Managing Arrays

with the OMR garbage collector

Prerequisites

THIS LAB IS “BRING YOUR OWN LAPTOP”

- You need:
  - Linux, osx, or windows laptop
  - a C++11 toolchain: msvc, clang, gcc
  - git
  - cmake
- Clone the skeleton project

```
git clone --recursive https://github.com/rwy0717/splash2018-omr-gc
```

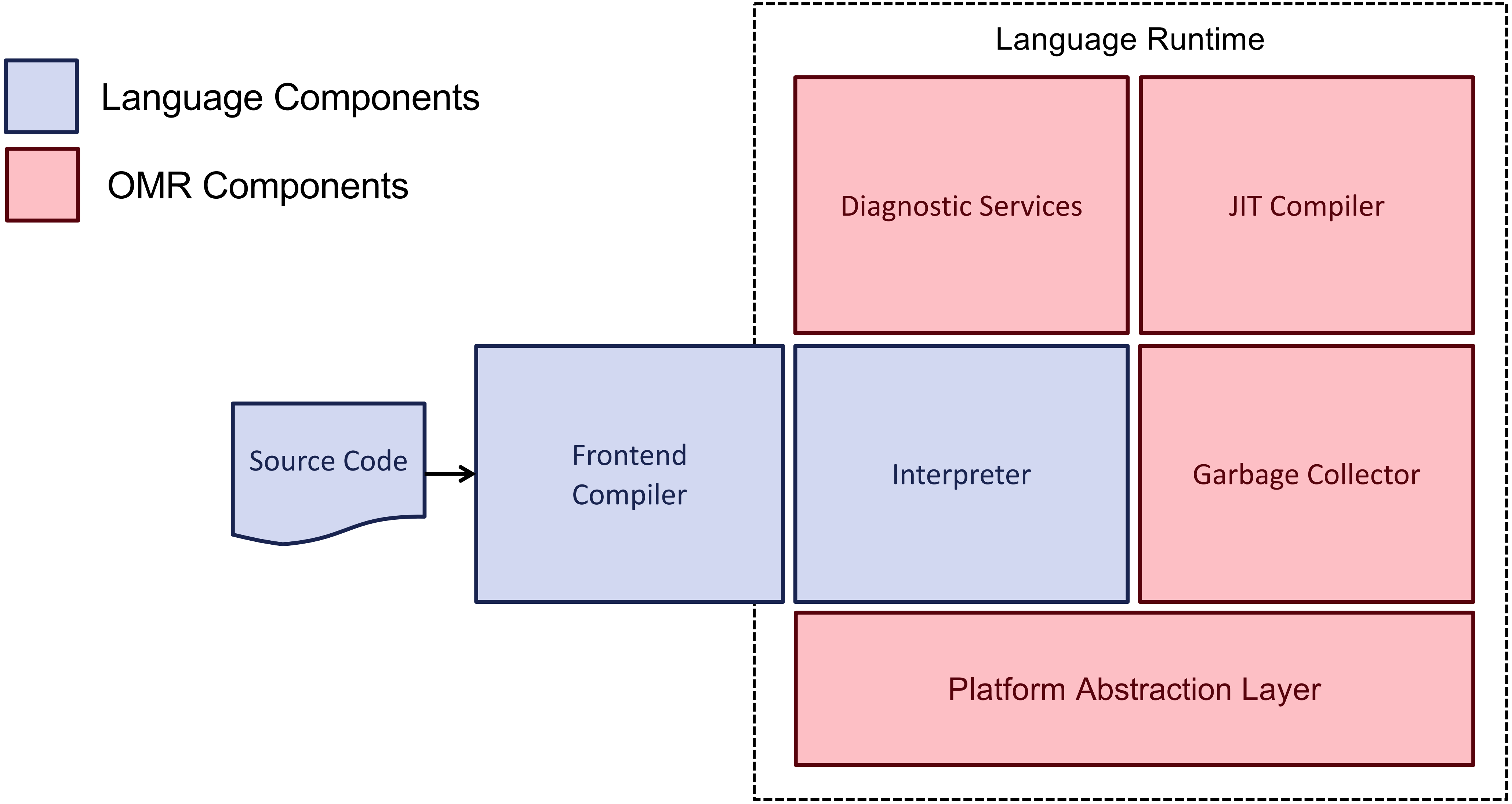
Don't forget your laptop charger!

Today, we’re going to implement a garbage collector for simple fixed-length arrays.

Eclipse OMR

A toolkit for building language runtimes

https://github.com/eclipse/omr



Language Components

OMR Components

Language Runtime

Diagnostic Services

JIT Compiler

Source Code

Frontend Compiler

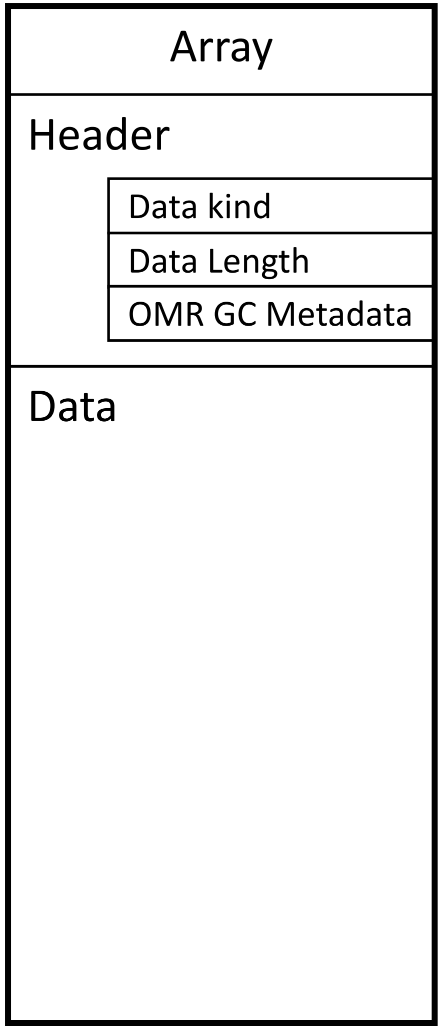
Interpreter

Garbage Collector

Platform Abstraction Layer

Our array object model

Our array object model:



Array

Header

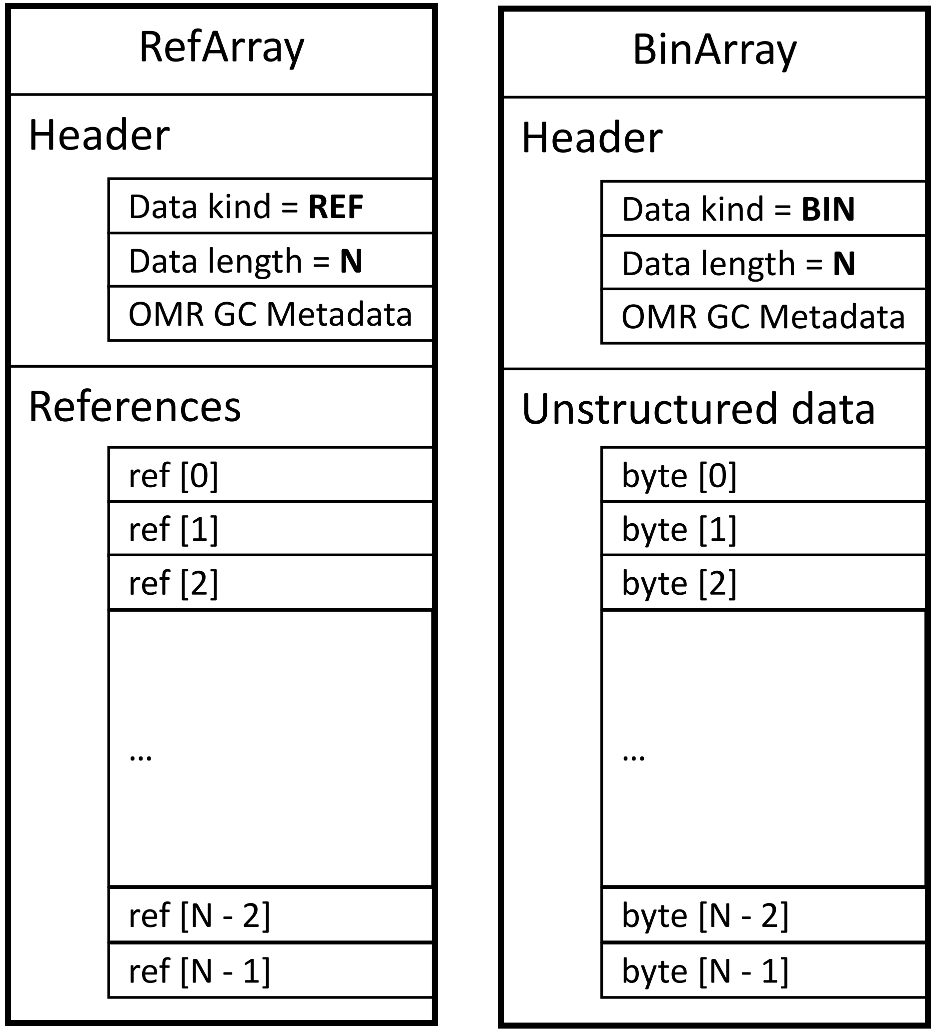
Data kind

Data Length

OMR GC Metadata

Data

Two kinds of Data: References and bytes



RefArray

Header

Data kind = **REF**

Data length = **N**

OMR GC Metadata

References

ref [0]

ref [1]

ref [2]

…

ref [N - 2]

ref [N - 1]

BinArray

Header

Data kind = **BIN**

Data length = **N**

OMR GC Metadata

Unstructured data

byte [0]

byte [1]

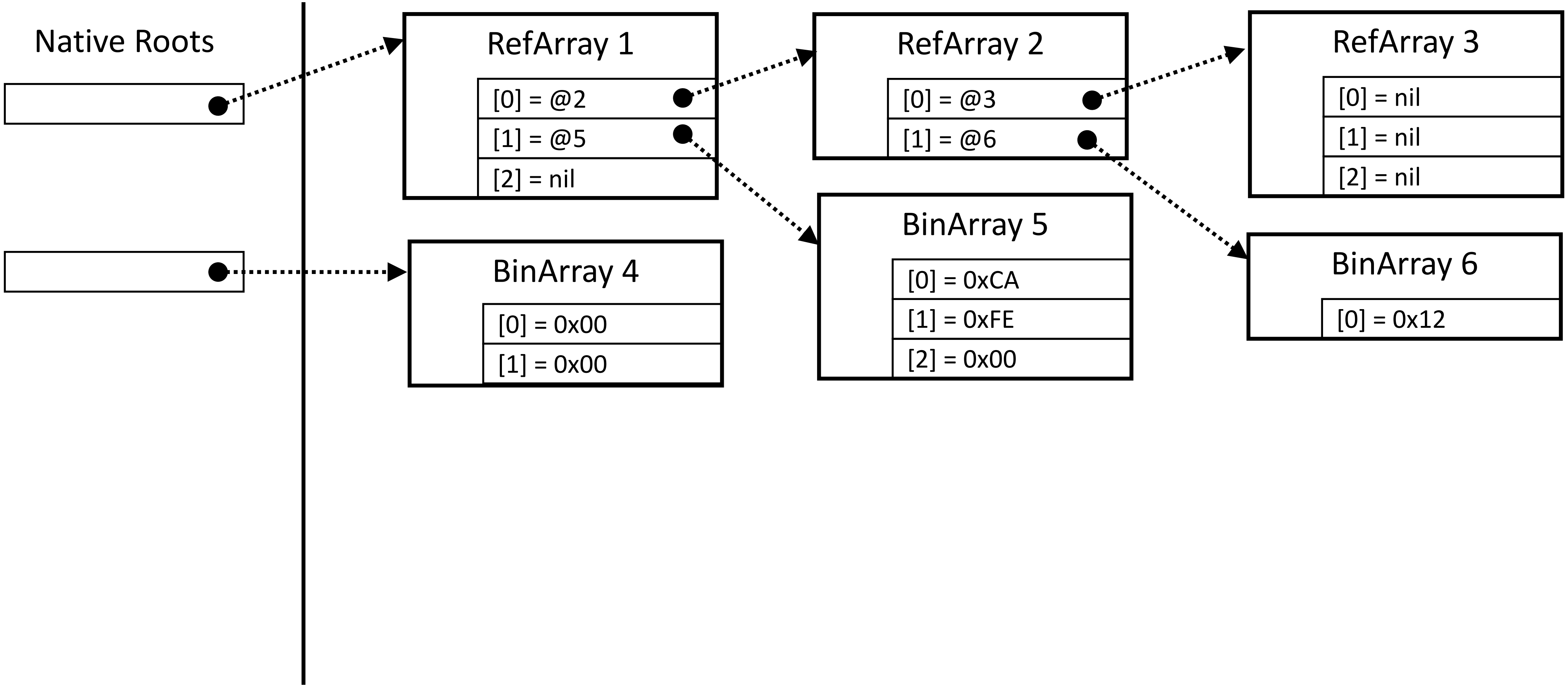
byte [2]

