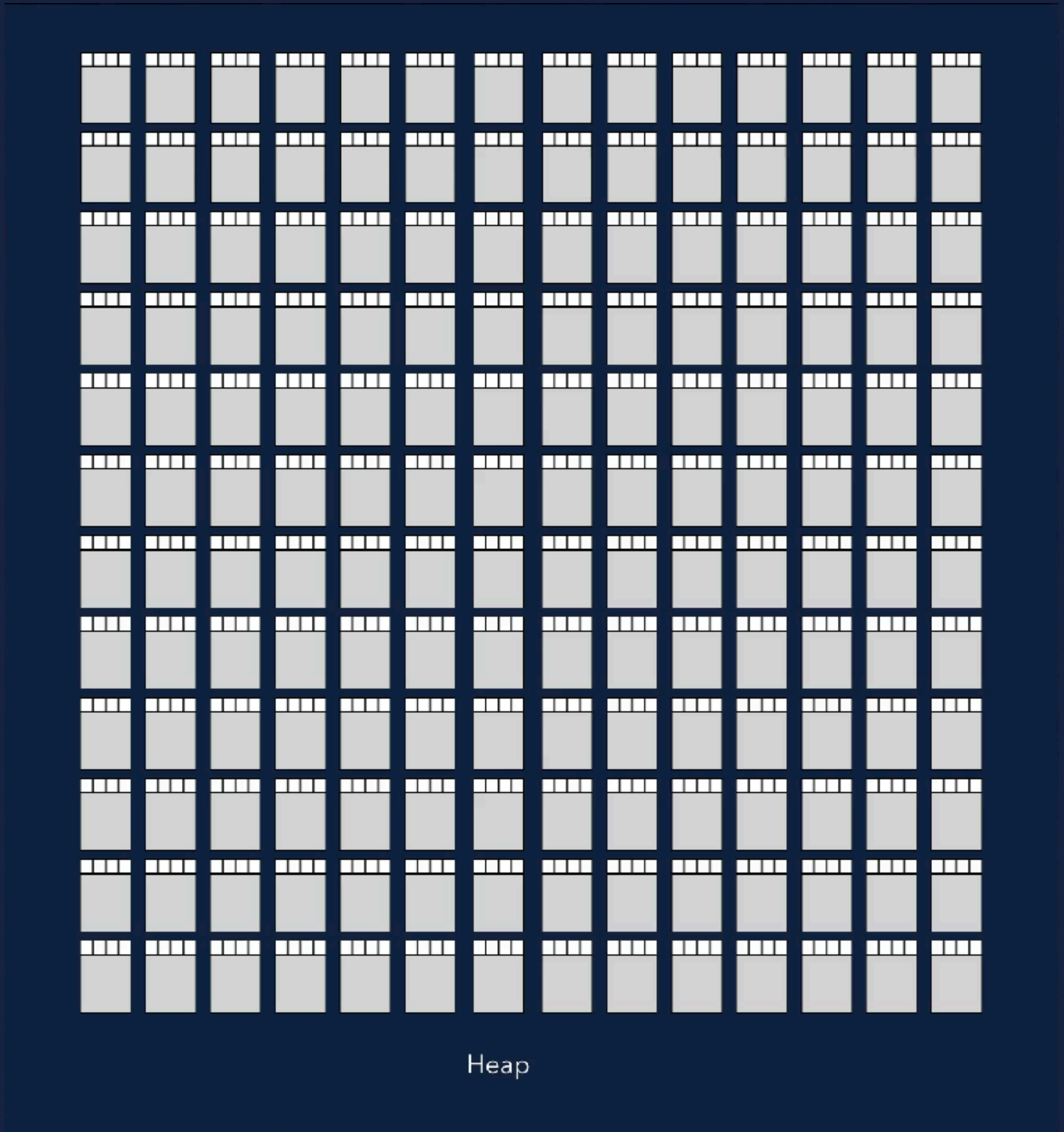
Mark & Sweep

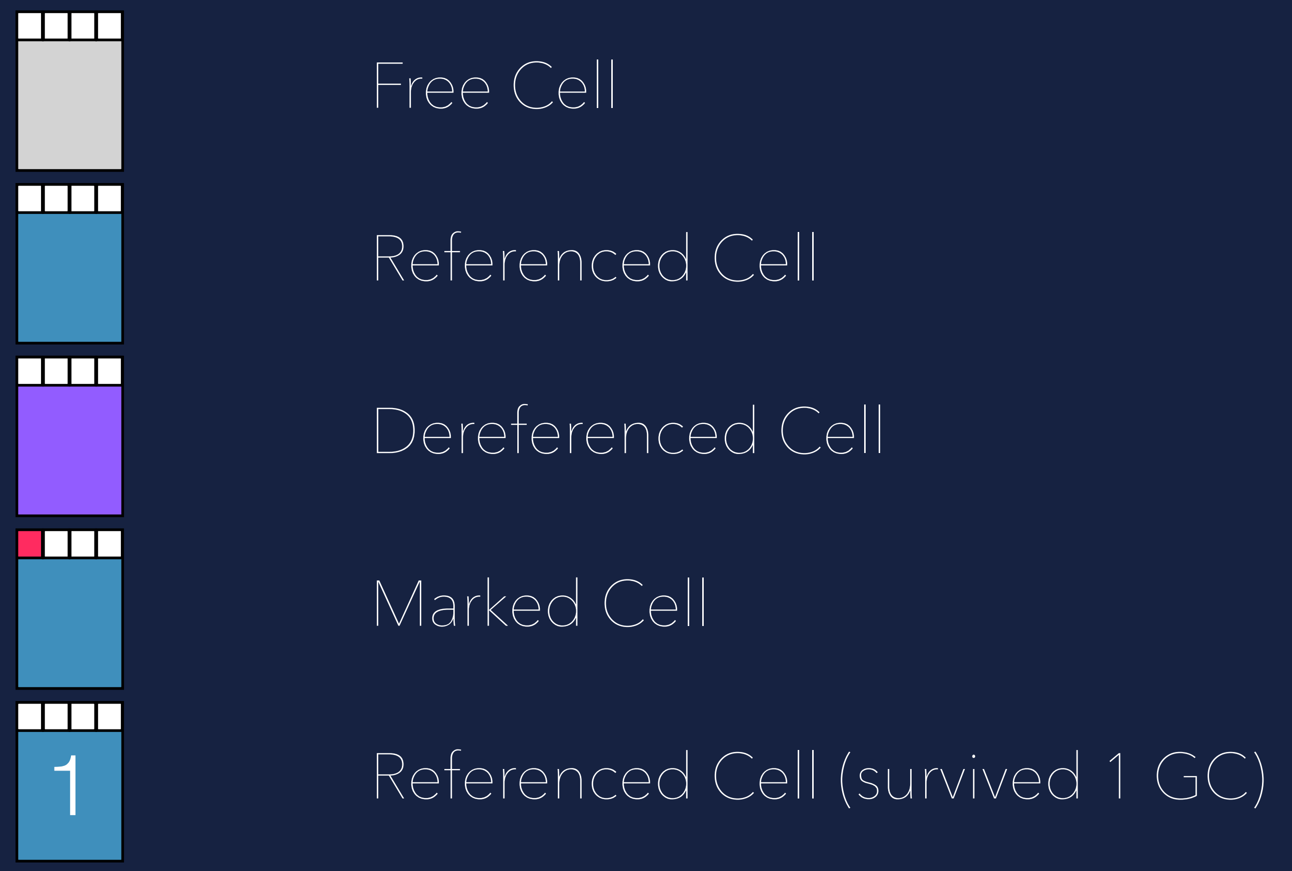
azul

NON MOVING COLLECTOR

Demo

1. Mutator allocates cells in Heap
2. Heap is out of memory -> GC
3. Mark all live cells
4. Free all dead cells
5. Unmark all live cells
6. Resume Mutator





⚠ Fragmentation

azul

MOVING COLLECTORS

Compacting Collector & Copy Collector

azul

COMPACTING COLLECTOR

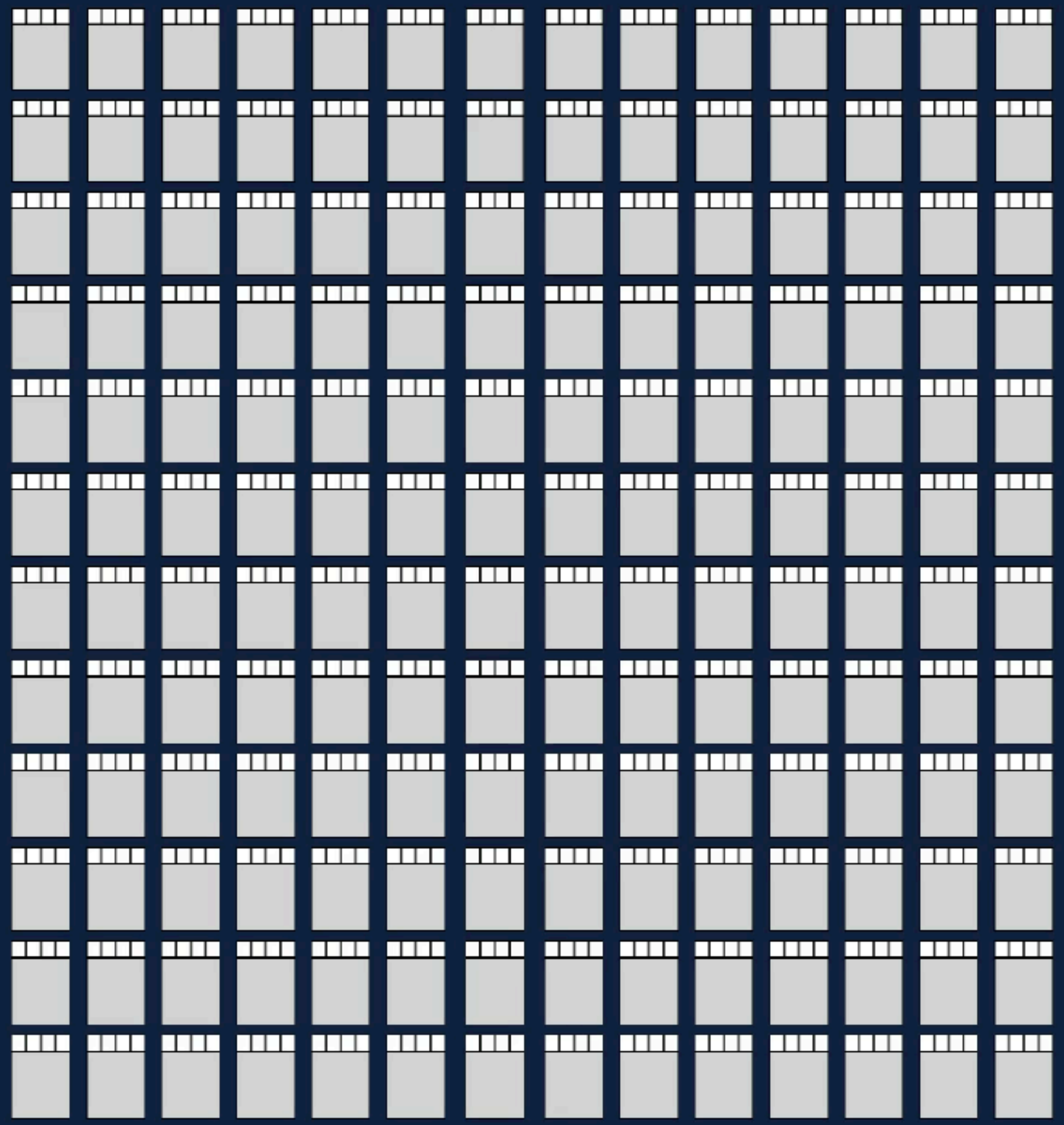
Mark & Compact

azul

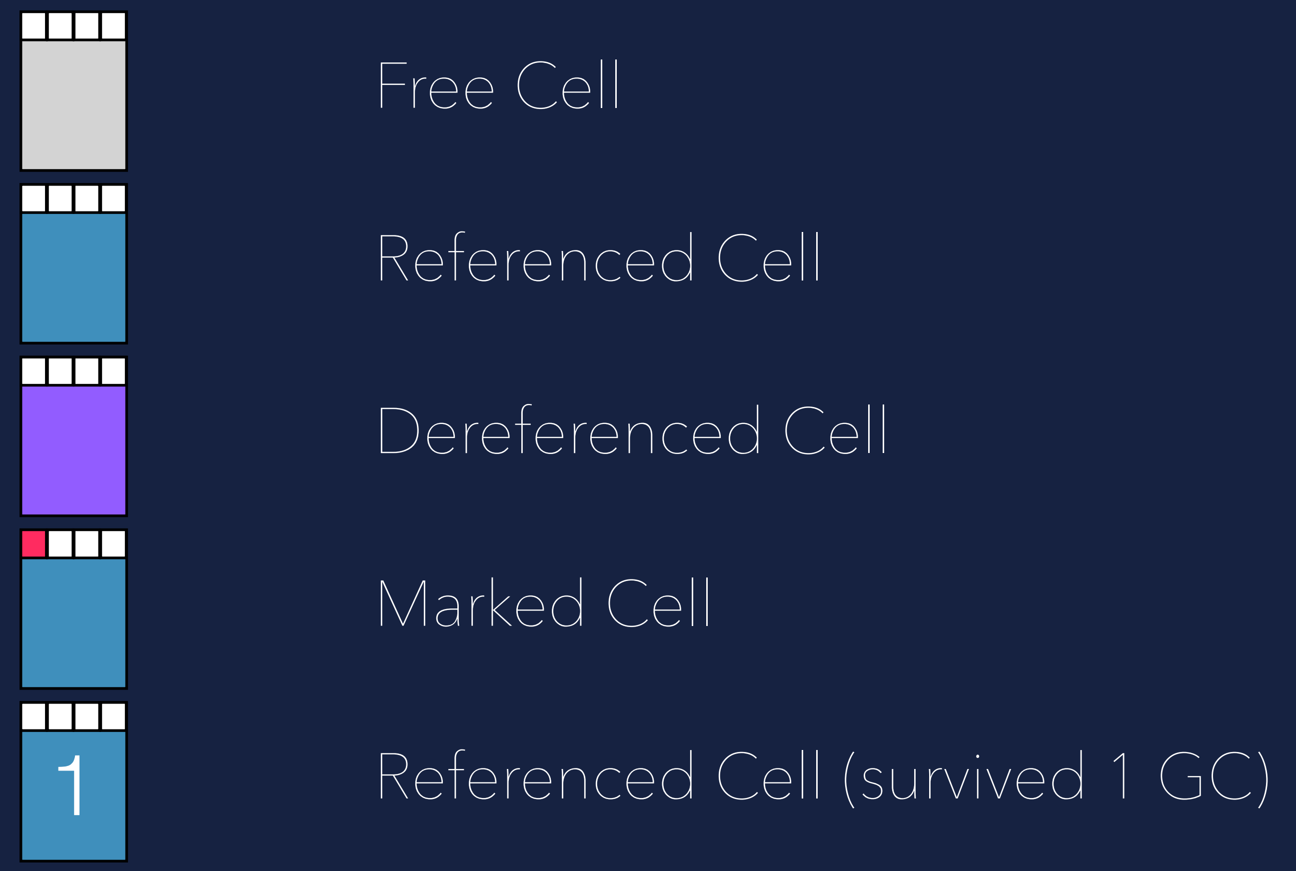
COMPACTING COLLECTOR

Demo

1. Mutator allocates cells in Heap
2. Heap is out of memory -> GC
3. Mark all live cells
4. Free all dead cells
5. Unmark all live cells
6. Compact all live cells
7. Resume Mutator



Heap



Headroom
20-50%

azul

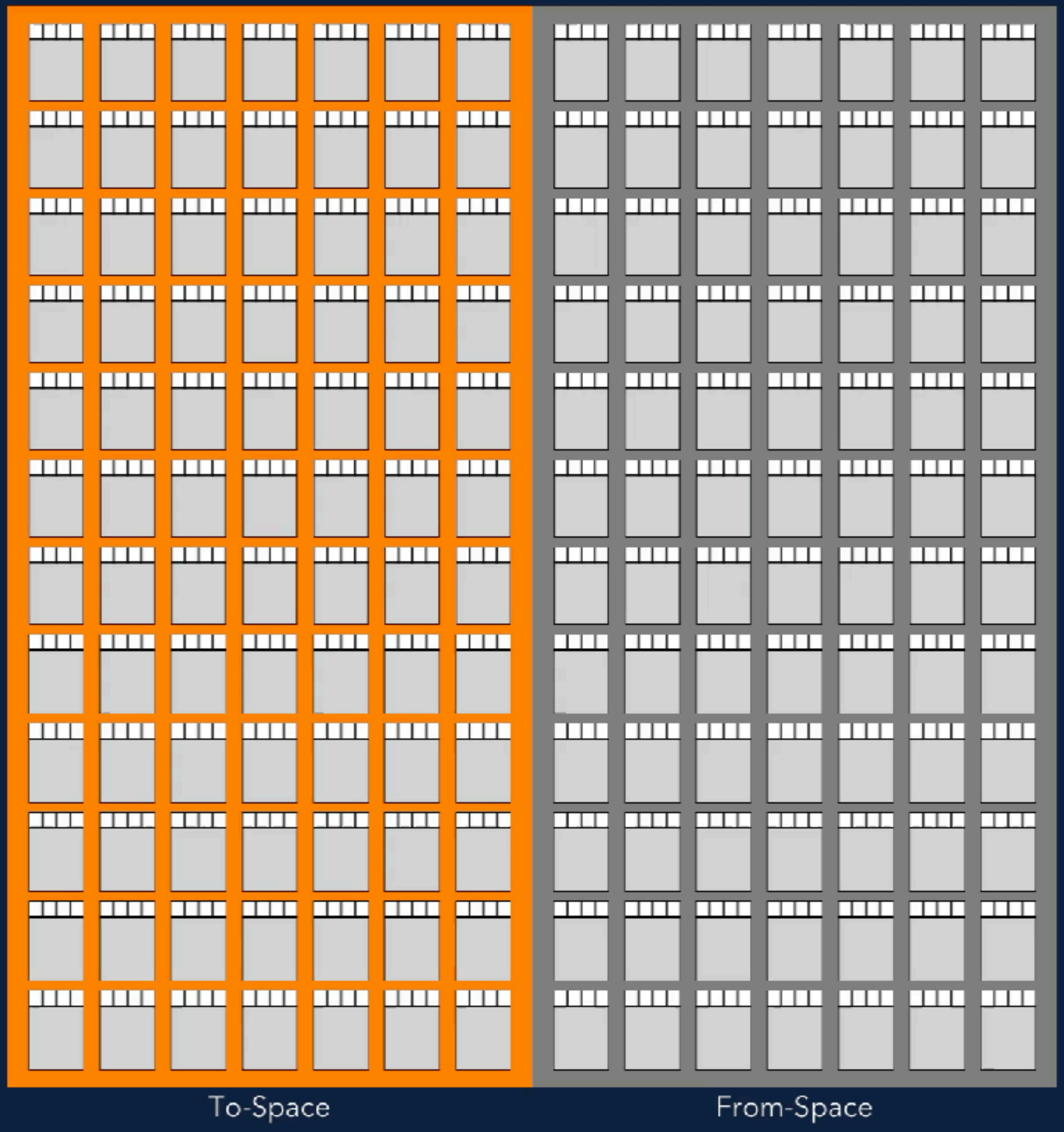
COPY COLLECTOR

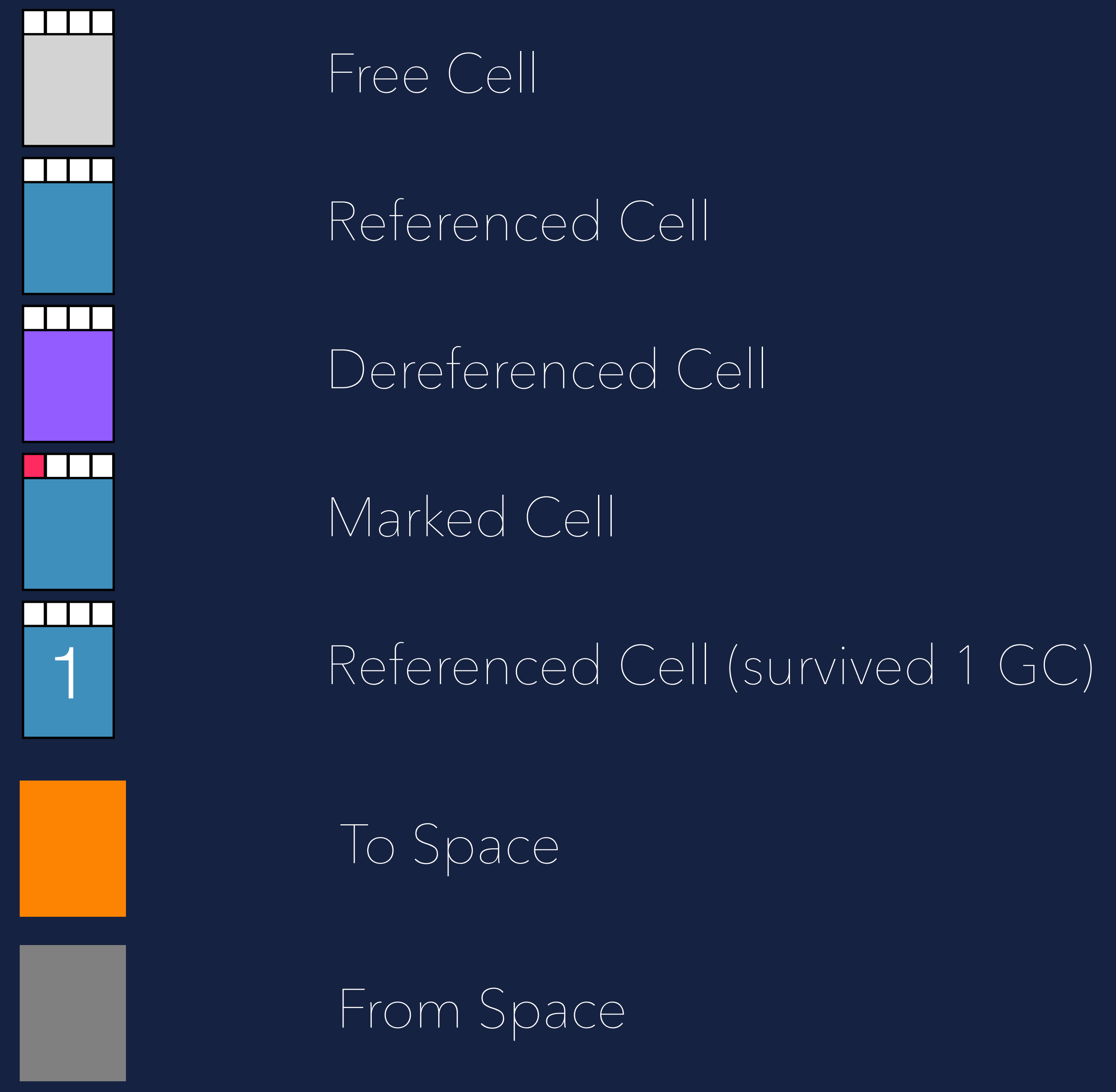
Mark & Copy

COPY COLLECTOR

Demo

1. Allocating in ToSpace
2. ToSpace is out of memory -> GC
3. Toggle To- and FromSpace
4. Mark live cells in FromSpace
5. Copy live cells to ToSpace
6. Free all cells in FromSpace
7. Resume Mutator





⚠ Long living objects and twice as much memory

azul

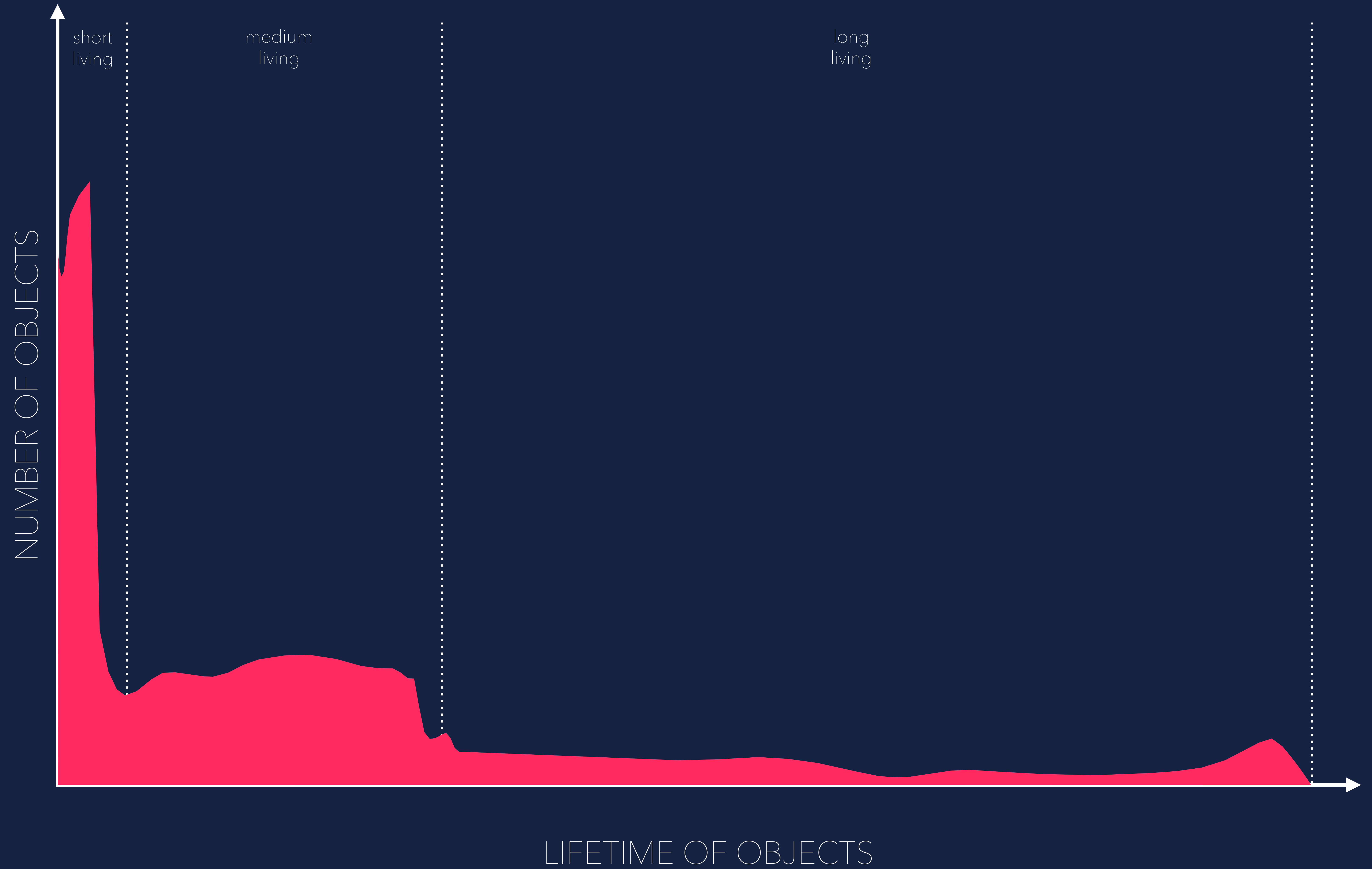
GENERATIONAL COLLECTOR

Generational Mark & Compact

azul

GENERATIONAL COLLECTOR

Weak Generational Hypothesis (Most objects die young)



azul

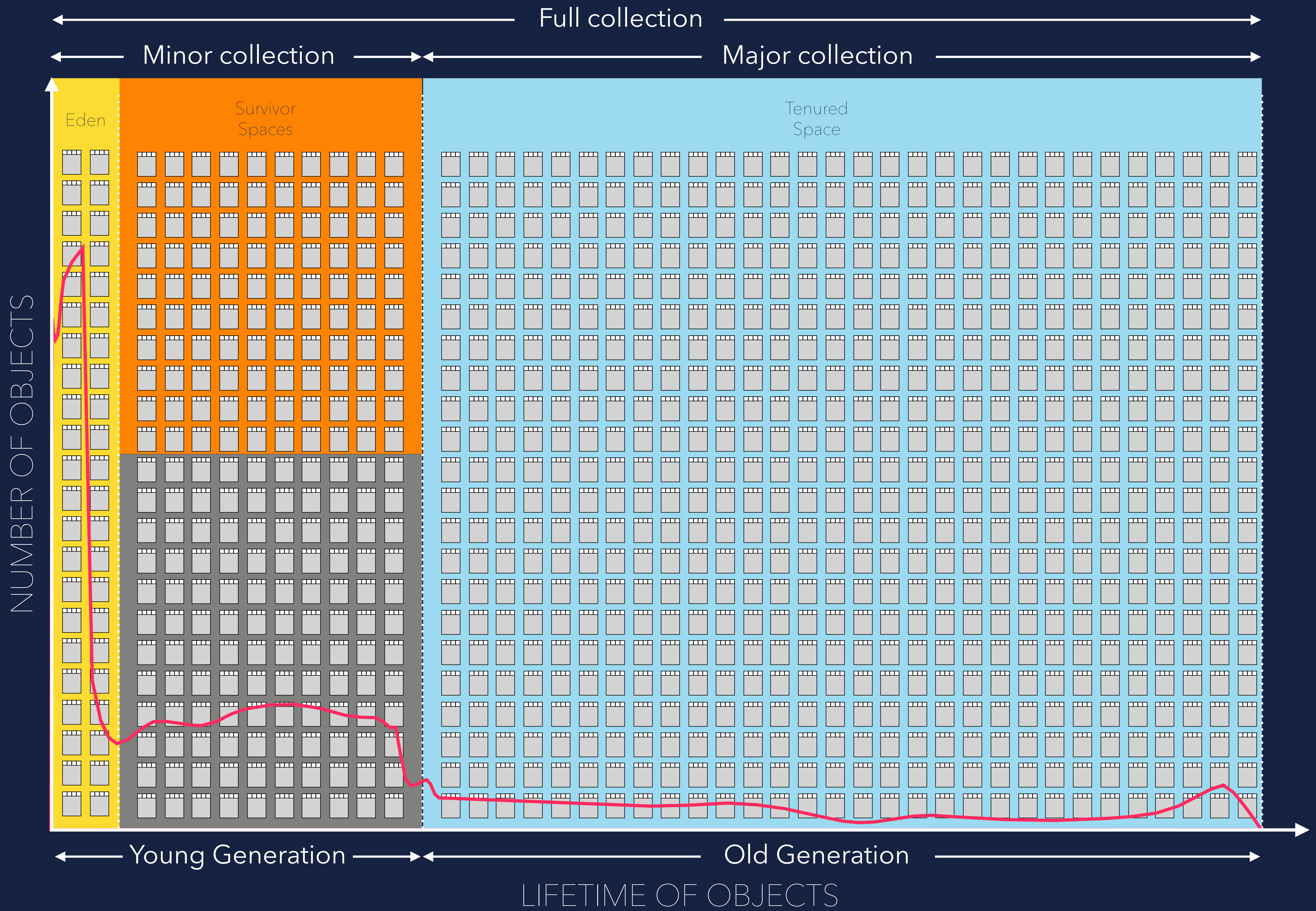
GENERATIONAL COLLECTOR

Weak Generational Hypothesis (Most objects die young)

Eden space for short living objects (can be collected quickly)

Survivor spaces for medium living objects

Tenured space for long living objects



azul

GENERATIONAL COLLECTOR

Demo

1. Mutator allocates cells in Eden
2. Eden is out of memory -> GC
3. Toggle To- and FromSpace
4. Copy all live cells from FromSpace to ToSpace
5. Copy all live cells from Eden to ToSpace
6. Promote live cells from FromSpace to TenuredSpace
7. Free all dead cells
8. Resume Mutator

REMEMBERED SET

Intergenerational References

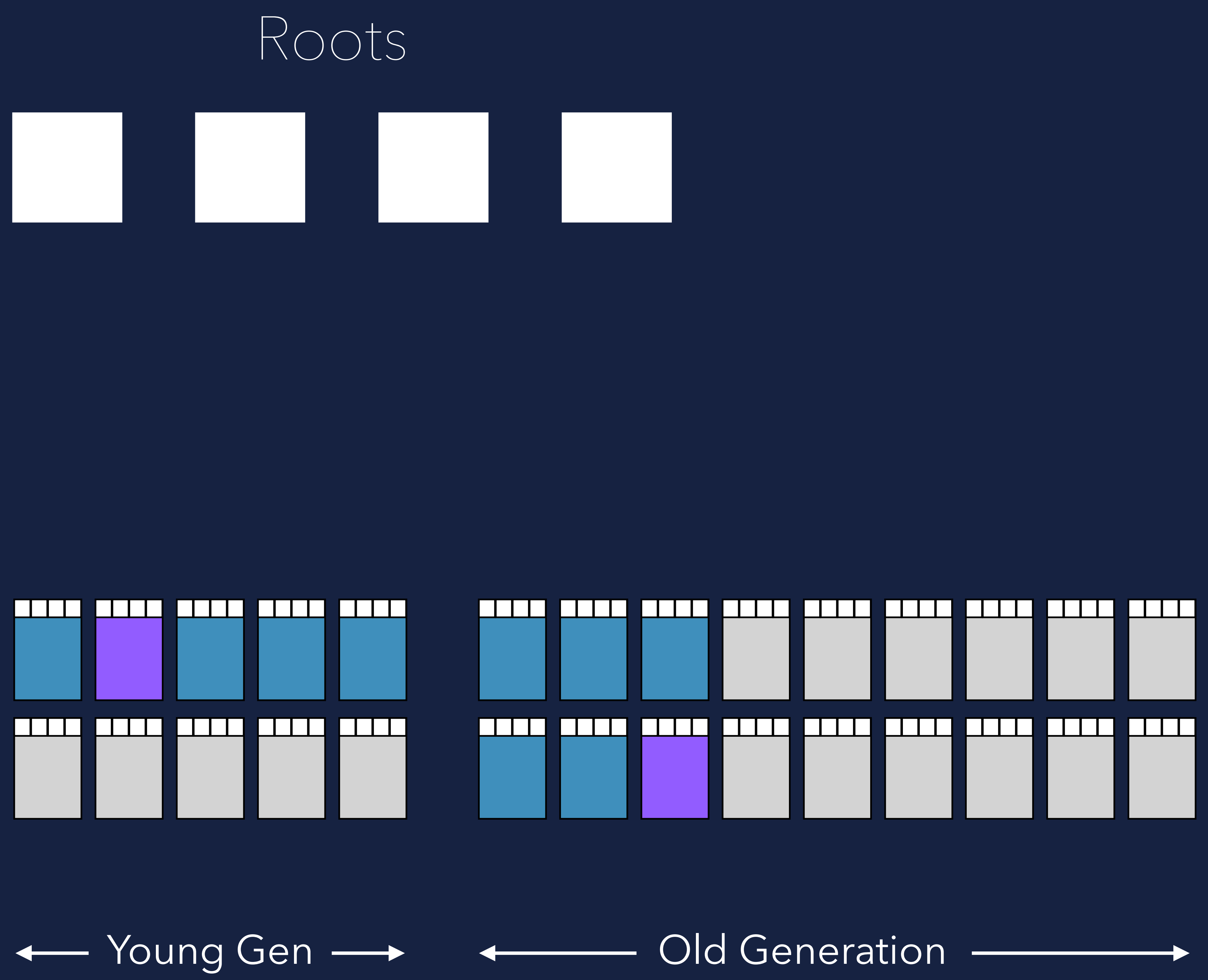
azul

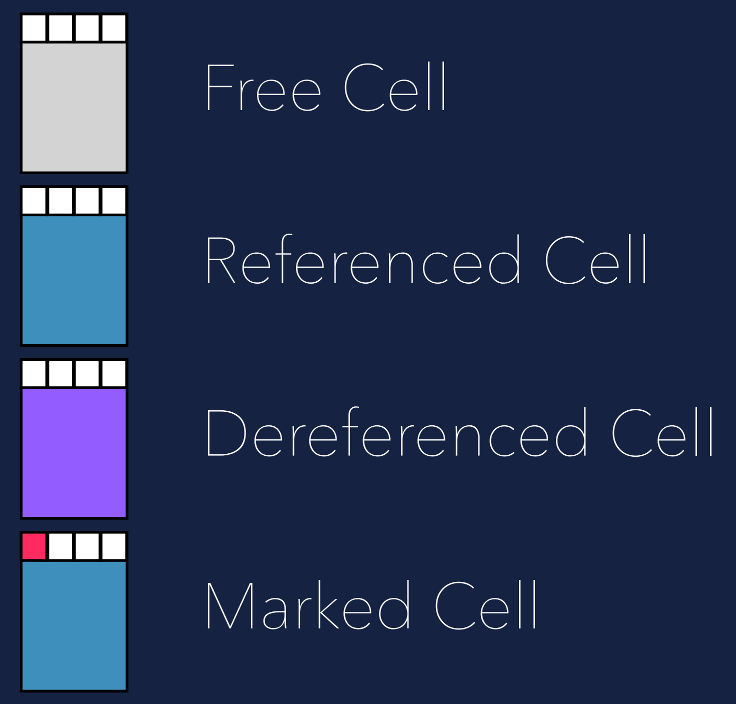
REMEMBERED SET

How to do a minor collection with references from old to young generation...?

