Multicore OCaml GC

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OCaml Labs

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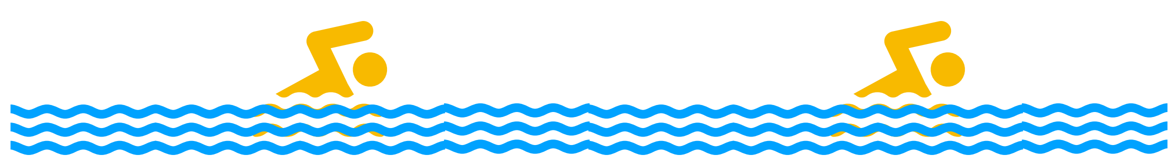

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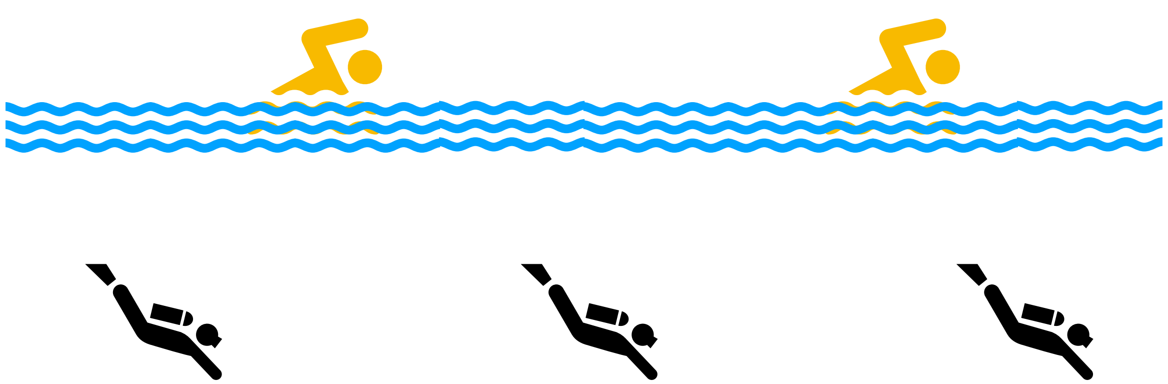
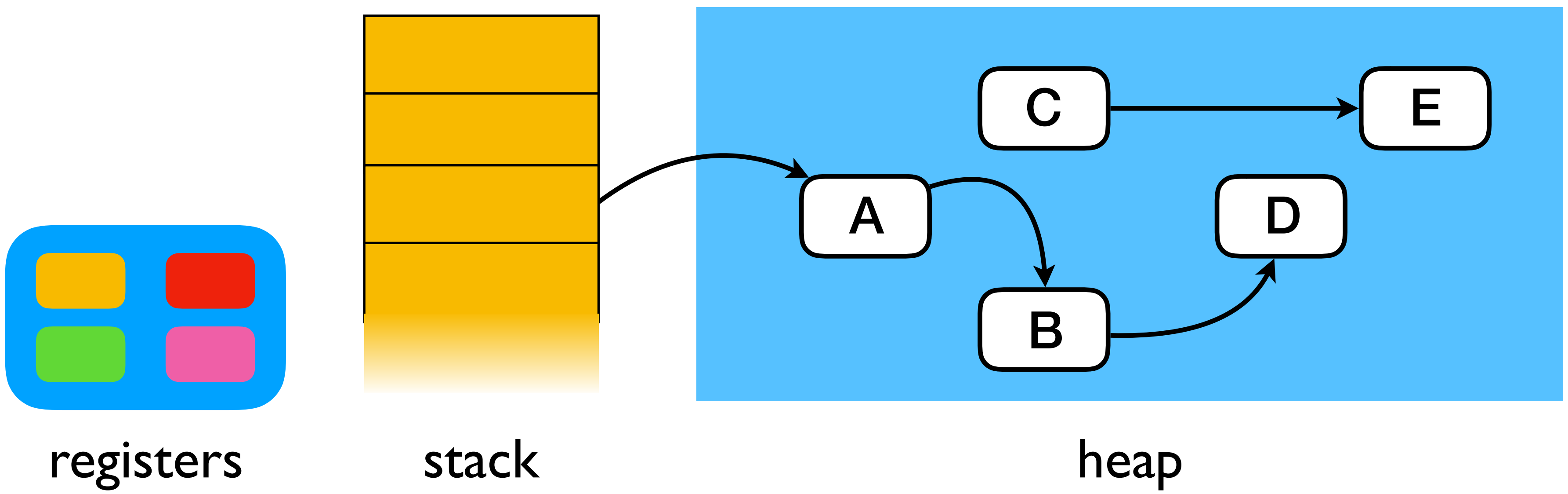