…

byte [N - 2]

byte [N - 1]

Memory: Graphs of objects



Native Roots

RefArray 1

[0] = @2

[1] = @5

[2] = nil

BinArray 4

[0] = 0x00

[1] = 0x00

RefArray 2

[0] = @3

[1] = @6

BinArray 5

[0] = 0xCA

[1] = 0xFE

[2] = 0x00

RefArray 3

[0] = nil

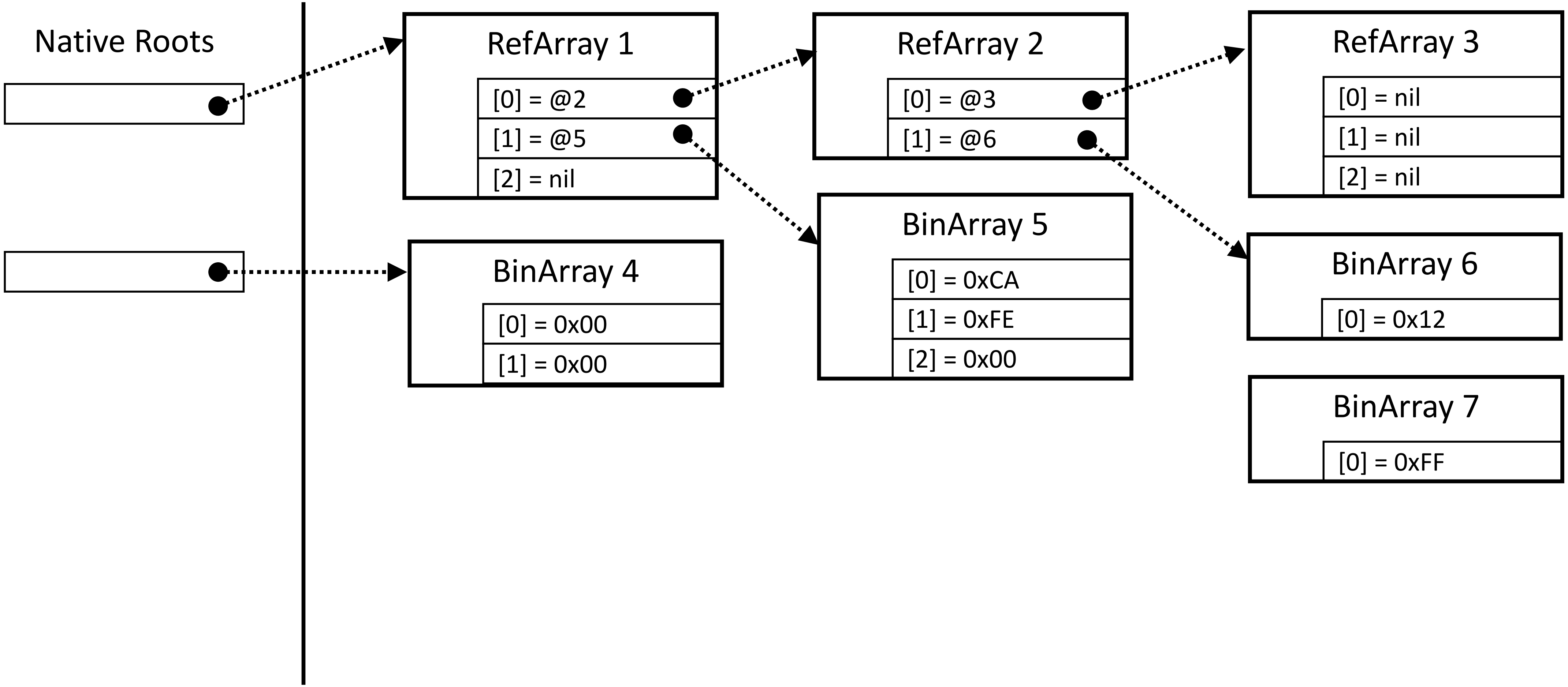
[1] = nil

[2] = nil

BinArray 6

[0] = 0x12

Memory: Graphs of objects



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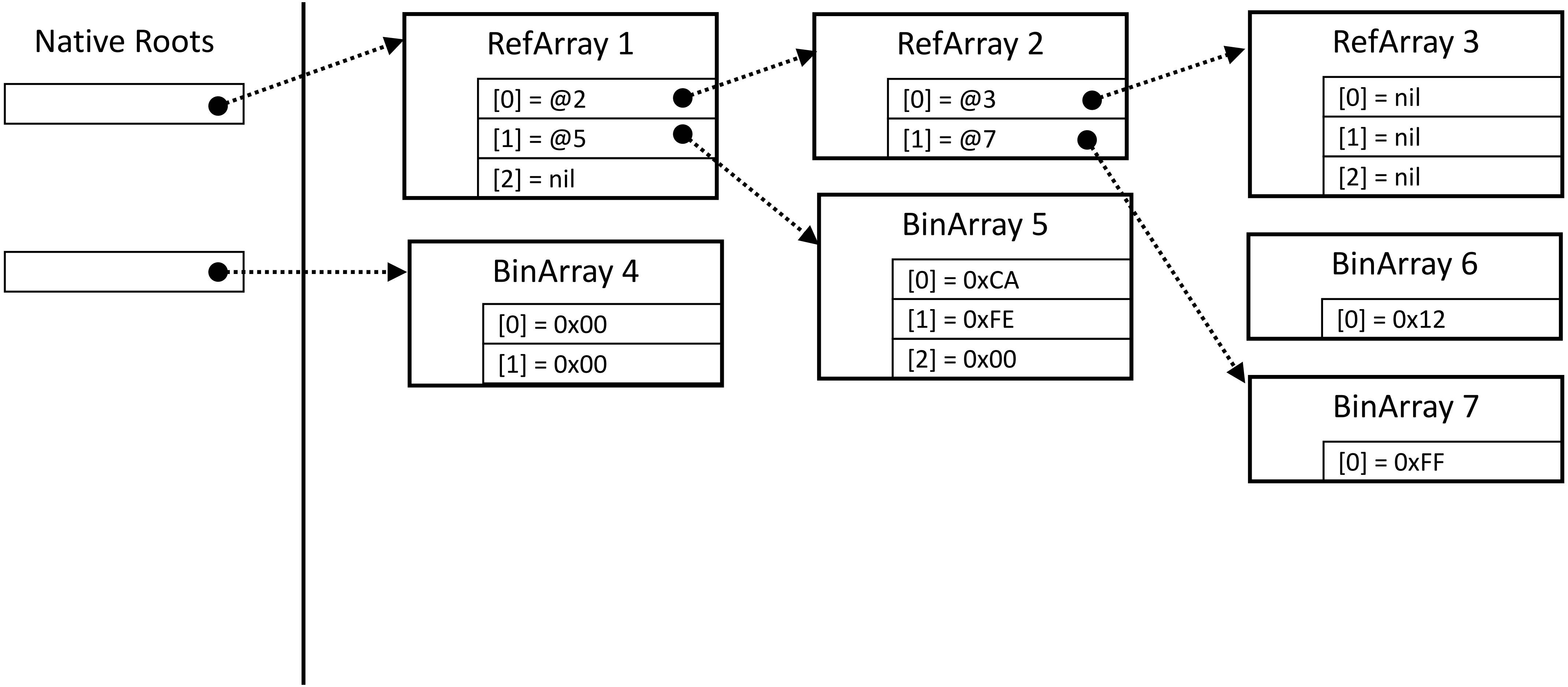

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BinArray 4

[0] = 0x00

[1] = 0x00

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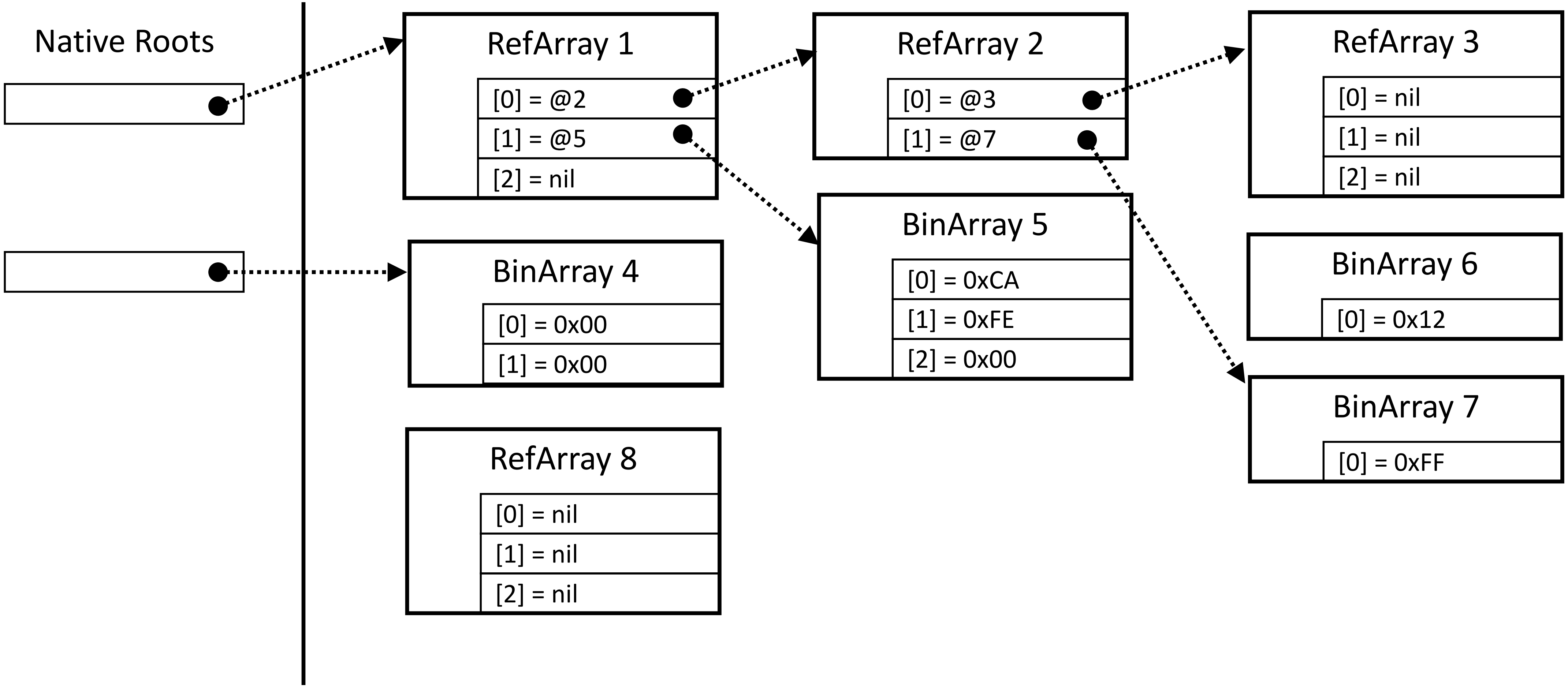