REMEMBERED SET

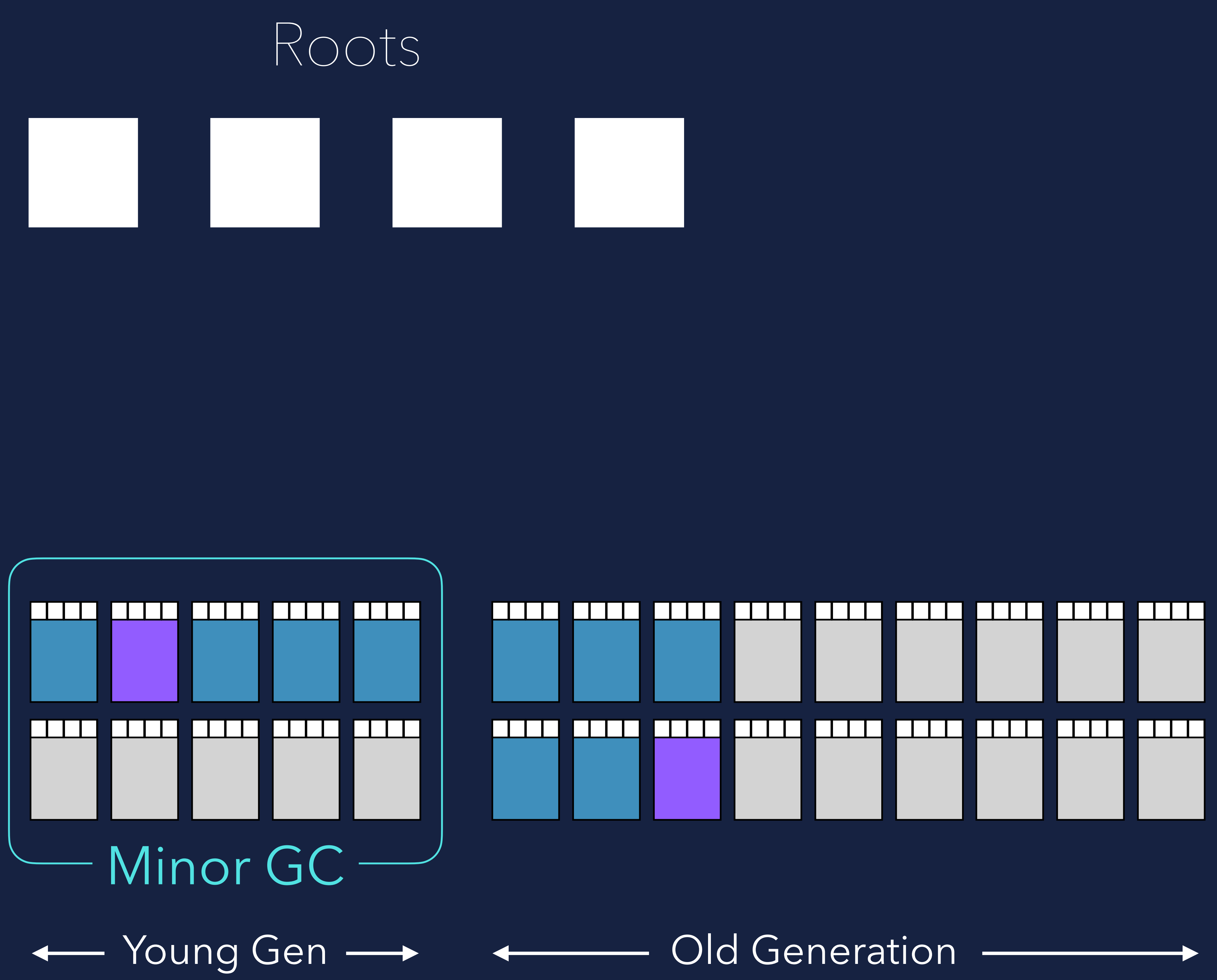
Also known as Card Table

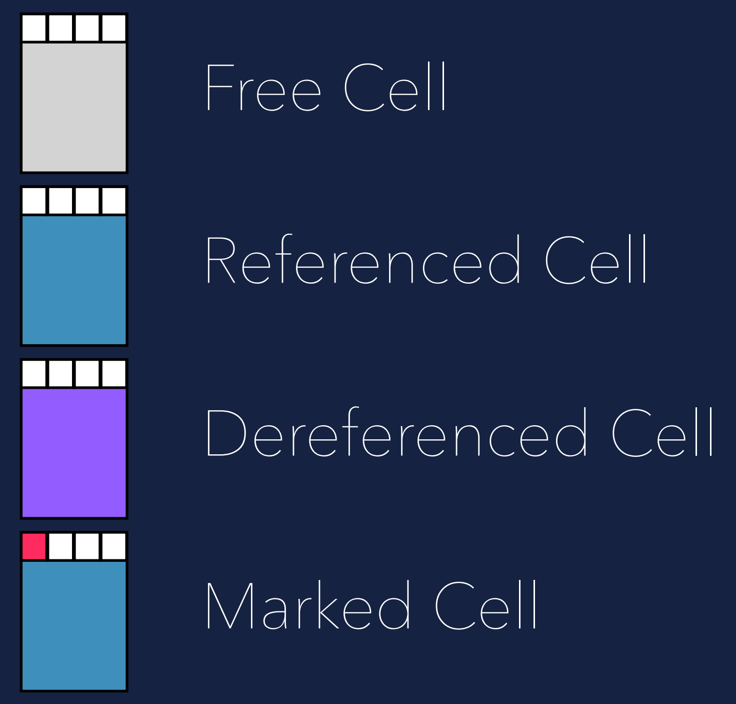




REMEMBERED SET

Also known as Card Table

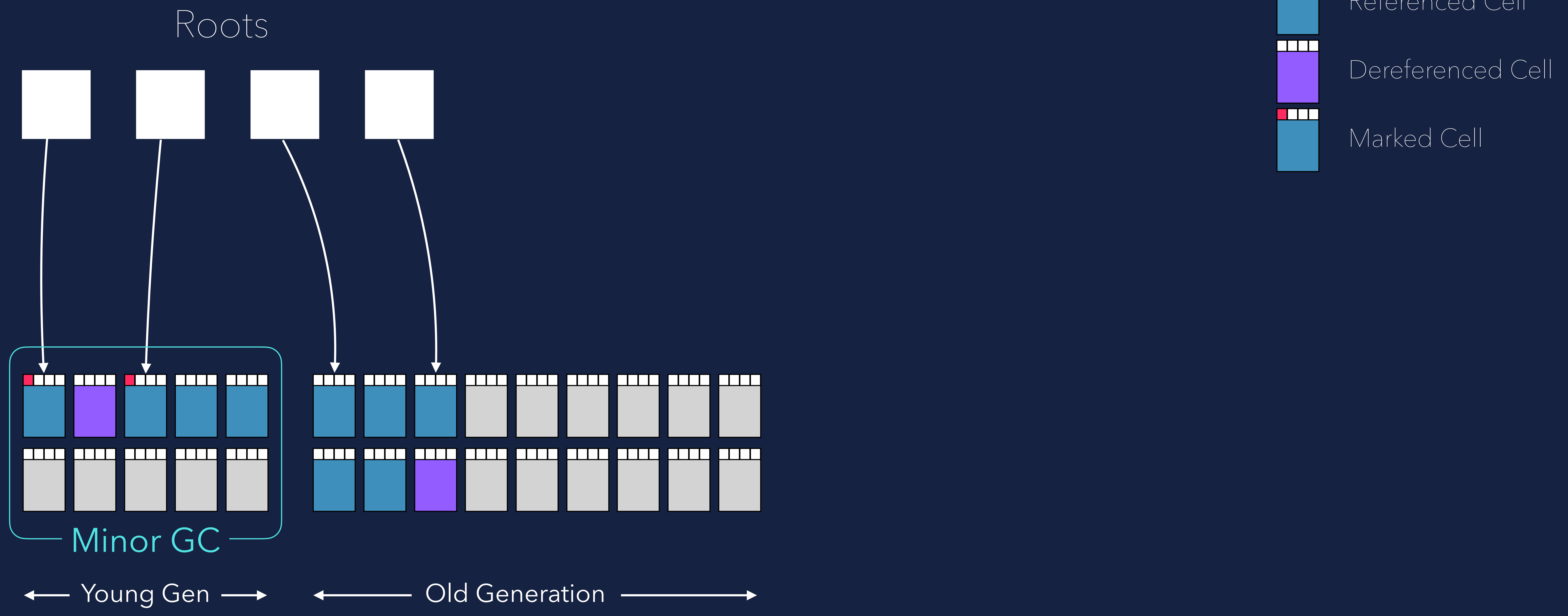




azul

REMEMBERED SET

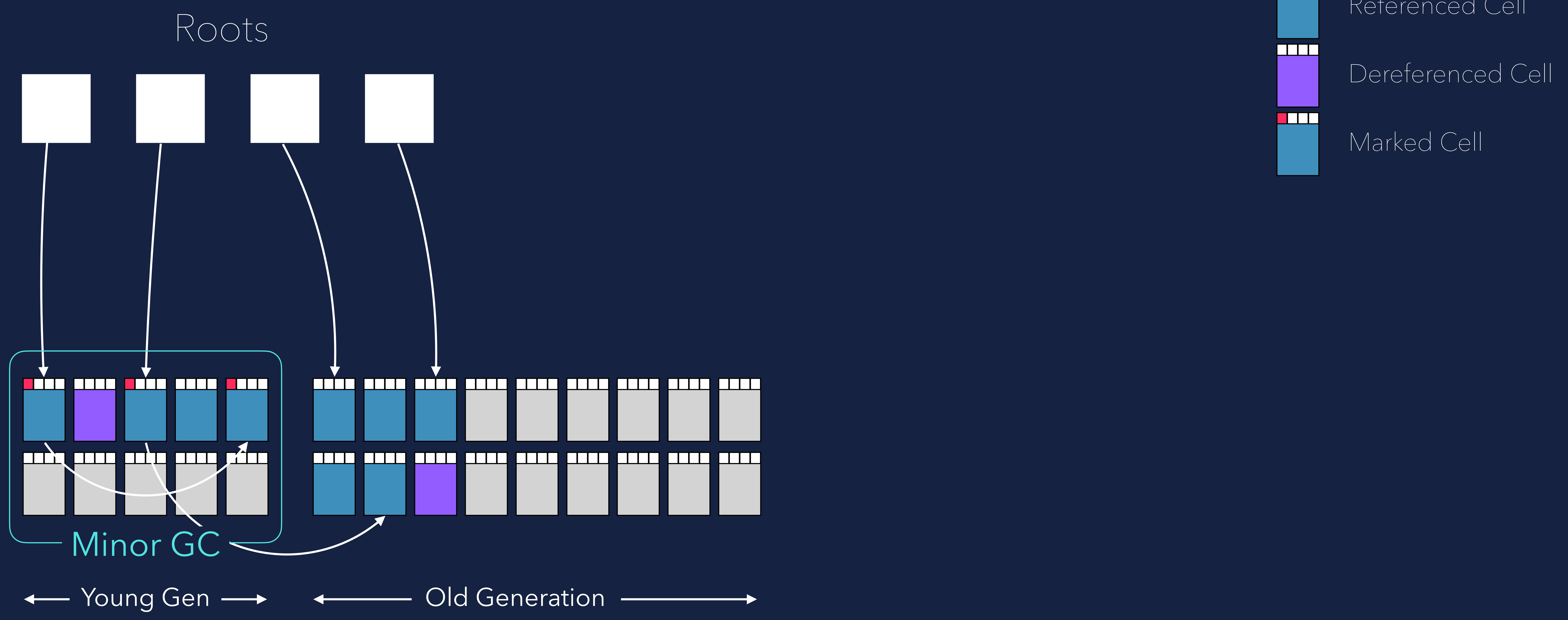
Also known as Card Table



azul

REMEMBERED SET

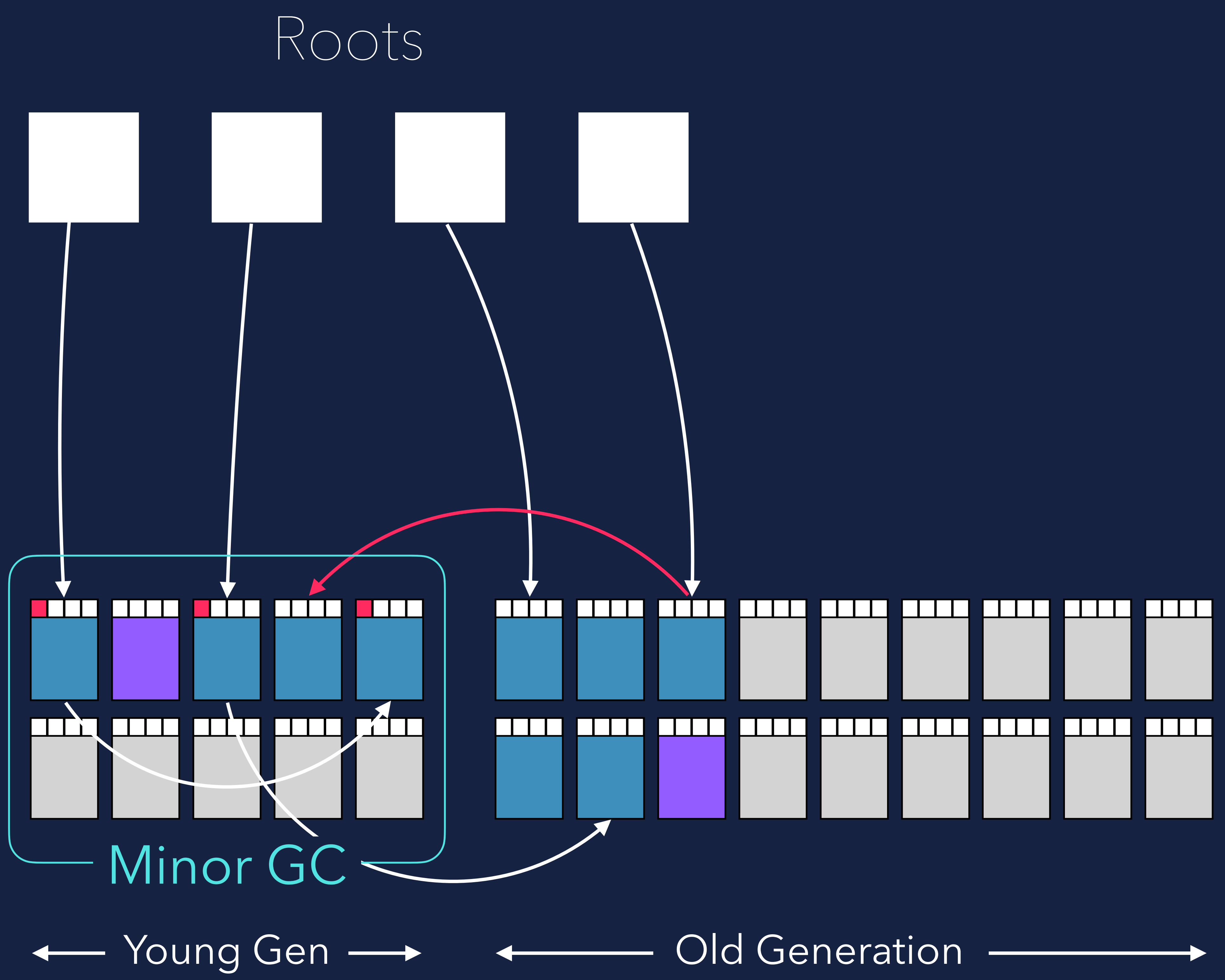
Also known as Card Table

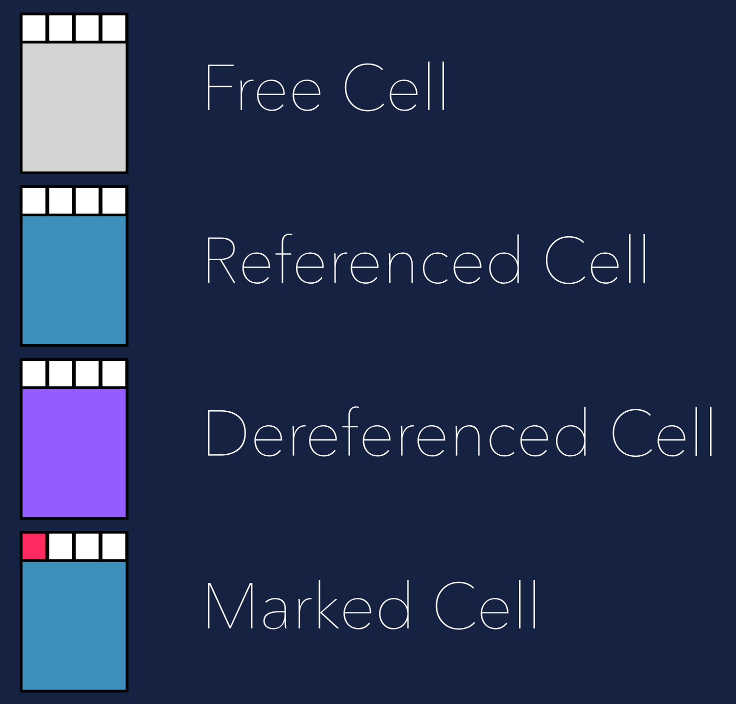


azul

REMEMBERED SET

Also known as Card Table

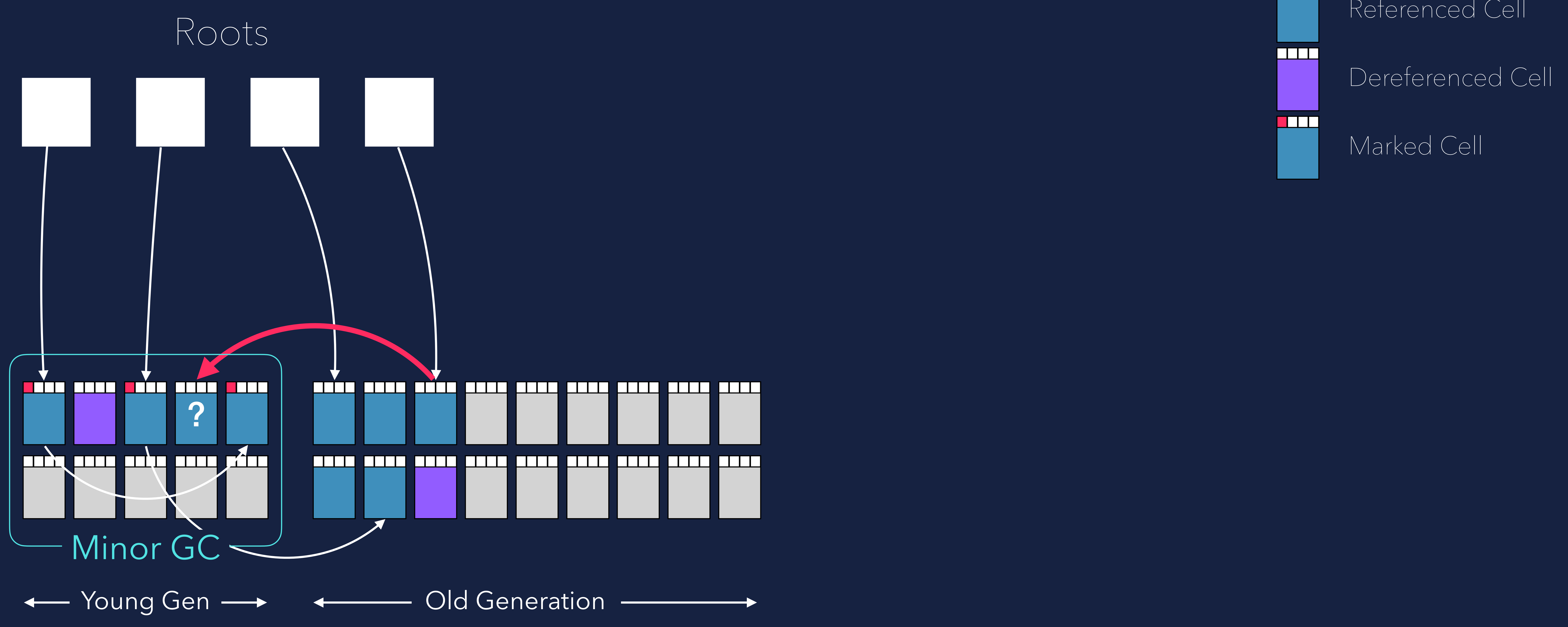




azul

REMEMBERED SET

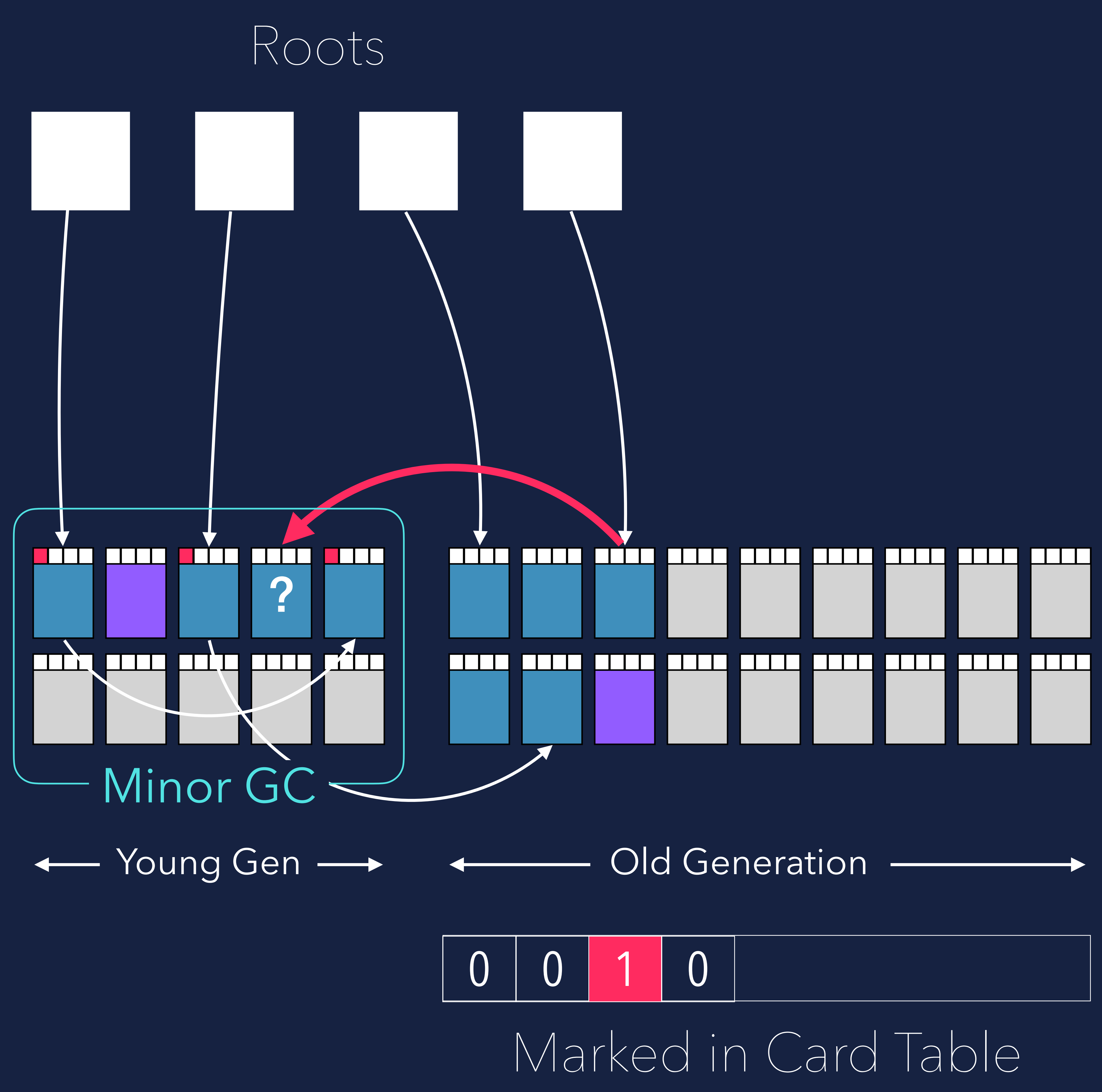
Also known as Card Table

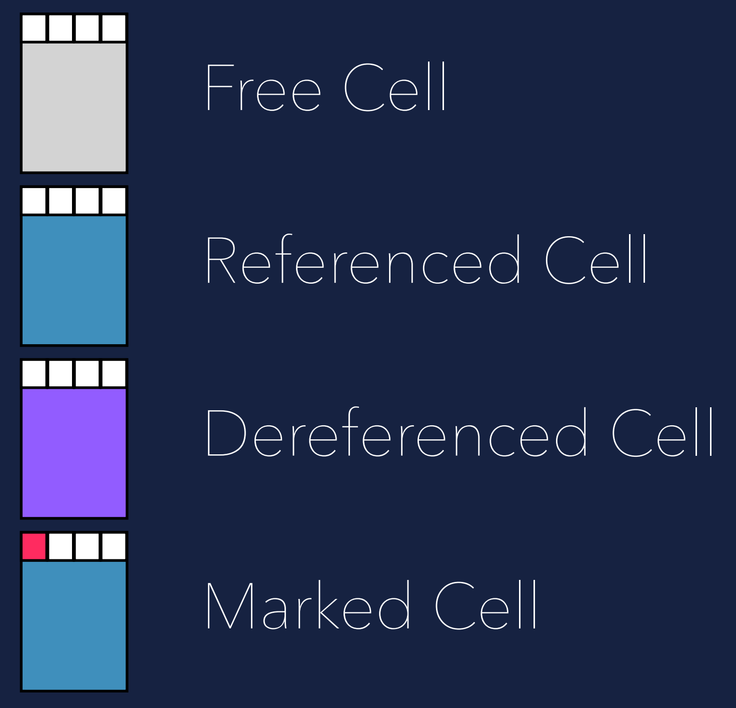


azul

REMEMBERED SET

Also known as Card Table

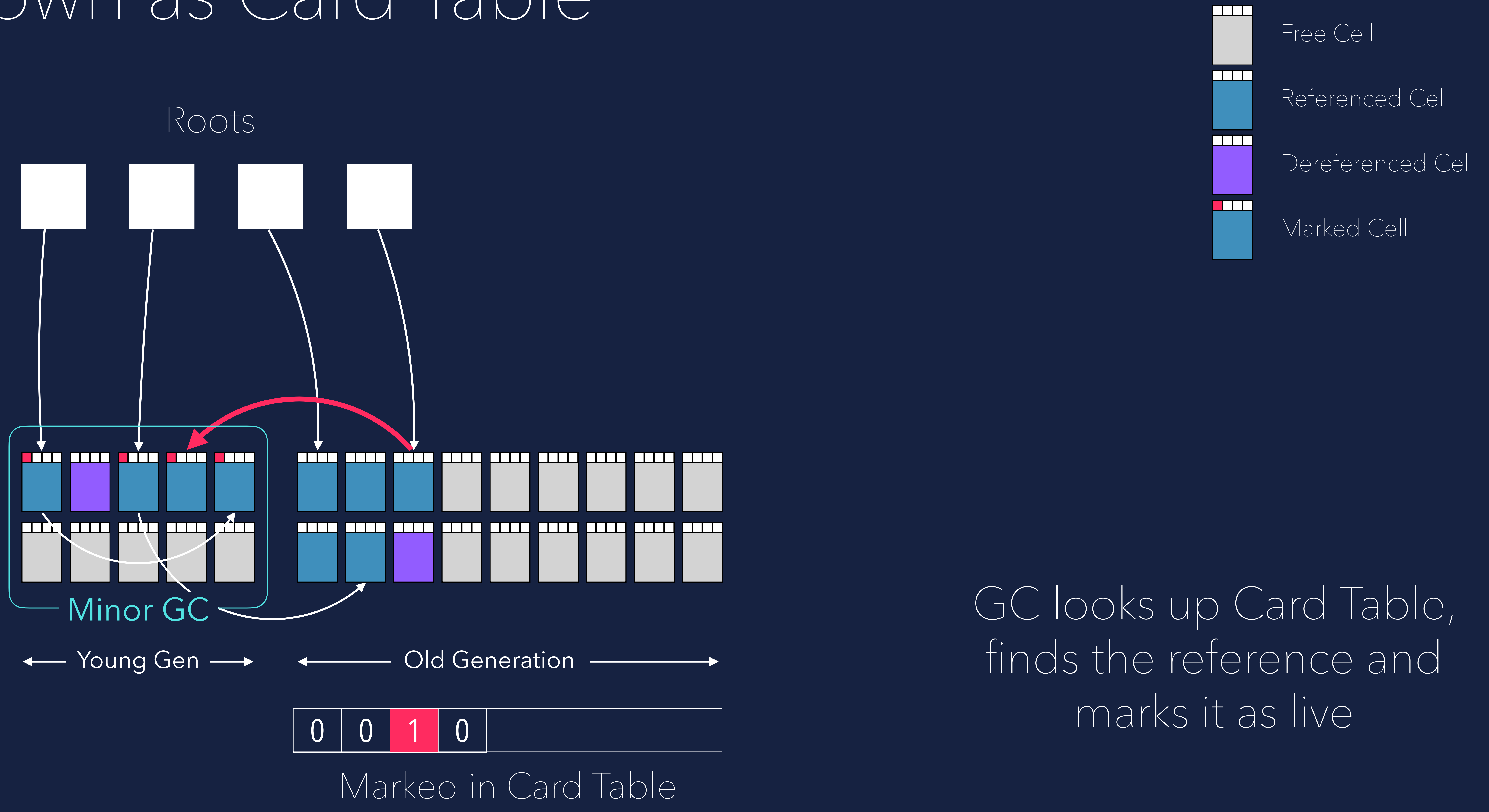




azul

REMEMBERED SET

Also known as Card Table



GC looks up Card Table, finds the reference and marks it as live

azul

CONCURRENT COLLECTION ?

azul

CONCURRENCY IS HARD...

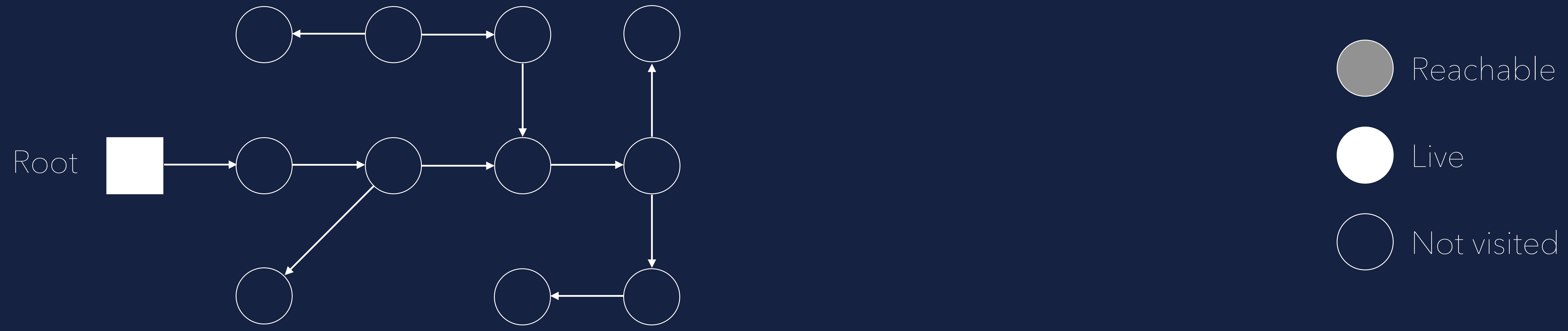
azul

CONCURRENT MARKING

azul

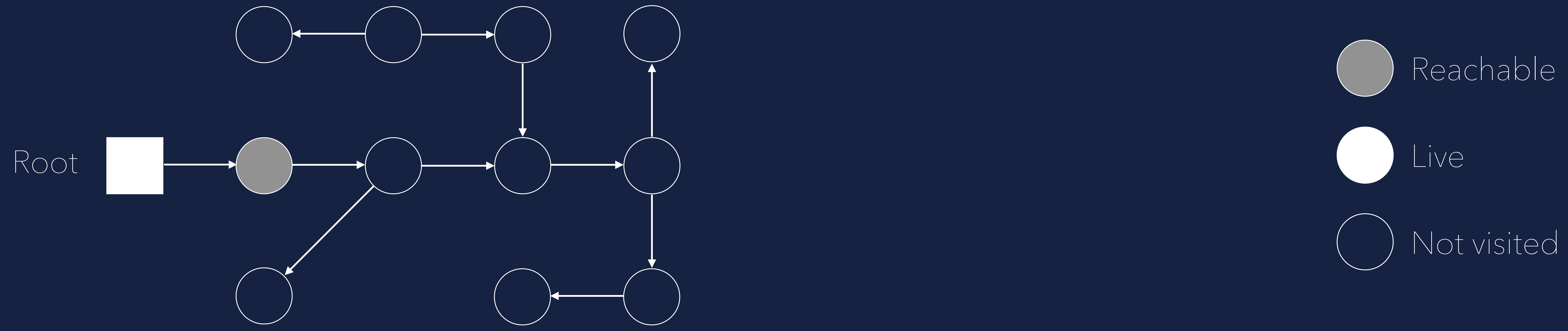
CONCURRENCY IS HARD...

Concurrent Marking



CONCURRENCY IS HARD...

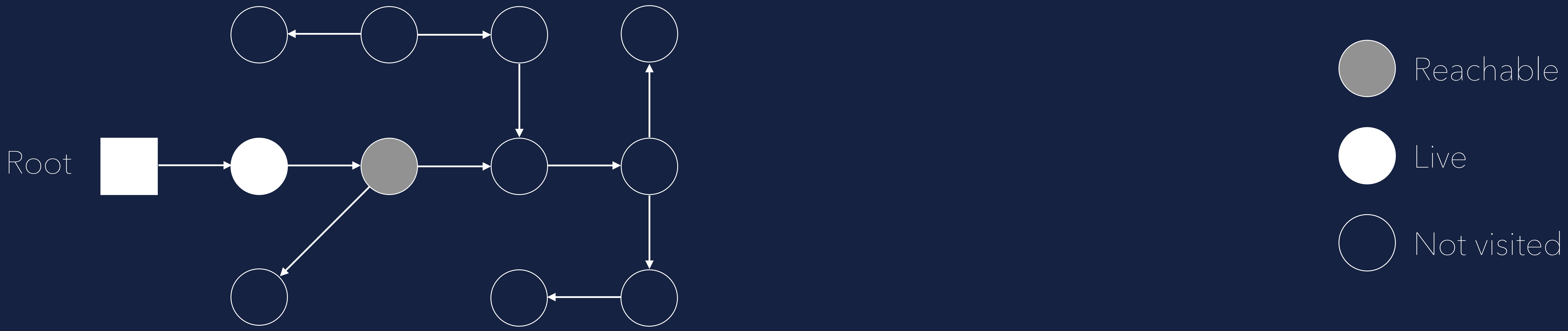
Concurrent Marking



Collector starts marking objects

CONCURRENCY IS HARD...

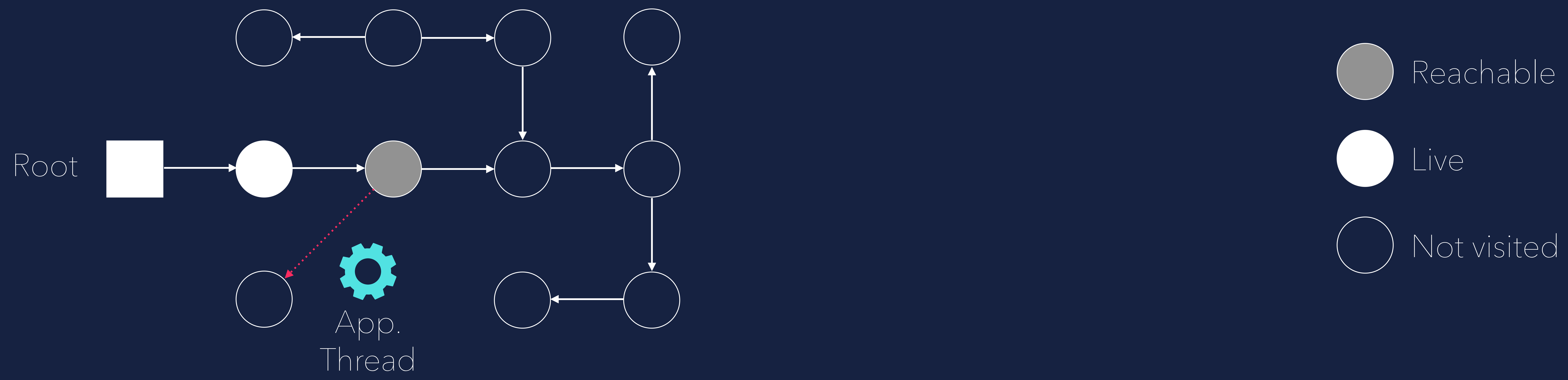
Concurrent Marking



azul

CONCURRENCY IS HARD...

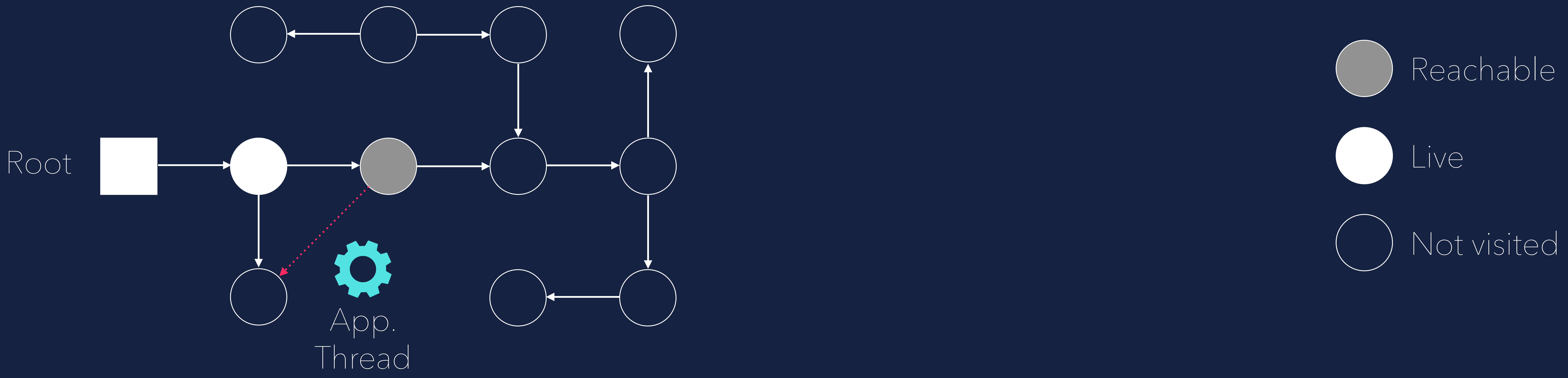
Concurrent Marking



Mutator removes reference and creates a new one from an already visited cell !

CONCURRENCY IS HARD...

Concurrent Marking

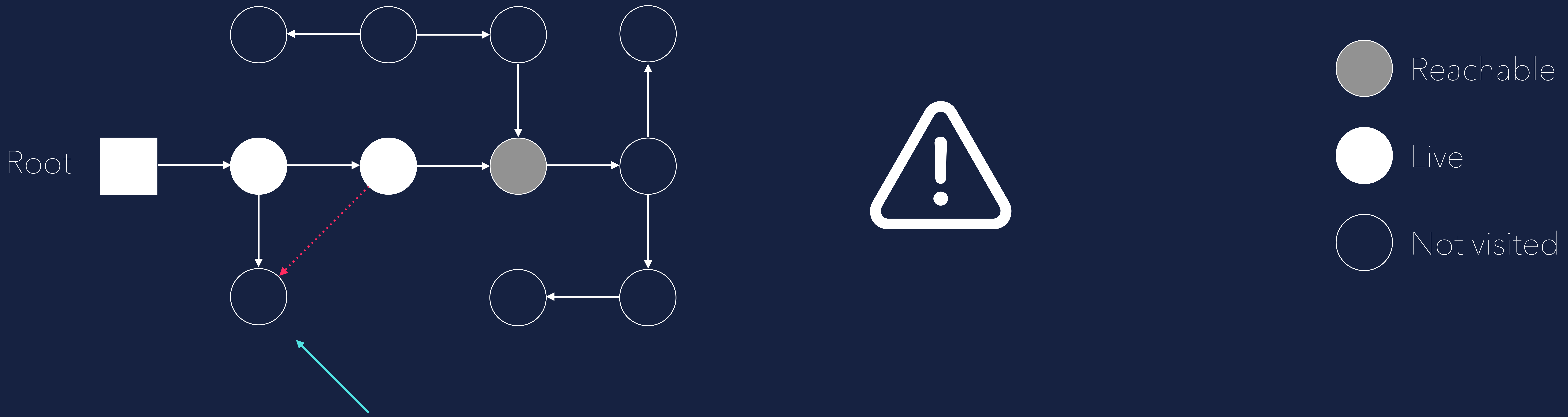


Mutator removes reference and creates a new one from an already visited cell !

azul

CONCURRENCY IS HARD...