Outline

- Difficult to appreciate GC choices in isolation
- Begin with a GC for a *sequential purely functional* language
  - Gradually add mutations, parallelism and concurrency

Purely functional



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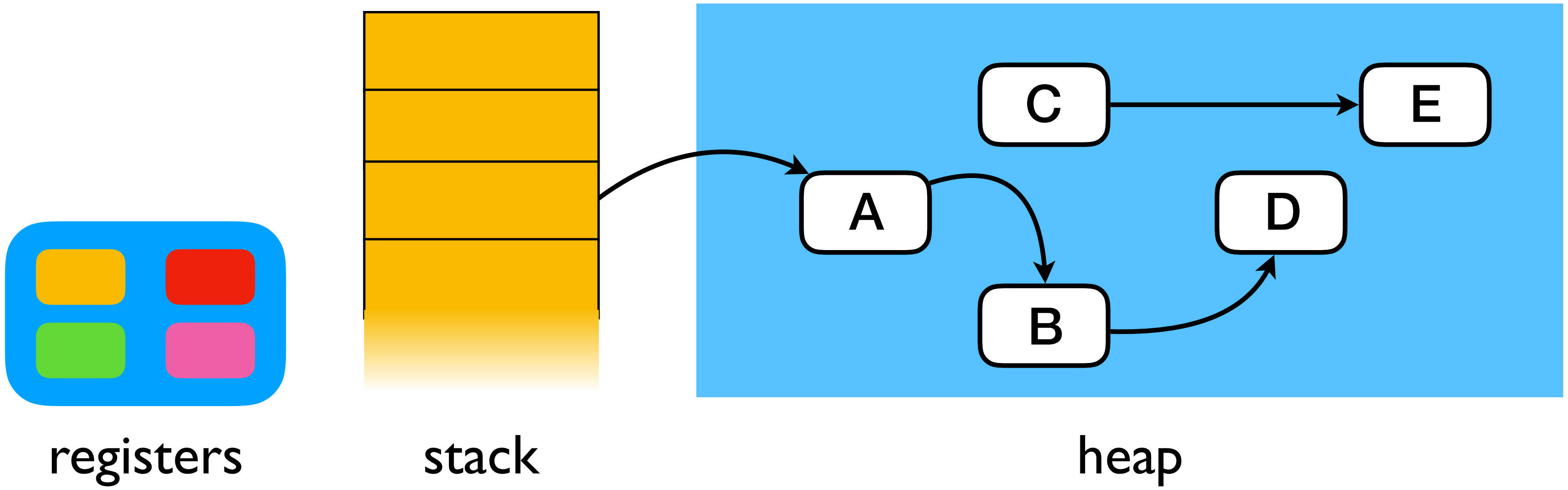