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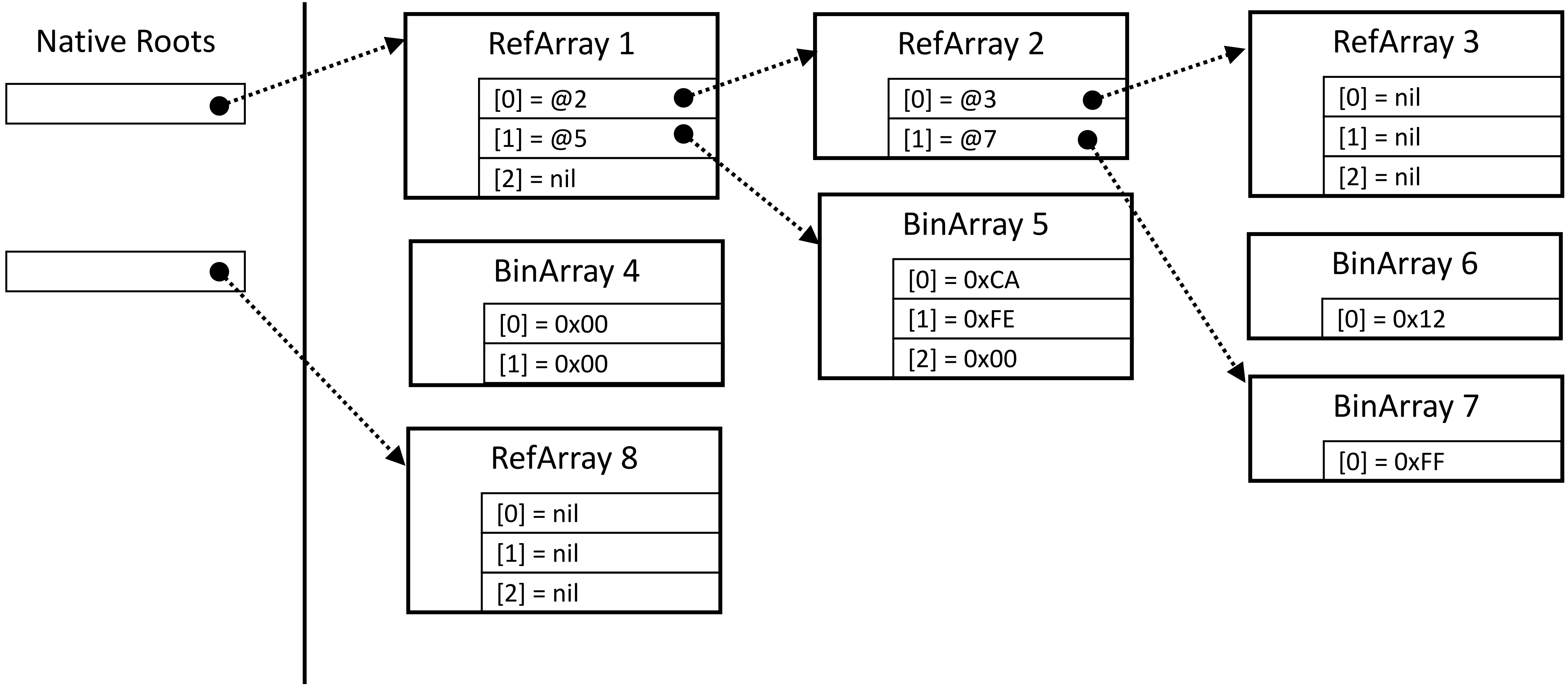

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[1] = 0xFE

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BinArray 6

[0] = 0x12

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RefArray 8

[0] = nil

[1] = nil

[2] = nil

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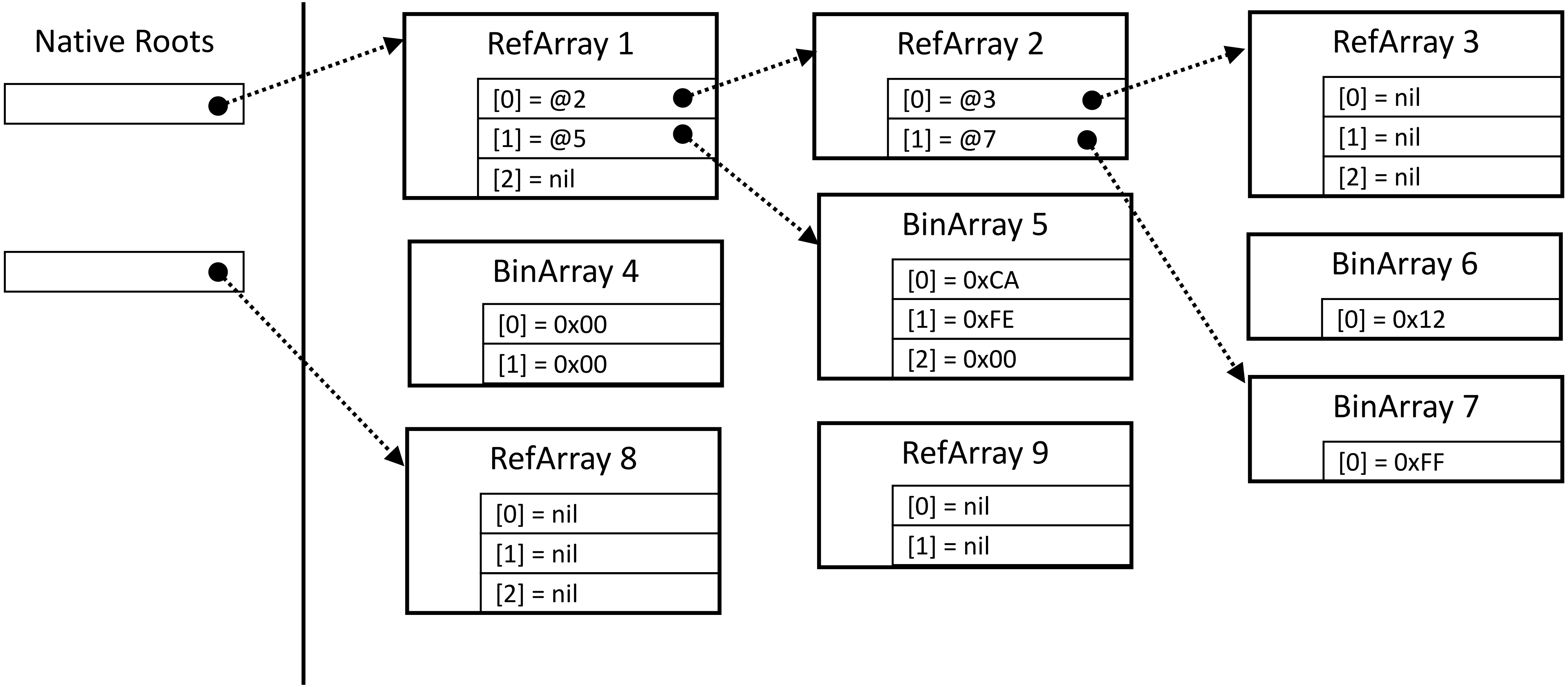

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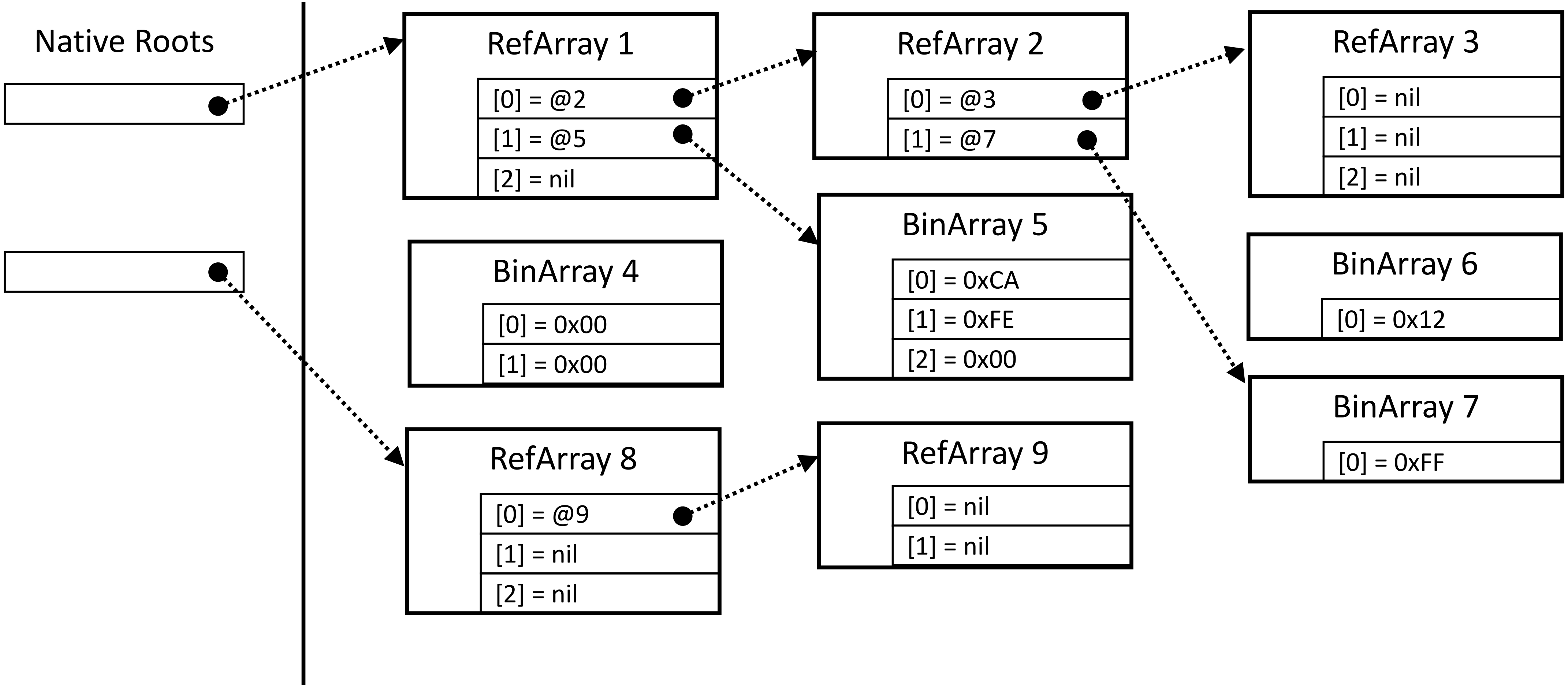