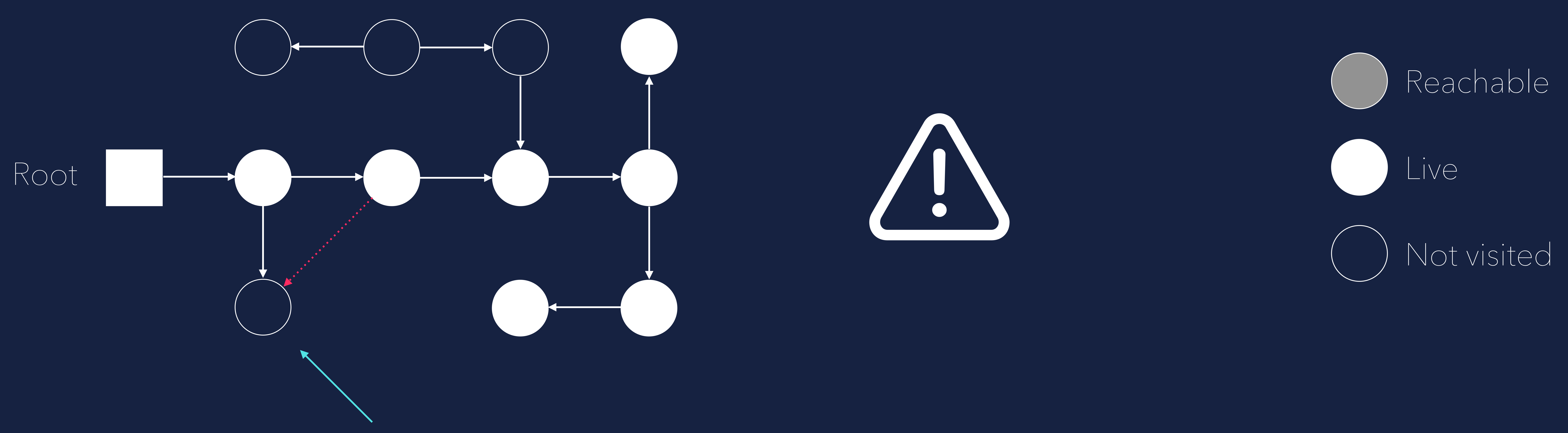
Concurrent Marking



Won't be detected by the Garbage Collector !

CONCURRENCY IS HARD...

Concurrent Marking



Won't be detected by the Garbage Collector !

azul

???

azul

BARRIERS TO THE RESCUE

azul

BARRIERS

Read / Write Barriers

- Mechanisms to execute memory management code when a read/write on some object takes place

BARRIERS

Read / Write Barriers

- Mechanisms to execute memory management code when a read/write on some object takes place

- Used to keep track of inter-generational references.
  (references from old generation to young generation, the so called Rembered Set)

BARRIERS

Read / Write Barriers

- Mechanisms to execute memory management code when a read/write on some object takes place

- Used to keep track of inter-generational references.
  (references from old generation to young generation, the so called Rembered Set)

- Used to synchronize action between mutator and collector
  (allocation concurrent to collection)

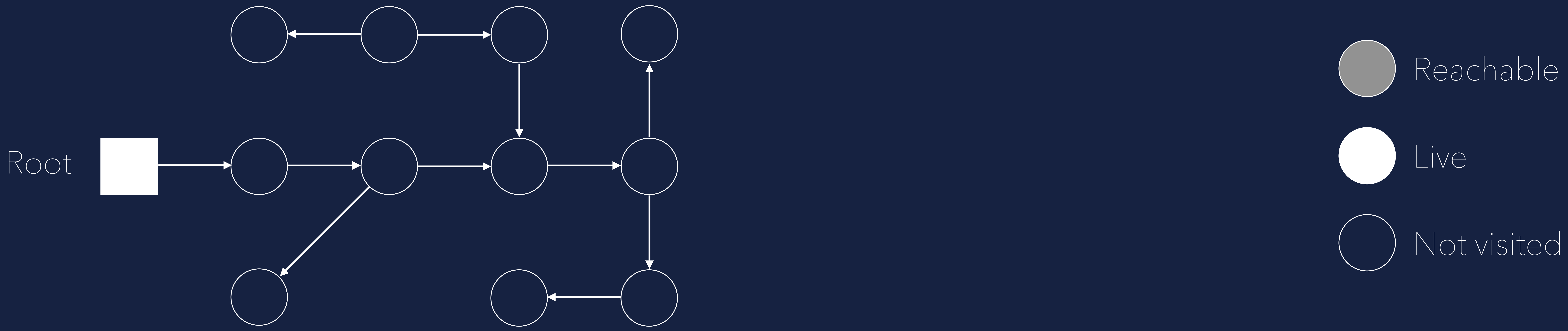
BARRIERS

Read / Write Barriers

- Mechanisms to execute memory management code when a read/write on some object takes place
- Used to keep track of inter-generational references.
  (references from old generation to young generation, the so called Rembered Set)
- Used to synchronize action between mutator and collector
  (allocation concurrent to collection)
- Read Barriers are usually more expensive
  (reads 75% to writes 25% -> Read Barriers must be very efficient)

CONCURRENCY IS HARD...

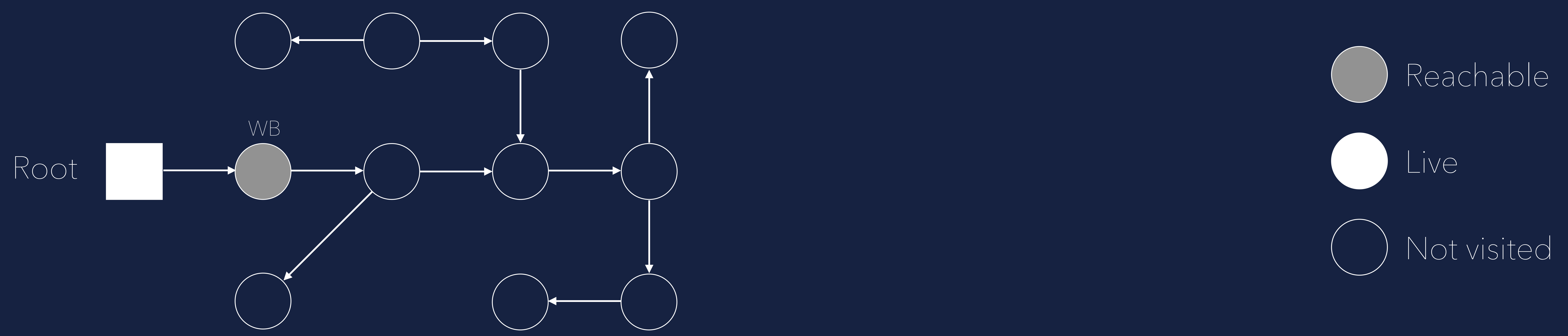
Concurrent Marking using Write Barriers



azul

CONCURRENCY IS HARD...

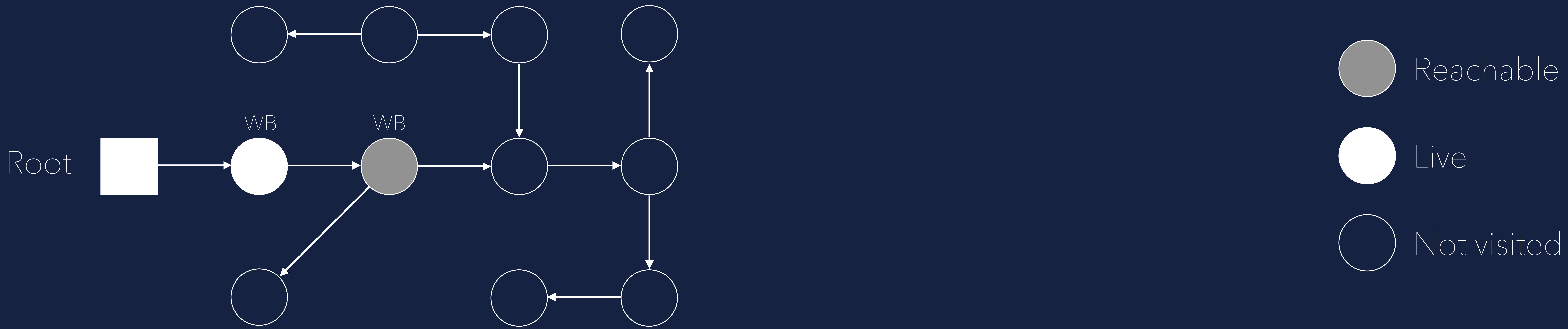
Concurrent Marking using Write Barriers



Collector starts marking objects

CONCURRENCY IS HARD...

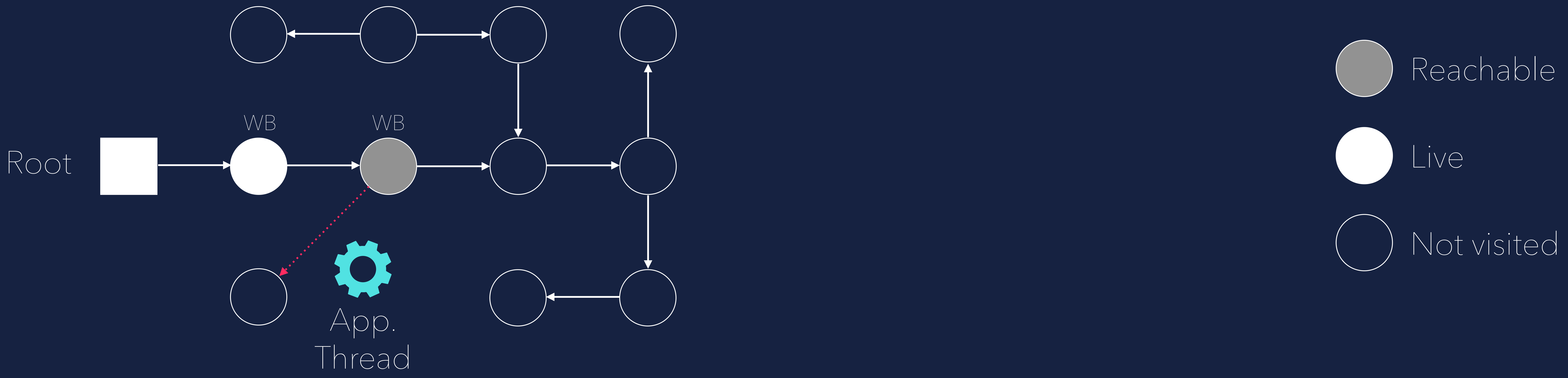
Concurrent Marking using Write Barriers



azul

CONCURRENCY IS HARD...

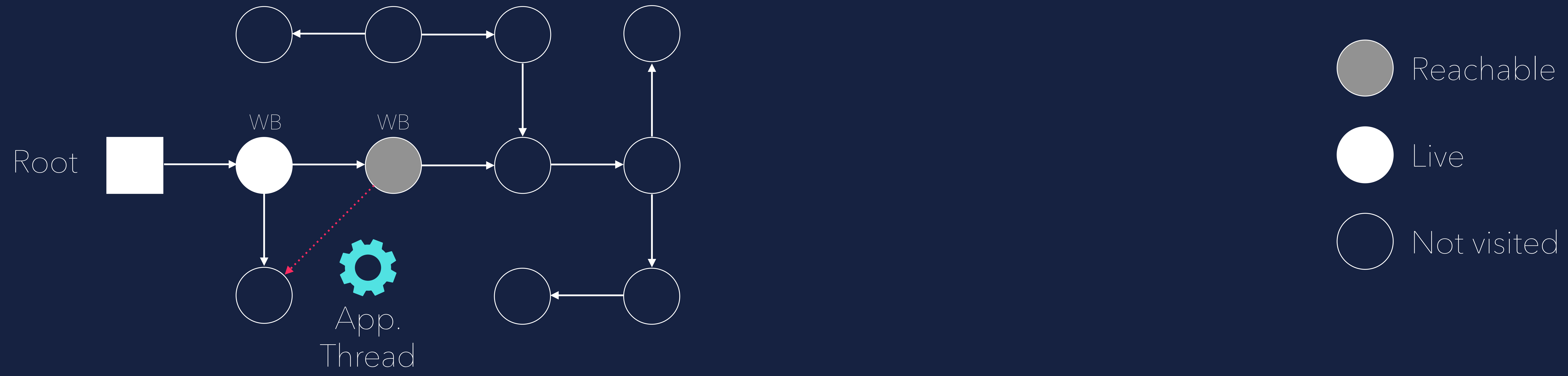
Concurrent Marking using Write Barriers



Mutator hits write barrier and removes reference and adds a new one

CONCURRENCY IS HARD...

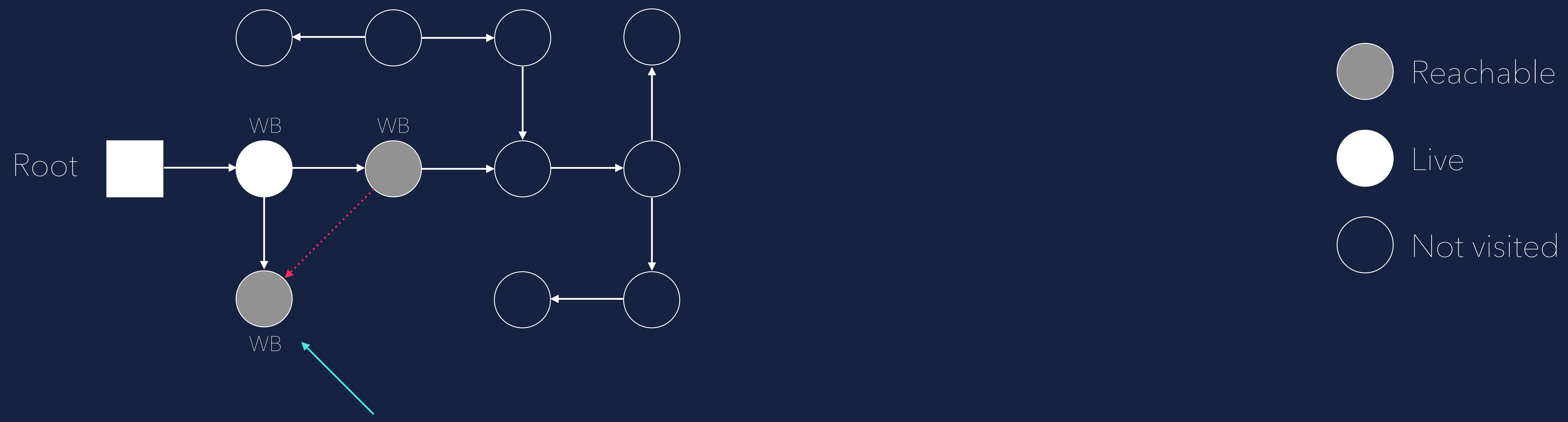
Concurrent Marking using Write Barriers



Mutator hits write barrier and removes reference and adds a new one

CONCURRENCY IS HARD...

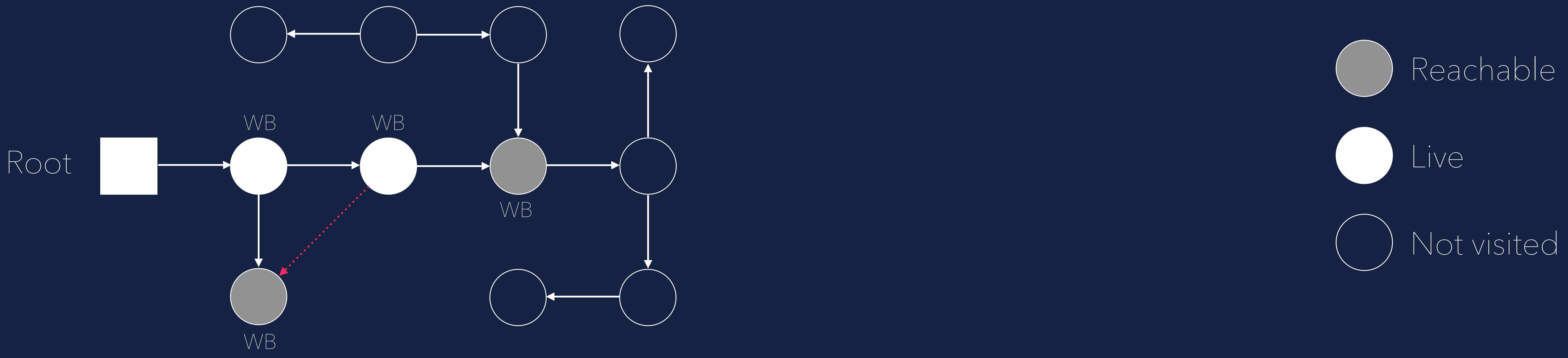
Concurrent Marking using Write Barriers



Removed references will be marked as reachable by Write Barrier

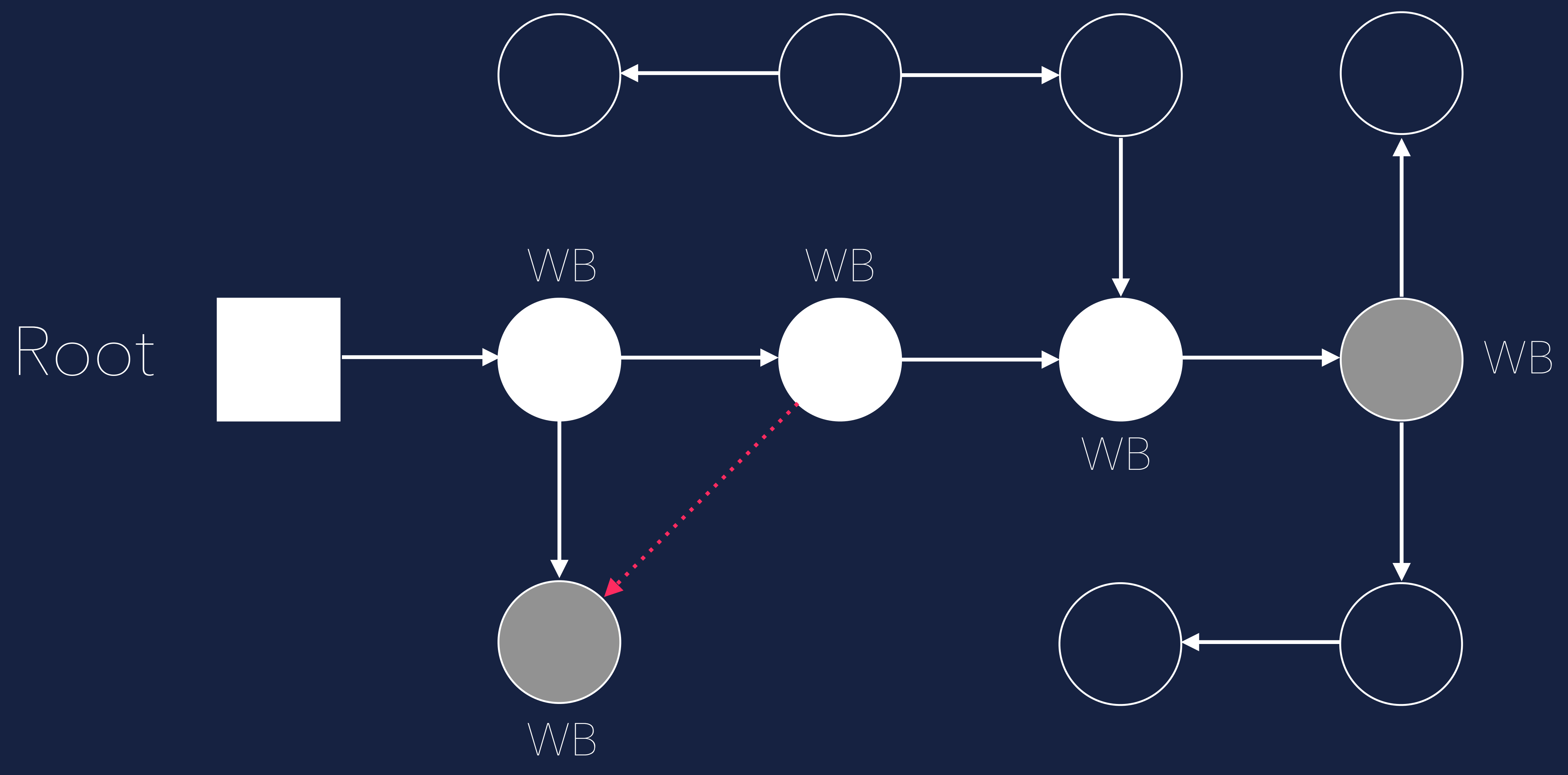
CONCURRENCY IS HARD...

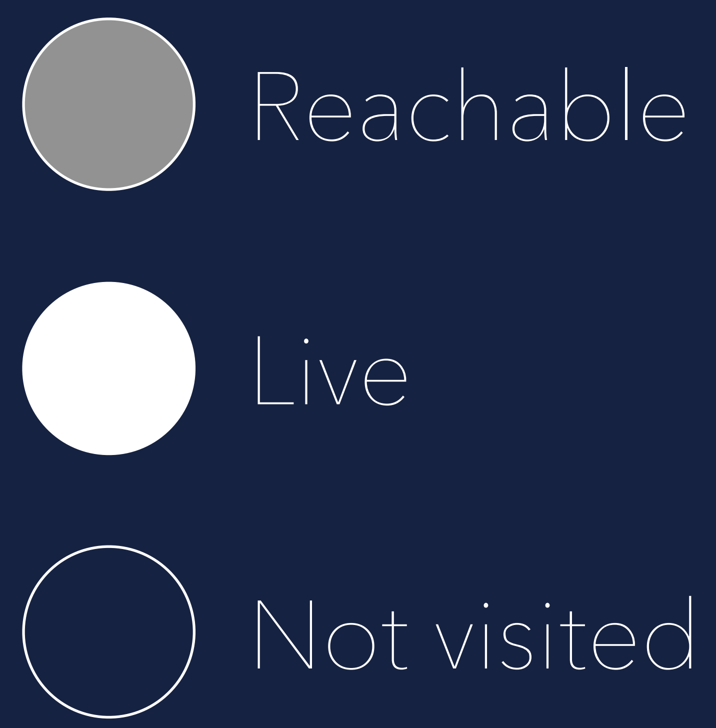
Concurrent Marking using Write Barriers



CONCURRENCY IS HARD...

Concurrent Marking using Write Barriers

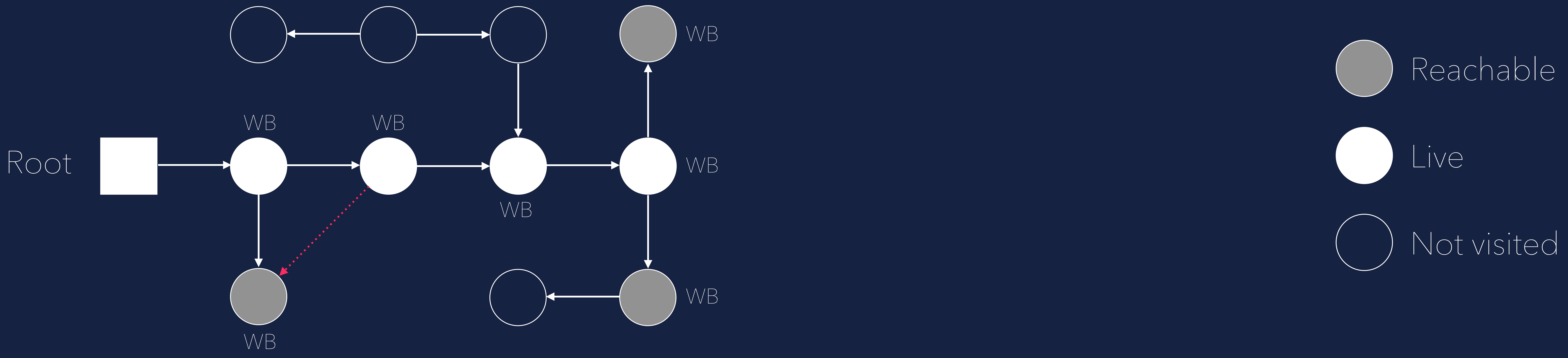




azul

CONCURRENCY IS HARD...

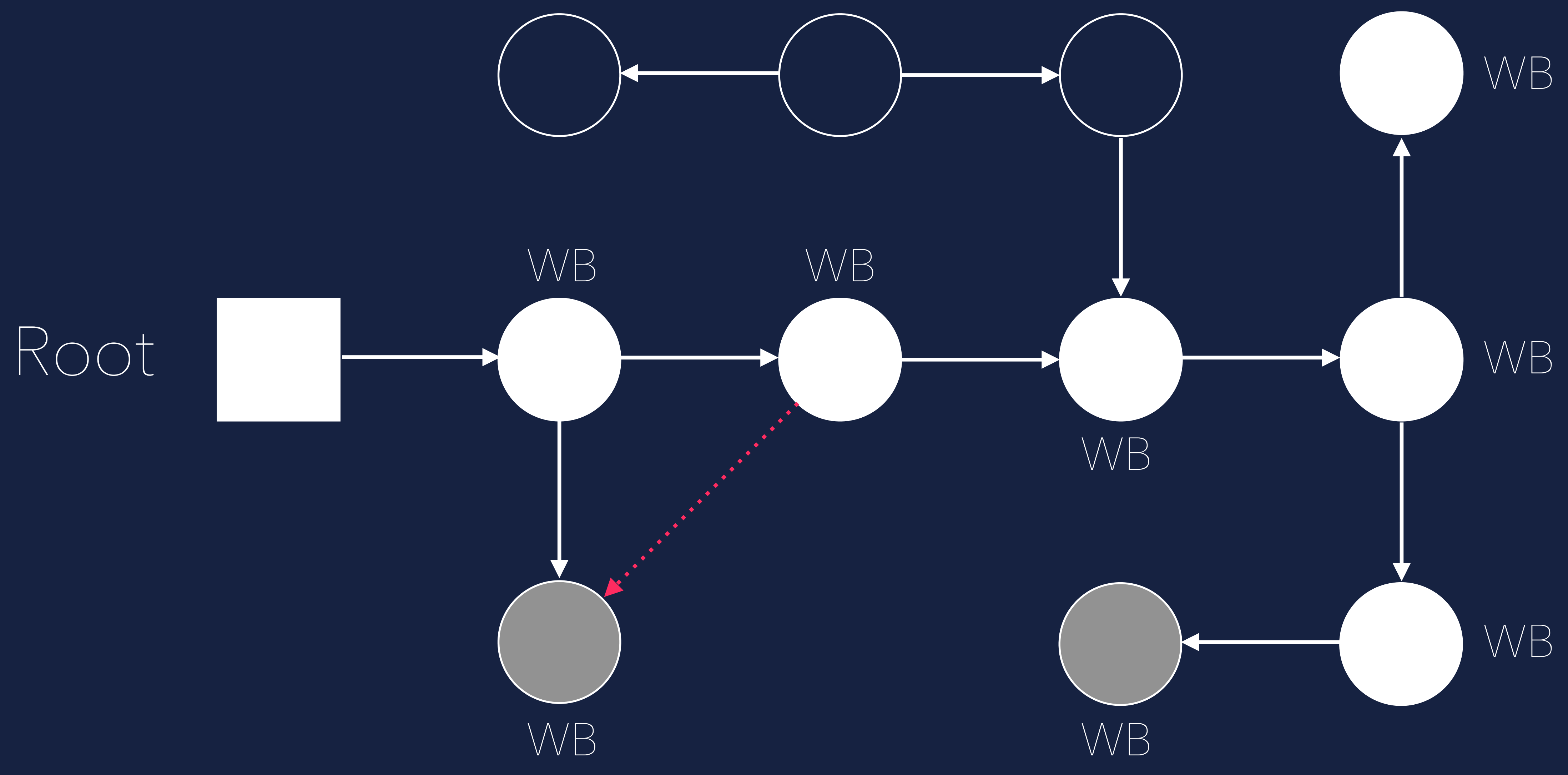
Concurrent Marking using Write Barriers

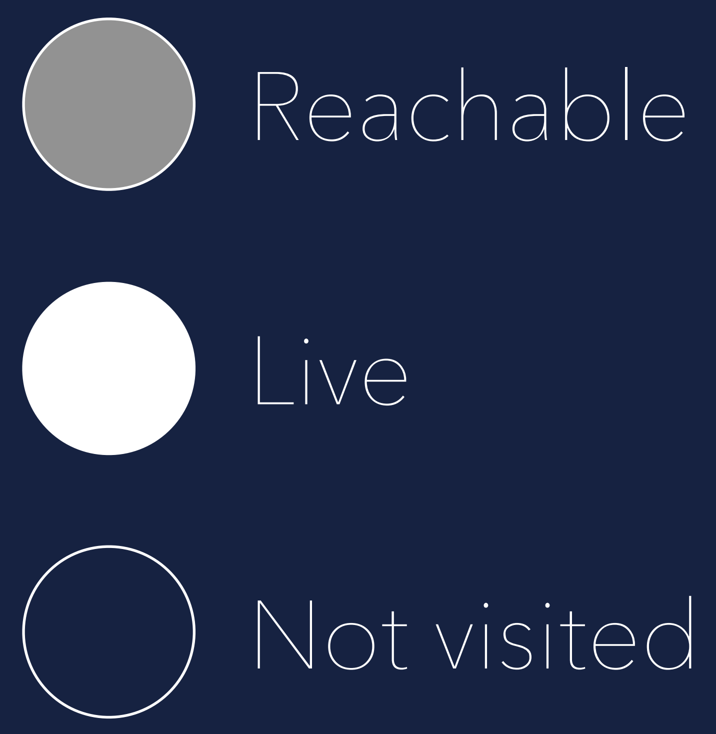


azul

CONCURRENCY IS HARD...

Concurrent Marking using Write Barriers

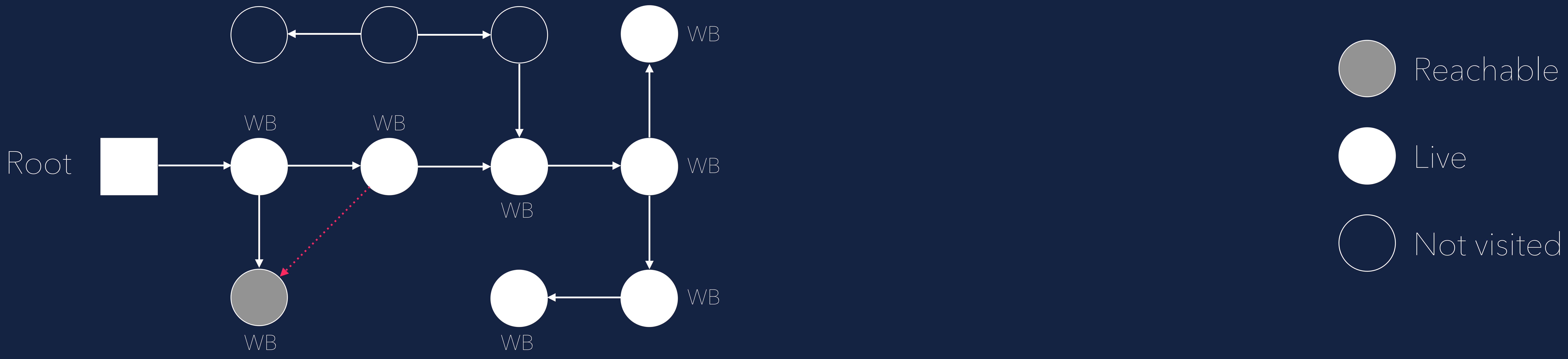




azul

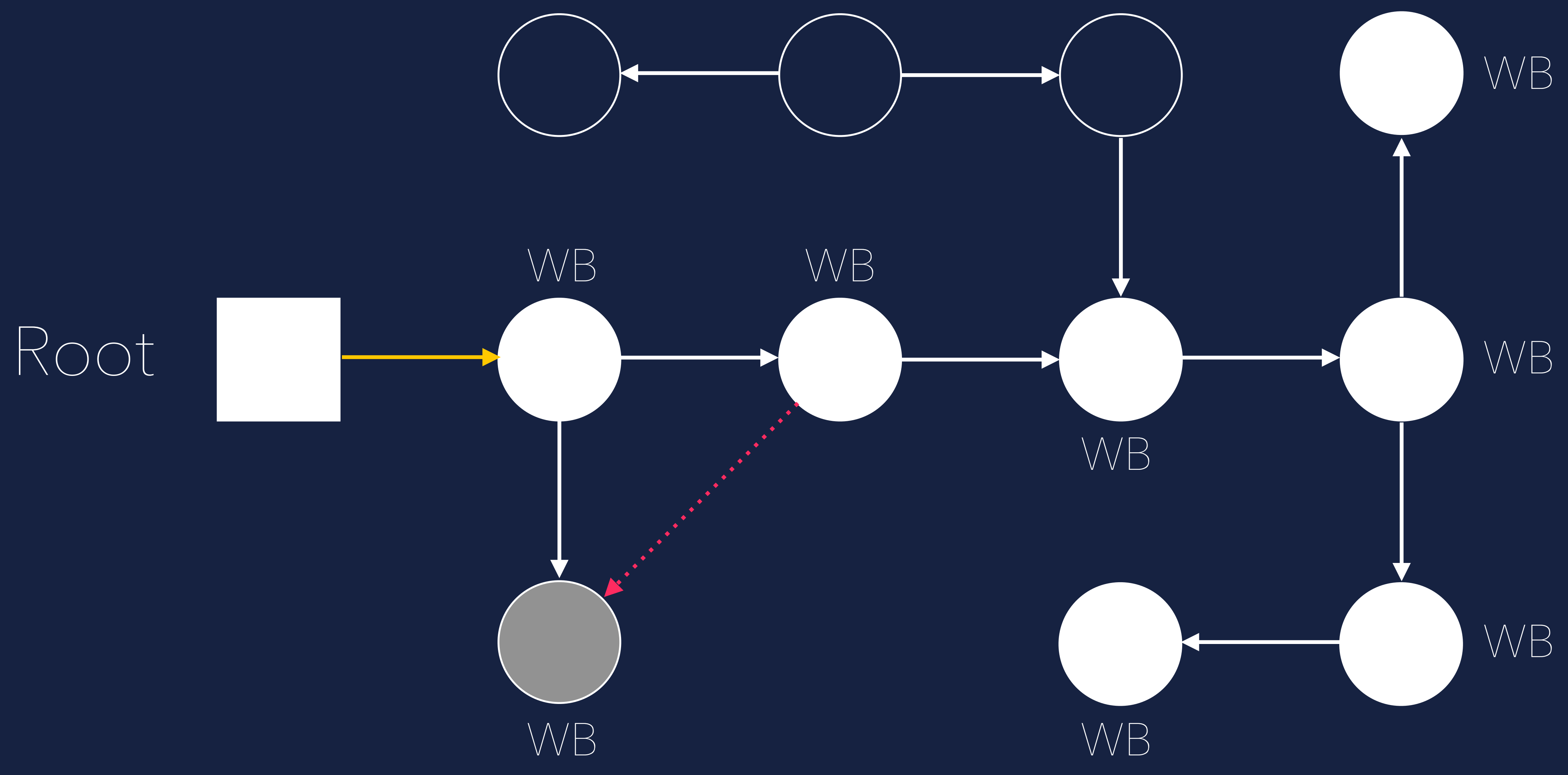
CONCURRENCY IS HARD...

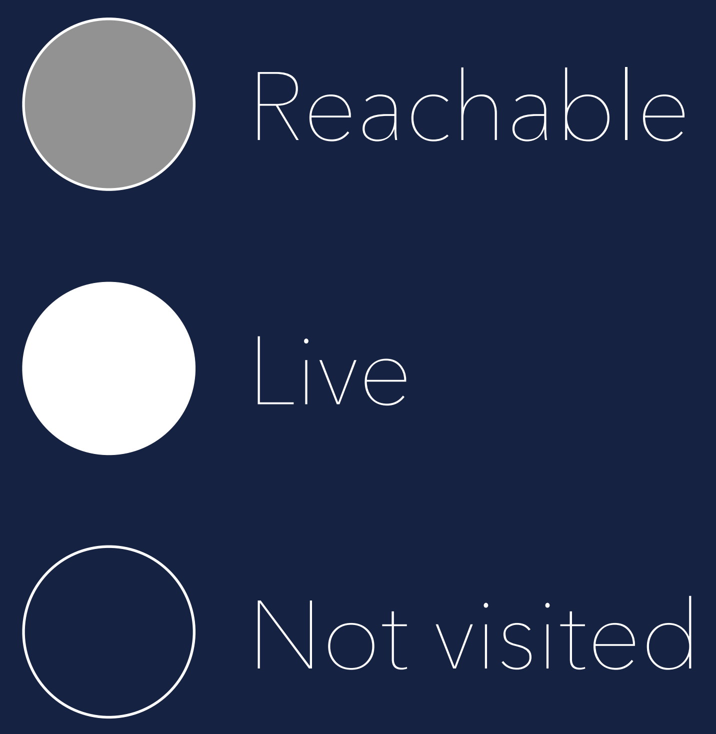
Concurrent Marking using Write Barriers



CONCURRENCY IS HARD...

Concurrent Marking using Write Barriers

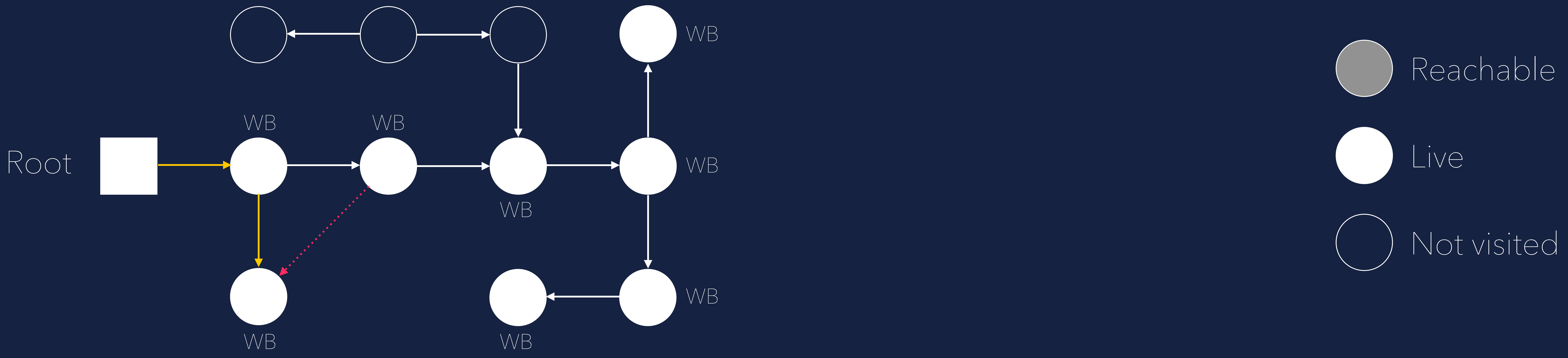




In the Re-Marking phase, in between marked references will be marked as live

CONCURRENCY IS HARD...