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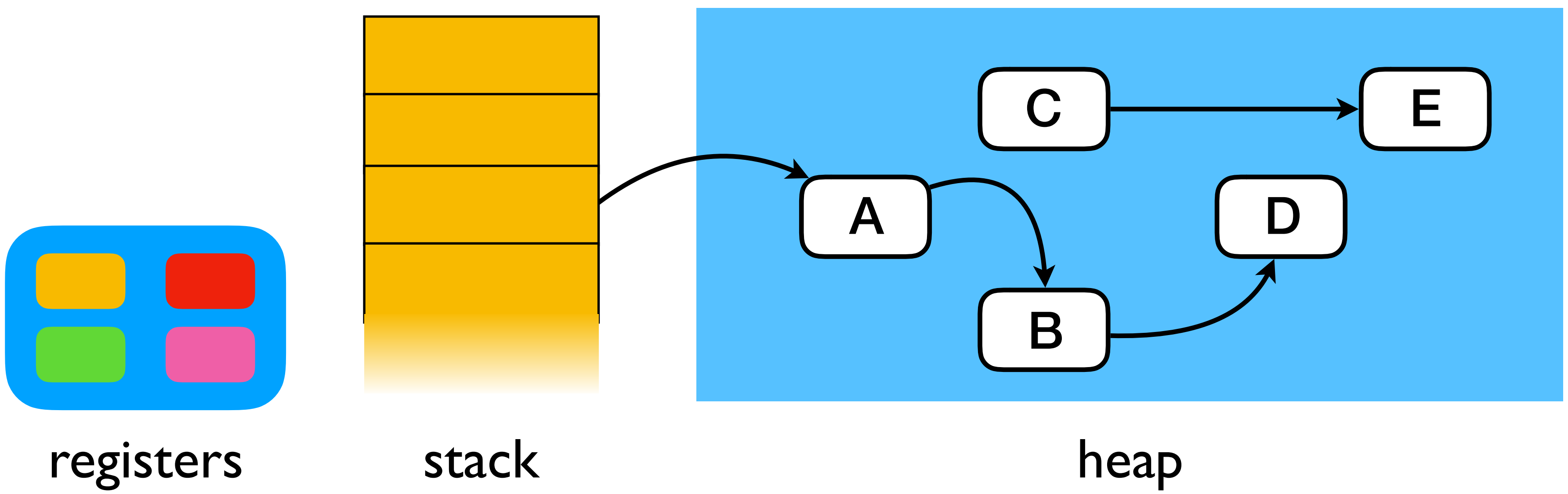

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  - States: White (Unmarked), Grey (Marking), Black (Marked)

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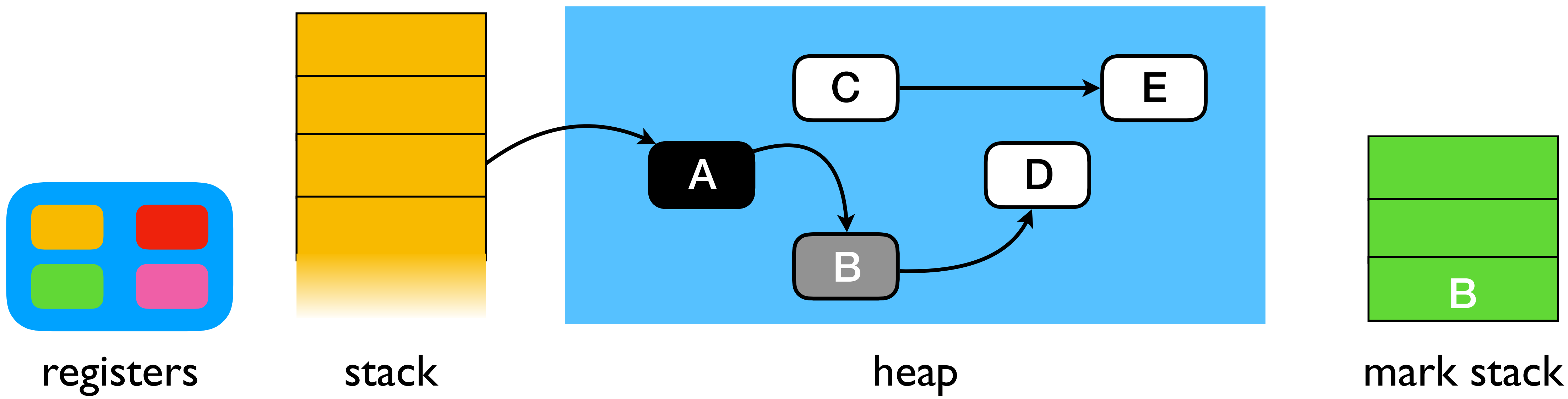