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[2] = 0x00

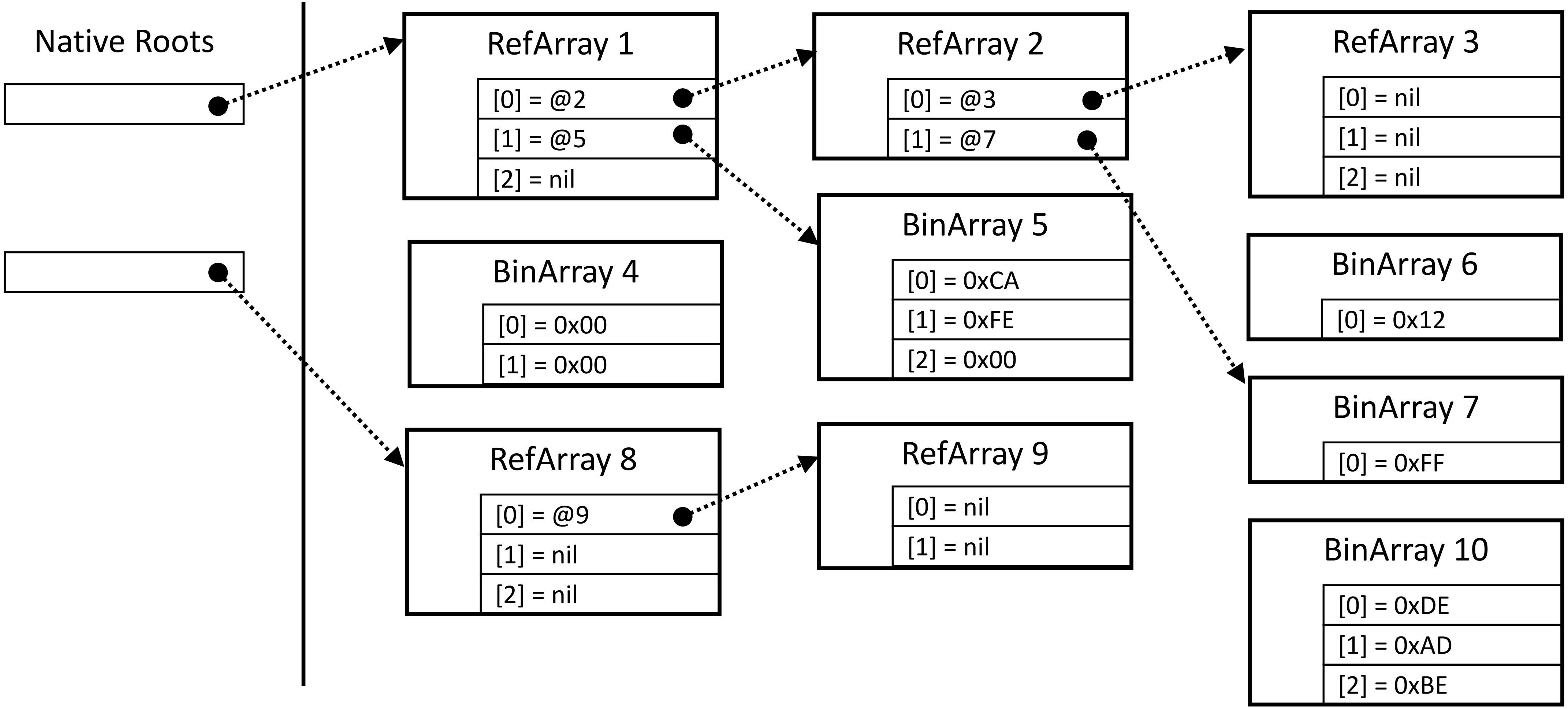
BinArray 6
[0] = 0x12

BinArray 7
[0] = 0xFF

RefArray 8
[0] = @9
[1] = nil
[2] = nil

RefArray 9
[0] = nil
[1] = nil

Memory: Graphs of objects



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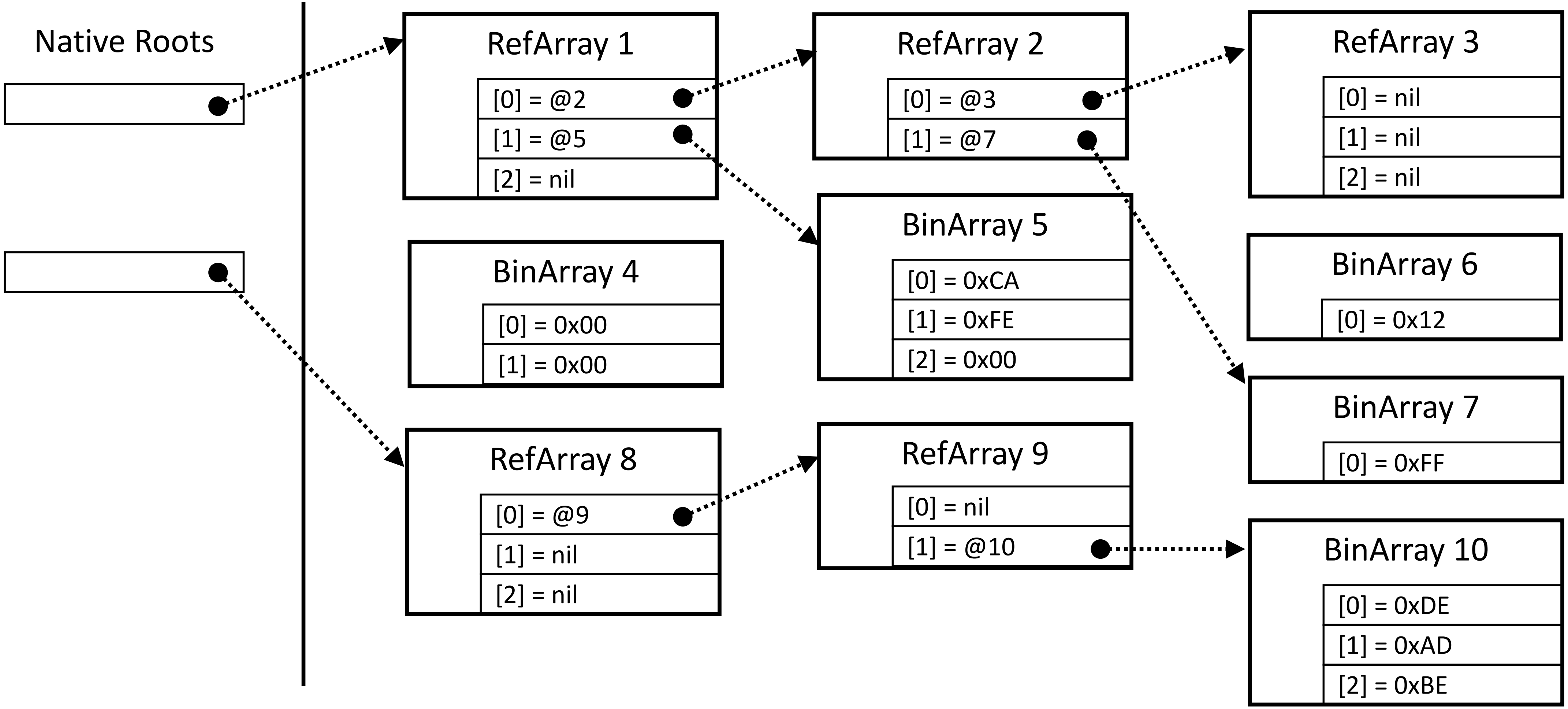

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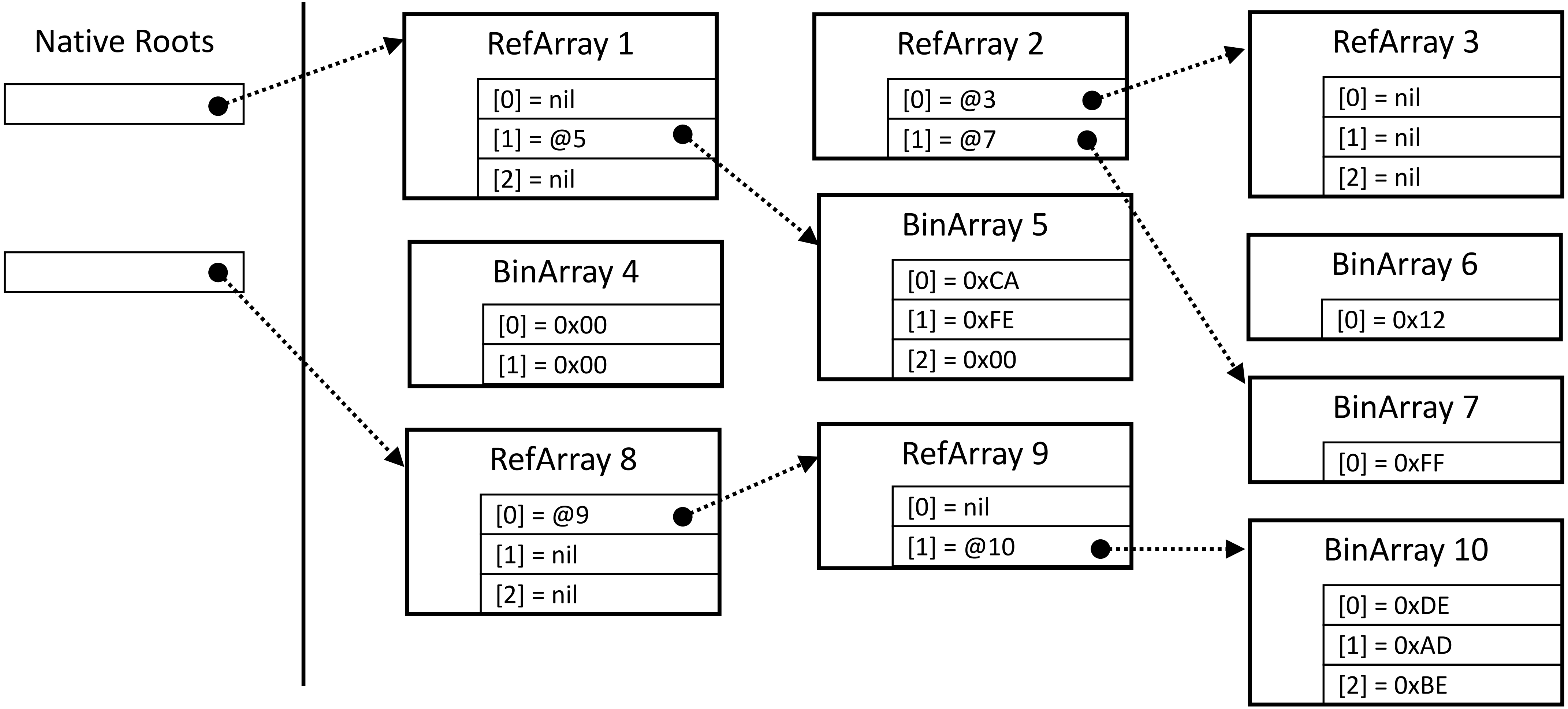

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[1] = 0xFE

[2] = 0x00

BinArray 6

[0] = 0x12

BinArray 7

[0] = 0xFF

RefArray 8

[0] = @9

[1] = nil

[2] = nil

RefArray 9

[0] = nil

[1] = @10

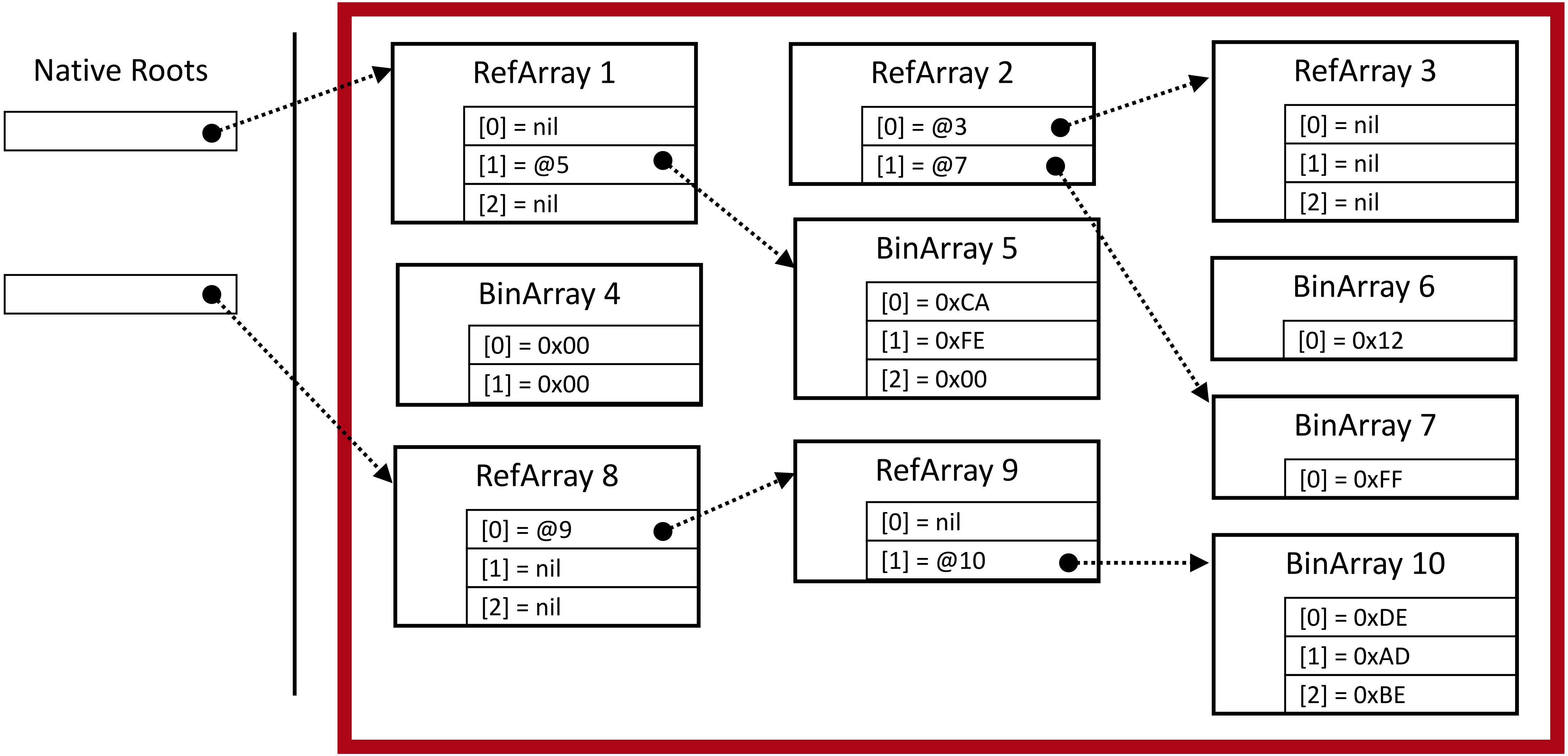
BinArray 10

[0] = 0xDE

[1] = 0xAD

[2] = 0xBE

Out of memory!