Concurrent Marking using Write Barriers



In the Re-Marking phase, in between marked references will be marked as live

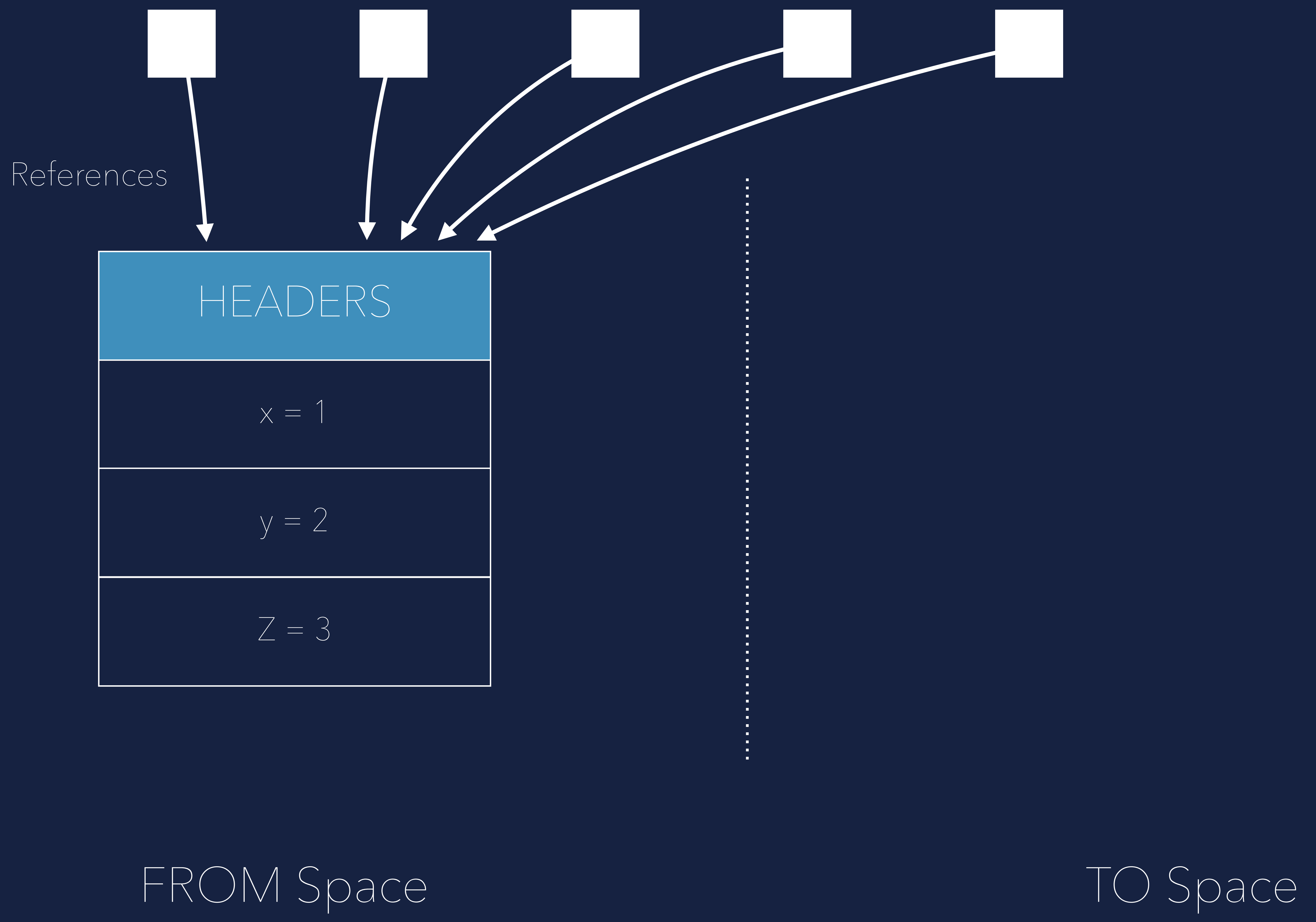
azul

CONCURRENT COPYING

azul

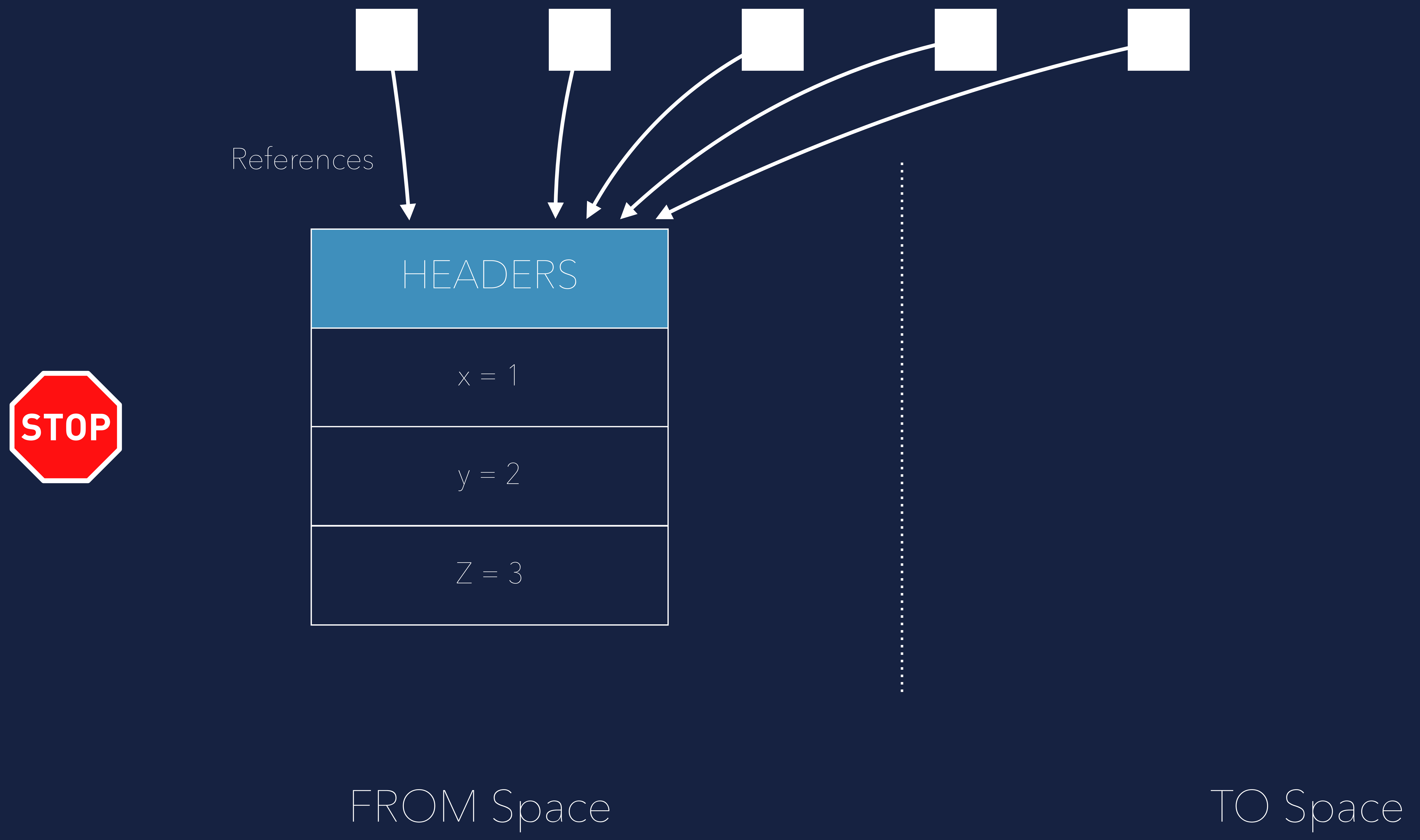
CONCURRENCY IS HARD...

Stop the world copying



CONCURRENCY IS HARD...

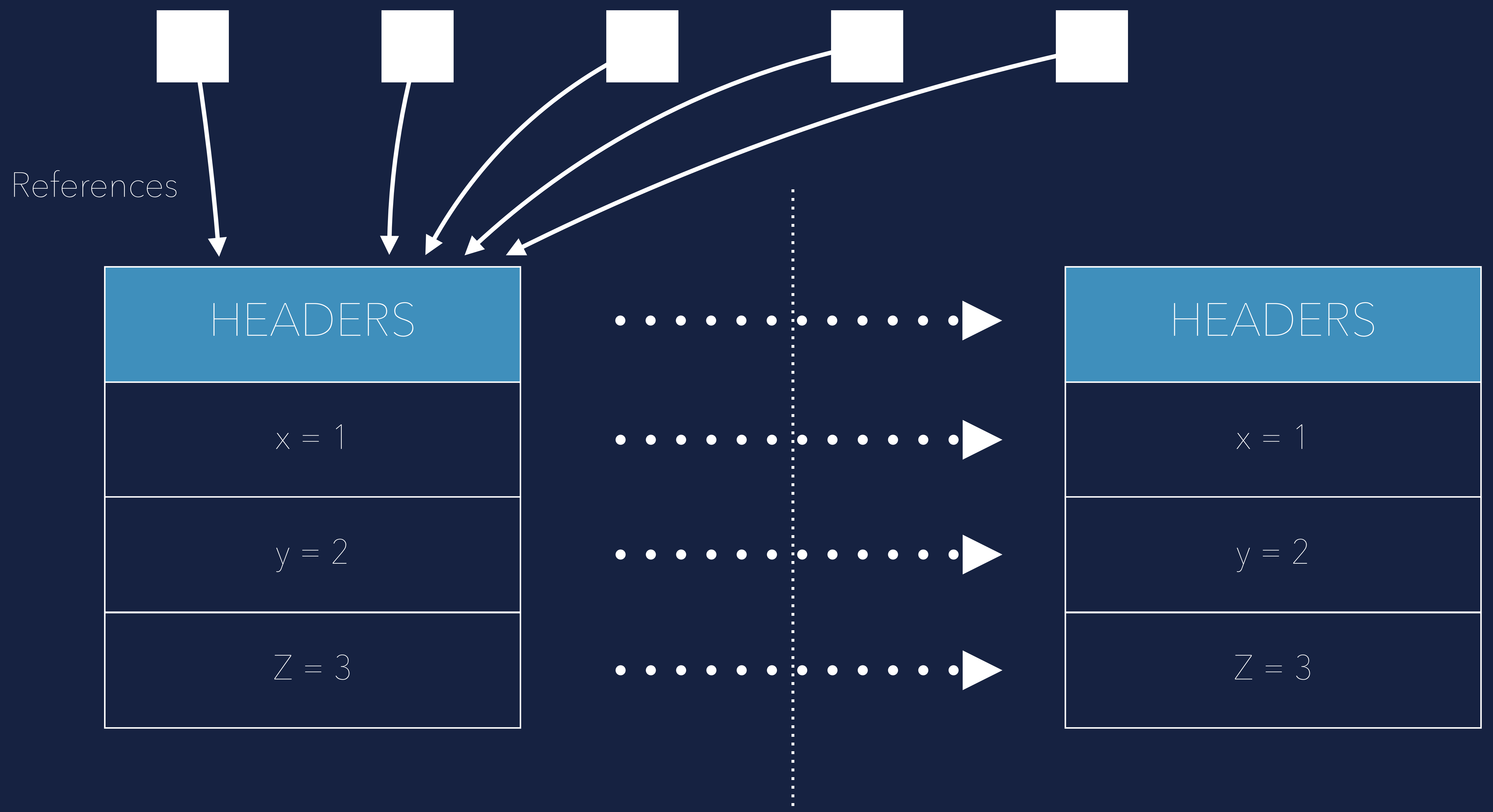
Stop the world copying



Stop the World
(the Mutator)

CONCURRENCY IS HARD...

Stop the world copying



FROM Space

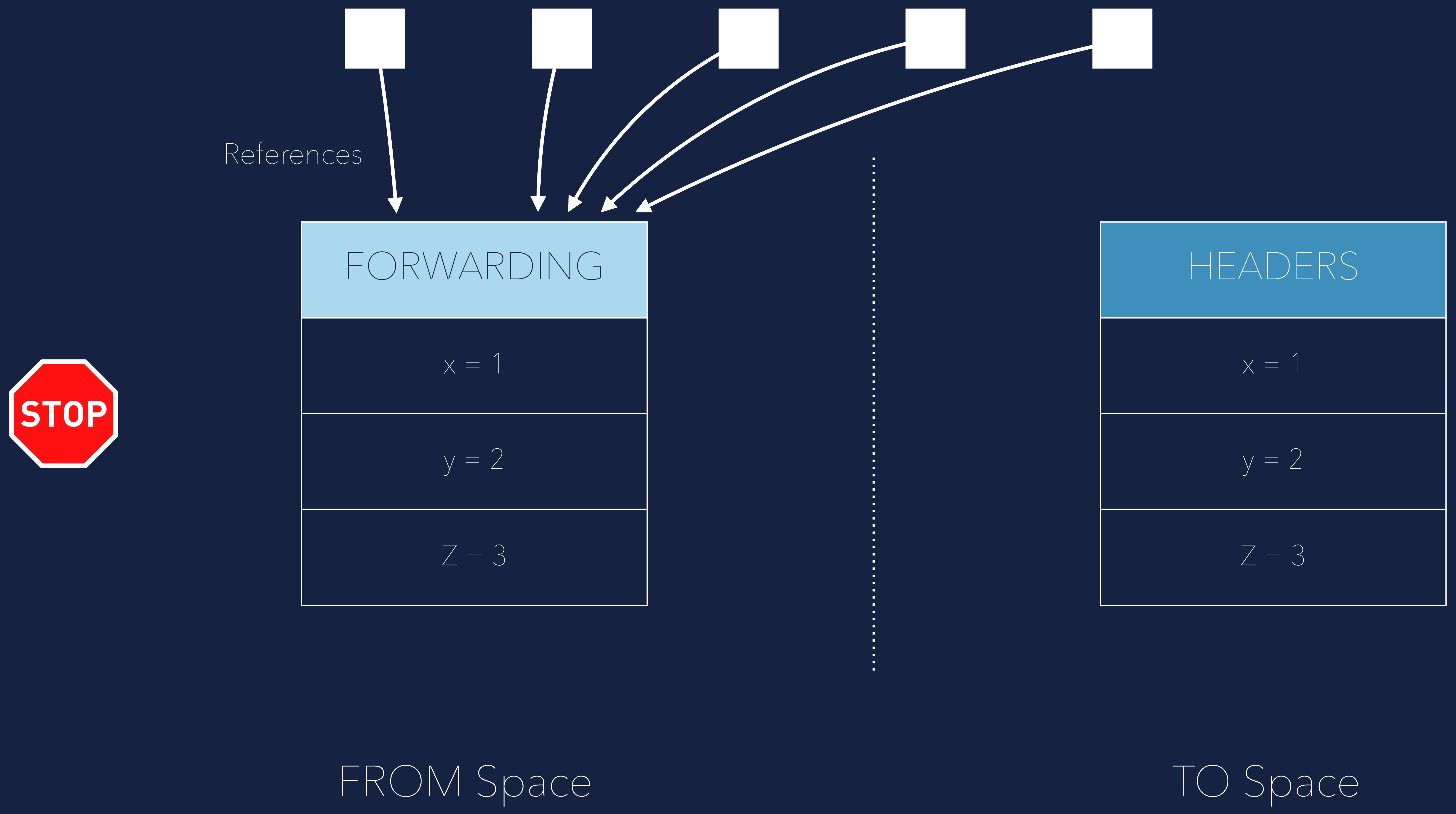
TO Space

Copy the Object
(Create forwarding pointer)

azul

CONCURRENCY IS HARD...

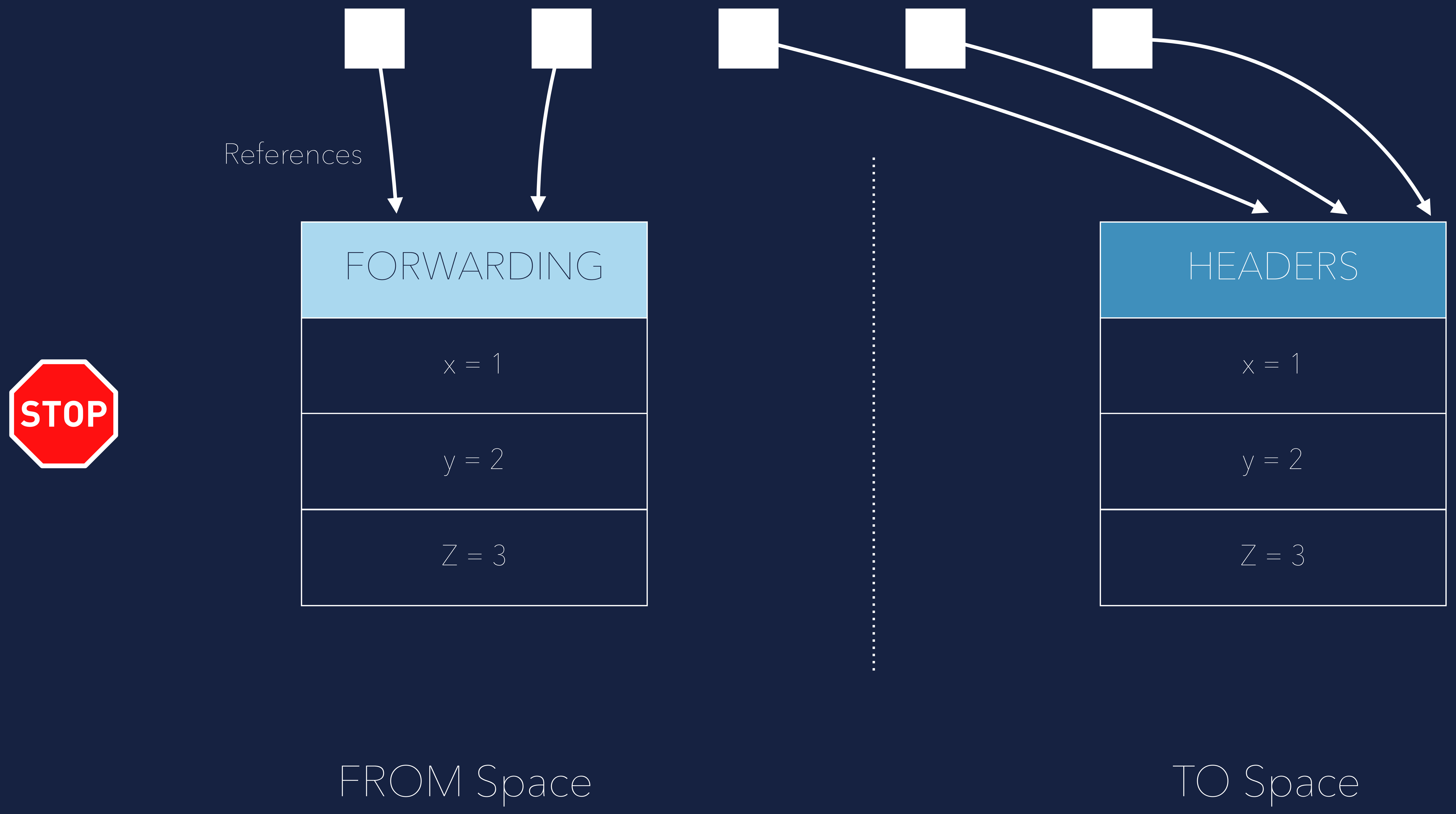
Stop the world copying



Update all references
(Save the pointer that fowards the copy)

CONCURRENCY IS HARD...

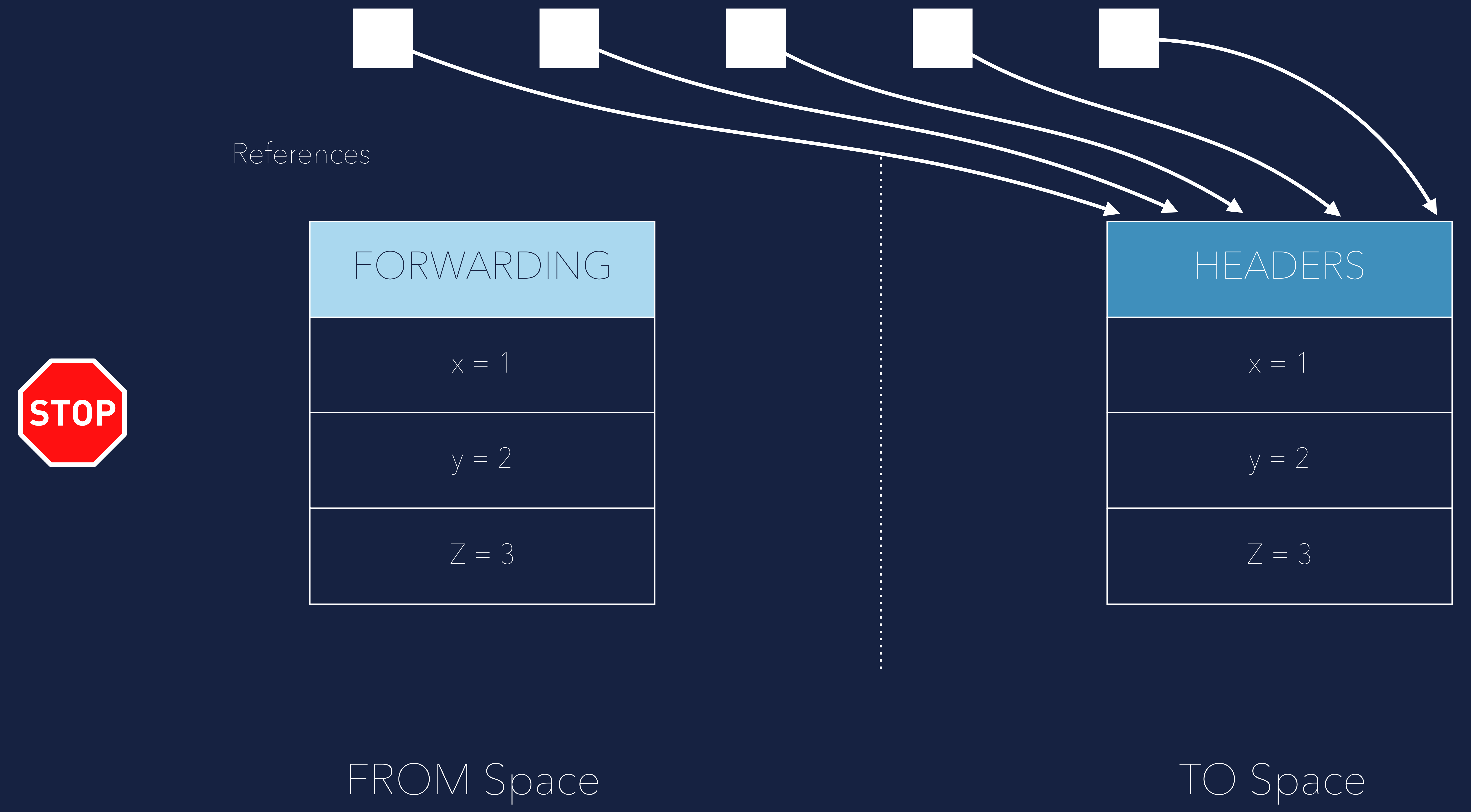
Stop the world copying



Update all references
(Walk the heap and replace all references with forwarding pointer to new location)

CONCURRENCY IS HARD...

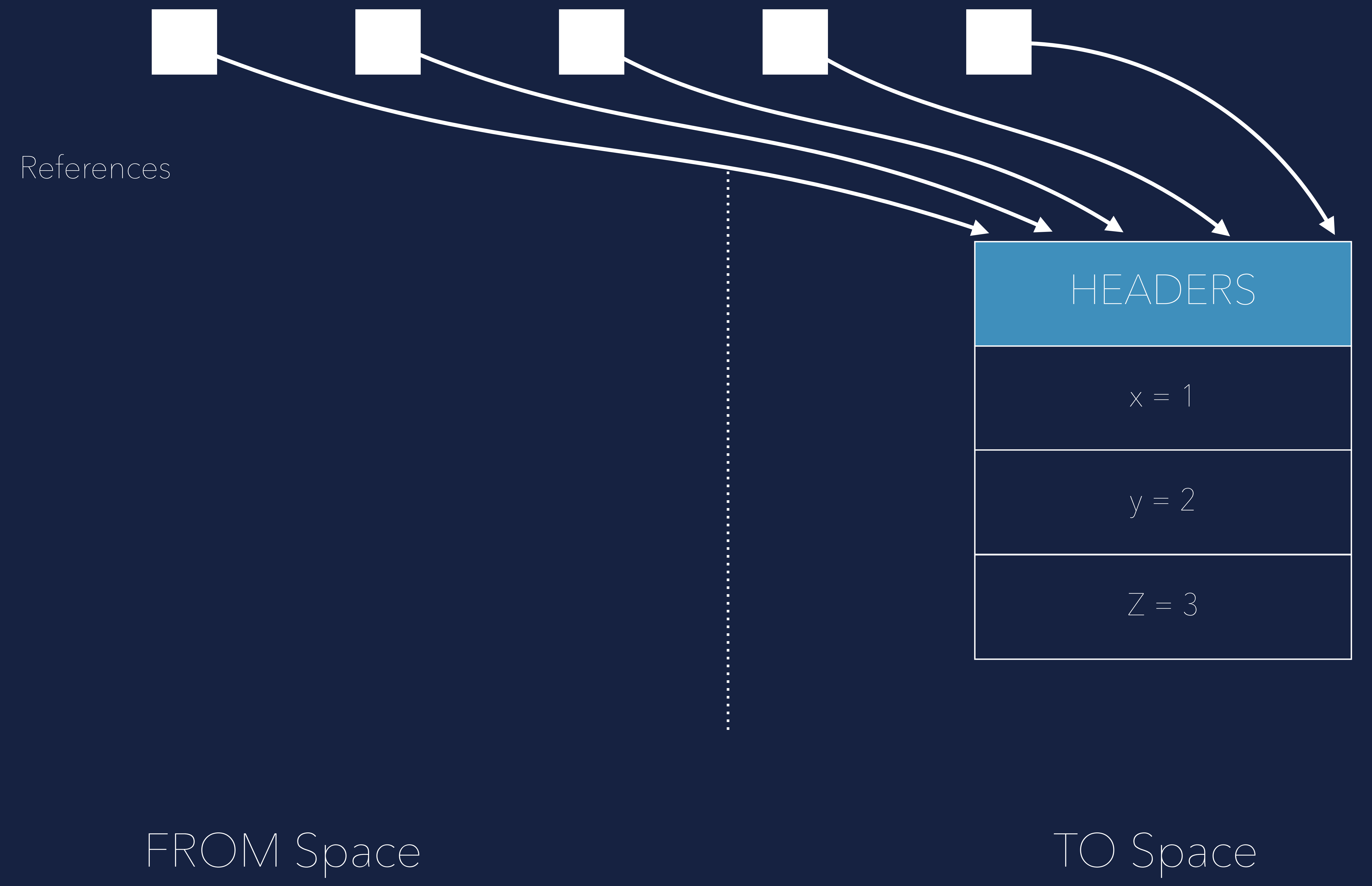
Stop the world copying



Update all references
(Walk the heap and replace all references with forwarding pointer to new location)

CONCURRENCY IS HARD…

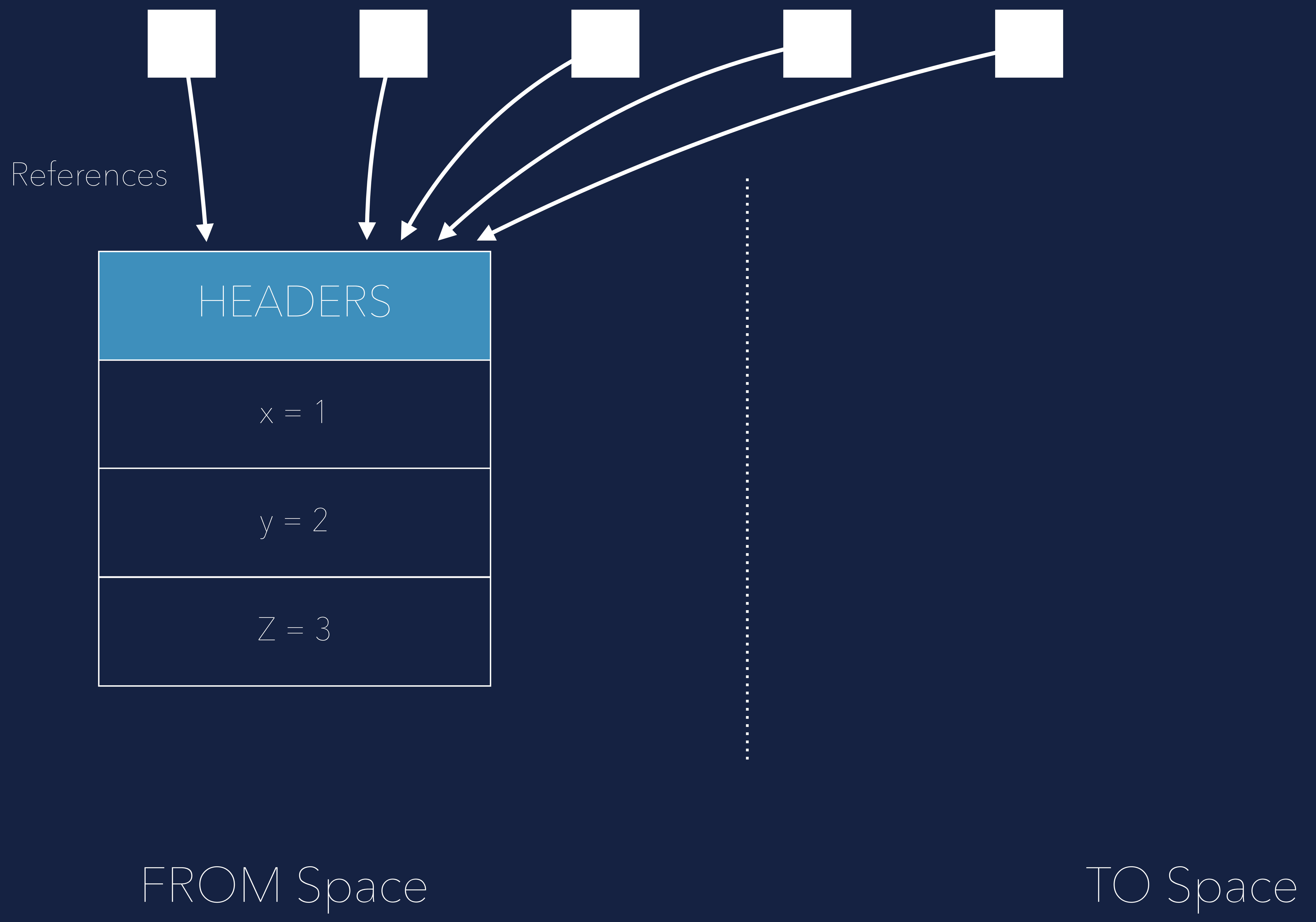
Stop the world copying



Remove old objects and continue running the Mutator

CONCURRENCY IS HARD...

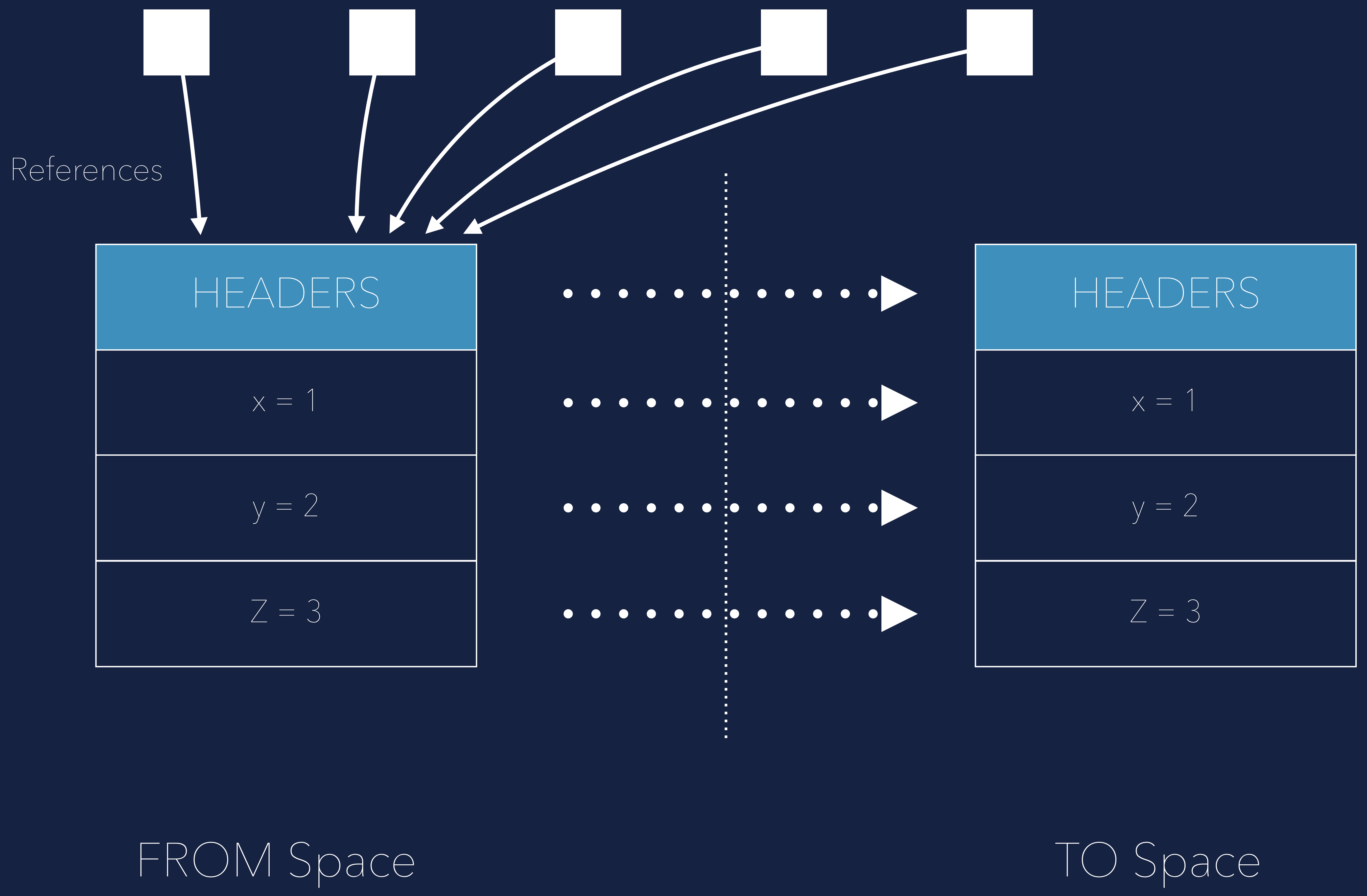
Concurrent copying



azul

CONCURRENCY IS HARD...

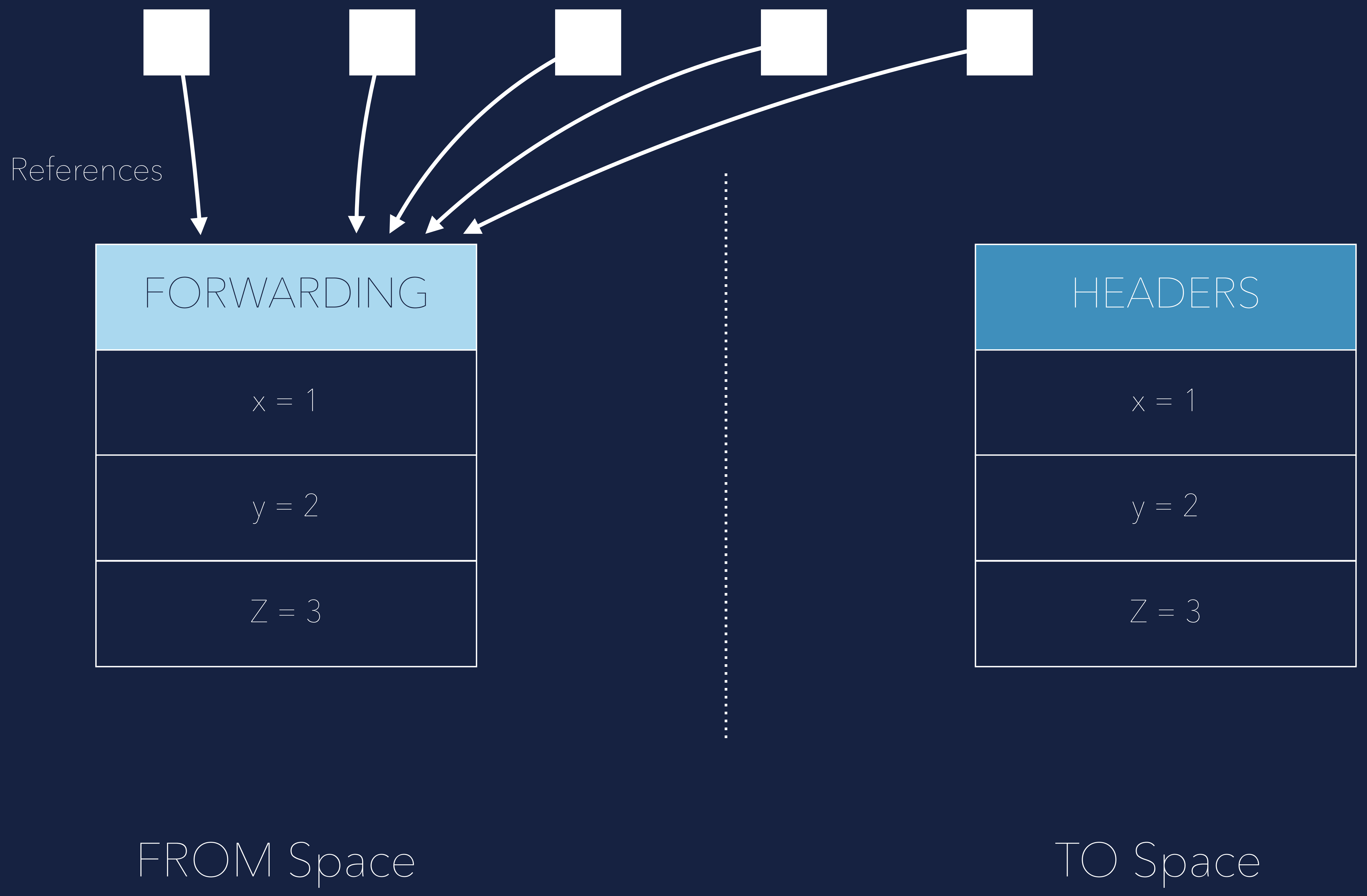
Concurrent copying



While copying the Object...

CONCURRENCY IS HARD...