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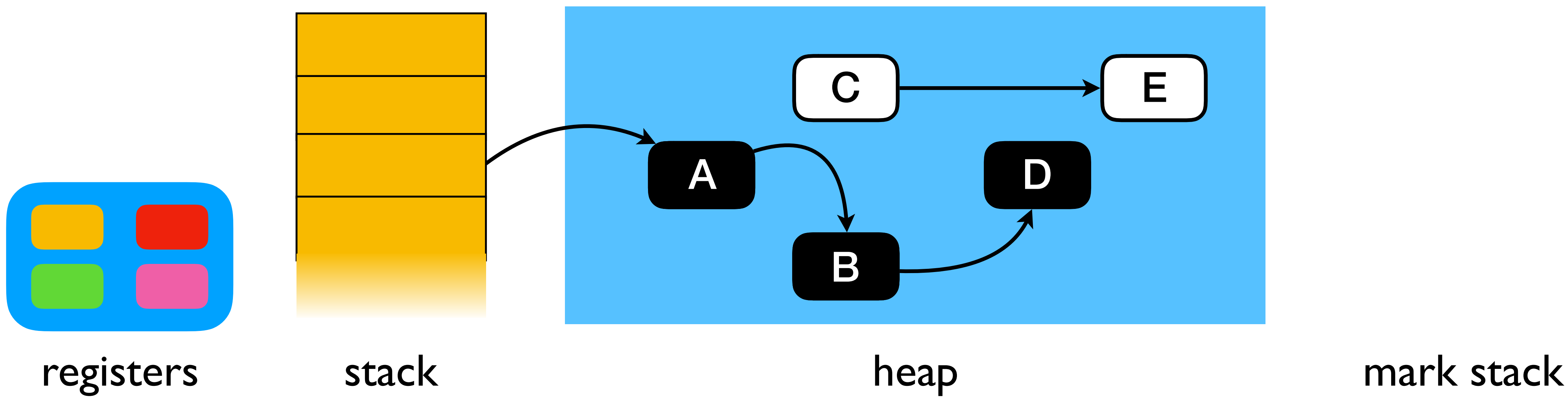

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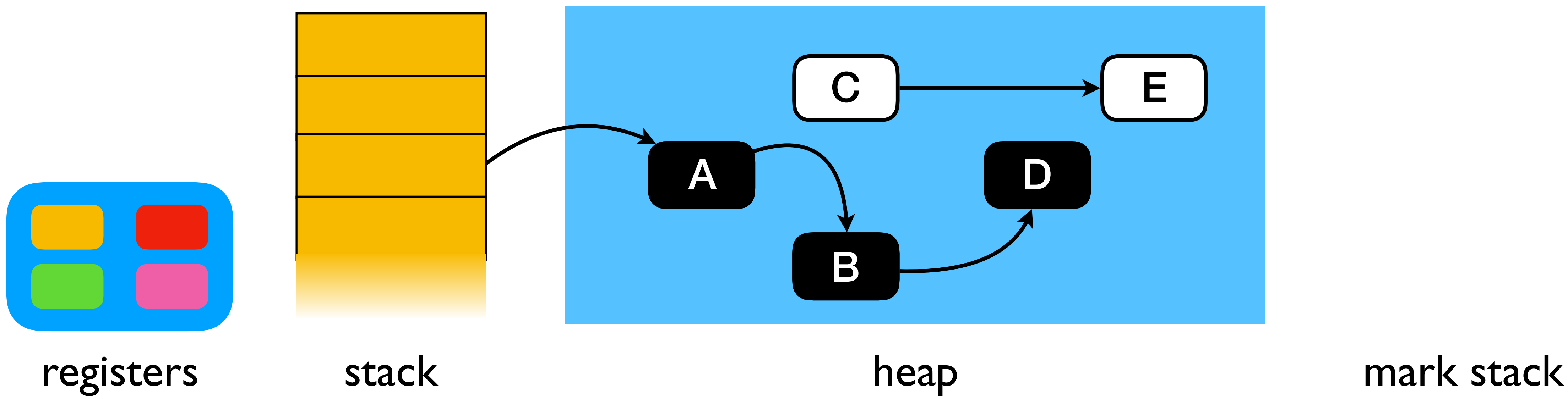

- Stop-the-world mark and sweep
- Tri-color marking
  - States: White (Unmarked), Grey (Marking), Black (Marked)
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- Mark stack is empty => *done*
- Tri-color invariant: *No black object points to a white object*