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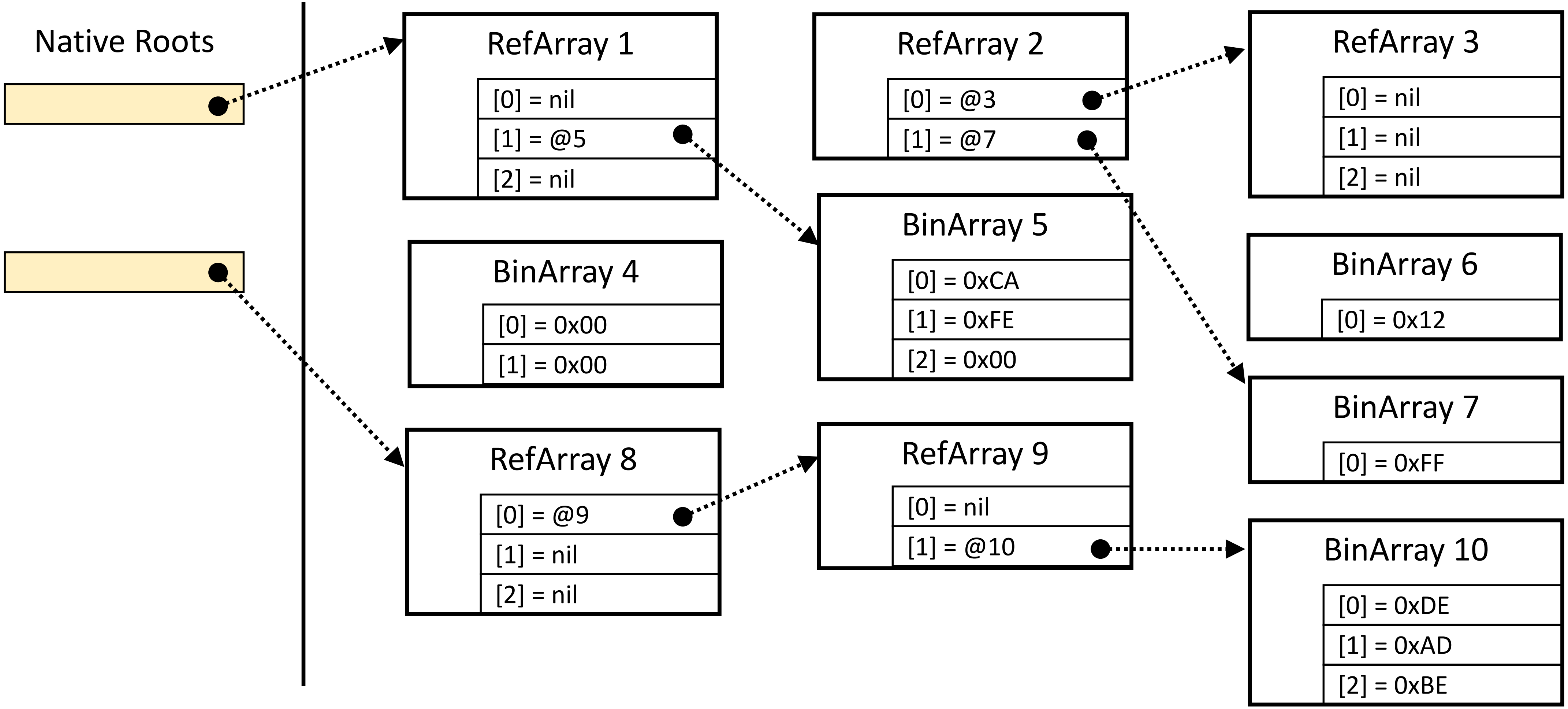

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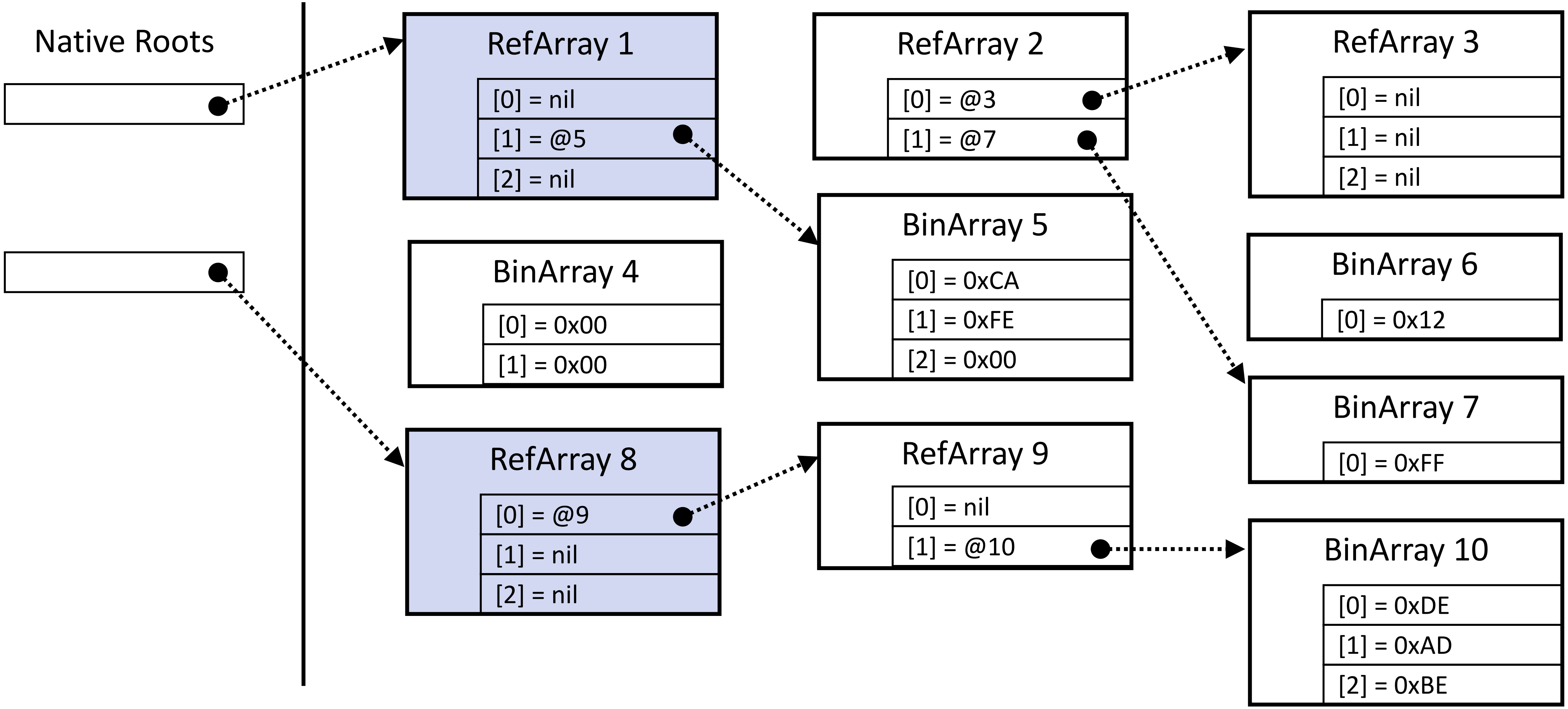

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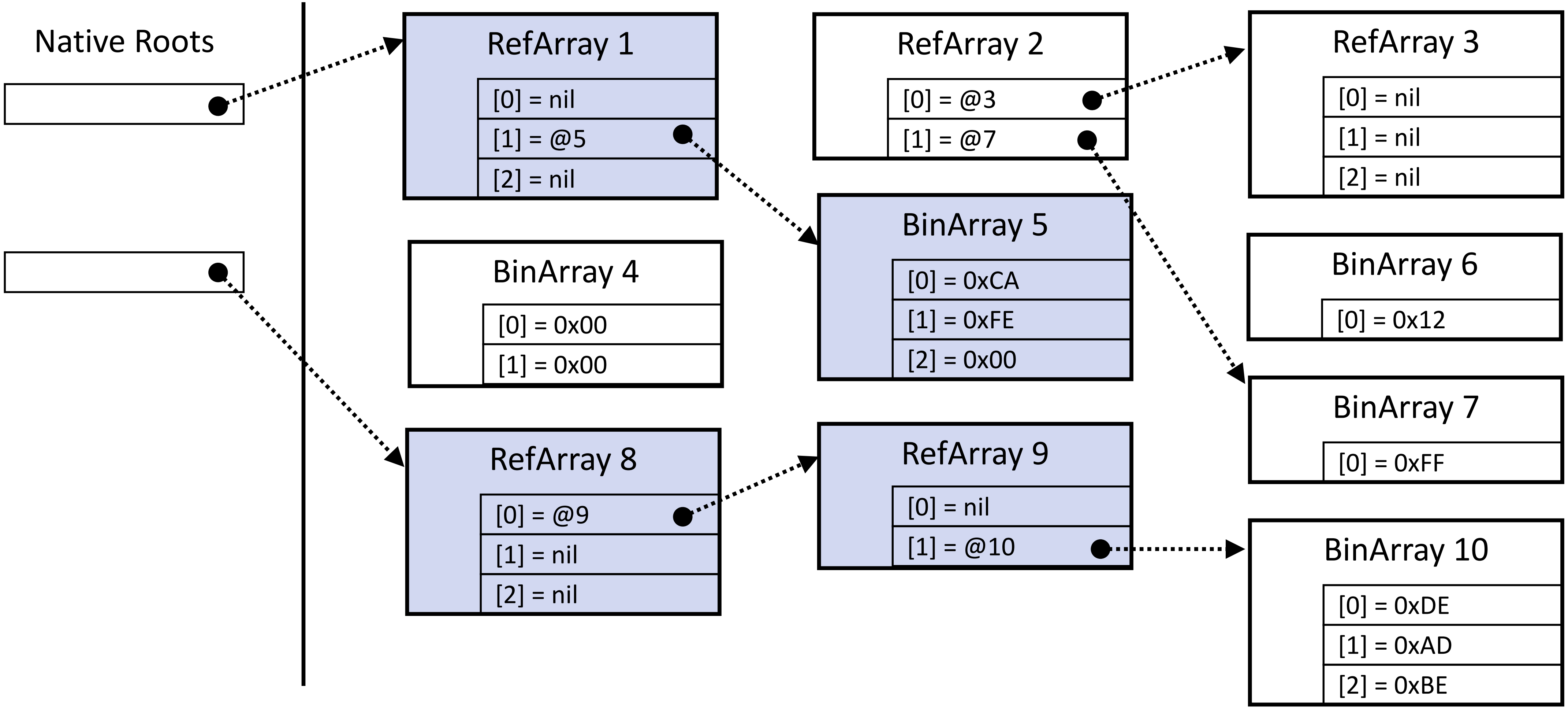
Memory: Graphs of objects