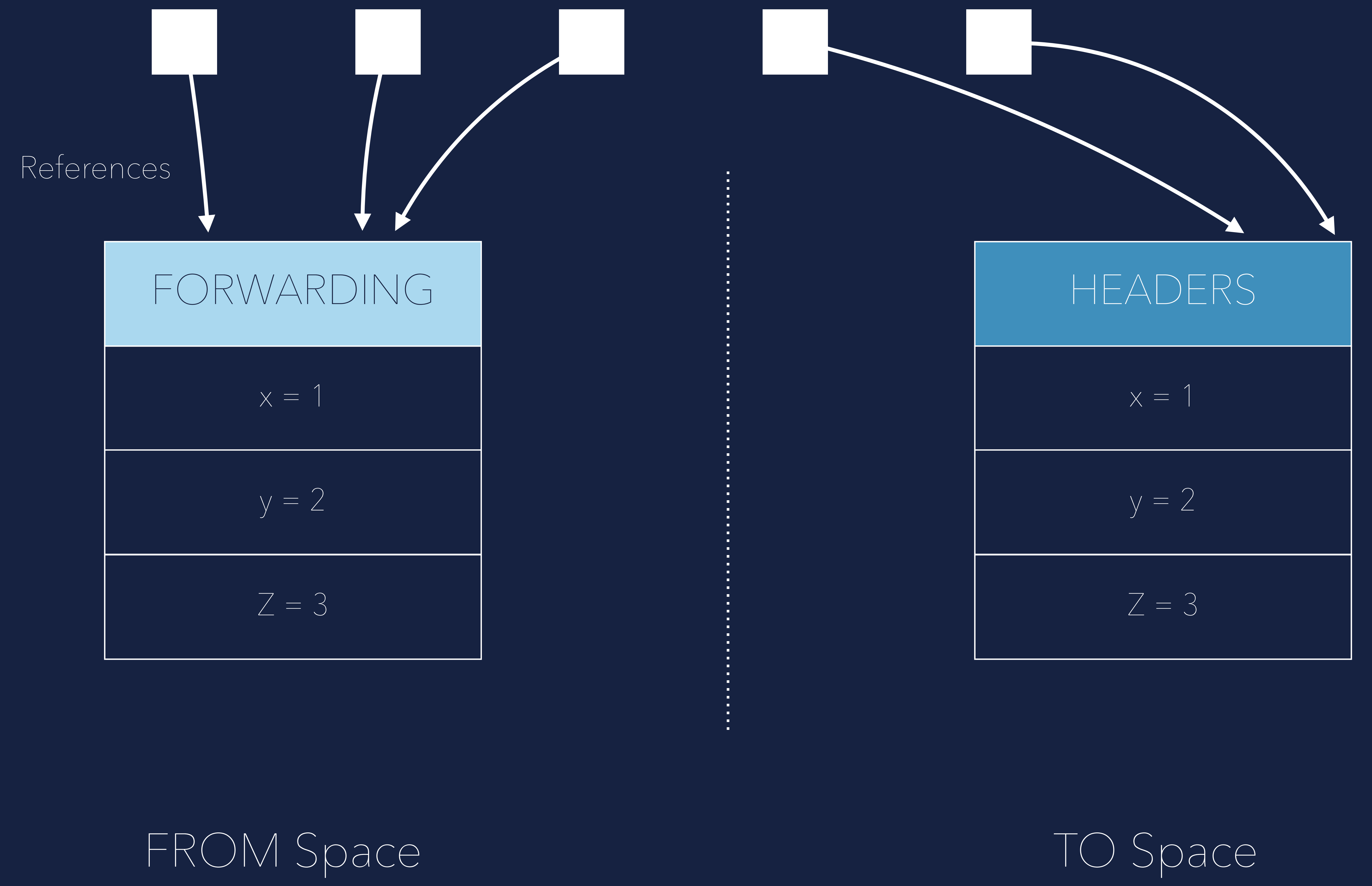
Concurrent copying



While copying the Object...

CONCURRENCY IS HARD...

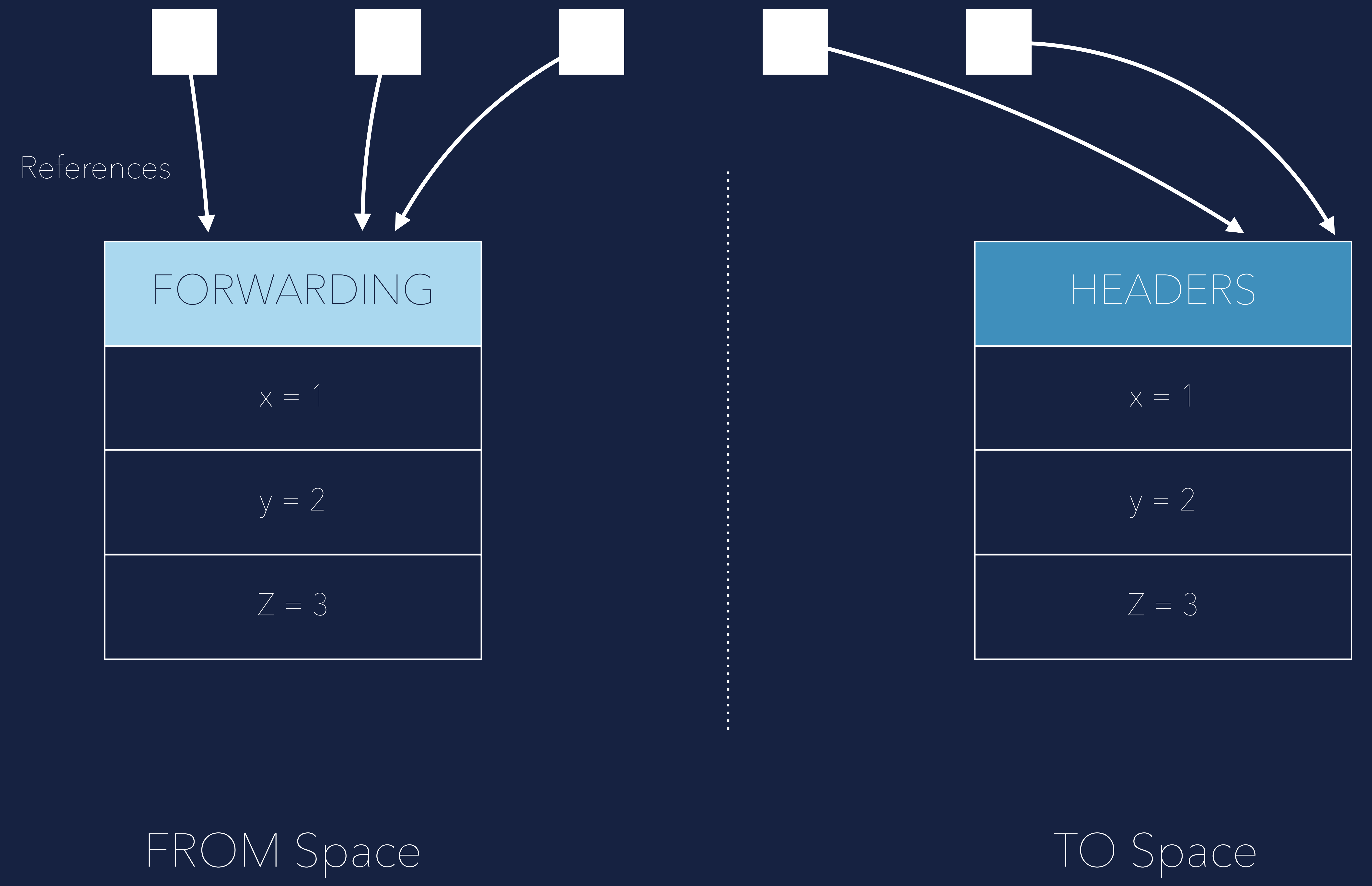
Concurrent copying



...when updating the references...

CONCURRENCY IS HARD...

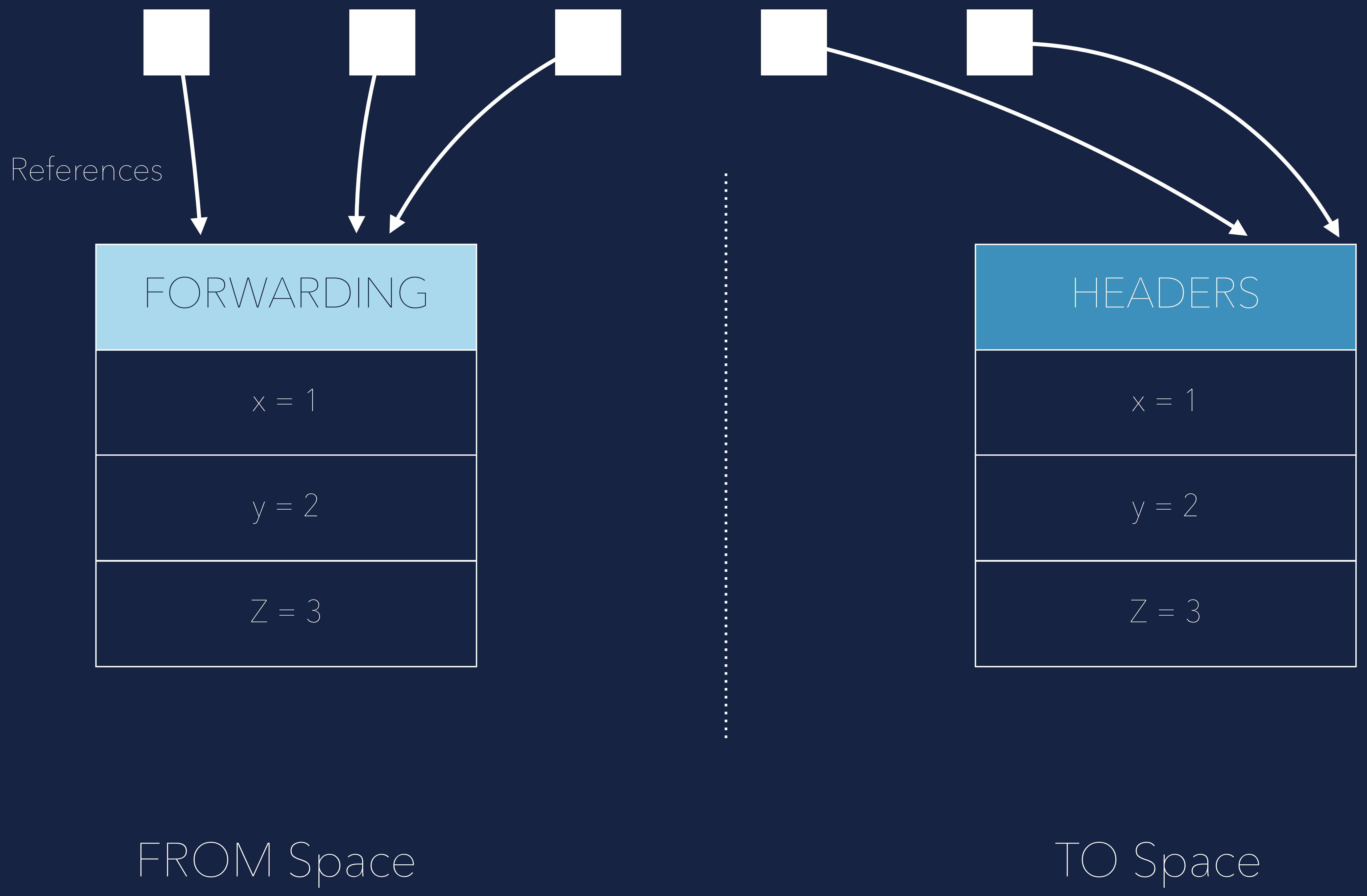
Concurrent copying



...both Objects are reachable !

CONCURRENCY IS HARD...

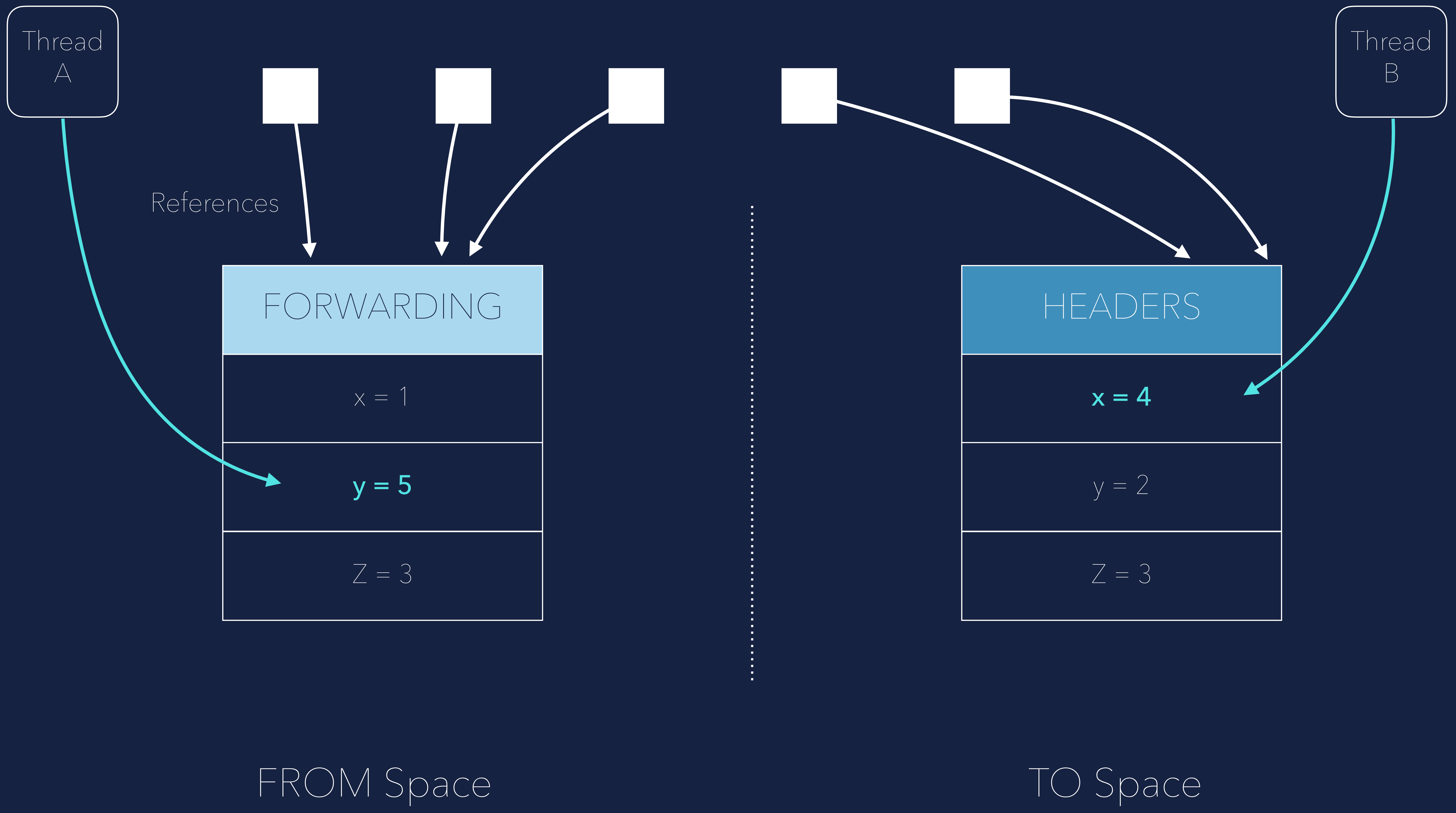
Concurrent copying



...both Objects are reachable !
And can be accessed in parallel by different Threads.

CONCURRENCY IS HARD...

Concurrent copying

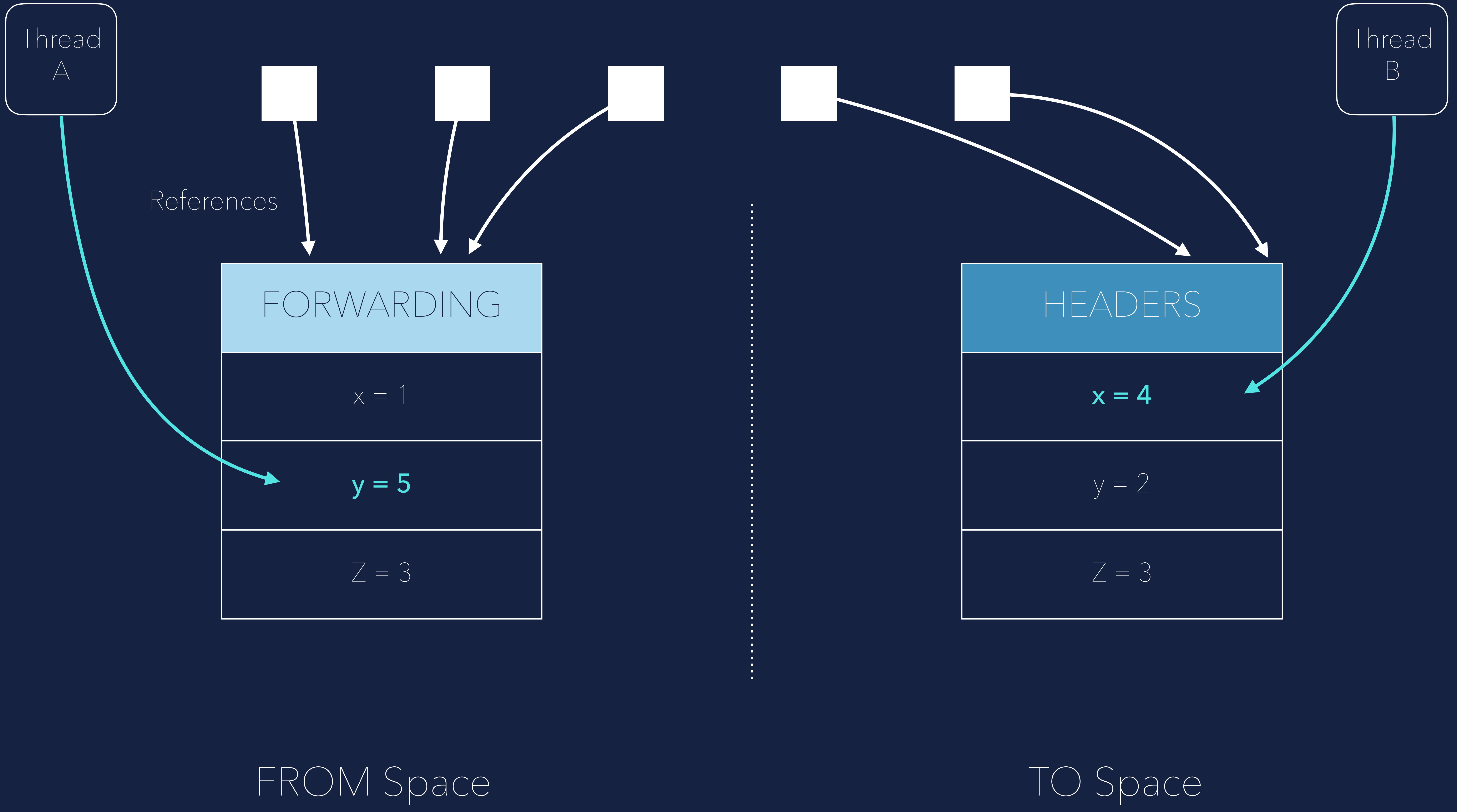


Threads can write to both Objects !

azul

CONCURRENCY IS HARD...

Concurrent copying



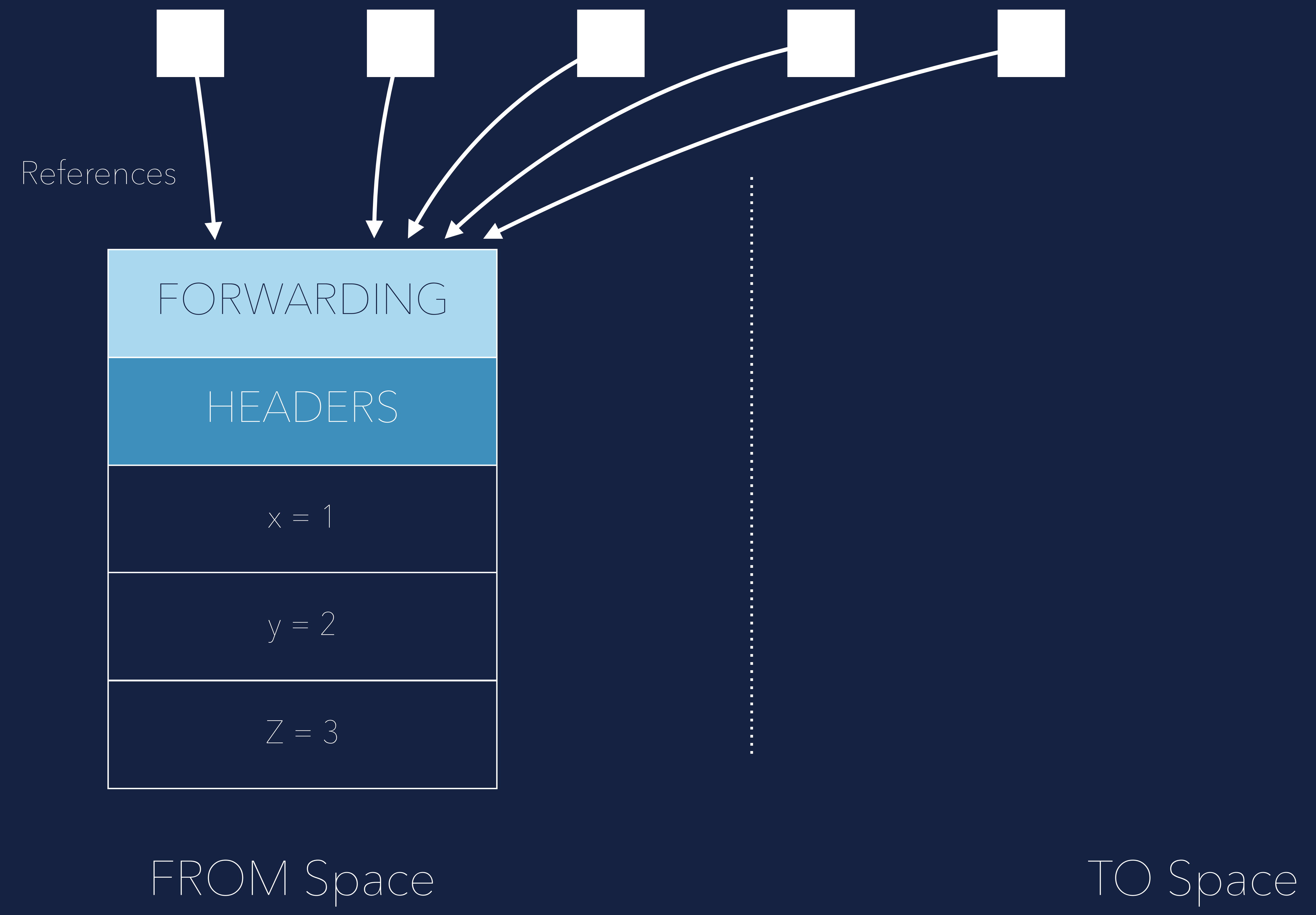
Threads can write to both Objects !

Which copy is correct ?

azul

CONCURRENCY IS HARD...

Concurrent copying

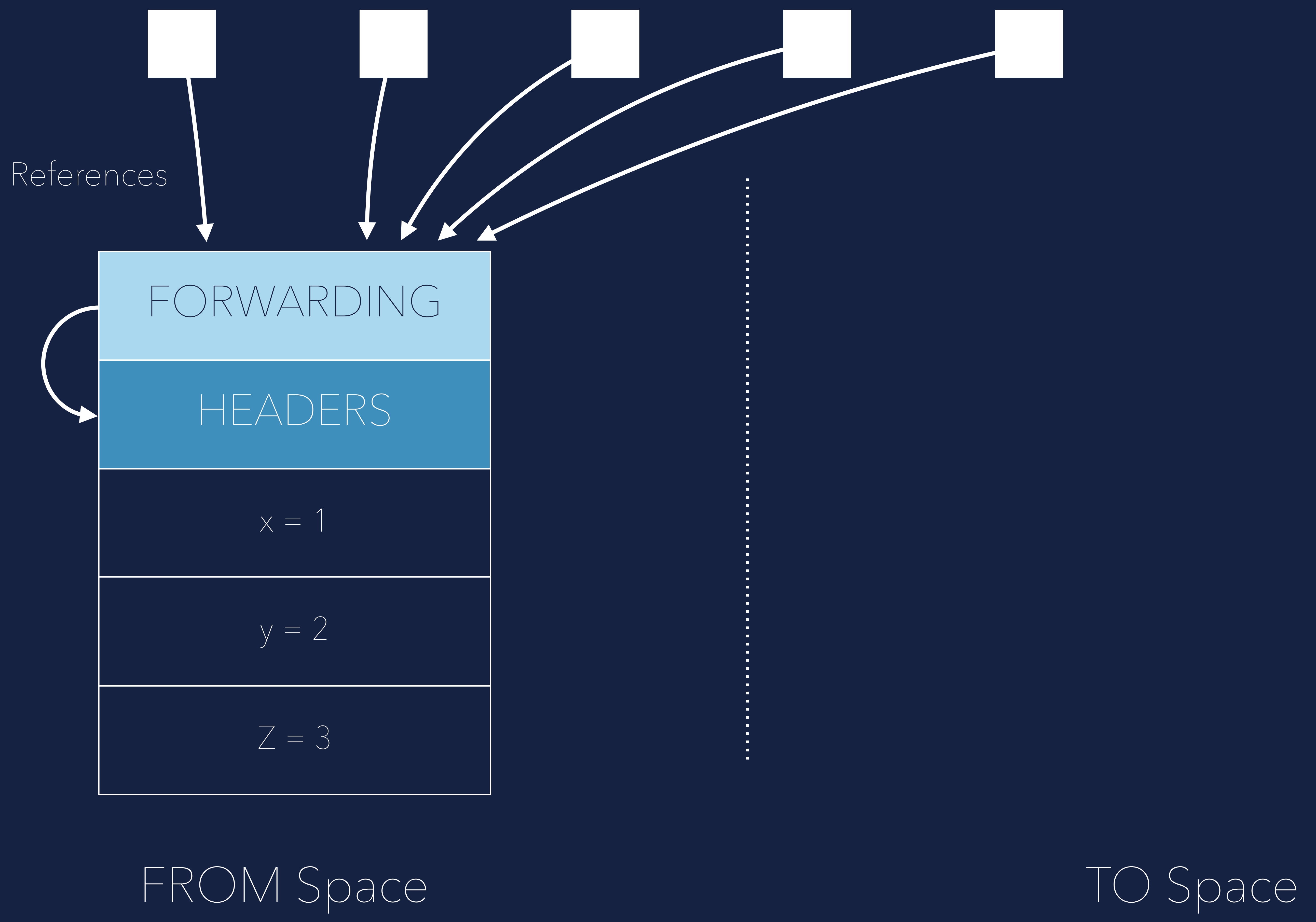


Solution could be installing a Brooks Pointer...

azul

CONCURRENCY IS HARD...

Concurrent copying

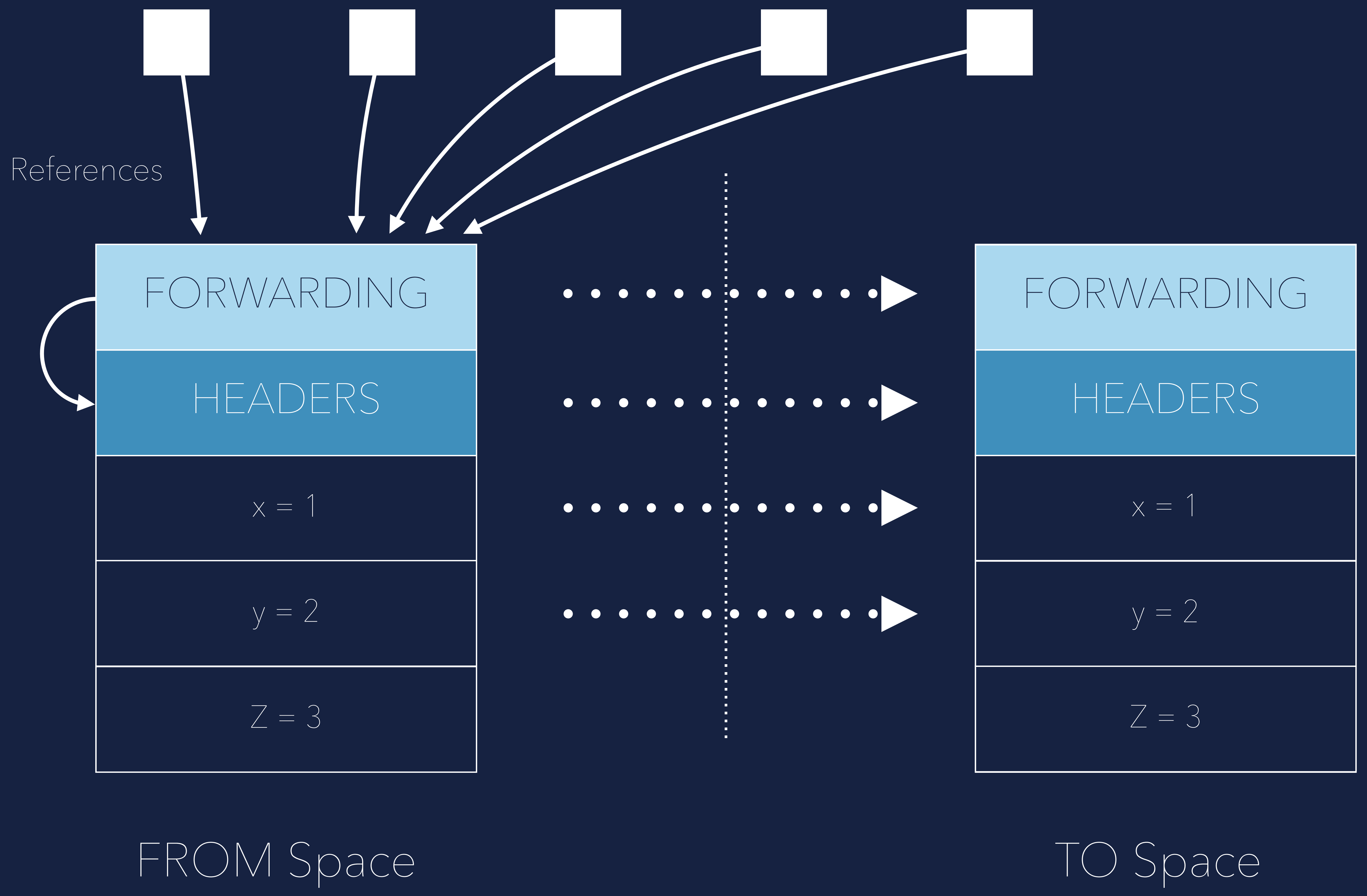


...which points to object header itself

azul

CONCURRENCY IS HARD...

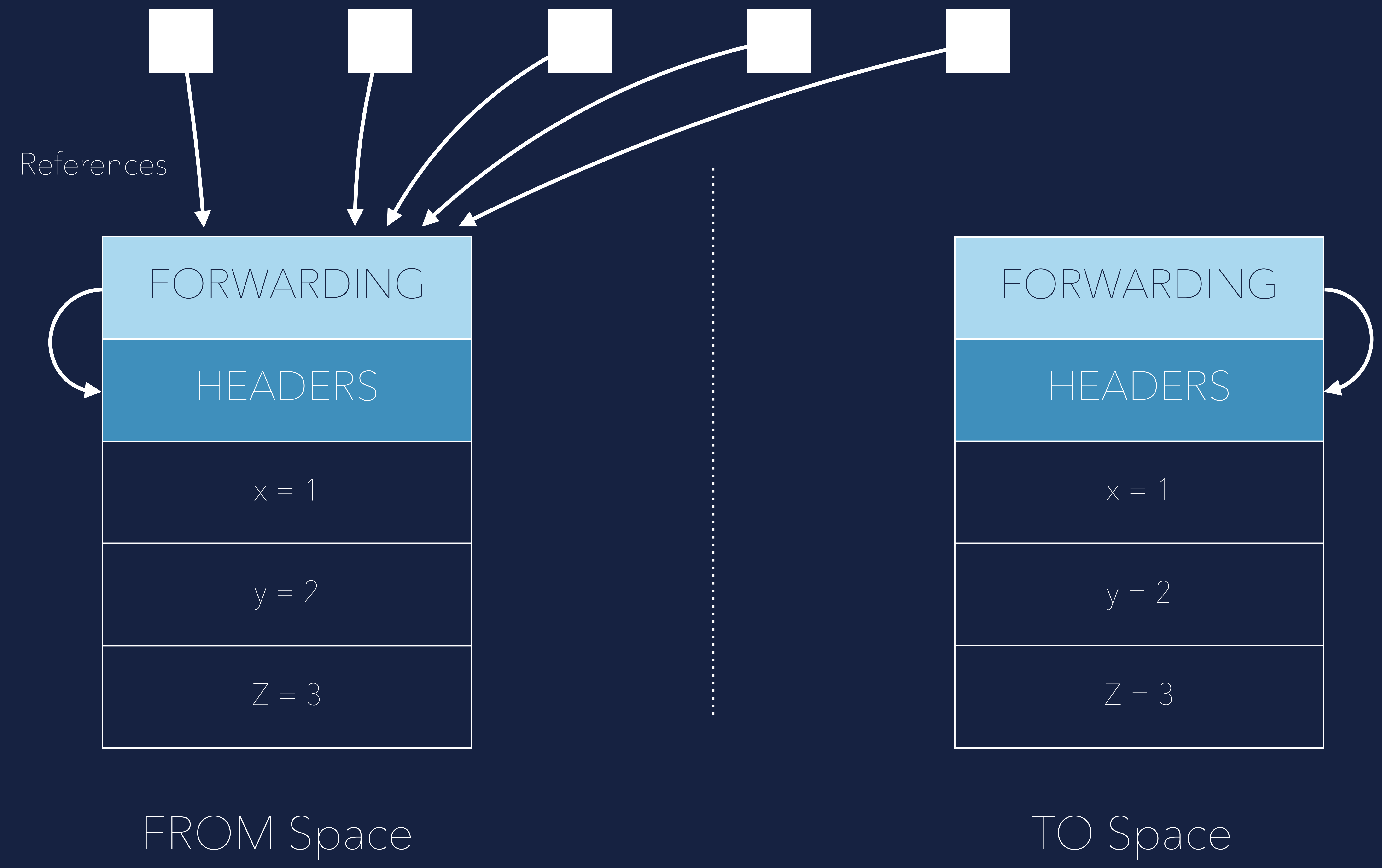
Concurrent copying



Copy the Object

CONCURRENCY IS HARD...

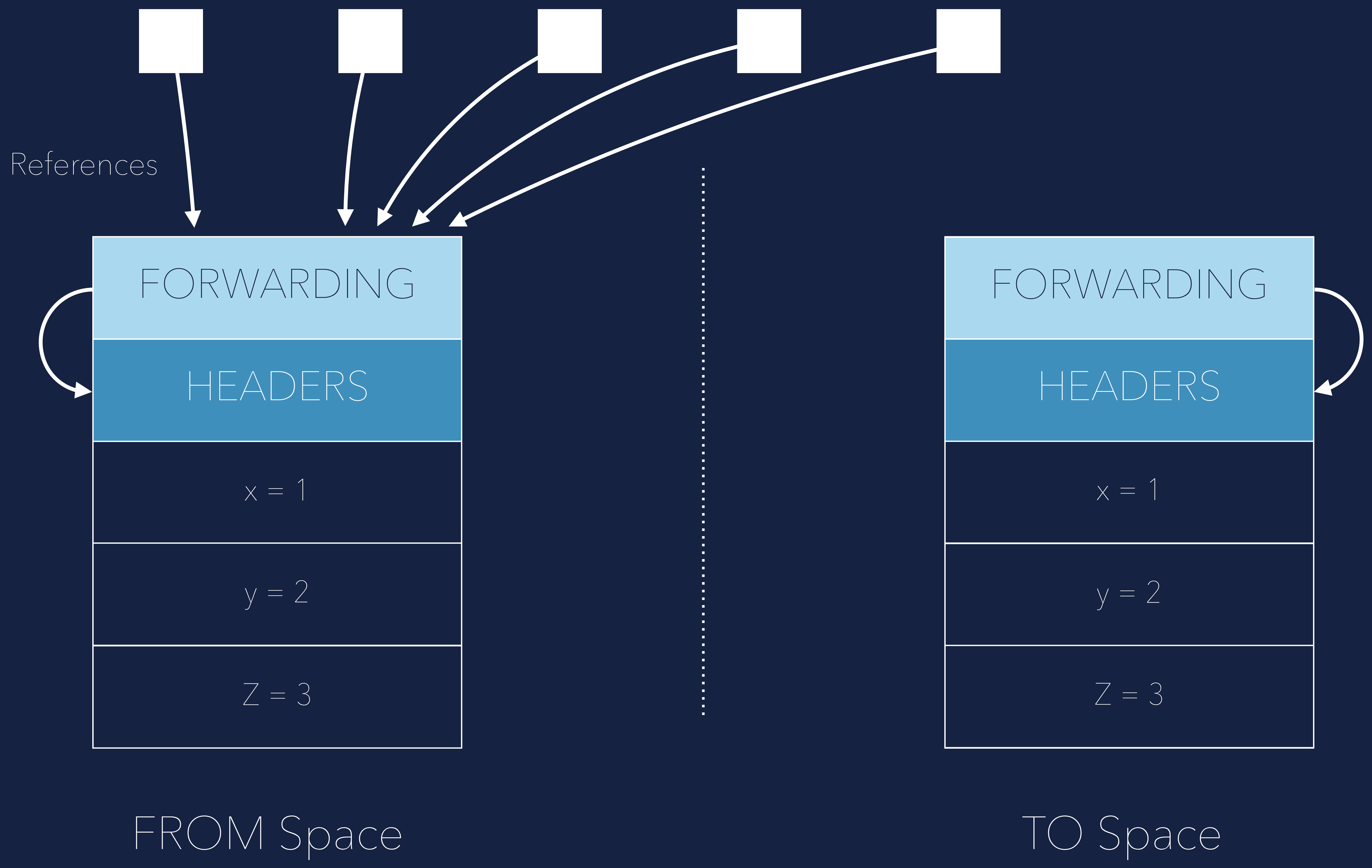
Concurrent copying



Install forwarding pointer
to itself

CONCURRENCY IS HARD...

Concurrent copying

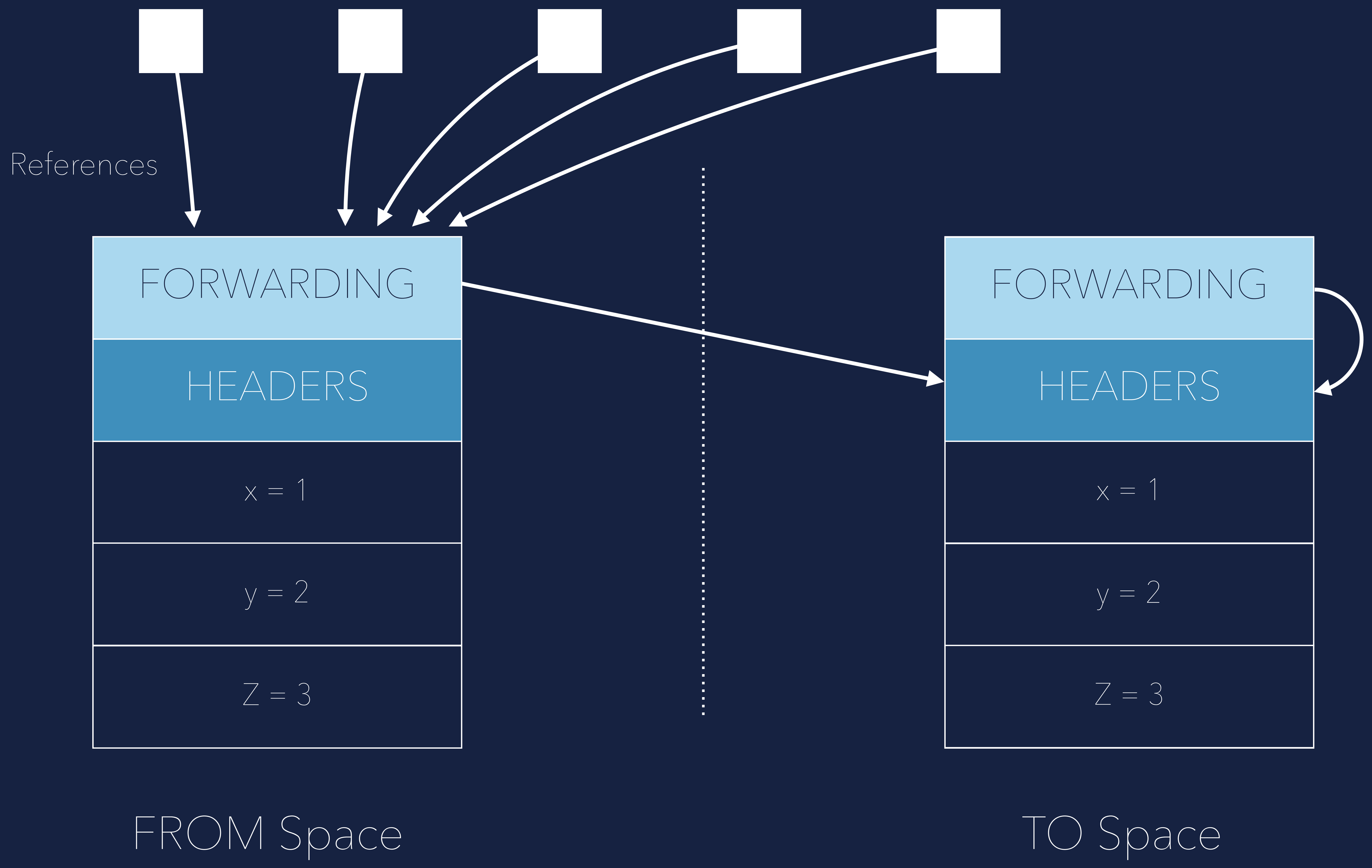


Nobody knows about copy

azul

CONCURRENCY IS HARD...