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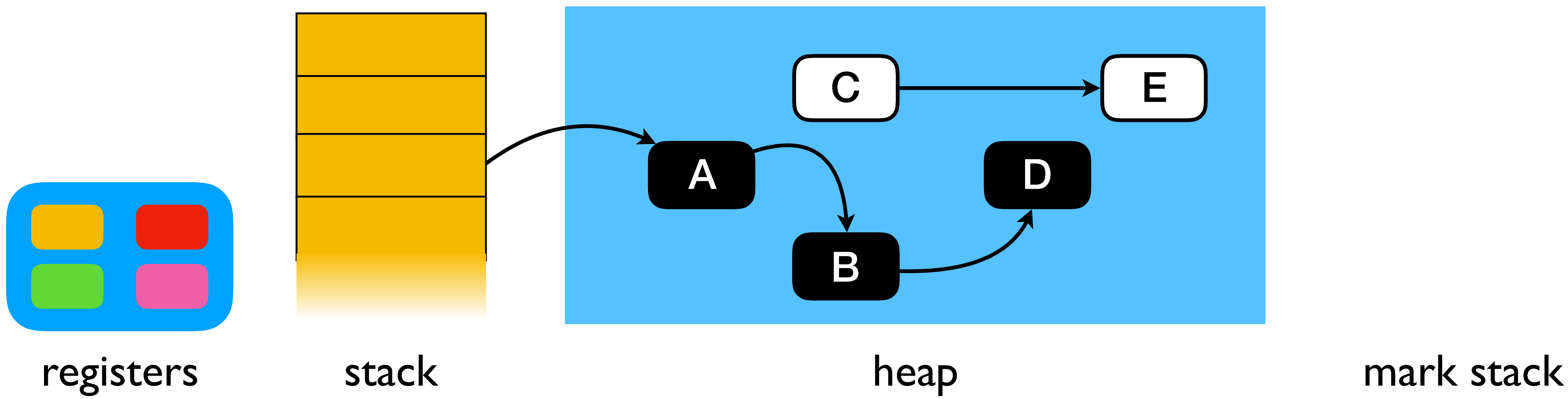

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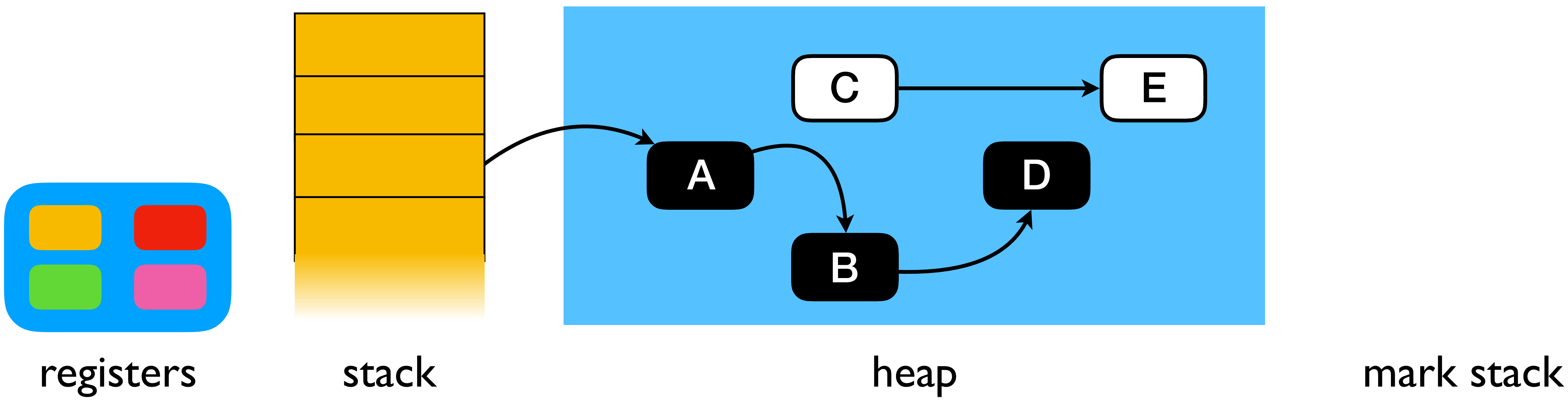