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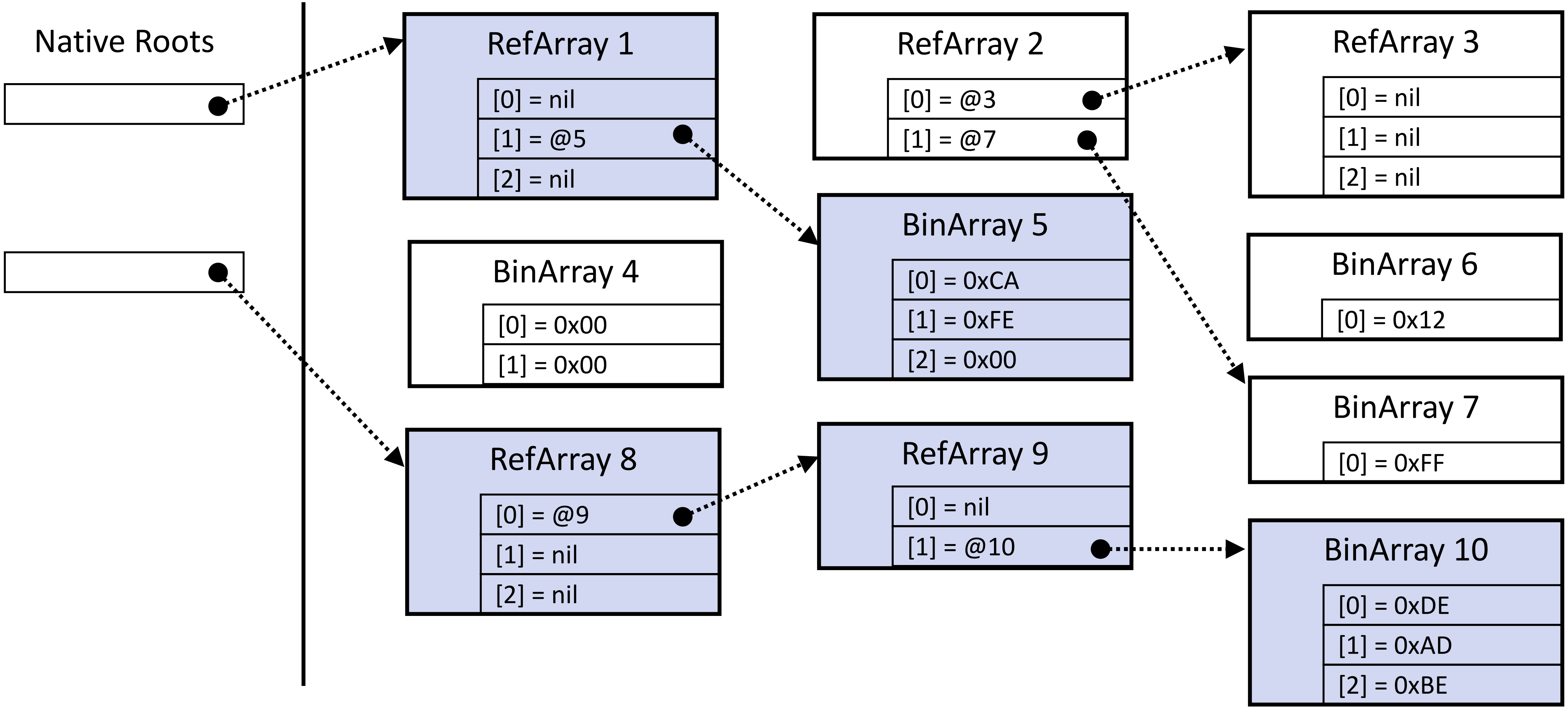

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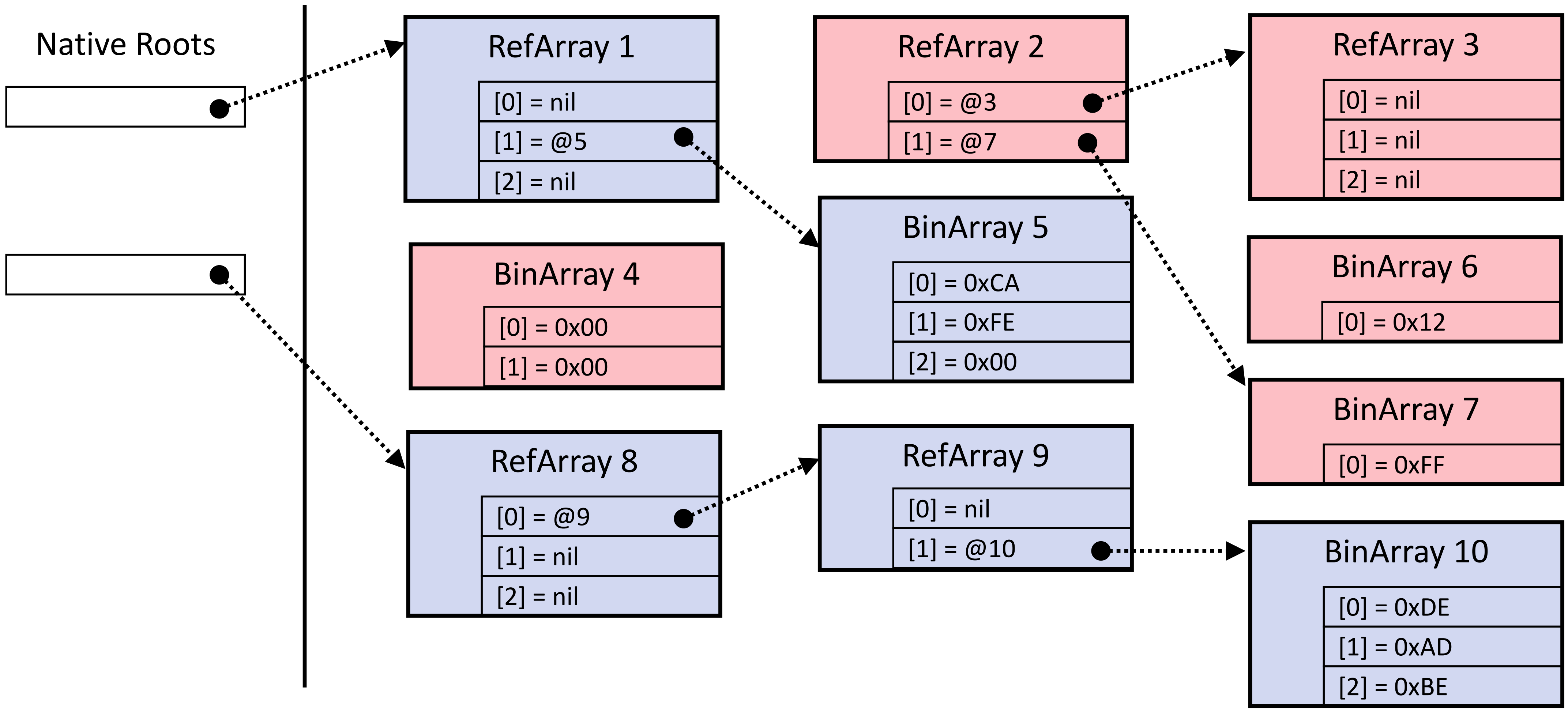

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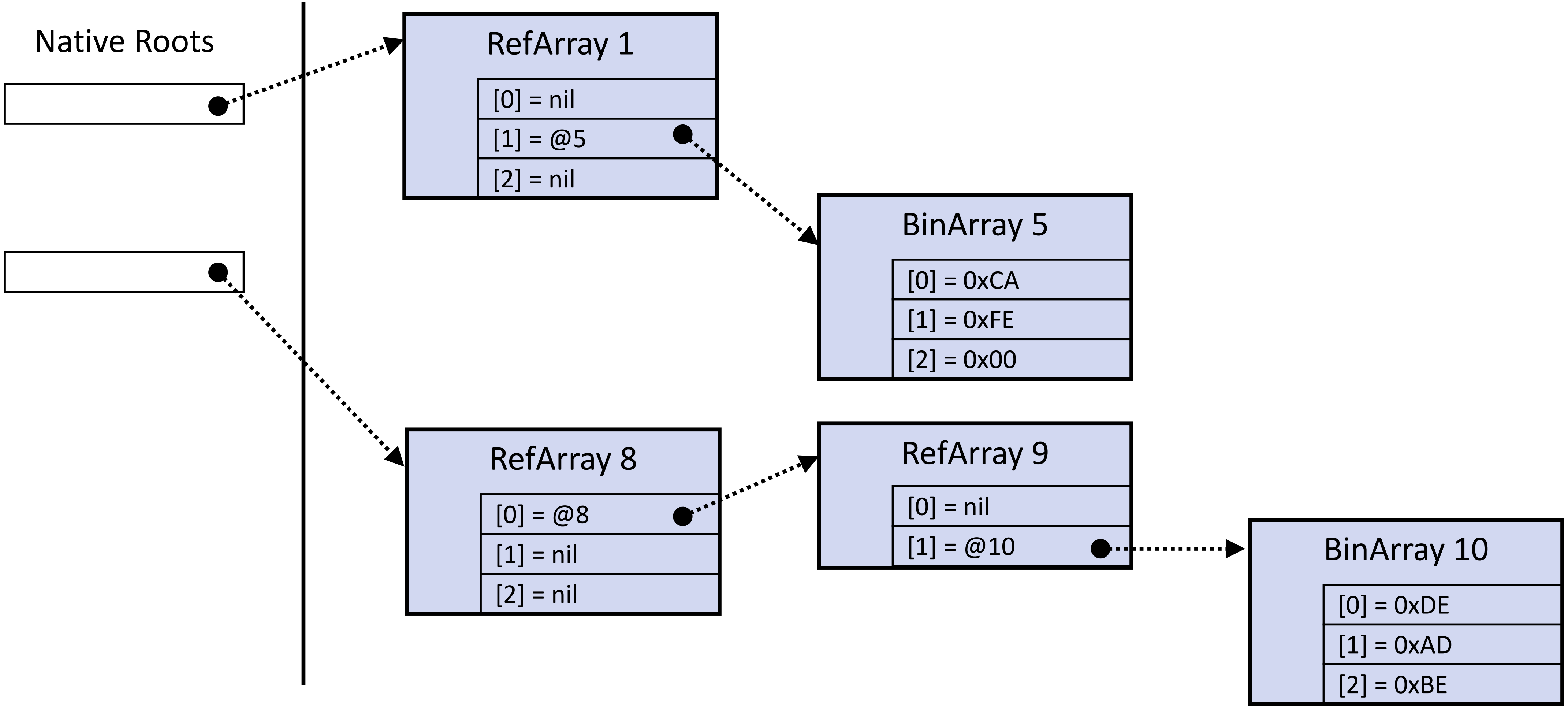


What’s going on?

1. The collector is using a classic “mark and sweep” algorithm
    1. Scan roots, mark reachable objects, put them on a work stack
    2. Scan the objects on the works stack, to find new live objects
    3. Build a map of the used and unused portions of the heap
    4. Add unused portions of the heap to the free list

- Memory is reclaimed in bulk, on demand
- Free memory is found in the space “between” live objects
- The GC has no “per-object” free operation (no destructors)

What does the GC need to know?

- Root scanning – what objects are we working with?
- Object size
- How to find references between objects:
  - Slot Location: object + offset
  - Slot Encoding: need to read and write references
- When is the graph changed?