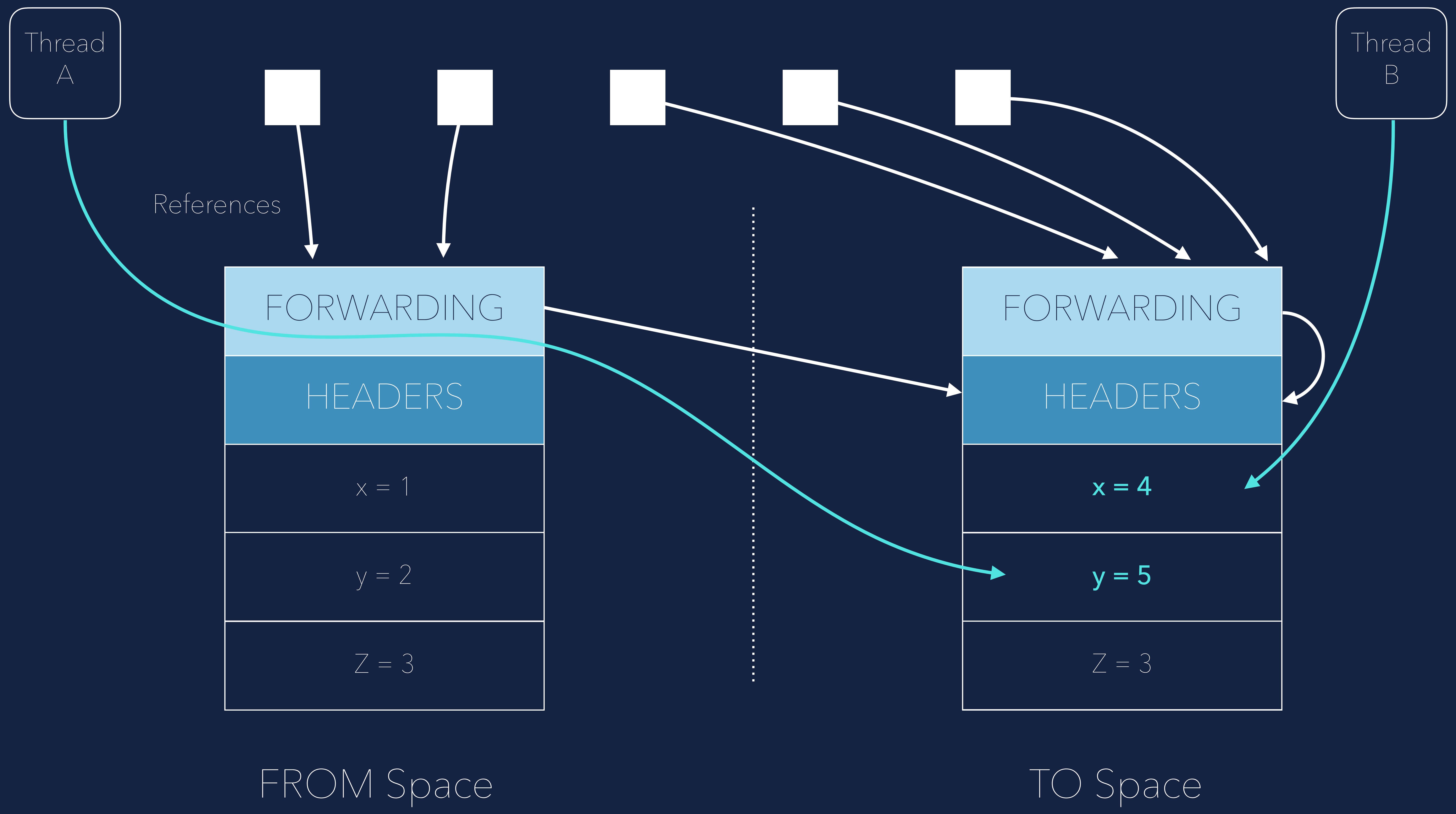
Concurrent copying



Atomically update forwarding pointer of original object to new copy

CONCURRENCY IS HARD...

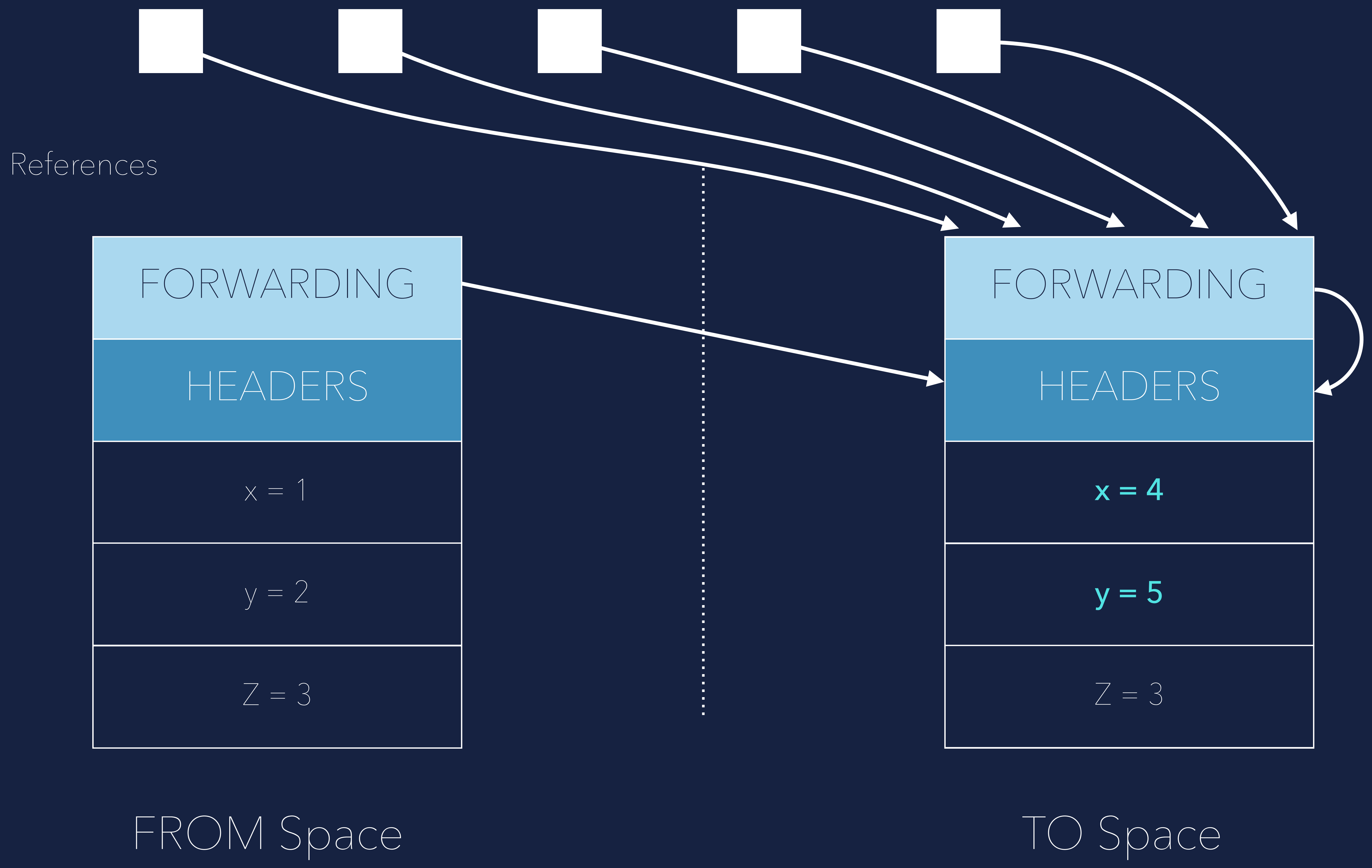
Concurrent copying



Threads now will always find the right object

CONCURRENCY IS HARD...

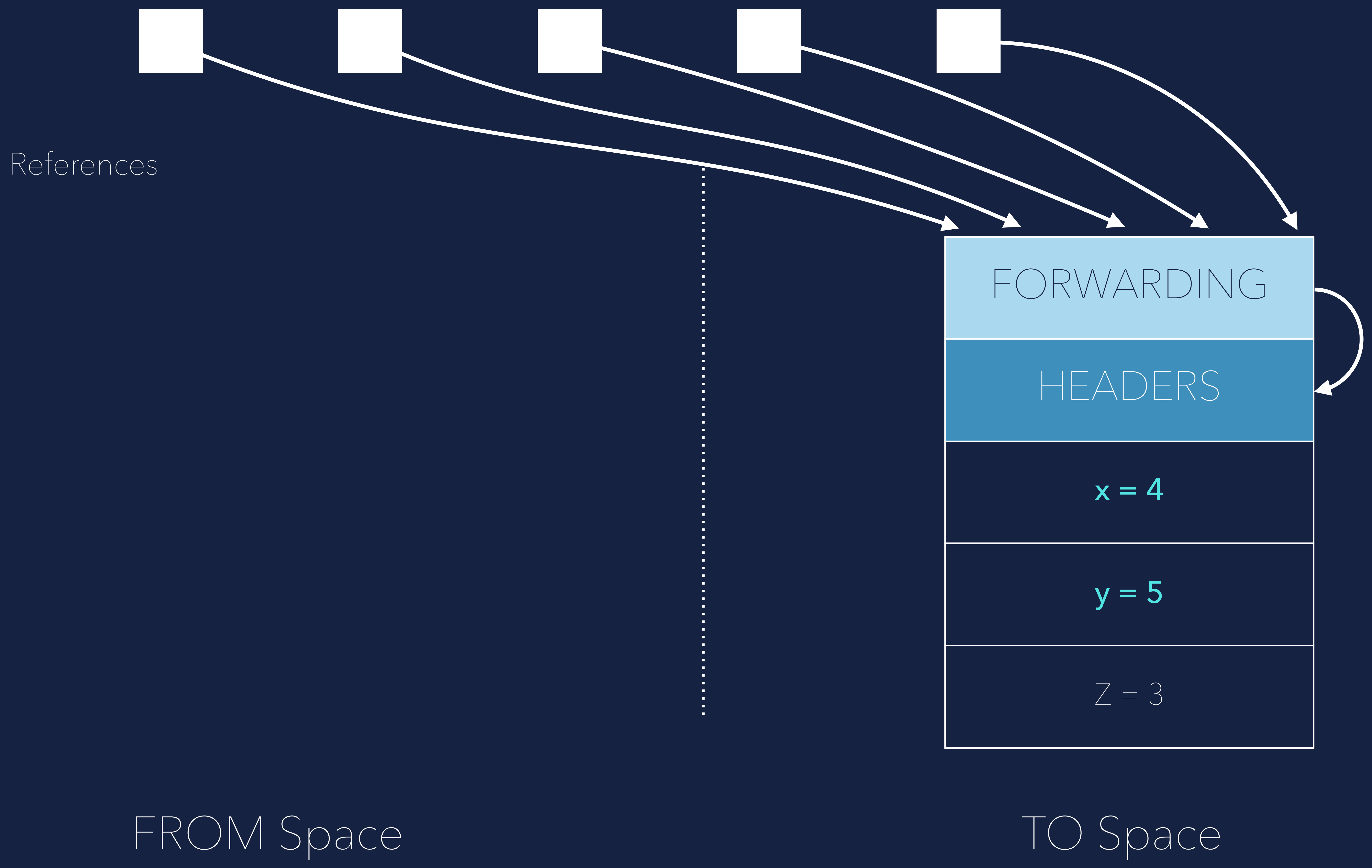
Concurrent copying



When all references are updated...

CONCURRENCY IS HARD...

Concurrent copying



Remove the old object

azul

COLLECTORS IN THE JVM

SERIAL

SERIAL

AVAILABILITY	ALL JDK'S
PARALLEL	NO
CONCURRENT	NO
GENERATIONAL	YES
HEAP SIZE	SMALL - MEDIUM
PAUSE TIMES	LONGER
THROUGHPUT	LOW
LATENCY	HIGHER
CPU OVERHEAD	LOW (1-5%)

CHOOSE WHEN

- Single core systems with small heap (<4GB)
- No pause time requirements

BEST SUITED FOR

- Single threaded applications
- Development environments
- Microservices on small nodes

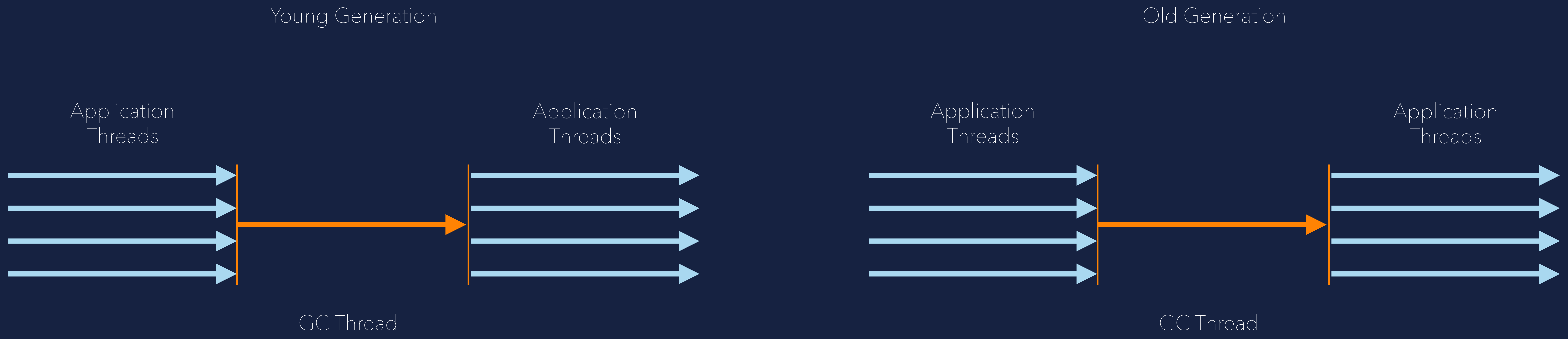
OS SUPPORT	Linux, Windows, macOS
JVM SWITCH	`> java -XX:+UseSerialGC`

azul

SERIAL

NOTES

- Automatically selected if only a single processor is available
- Automatically selected if the avail. memory less than 1792 MB



PARALLEL

azul

PARALLEL

AVAILABILITY	ALL JDK'S
PARALLEL	YES
CONCURRENT	NO
GENERATIONAL	YES
HEAP SIZE	MEDIUM - LARGE
PAUSE TIMES	MODERATE
THROUGHPUT	HIGH
LATENCY	LOWER
CPU OVERHEAD	MODERATE (5-10%)

CHOOSE WHEN

- Multi-core systems with small heap (<4GB)
- Peak performance is needed without pause time requirements

BEST SUITED FOR

- Batch processing
- Scientific computing
- Data analysis

OS SUPPORT

JVM SWITCH

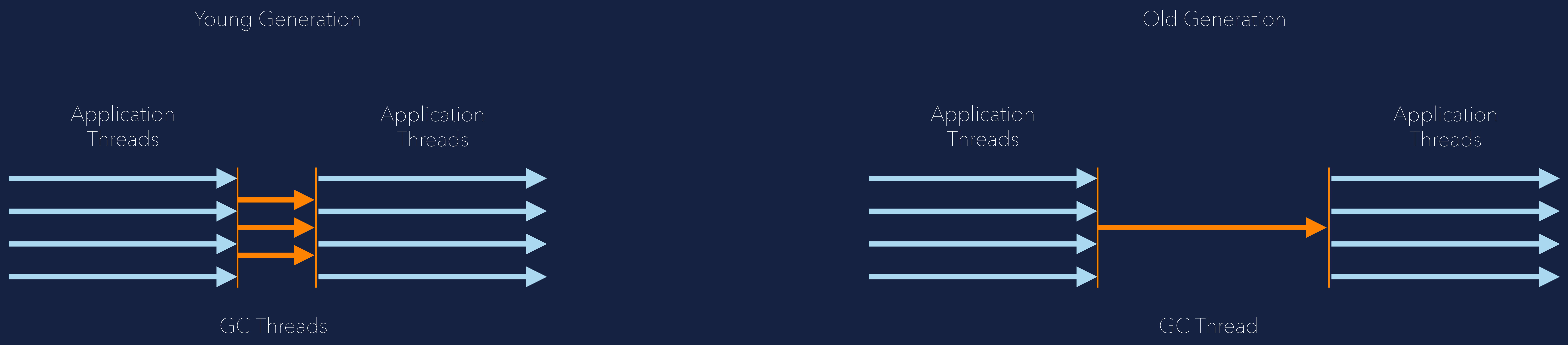
```
> java -XX:+UseParallelOldGC
```

azul

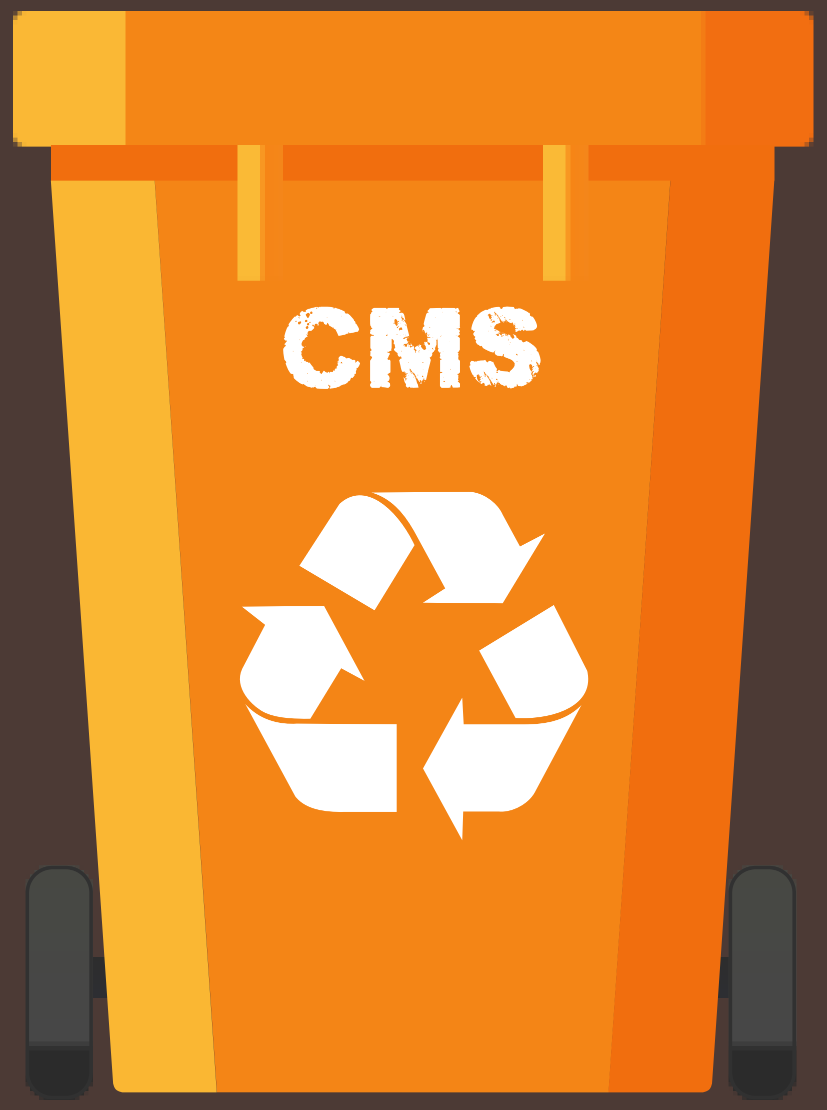
PARALLEL

NOTES

- Default garbage collector from JDK 5 to JDK 8



azul



CMS

Concurrent Mark and Sweep

DEPRECATED

CMS

AVAILABILITY	JDK 1.4 - 13
PARALLEL	YES
CONCURRENT	PARTIALLY
GENERATIONAL	YES
HEAP SIZE	MEDIUM - LARGE
PAUSE TIMES	MODERATE
THROUGHPUT	MODERATE
LATENCY	MODERATE
CPU OVERHEAD	MODERATE (5-15%)

CHOOSE WHEN

- Response time is more important than throughput
- Pause time must be kept shorter than 1 sec

BEST SUITED FOR

- Web applications
- Mediums sized enterprise systems

OS SUPPORT

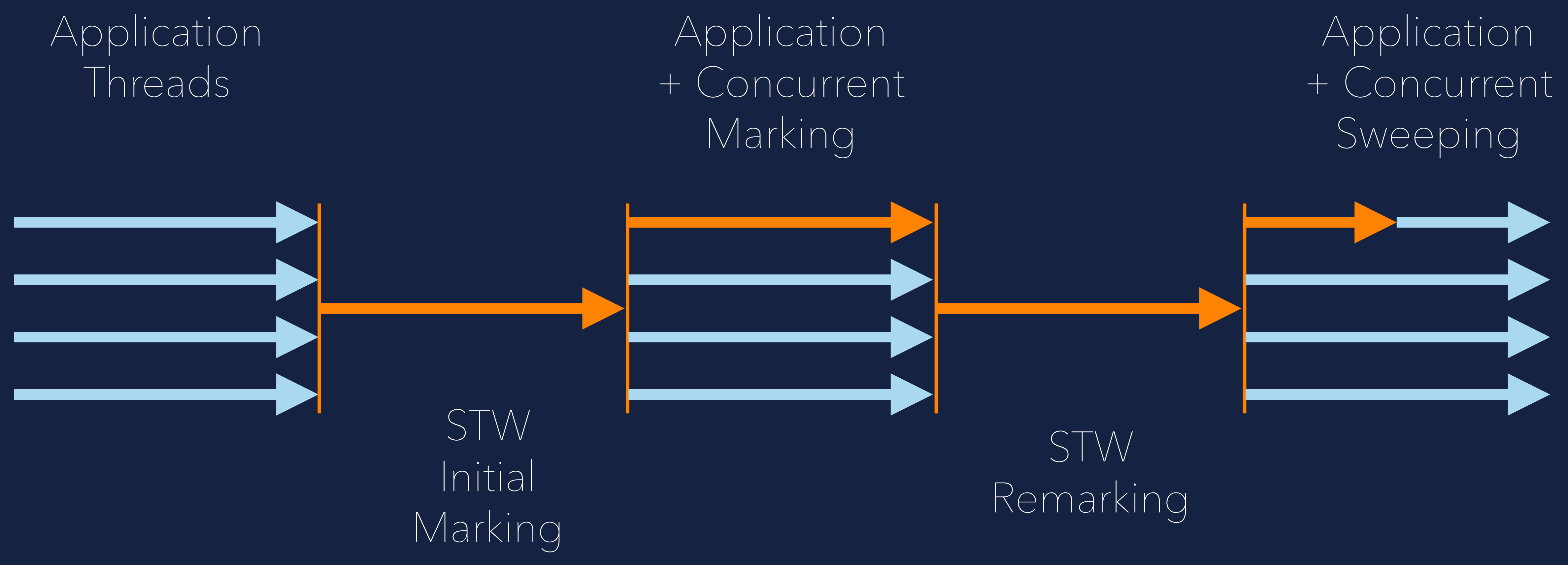
JVM SWITCH

```
> java -XX:+UseConcMarkSweepGC
```

CMS

NOTES

- Deprecated as of JDK 9
- Removed from JDK 14
- Concurrent marking



G1

Garbage First

G1

Heap-Layout

Region size 1 - 32 MB

Max no. of region <= 2048

Heap	Region
< 4 GB	1 MB
< 8 GB	2 MB
< 16 GB	4 MB
< 32 GB	8 MB
< 64 GB	16 MB
> 64 GB	32 MB

Example 8GB Heap:

8 GB Heap = 8192 MB

8192 MB / 2048 = 4 MB region size

azul

G1

Heap-Layout

Region size 1 - 32 MB

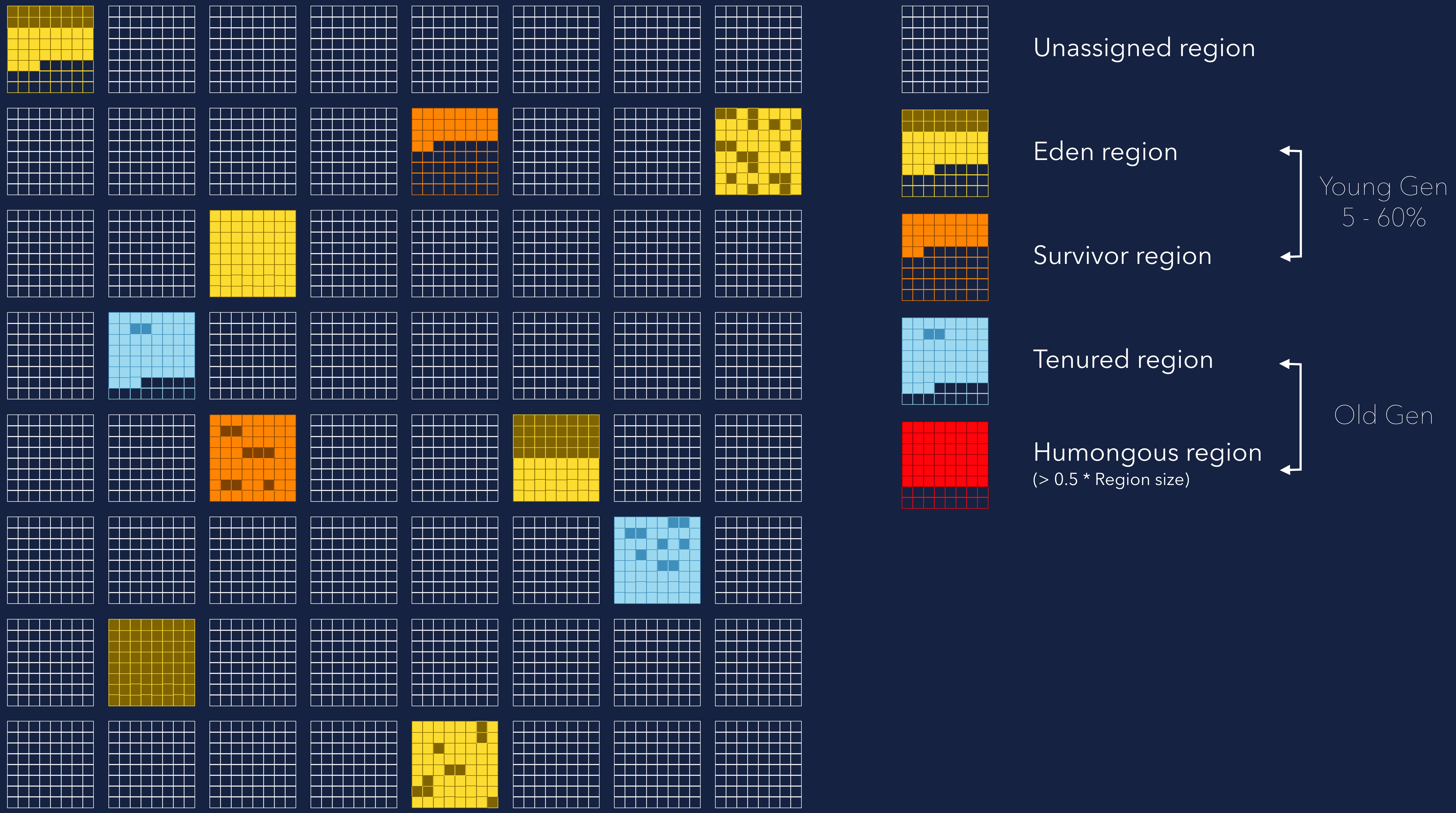
Max no. of region <= 2048

Heap	Region
< 4 GB	1 MB
< 8 GB	2 MB
< 16 GB	4 MB
< 32 GB	8 MB
< 64 GB	16 MB
> 64 GB	32 MB

Example 8GB Heap:

8 GB Heap = 8192 MB

8192 MB / 2048 = 4 MB region size



G1

Heap-Layout

Region size 1 - 32 MB

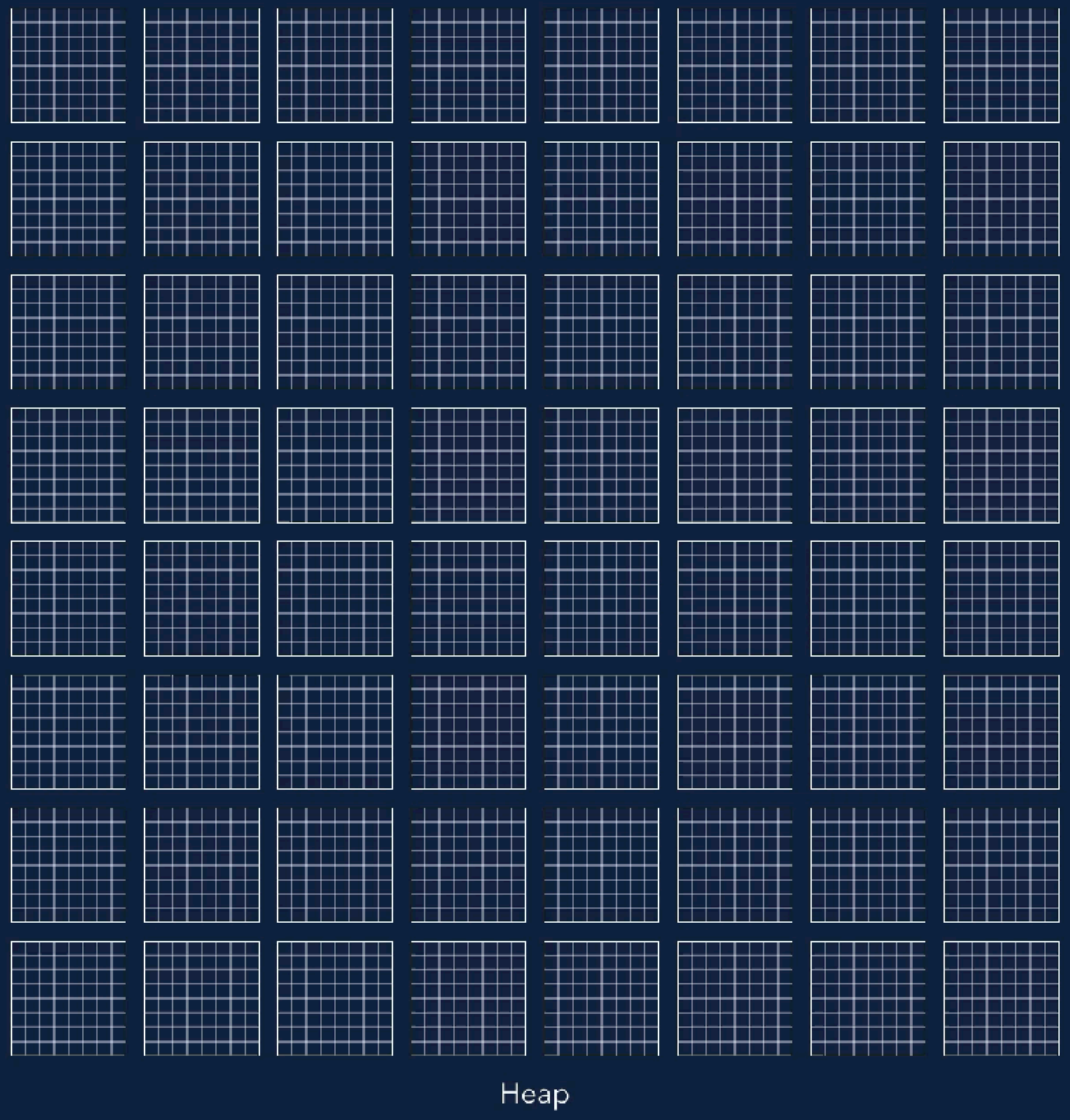
Max no. of region <= 2048

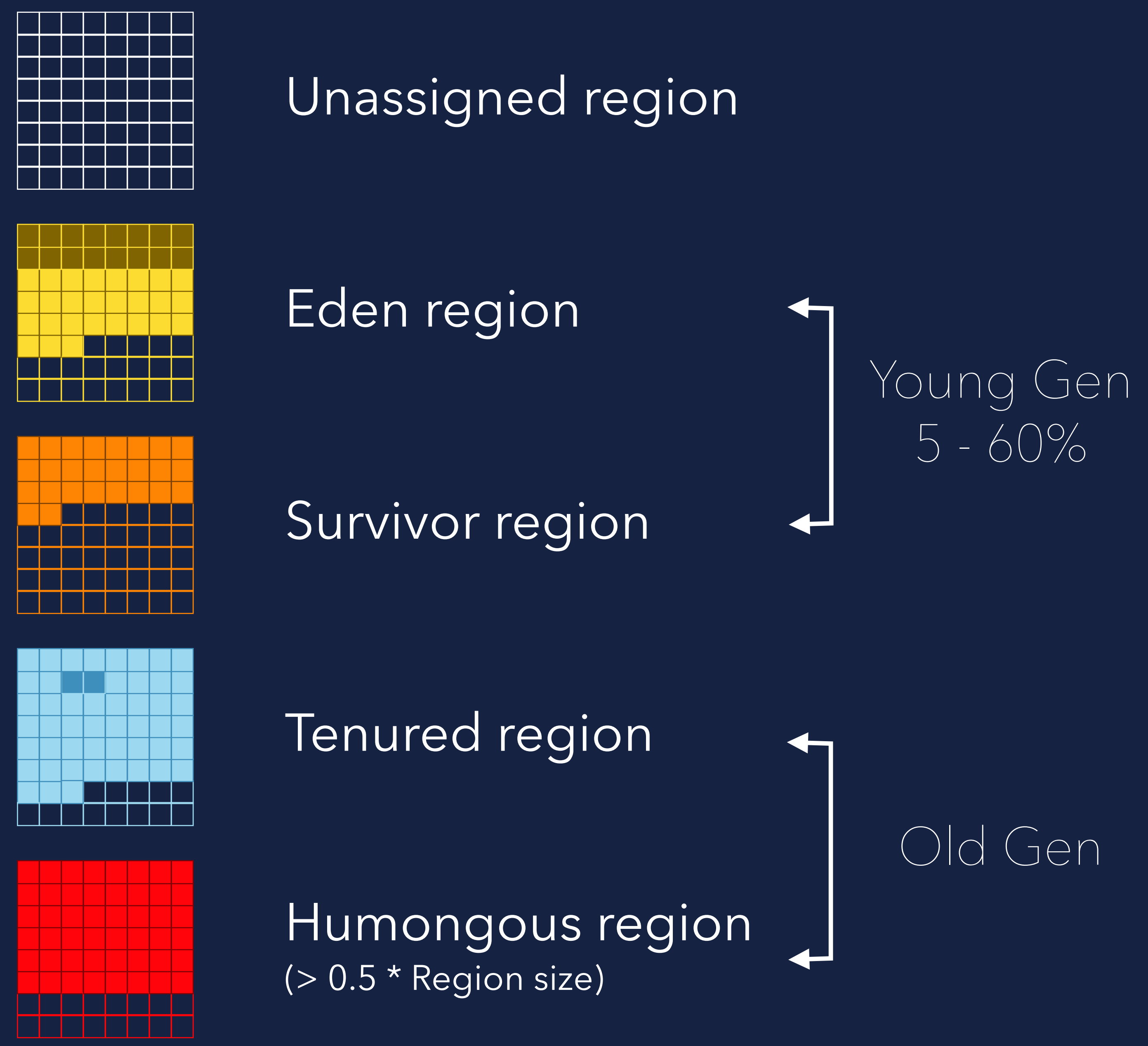
Heap	Region
< 4 GB	1 MB
< 8 GB	2 MB
< 16 GB	4 MB
< 32 GB	8 MB
< 64 GB	16 MB
> 64 GB	32 MB

Example 8GB Heap:

8 GB Heap = 8192 MB

8192 MB / 2048 = 4 MB region size





Example:
6 Eden Regions
3 Survivor Regions

2 Regions with most garbage will be collected/promoted

azul

G1

AVAILABILITY	JDK 7U4+
PARALLEL	YES
CONCURRENT	PARTIALLY
GENERATIONAL	YES
HEAP SIZE	MEDIUM - LARGE
PAUSE TIMES	SHORT - MEDIUM
THROUGHPUT	HIGH
LATENCY	LOWER
CPU OVERHEAD	MODERATE (5-15%)

CHOOSE WHEN

- Response time is more important than throughput
- Pause time should be around 200 ms
- Heap size is not larger than 16-32 GB

BEST SUITED FOR

- Mixed workloads
- Large sized enterprise systems
- Responsive in medium to large heaps

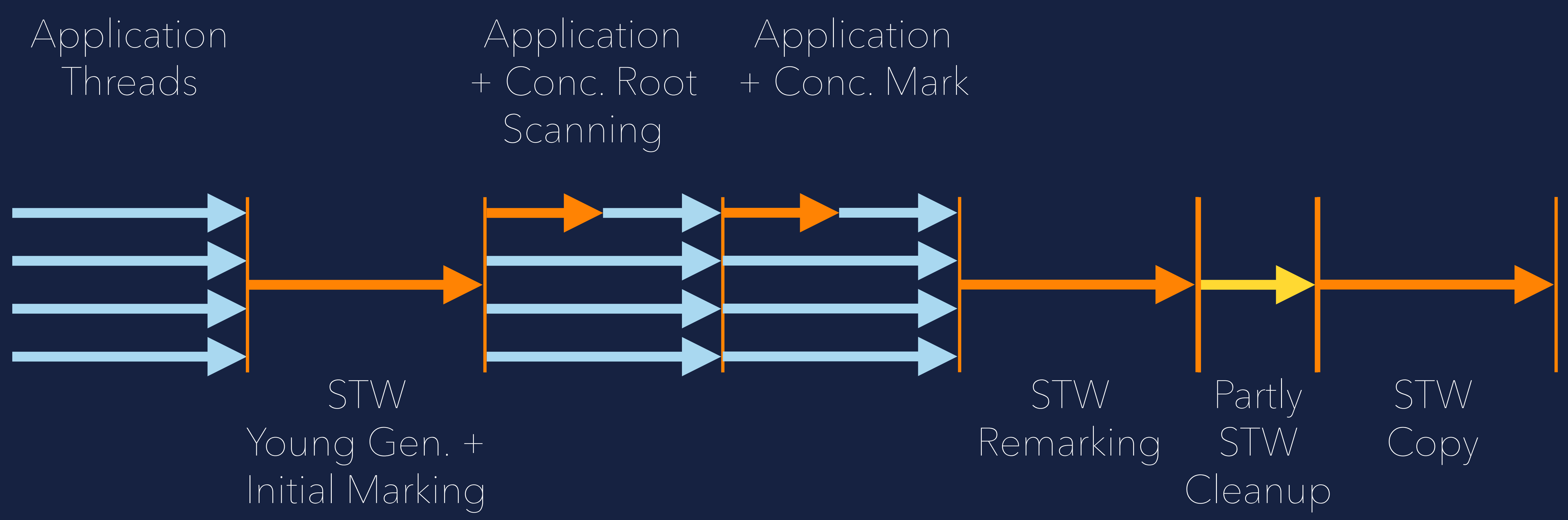
OS SUPPORT	Linux, Windows, macOS
JVM SWITCH	`> java -XX:+UseG1GC`

azul

G1

NOTES

- Default collector from JDK 9 onwards
- Concurrent marking



EPSILON

azul

EPSILON

AVAILABILITY	JDK 11+
PARALLEL	-
CONCURRENT	-
GENERATIONAL	-
HEAP SIZE	-
PAUSE TIMES	-
THROUGHPUT	-
LATENCY	-
CPU OVERHEAD	VERY LOW

CHOOSE WHEN

- Testing performance or memory pressure
- Highest performance is needed and nearly no garbage is created

BEST SUITED FOR

- Extremely short lived jobs
- Last drop latency improvements
- Last drop throughput improvements

OS SUPPORT: Linux, Windows, macOS

JVM SWITCH

```
> java -XX:+UnlockExperimentalVMOptions -XX:+UseEpsilonGC
```

SHENANDOAH

SHENANDOAH

AVAILABILITY	JDK 11.0.9+
PARALLEL	YES
CONCURRENT	FULLY
GENERATIONAL	NO
HEAP SIZE	MEDIUM - LARGE
PAUSE TIMES	SHORT
THROUGHPUT	VERY HIGH
LATENCY	VERY LOW
CPU OVERHEAD	MODERATE (10-20%)

CHOOSE WHEN

- Response time is a high priority
- Using a very large heap (100GB+)
- Predictable response times needed

BEST SUITED FOR

- Latency sensitive applications
- Large scale systems
- Highly concurrent applications

OS SUPPORT

JVM SWITCH

```
> java -XX:+UseShenandoahGC
```

SHENANDOAH

NOTES

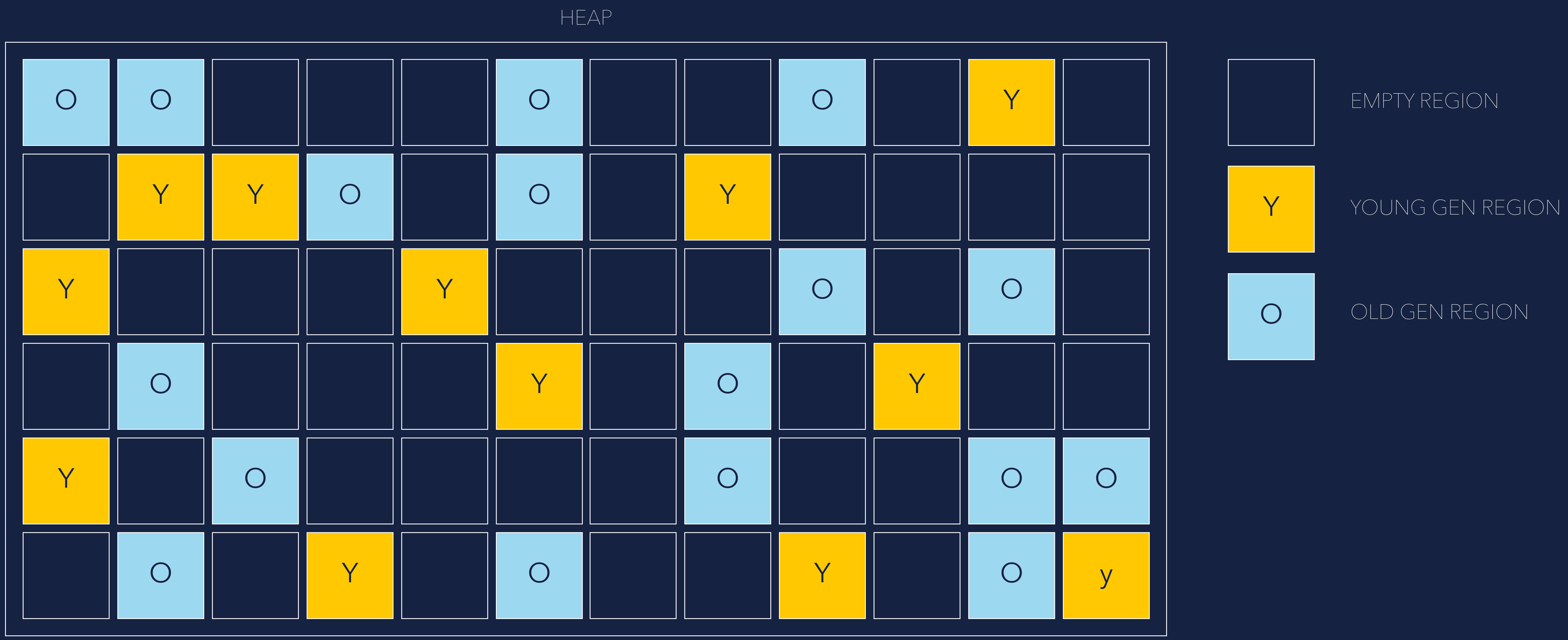
- Not available in Oracle JDK
- A bit reduced throughput due to concurrent GC
- Makes use of new barrier concept, load reference barrier

ZGC

Z Garbage Collector

ZGC

Heap-Layout



azul

ZGC

AVAILABILITY	JDK 15 / 21+
PARALLEL	YES
CONCURRENT	FULLY
GENERATIONAL	NO / YES
HEAP SIZE	LARGE
PAUSE TIMES	SHORT
THROUGHPUT	VERY HIGH
LATENCY	VERY LOW
CPU OVERHEAD	MODERATE (10-20%)

CHOOSE WHEN

- Response time is a high priority
- Using a very large heap (100GB+)
- Predictable response times needed

BEST SUITED FOR

- Low latency sensitive applications
- Large scale systems
- Highly concurrent applications

OS SUPPORT

JVM SWITCH

```
> java -XX:+UseZGC -XX:+ZGenerational*
```

* Not needed in the future, because generational ZGC will become the default

ZGC

NOTES

- Non-generational version will be deprecated

C4

Concurrent Continues Compacting Collector

C4

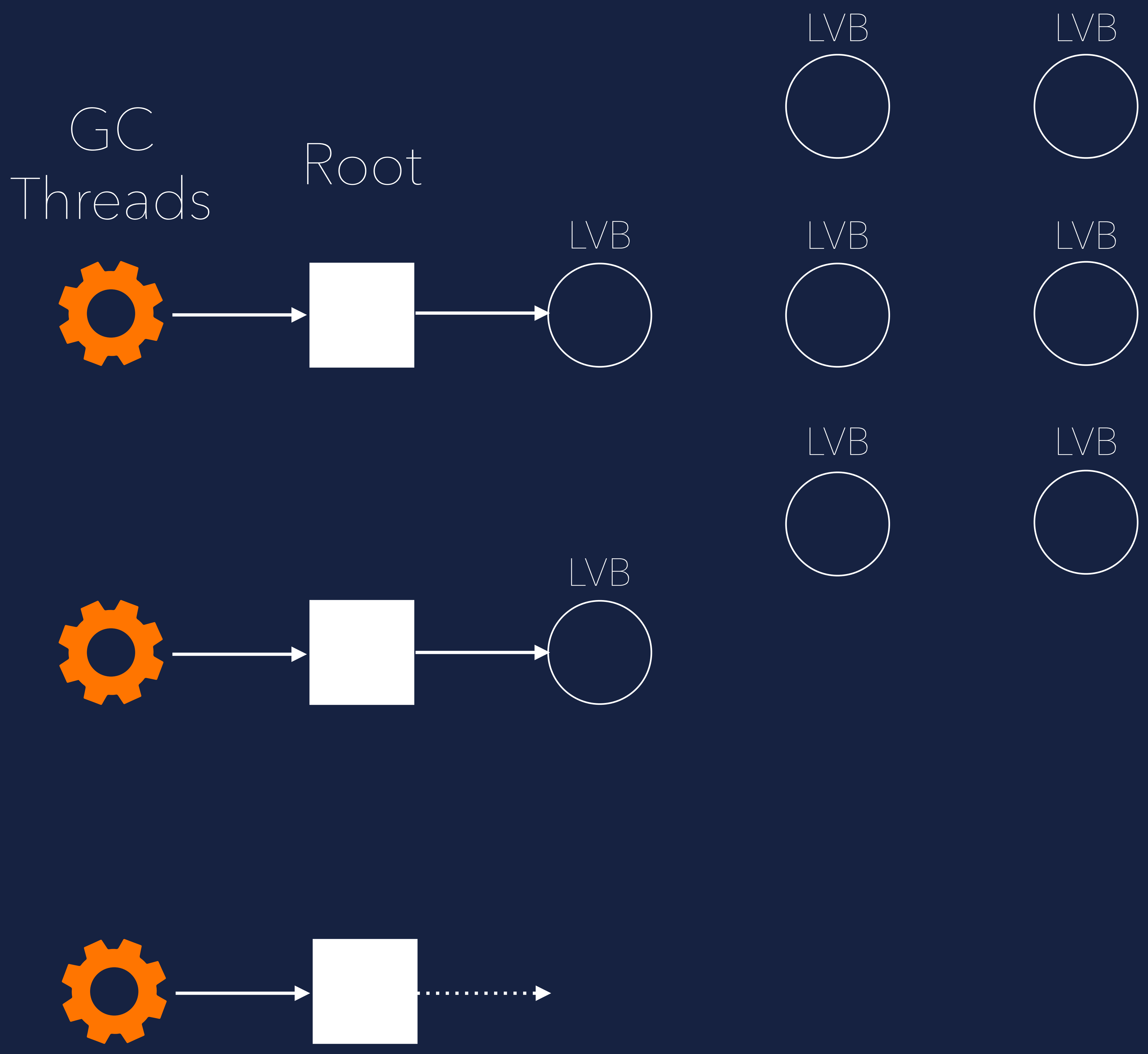
NOTES

- Part of Azul Zing JVM
- Makes use of Loaded Value Barrier (LVB) everywhere
  (Test + Jump which only takes 1 cpu cycle -> very fast)
- LVB is read and write barrier
  (guaranteed to be hit on every access)
- Best performance by using Transparent Huge Pages
  (Normal page size 4kB, THP size 2MB)