Configuring the GC

- OMR is massively configurable at compile time
- You must teach the GC about your objects and runtime
- Users (that’s us!) implement “client” code
- A set of APIs defined by OMR, but implemented by consumers
- Client code is compiled and inlined into OMR
- Clients can incrementally develop their client code to enable new technology

The OMR GC API

An experimental set of APIs for the collector

Initializing the collector

- OMR::Runtime
  - Process wide singleton
  - Responsible for initializing the port & thread library
  - Required to bring up the GC subsystem
- OMR::GC::System
  - A complete garbage collected heap
  - Static configuration is optionally passed in to the constructor
  - You can bring up multiple heaps per process (hopefully, haha !)
- OMR::GC::Context
  - A per-thread GC context, required for most public APIs
  - Provides local heap caches, heap access locks, and rooting utilities

Collector initialization

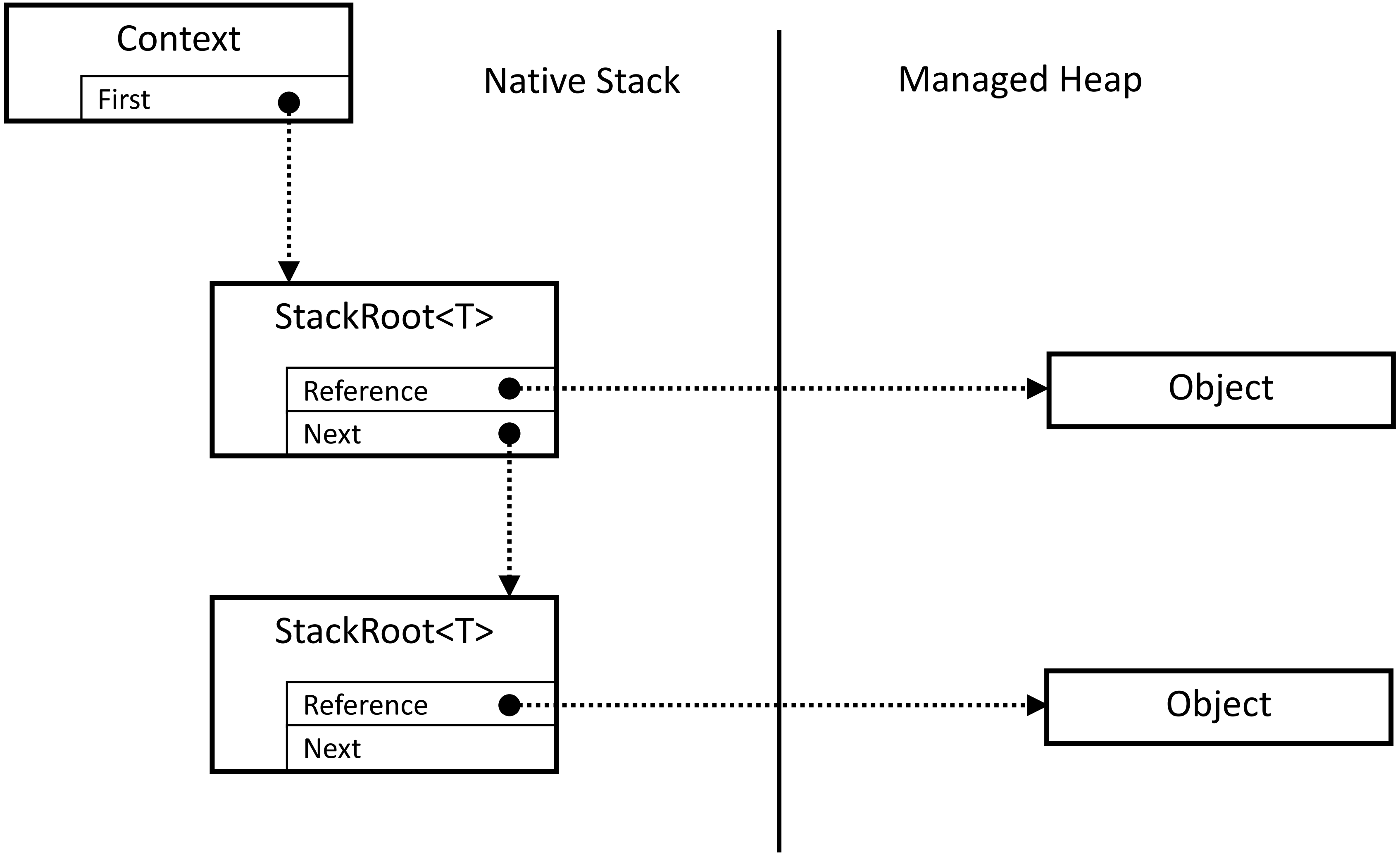
```
#include <OMR/GC/System.hpp>

// Process-wide singleton
OMR::Runtime runtime;

// Each system contains a unique heap. Per-VM.
OMR::GC::System system(runtime, config);

// Thread-local context to the GC::System.
GC::Context cx(sys);
```

The object-oriented allocator

```
template <typename T, typename Init>
T* OMR::GC::allocate<T>(cx, size, Init init);
```

- The return value is an unsafe heap reference.
- The initializer must put the new allocation into a scannable state
  - IE: set the objects size, and clear any reference slots.
  - The initializer cannot allocate.
- Collections can happen at allocation sites.
  - Do not hold raw heap reference across allocations sites!
  - Use the NoCollect API when it’s not safe to collect.

StackRoots: Automatically rooted pointers



StackRoot: Automatically Rooted References

Attached to a specific context, and null by default:

```
   StackRoot<Object> root(cx);
```

Assignable, and comparable:

```
   StackRoot<Object> r0(cx, allocateObject());
   StackRoot<Object> r1 = r0;
   r0 == r1; // true
```

Have a pointer-like API:

```
   Root->field = 42;
   (*root).field = 42;
```

Stack Roots have LIFO semantics and must be allocated on the stack.

Finding slots in Objects

- We need to show the GC how and where GC refs are stored
- We implement an object scanner that can notify GC visitors about edges between objects
- We give the visitor slot handles (pointers to slots).
- The GC uses these handles to read/write references from object slots.
- The OMR::GC::RefSlotHandle can be used for slots containing plain, untagged, full-width addresses
- Clients can provide their own slot handle types for defining custom read/write operations.

Let’s get started!

Coffee break!

Heap Compaction

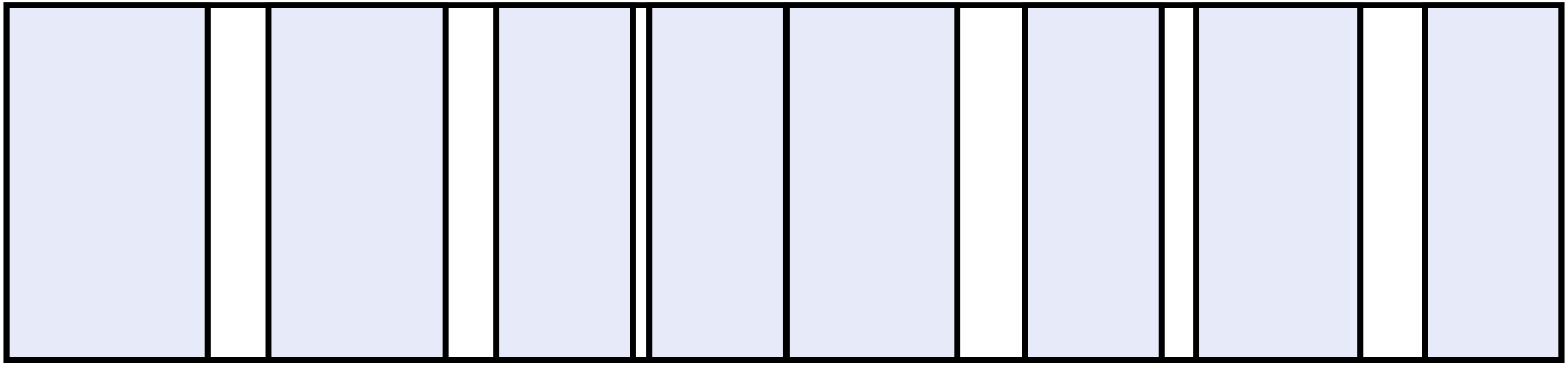
Heap Compaction

- Over time, heap memory becomes fragmented
- Fragmentation is bad
- The collector can slide left compaction
- Eliminates heap fragmentation
- Extremely important for long lived applications

The Heap

□ Free Space

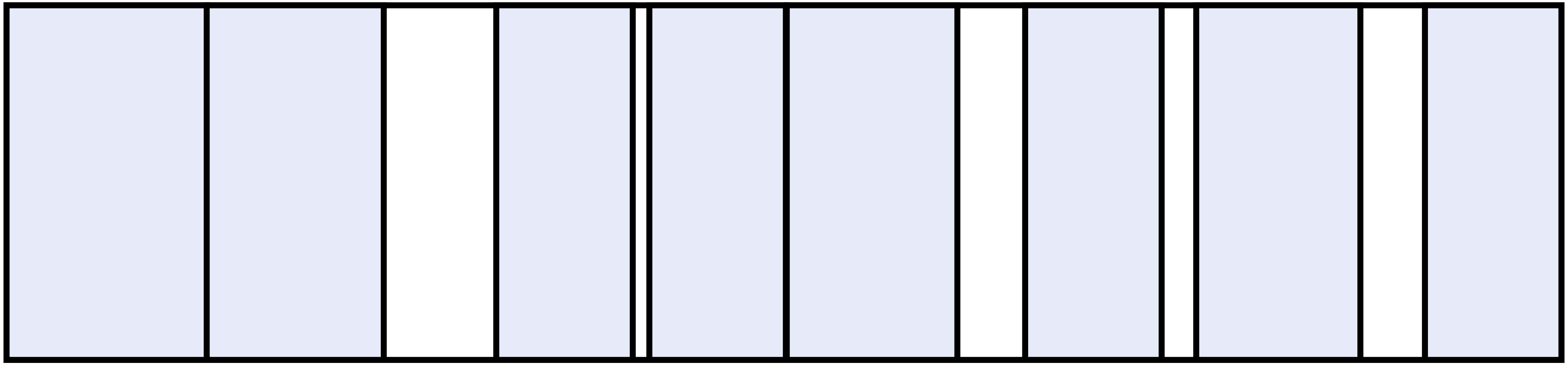
▨ Objects



The Heap

□ Free Space

▨ Objects



The Heap

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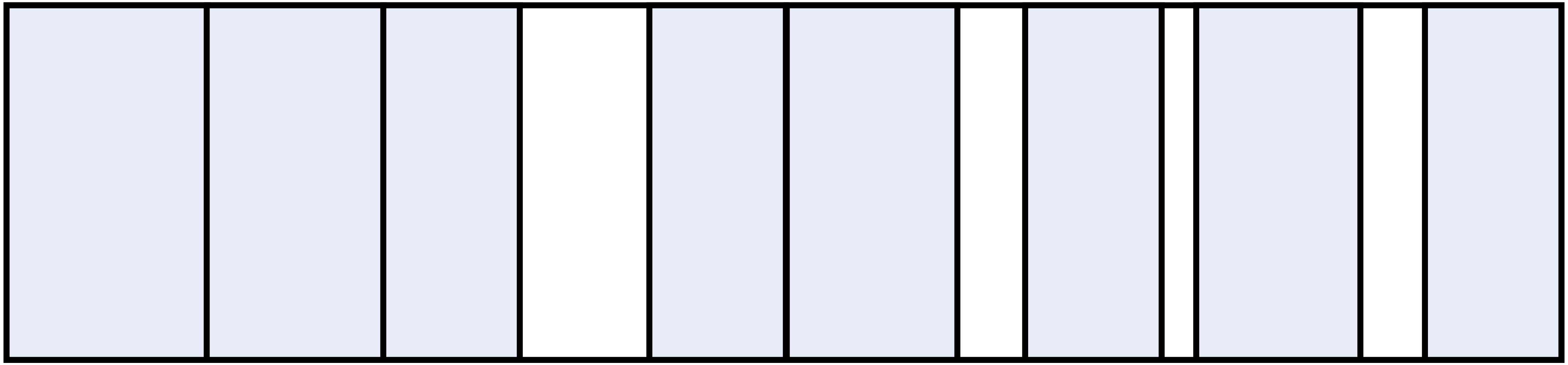