MARKING PHASE

C4

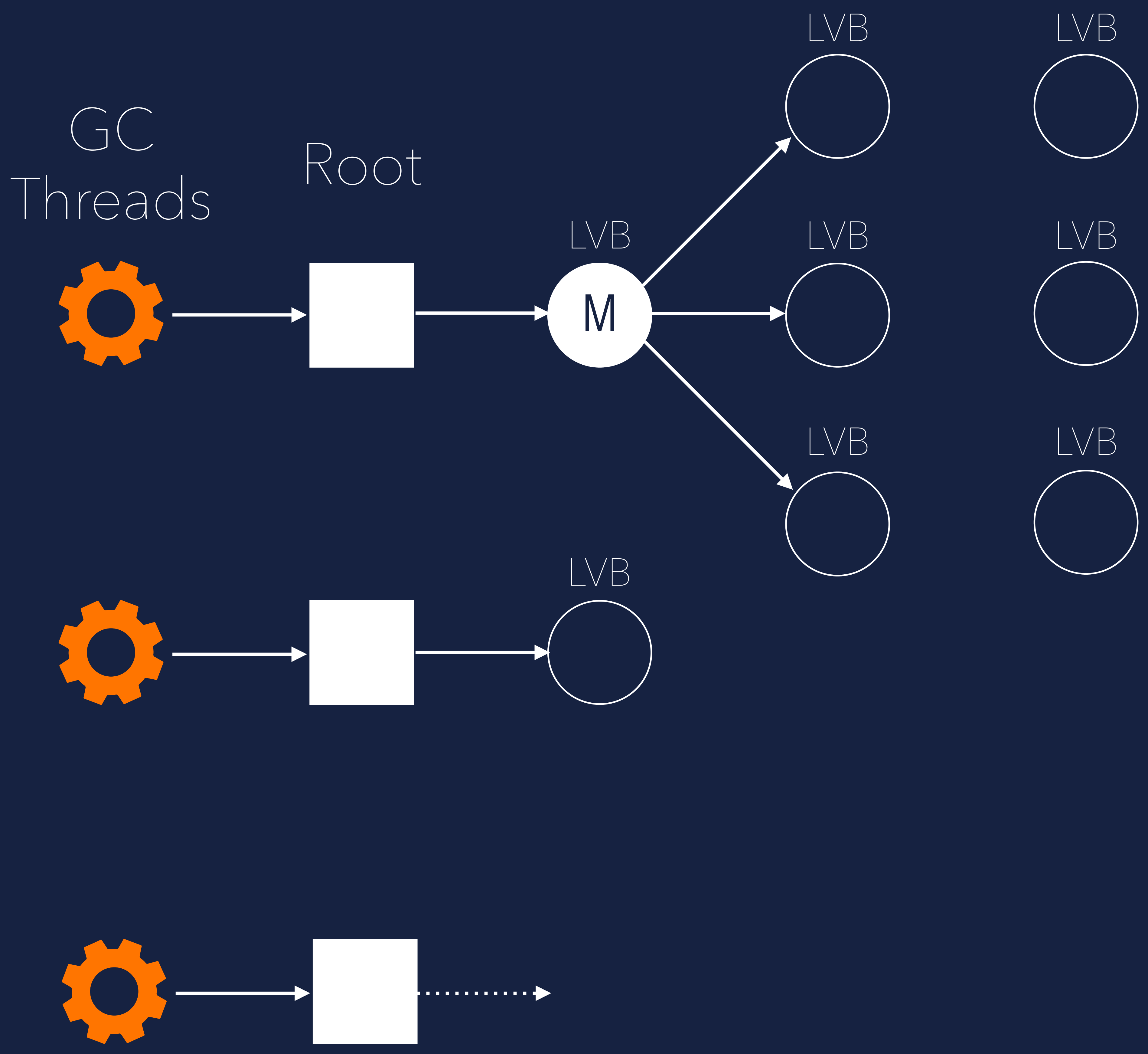
Marking Phase



azul

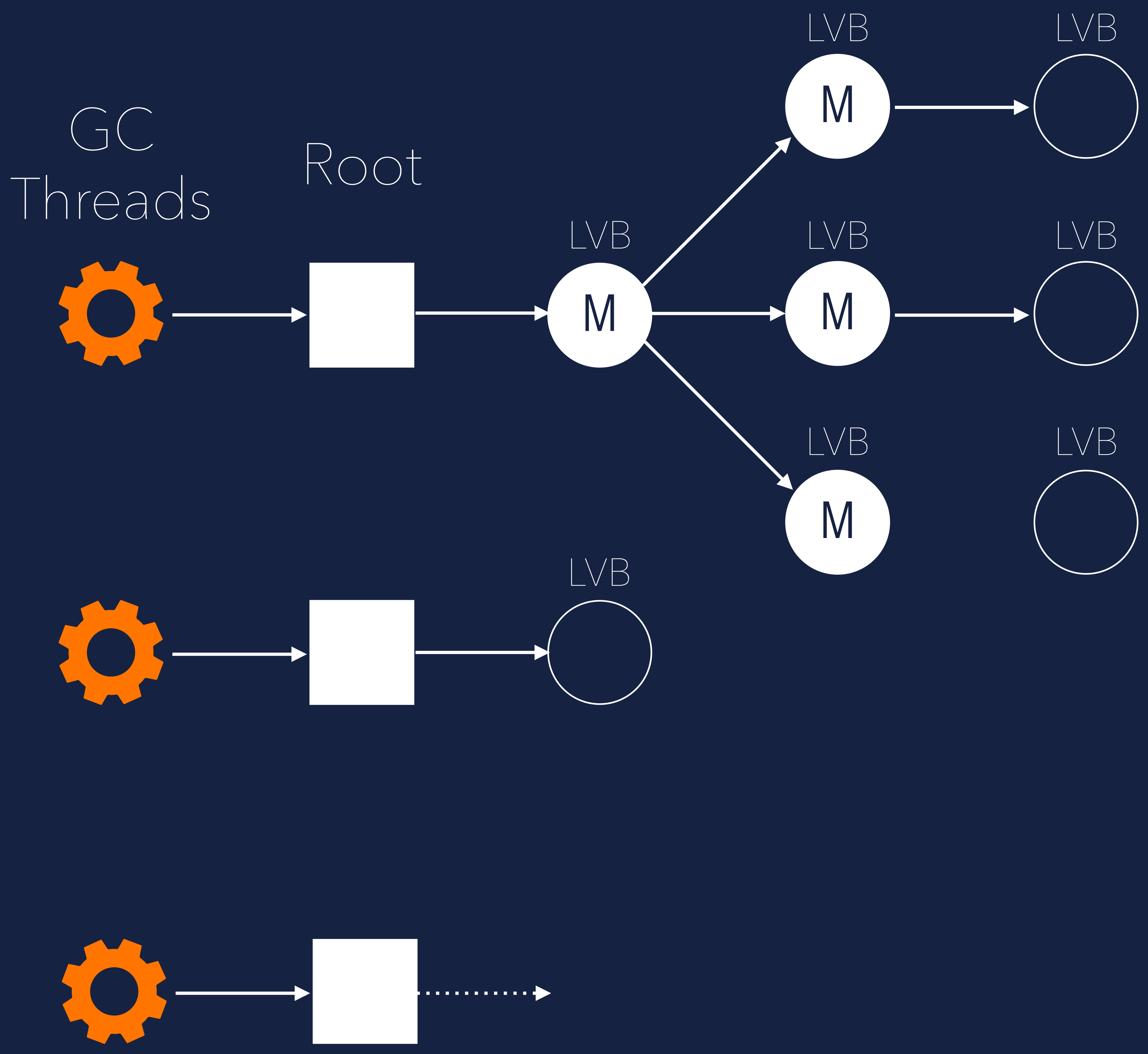
C4

Marking Phase



C4

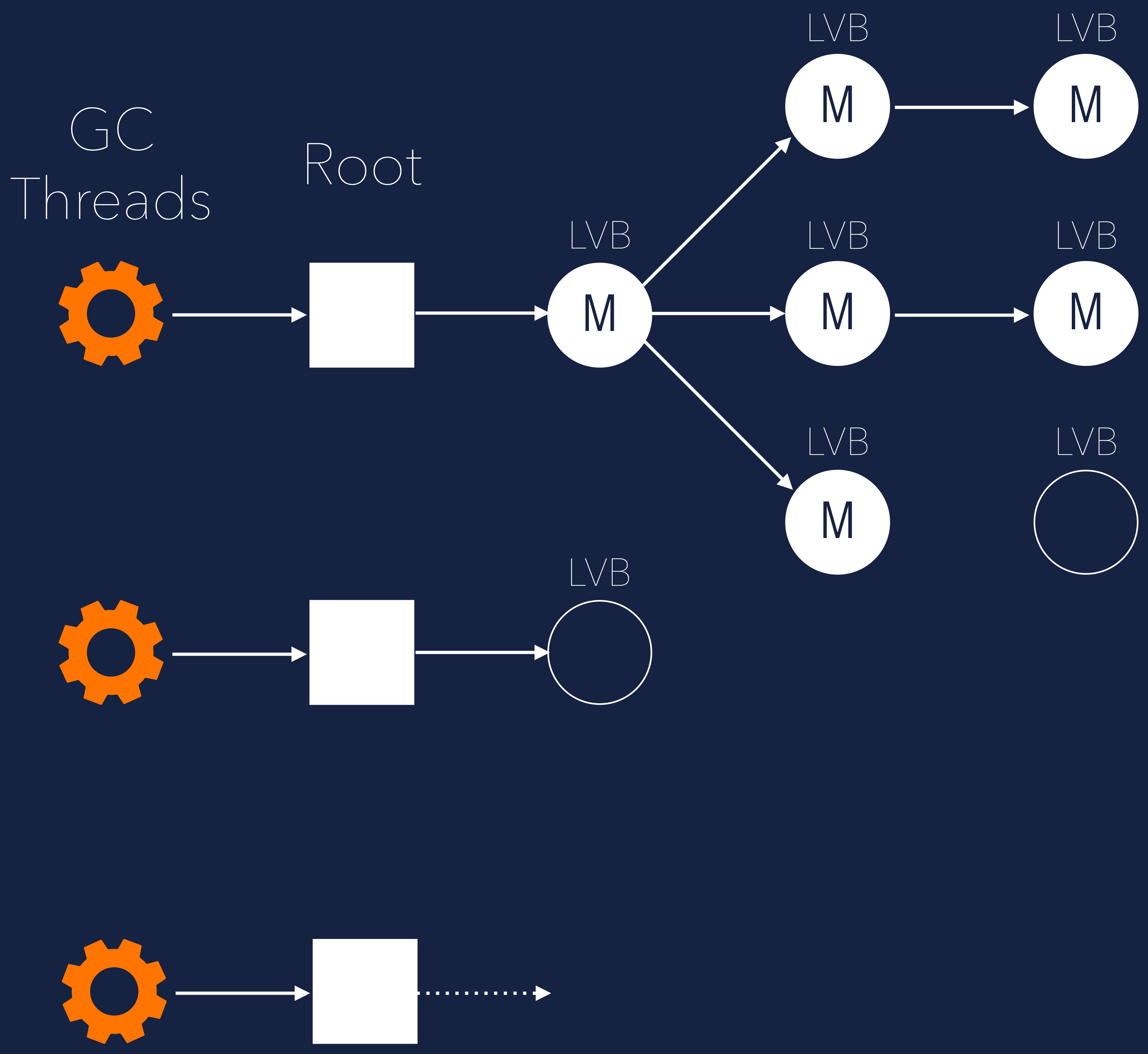
Marking Phase



azul

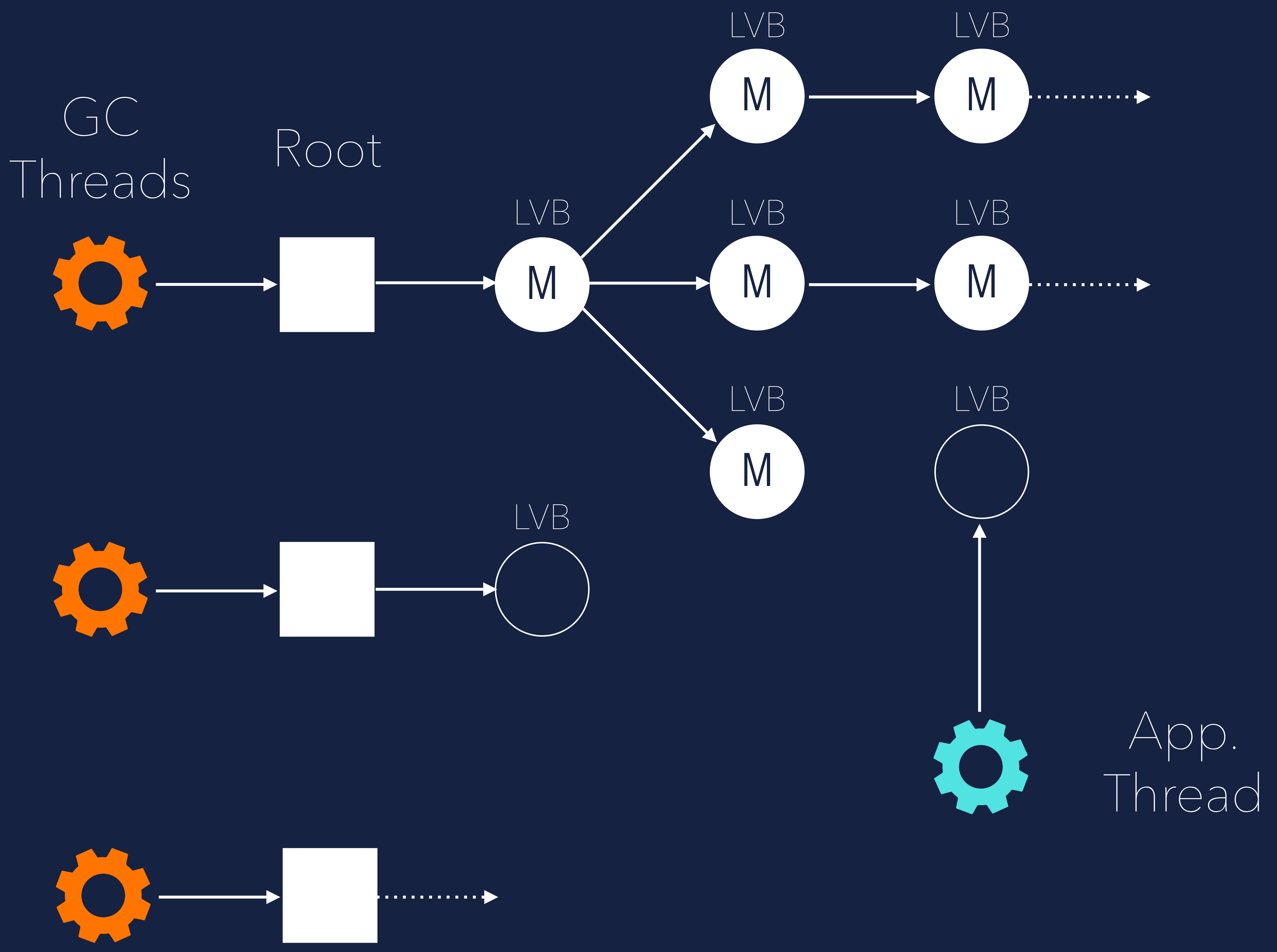
C4

Marking Phase



C4

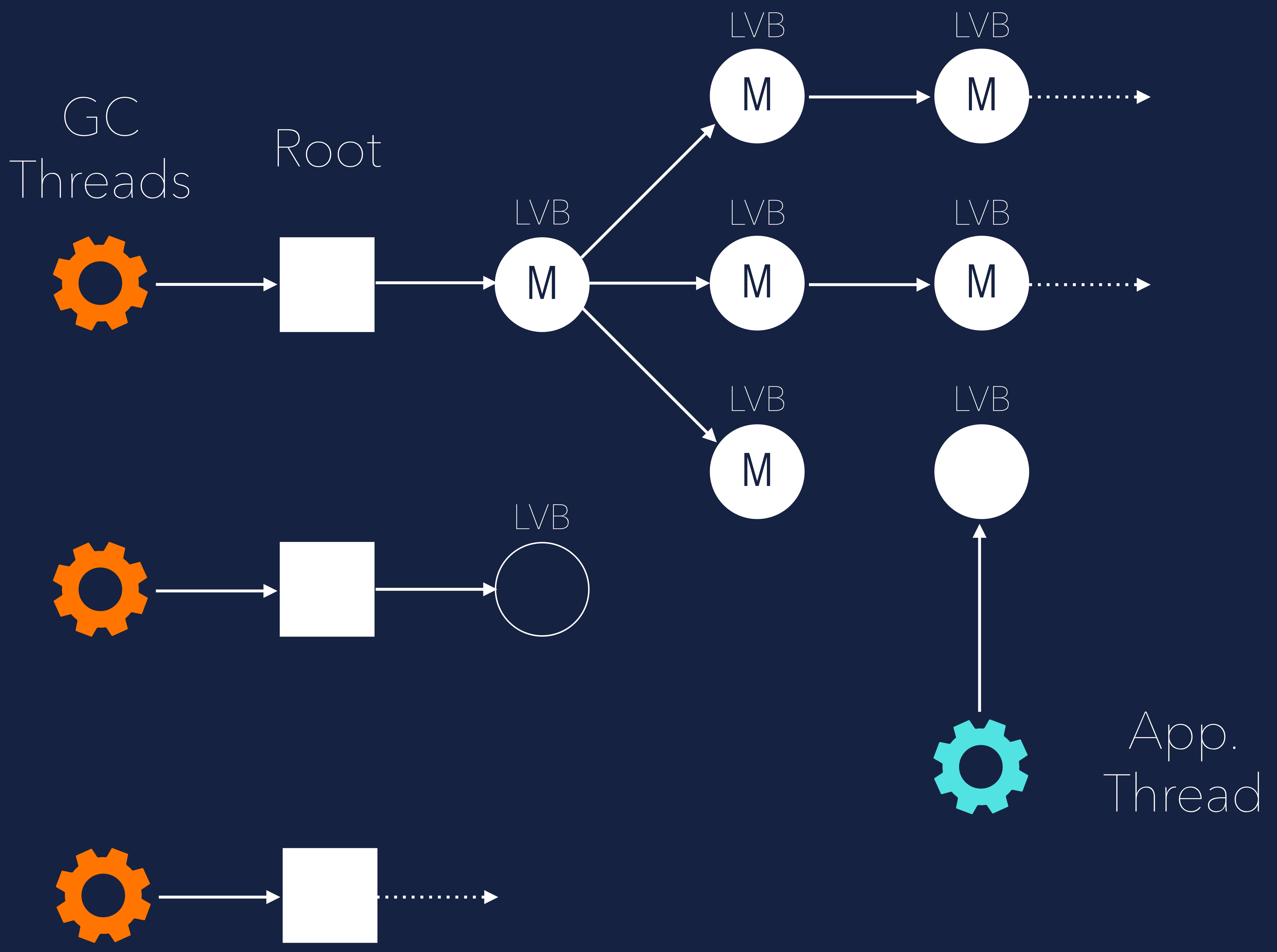
Marking Phase



azul

C4

Marking Phase

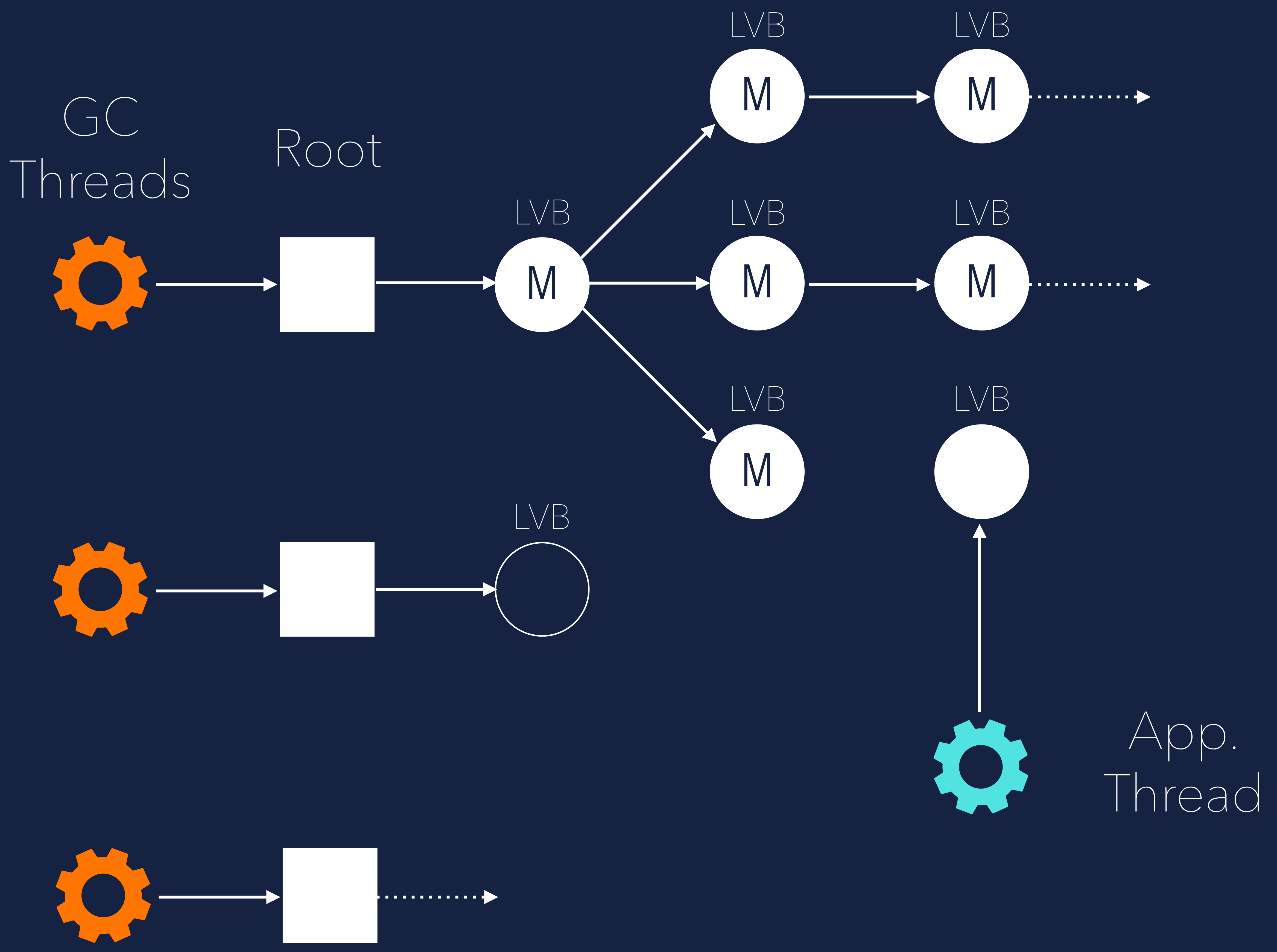


Trigger LVB

azul

C4

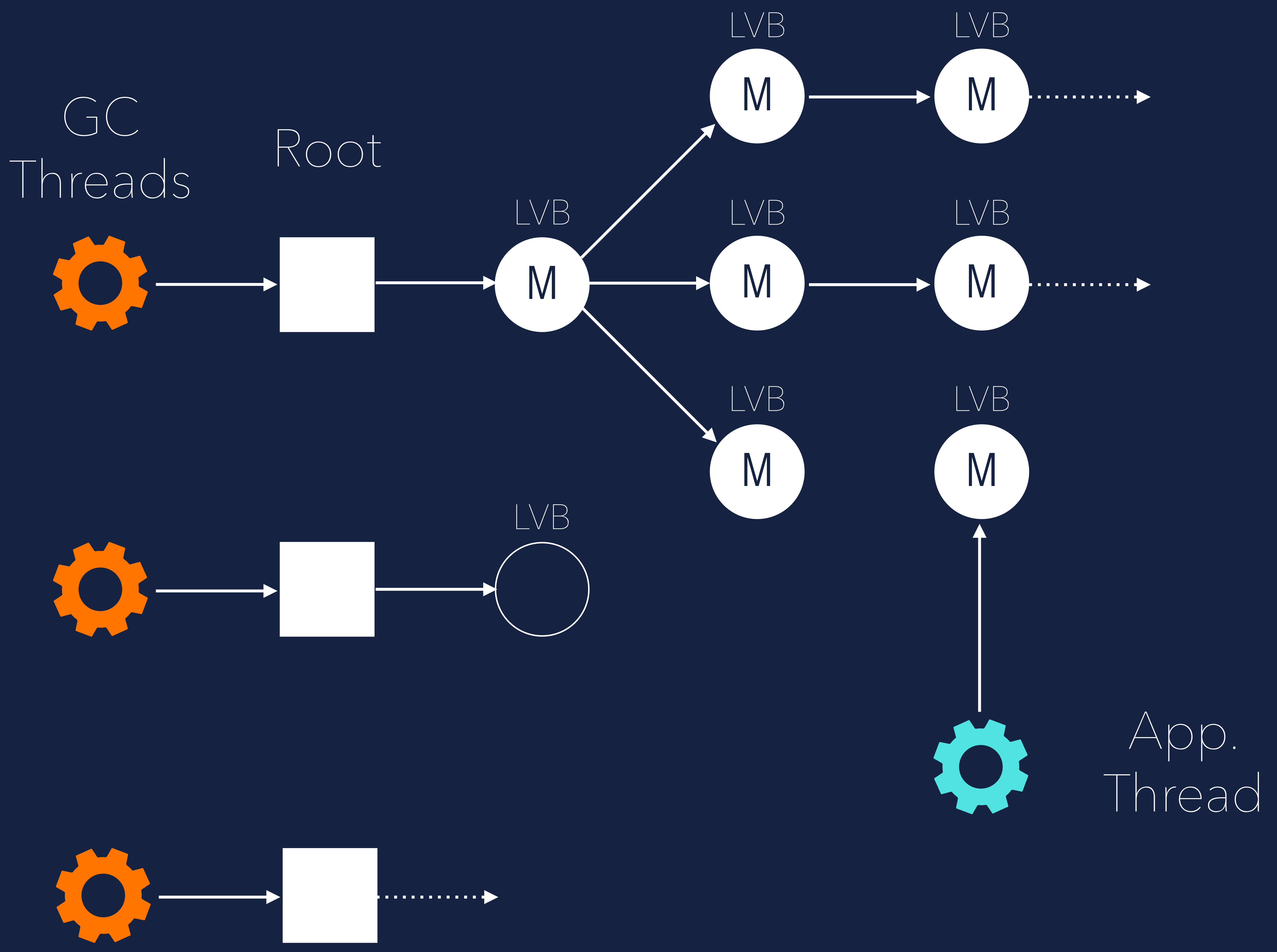
Marking Phase



Test+Jump

C4

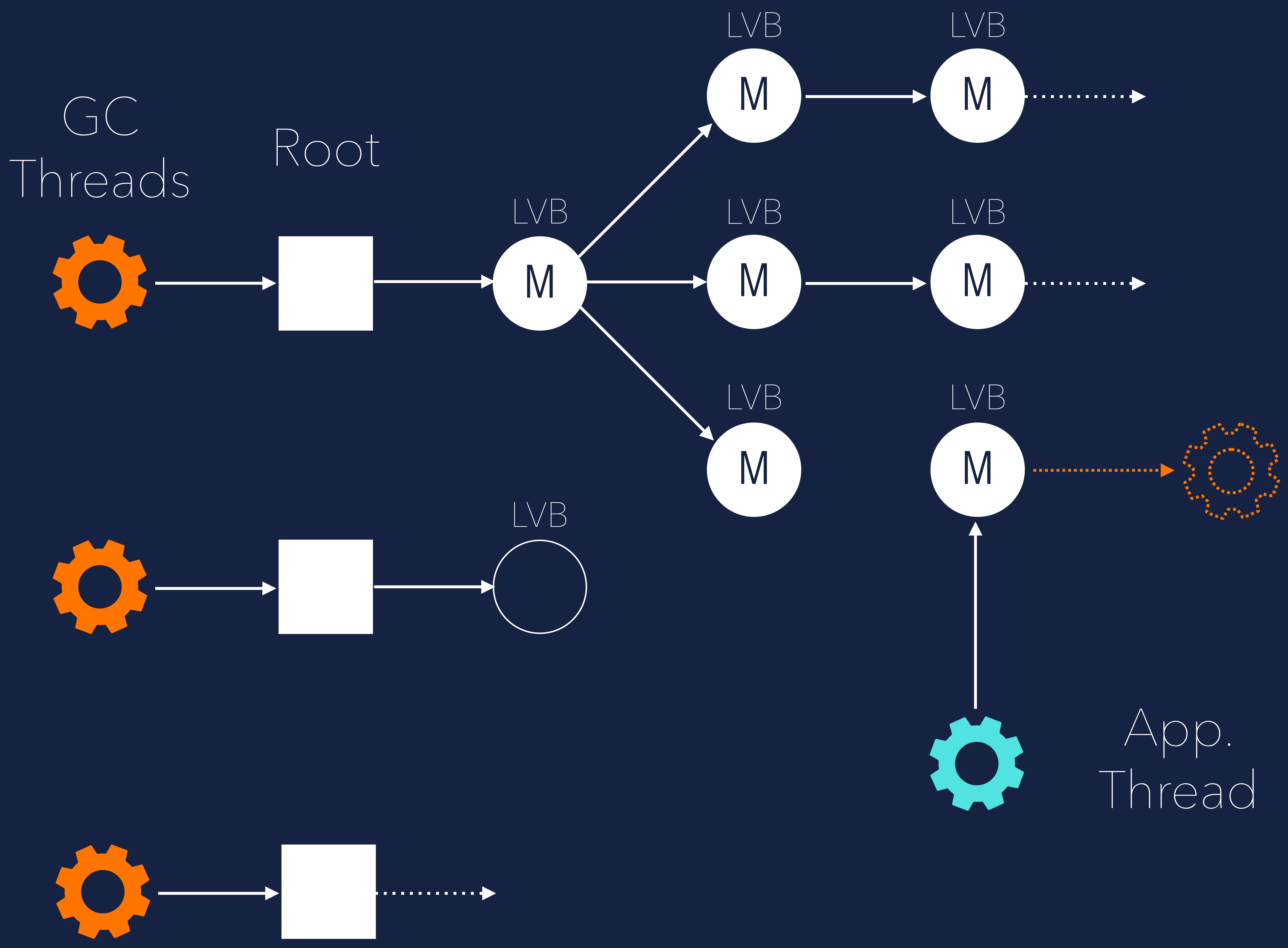
Marking Phase



Mark

C4

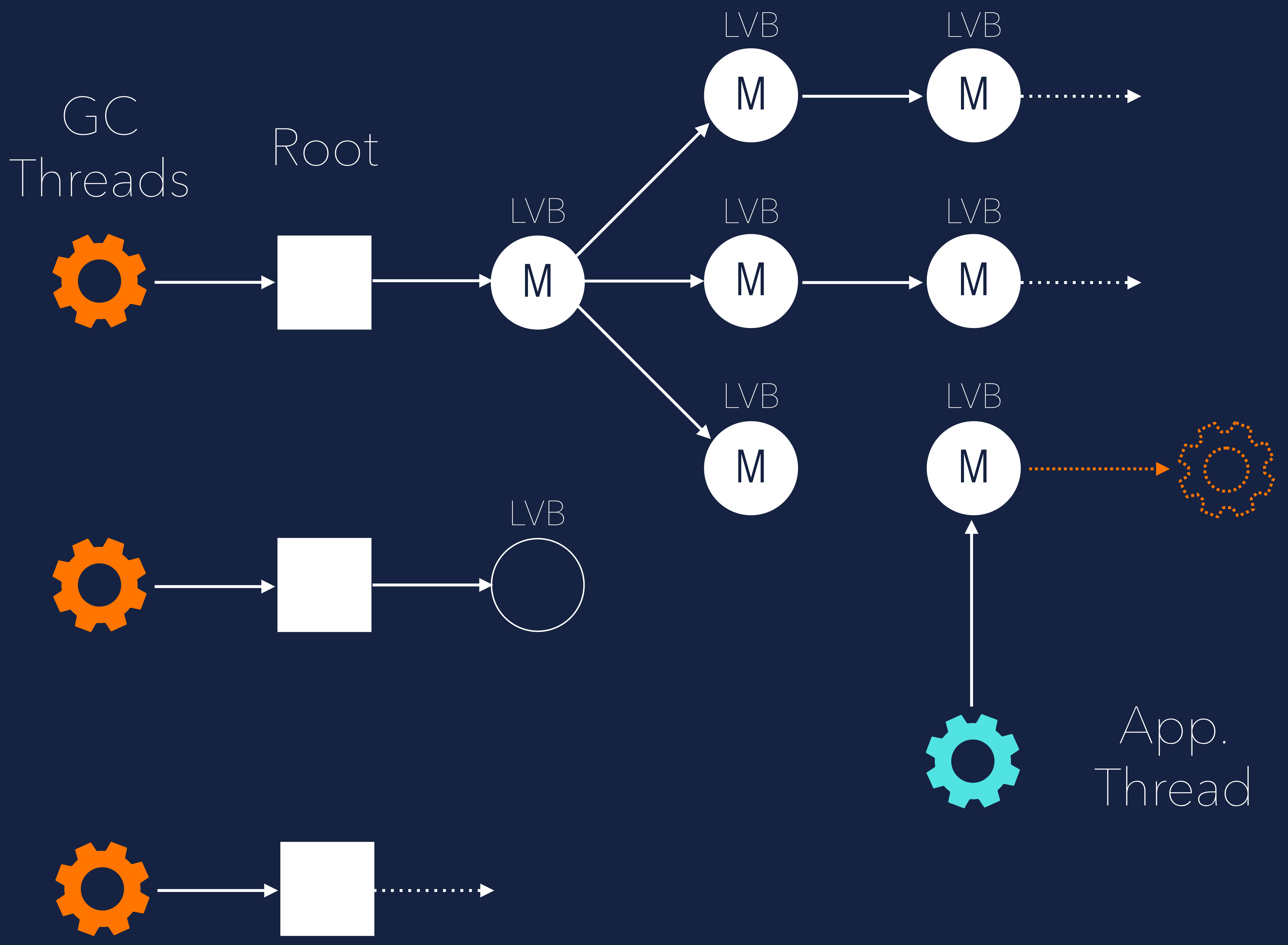
Marking Phase



Hand over to GC

C4

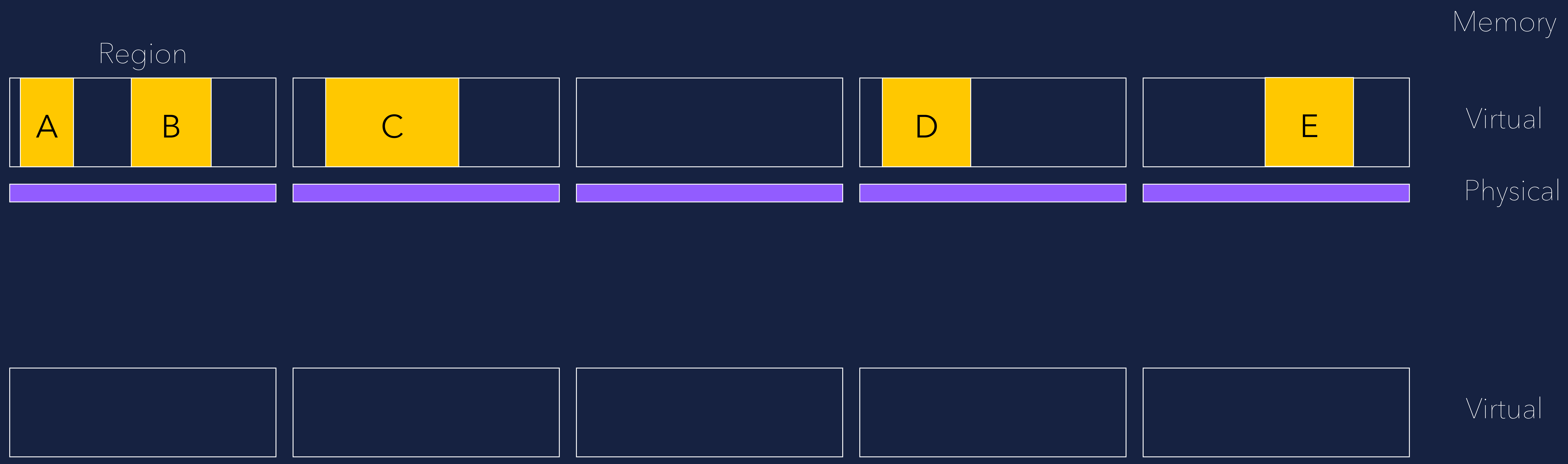
Marking Phase



No need to mark again by GC !

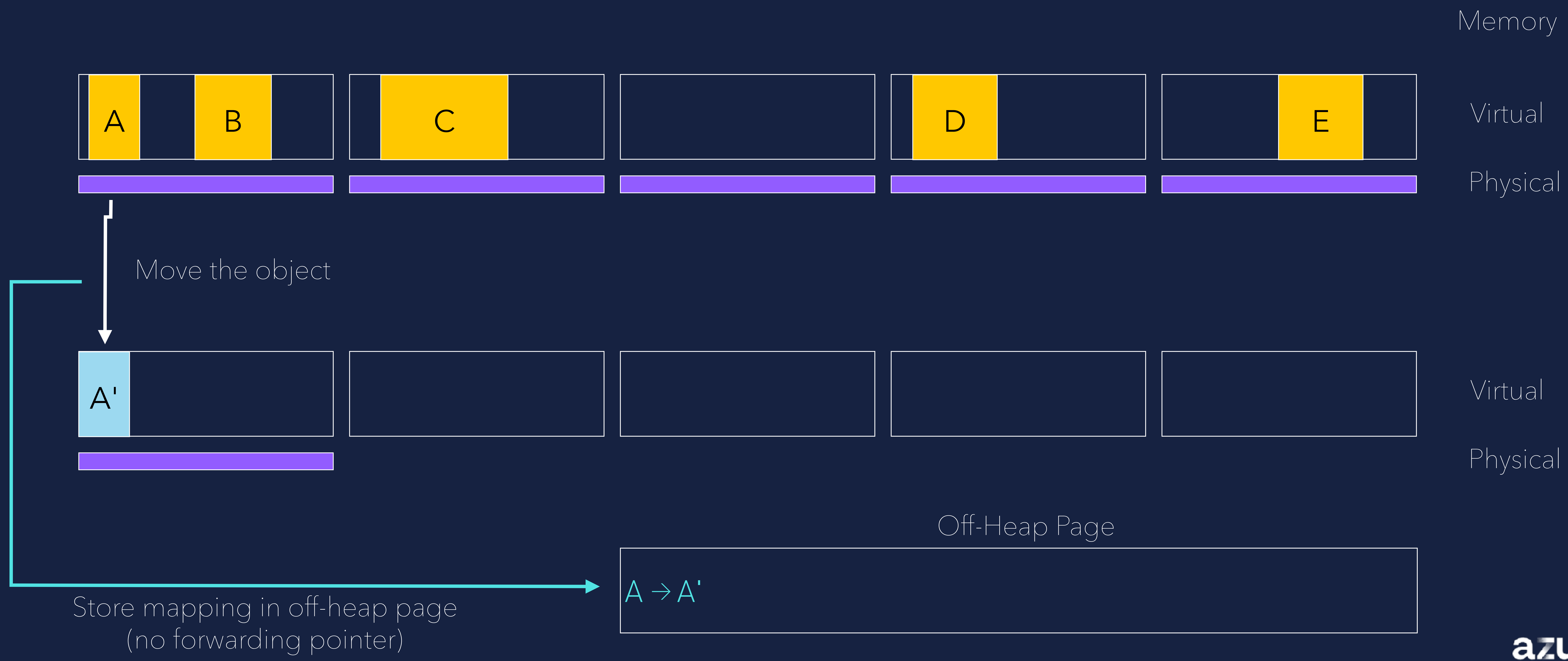
QUICK RELEASE

Relocation Phase



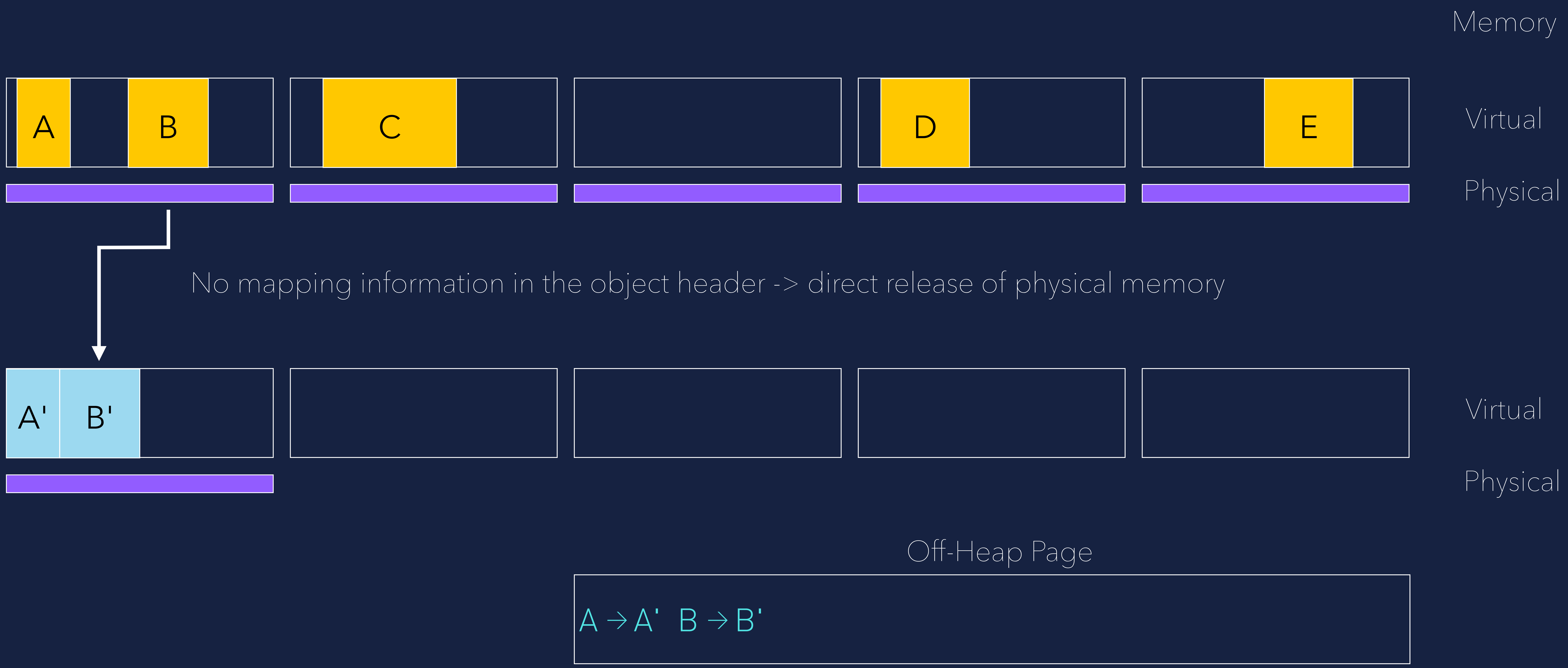
C4

Relocation Phase (Compaction)



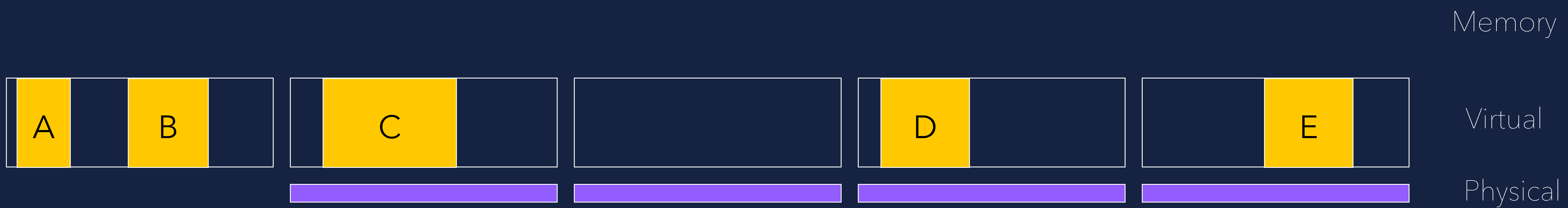
azul

Relocation Phase (Compaction)

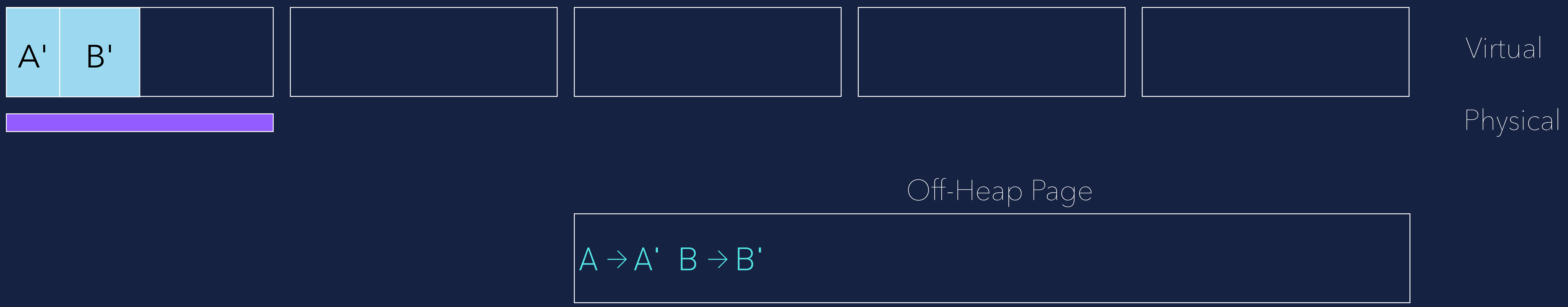


C4

Relocation Phase (Compaction)



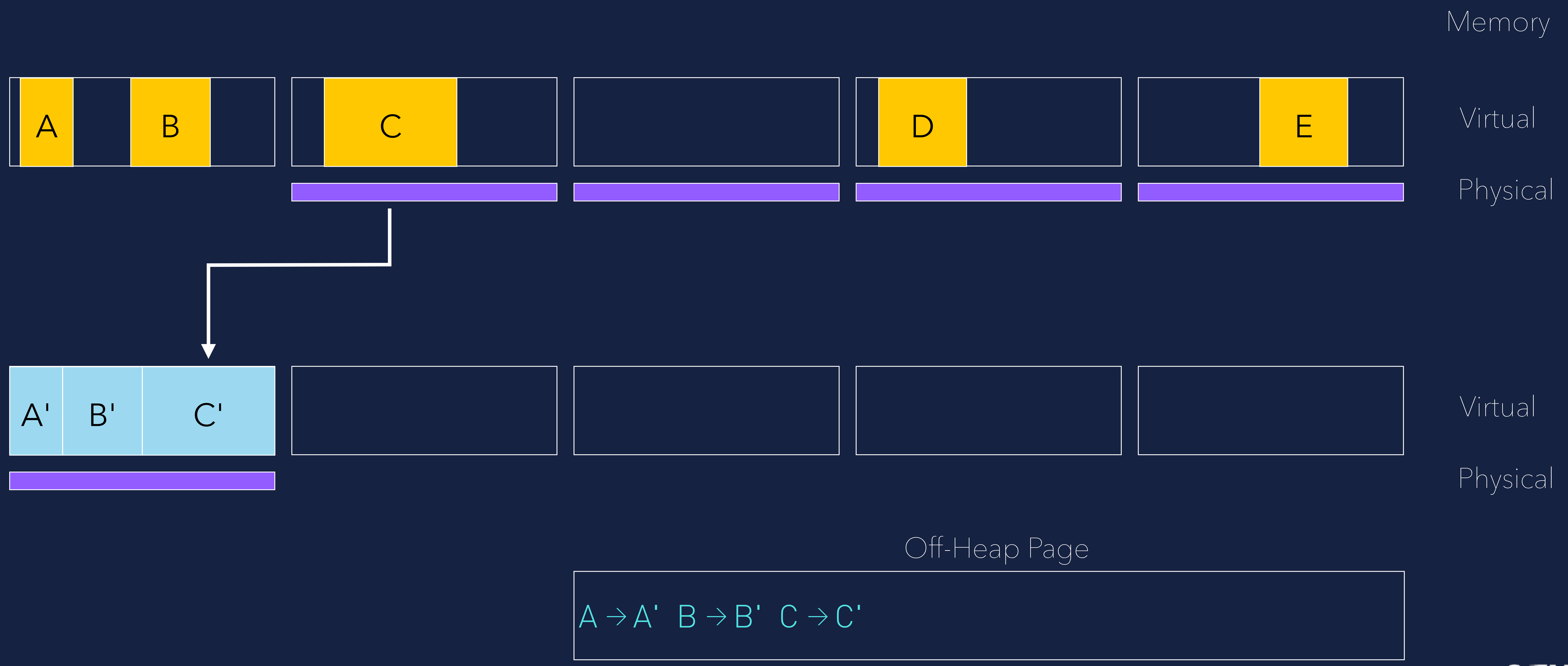
No mapping information in the object header -> direct release of physical memory



azul

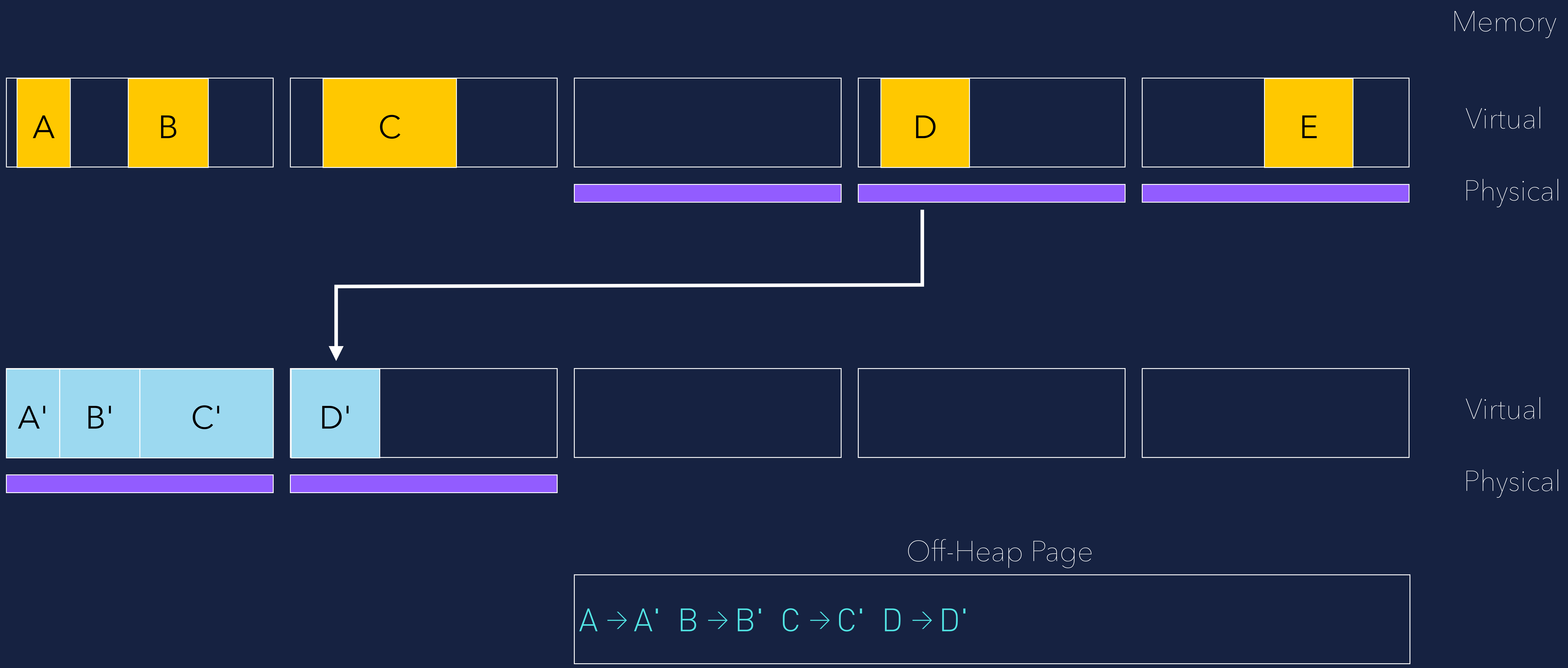
C4

Relocation Phase (Compaction)



C4

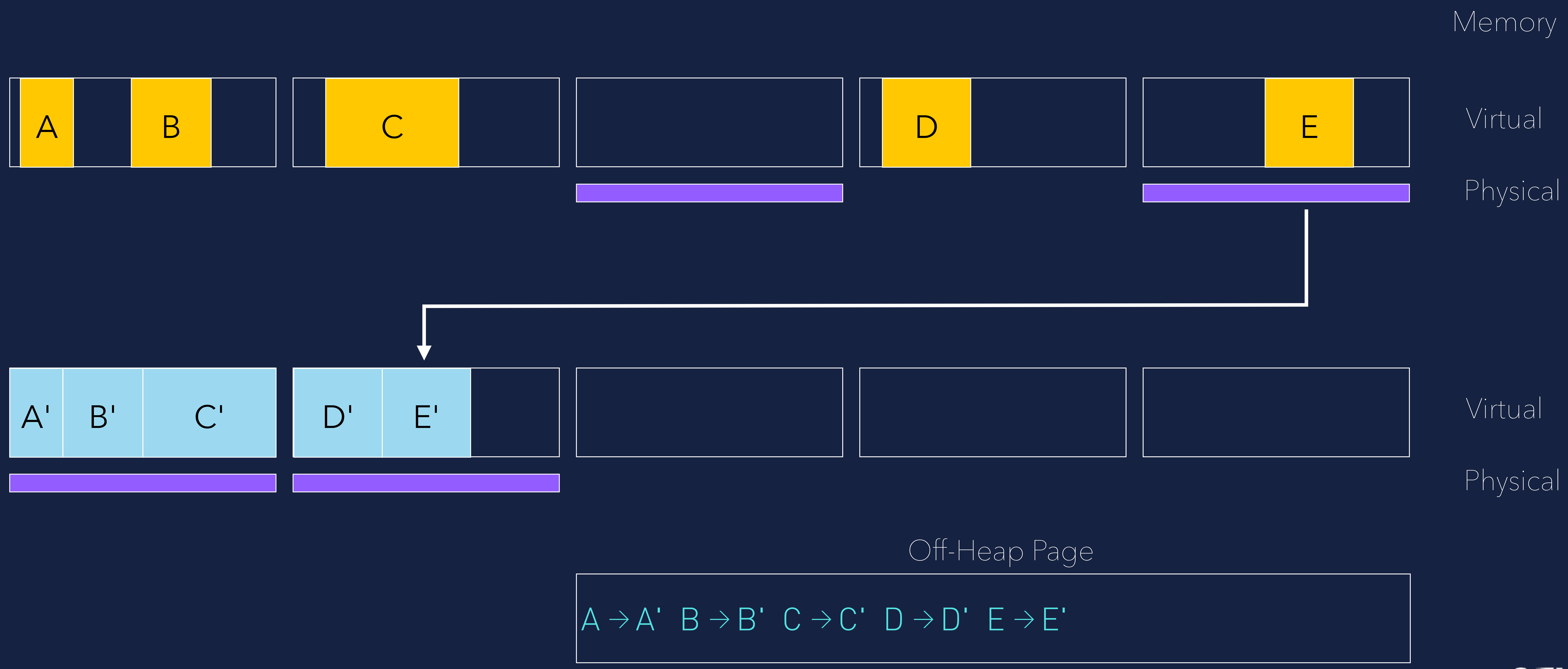
Relocation Phase (Compaction)



azul

C4

Relocation Phase (Compaction)



azul

C4

Relocation Phase (Quick Release)

C4

Relocation Phase (Quick Release)

C4

Relocation Phase (Quick Release)

azul

C4

AVAILABILITY	AZUL ZING JVM
PARALLEL	YES
CONCURRENT	FULLY
GENERATIONAL	YES
HEAP SIZE	LARGE
PAUSE TIMES	SHORT
THROUGHPUT	VERY HIGH
LATENCY	VERY LOW
CPU OVERHEAD	MODERATE (10-20%)

CHOOSE WHEN

- Response time is a high priority
- Using a very large heap (100GB+)
- Predictable response times needed

BEST SUITED FOR

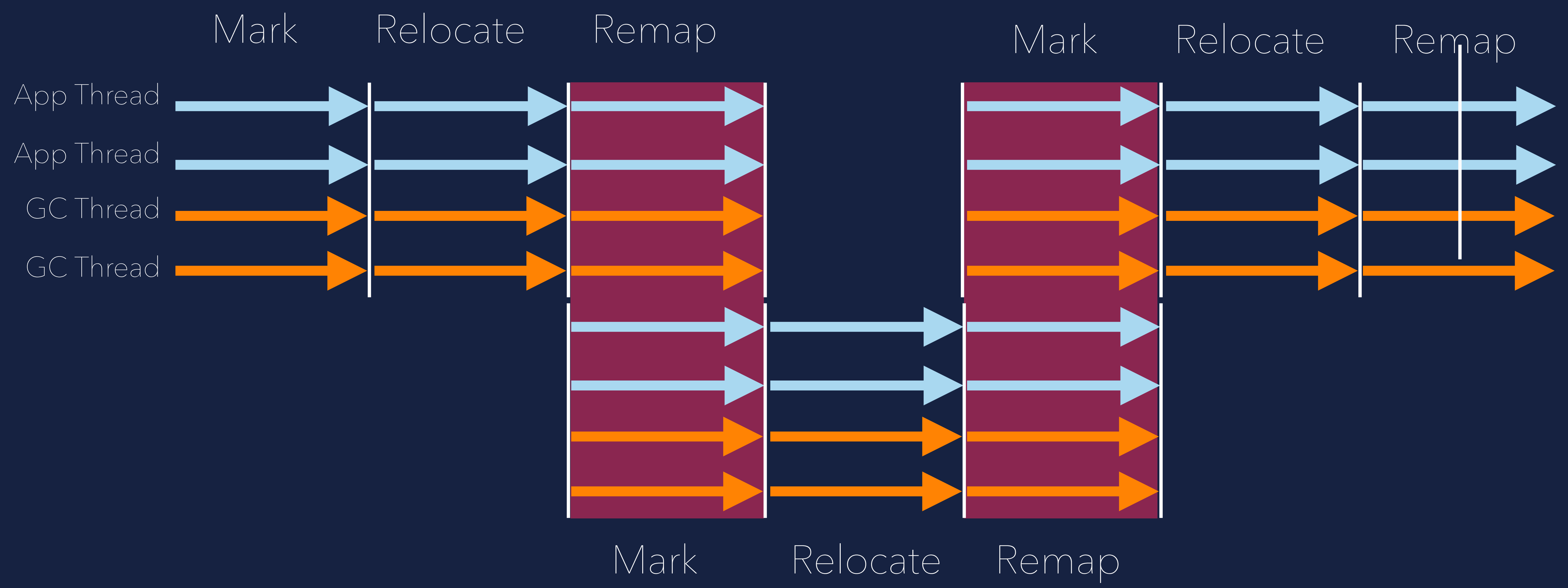
- Low latency sensitive applications
- Large scale systems
- Highly concurrent applications

OS SUPPORT	Linux
JVM SWITCH	> –

C4

NOTES

- Only available in Azul Zing JVM
- No performance overhead because of faster Falcon compiler



azul

WHICH ONE...?

WHICH ONE...?

Essential Criteria

- 🗑️ Throughput

  Percentage of total time spent in application vs. memory allocation and garbage collection

WHICH ONE...?

Essential Criteria

- **Throughput**
  Percentage of total time spent in application vs. memory allocation and garbage collection
- **Latency**
  Application responsiveness, affected by gc pauses

WHICH ONE...?

Essential Criteria

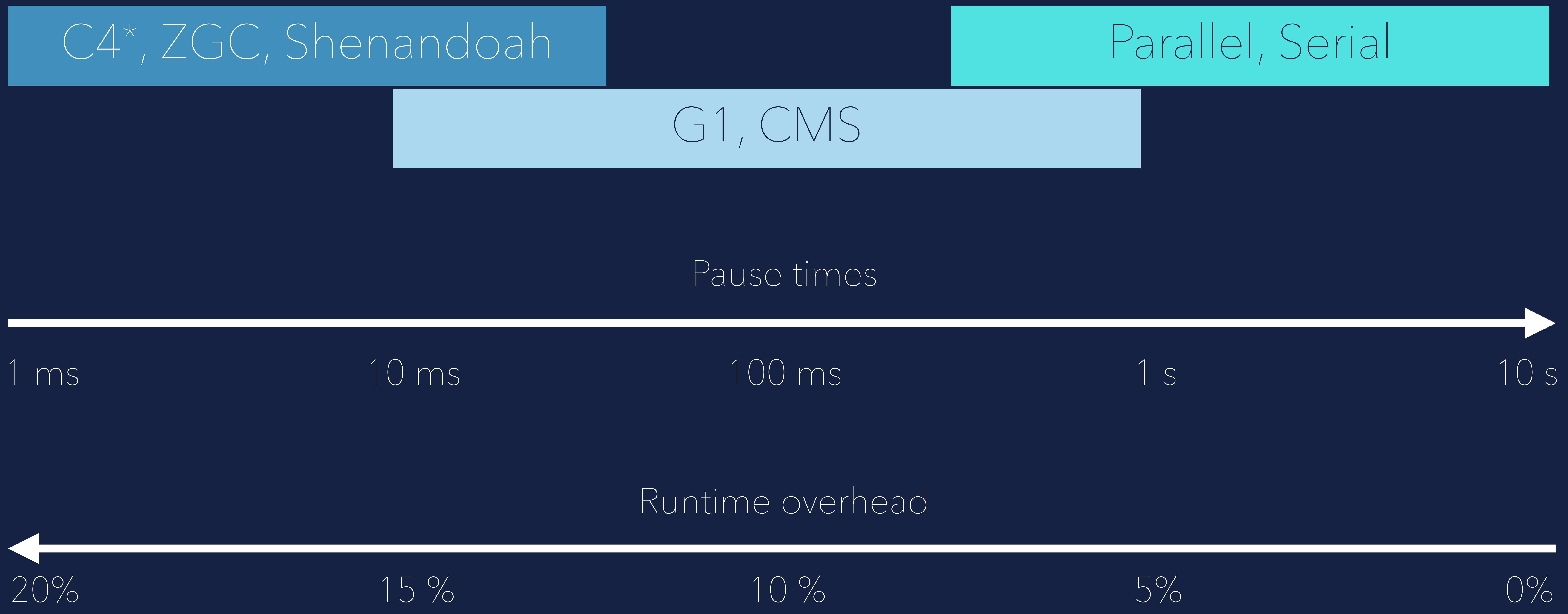
- **Throughput**
  Percentage of total time spent in application vs. memory allocation and garbage collection
- **Latency**
  Application responsiveness, affected by gc pauses
- **Resource usage**
  The working set of a process, measured in pages and cache lines

WHICH ONE…?

Essential Criteria

WHICH ONE…?

Choose dependent on your workload



* C4 has less overhead due to faster Falcon compiler

azul

OVERVIEW

OVERVIEW

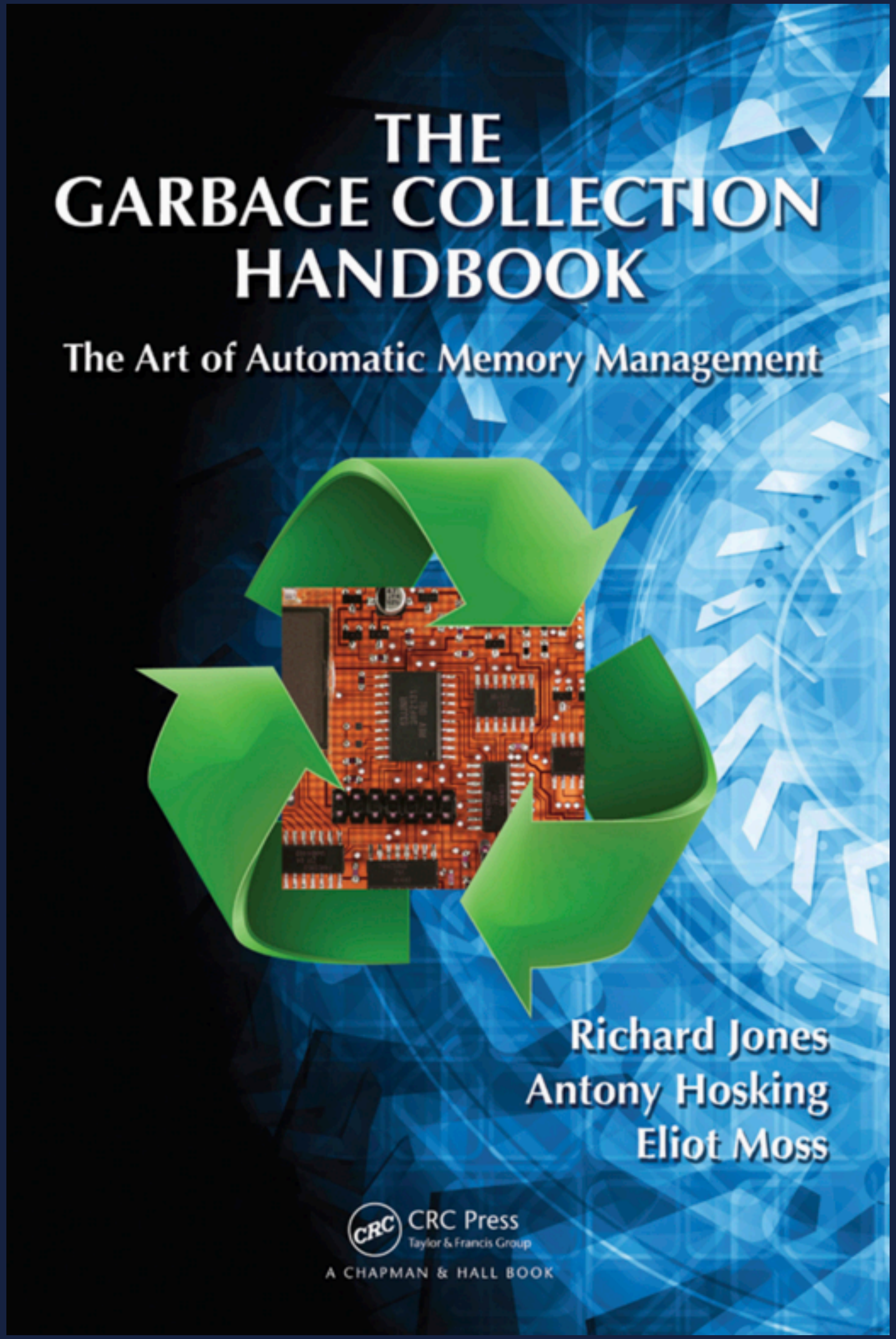
	Serial GC	Parallel GC	CMS GC	G1	Epsilon	Shenandoah	ZGC	C4
Availability	ALL JDK's	ALL JDK's	JDK 1.4-13	JDK 7u4+	JDK 11+	JDK 11.0.9+	JDK15 / 21+	Azul Prime
Parallel	NO	YES	YES	YES		YES	YES	YES
Concurrent	NO	NO	PARTIALLY	PARTIALLY		FULLY	FULLY	FULLY
Generational	YES	YES	YES	YES		NO	NO / YES	YES
Heap Size	SMALL - MEDIUM	MEDIUM - LARGE	MEDIUM - LARGE	MEDIUM - LARGE		LARGE	VERY LARGE	VERY LARGE
Pause Times	LONGER	MODERATE	MODERATE	SHORT - MEDIUM		VERY SHORT (<10ms)	VERY SHORT (<1ms)	VERY SHORT (<1ms)
Throughput	LOW	HIGH	MODERATE	HIGH		VERY HIGH	VERY HIGH	VERY HIGH
Latency	HIGHER	LOWER	MODERATE	LOWER		VERY LOW	VERY LOW	VERY LOW
Performance	LOWER	HIGHER	MODERATE	HIGHER	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH
CPU Overhead	LOW	LOWER	MODERATE	MODERATE	VERY LOW	LOW - MODERATE	MODERATE - HIGH	MODERATE - HIGH
Tail latency	HIGH	HIGH	HIGH	HIGH		MODERATE	LOW	LOW

WANNA KNOW MORE ?

azul

WANNA KNOW MORE ?

R. Jones et al. "The Garbage Collection Handbook". Chapman & Hall/CRC, 2012



THANK YOU

azul