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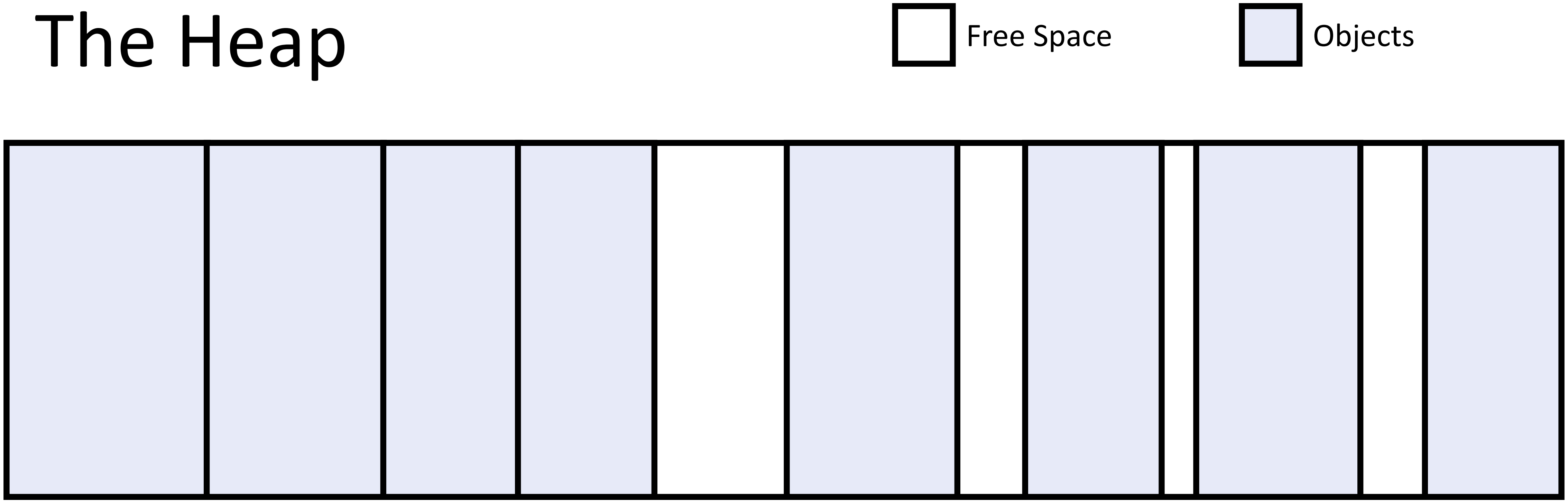

The Heap

□ Free Space

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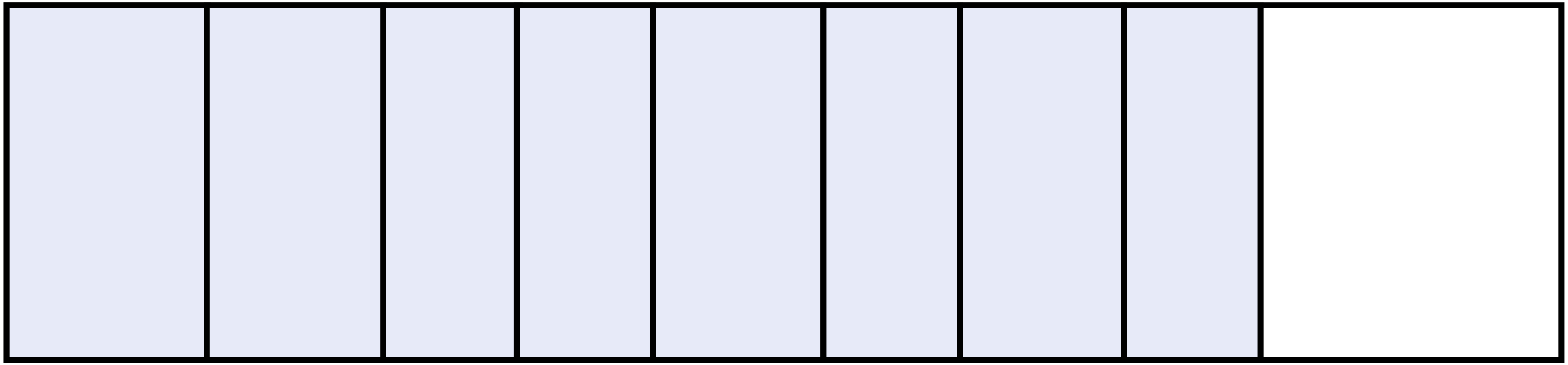


Generational collection (Scavenging objects)

What is generational GC?

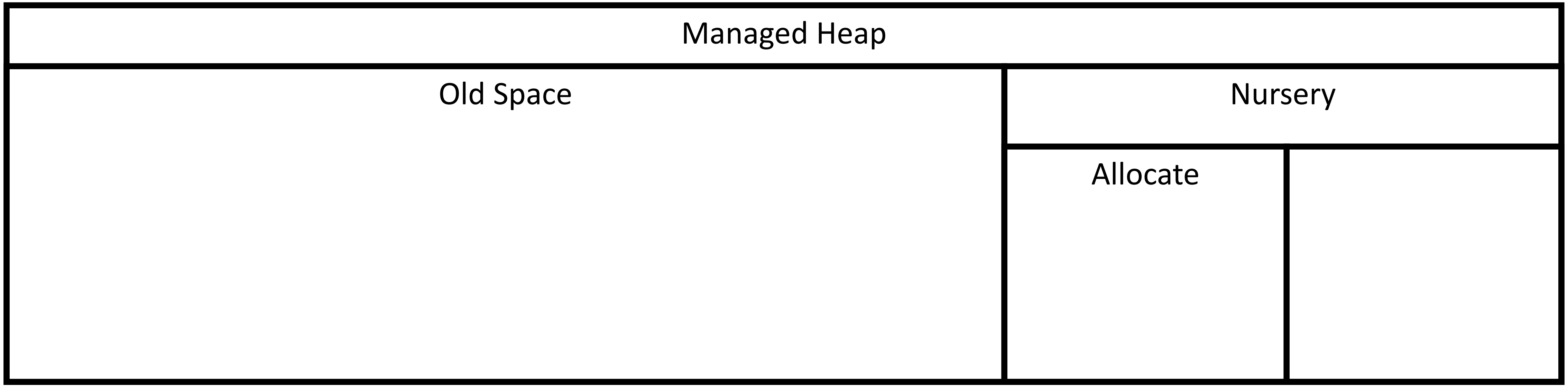
- Weak generational hypothesis:
    - Young objects are more likely to die, or
    - The longer an object lives, the more likely it is to survive.
- The plan: scan only newly allocated objects
- Old objects will survive
- When objects survive long enough, tenure to old-generation
- Also known as “local collection”

Remembering old objects

- When an old object references a new object, we “remember” it
- During a local collection old objects will survive
- In a local collection, treat remembered objects as roots
- How do we find old -> new references?
- Use a “write barrier” to track all object graph updates
- Every time a reference is stored:
  - Is the referrer in old space?
  - Is the referent in new space?

  => Remember the referrer

The Generational Heap



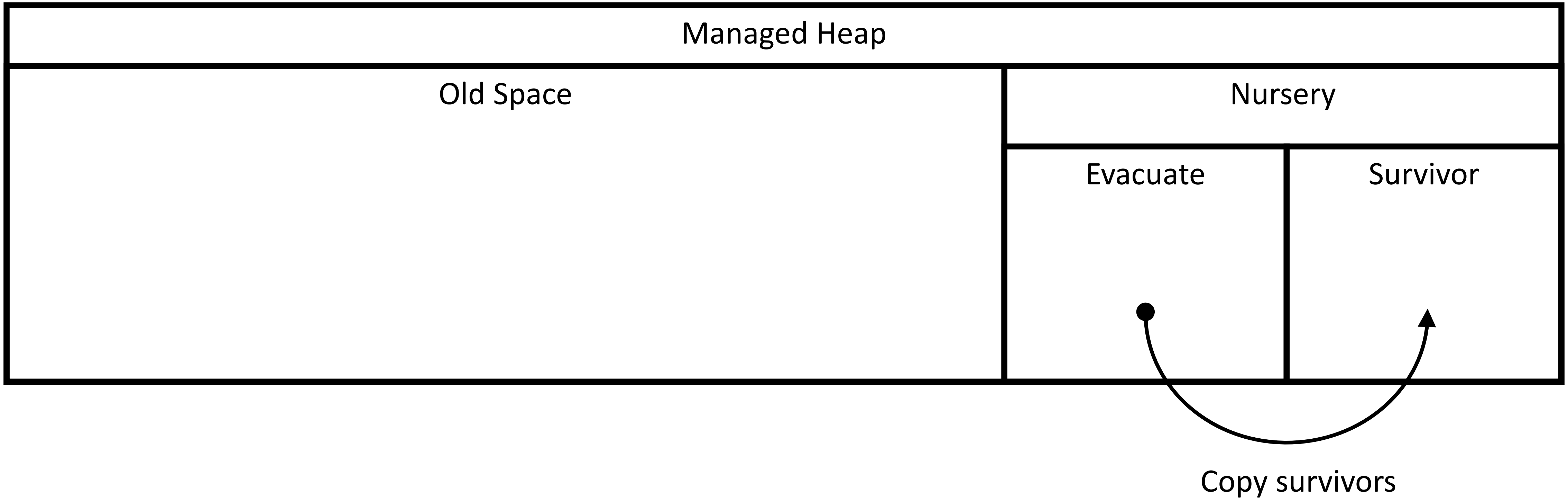
Managed Heap

Old Space

Nursery

Allocate

The Generational Heap: Scavenge



Managed Heap

Old Space

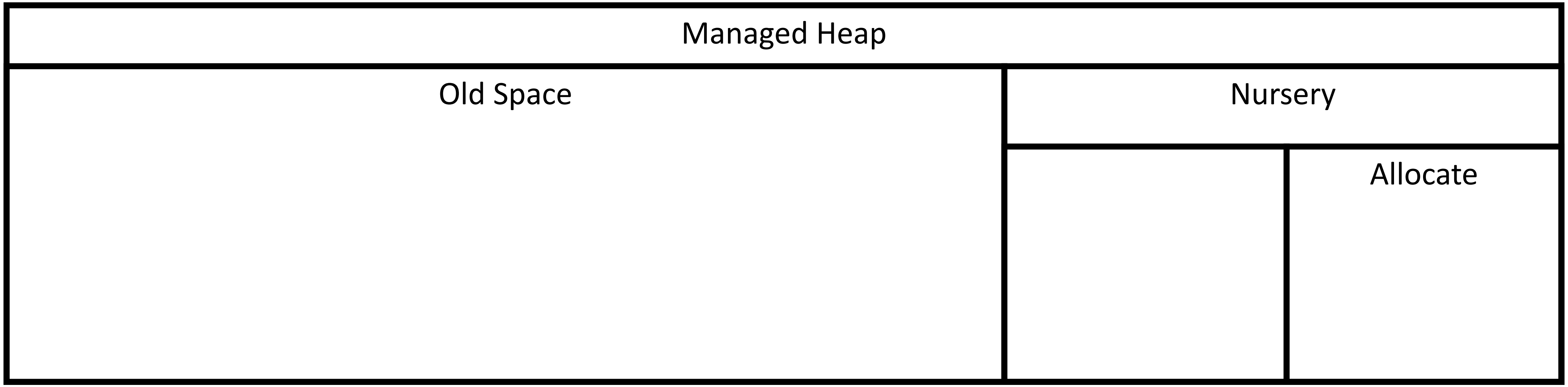
Nursery

Evacuate

Survivor

Copy survivors

The Generational Heap



Managed Heap

Old Space

Nursery

Allocate

OK, Back to work

Thank You!!