- Pros
  - ✦ Simple
  - ✦ Can perform the GC incrementally
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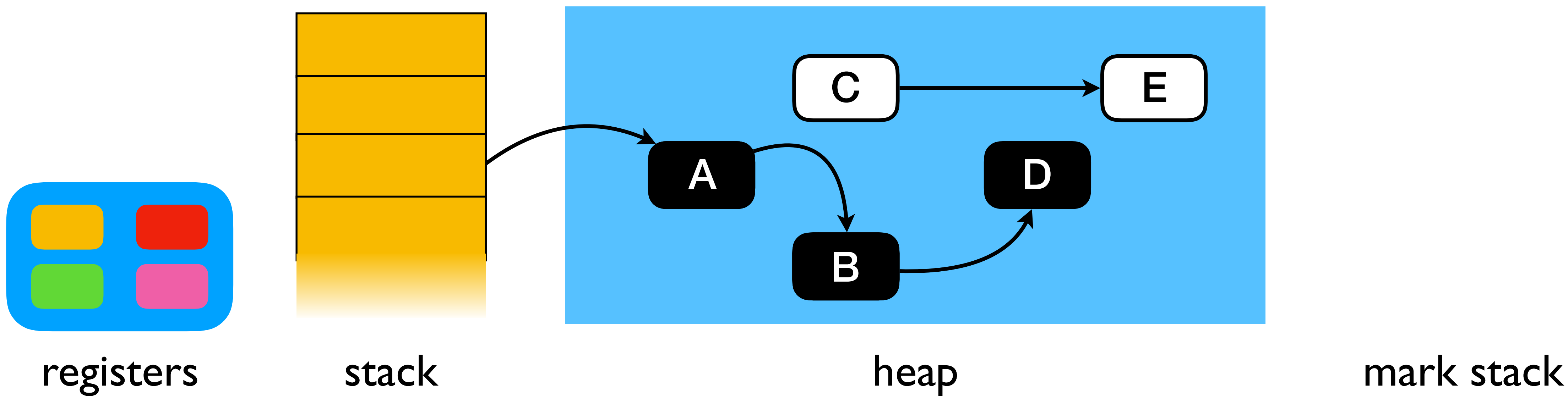

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- Cons
  - Need to maintain free-list of objects => allocations overheads + fragmentation

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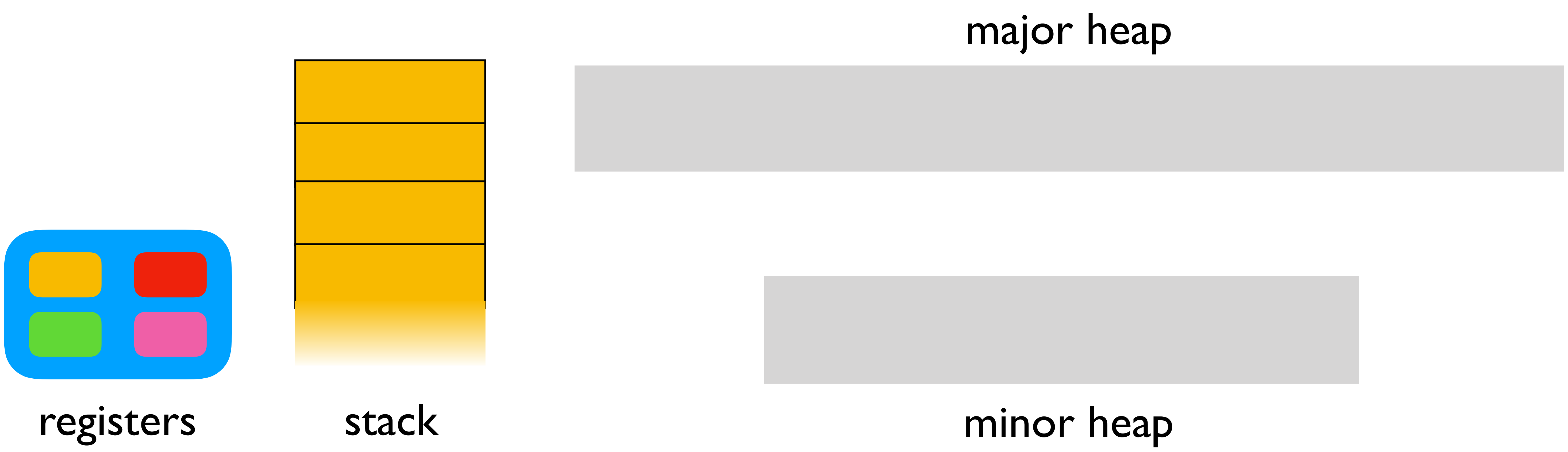

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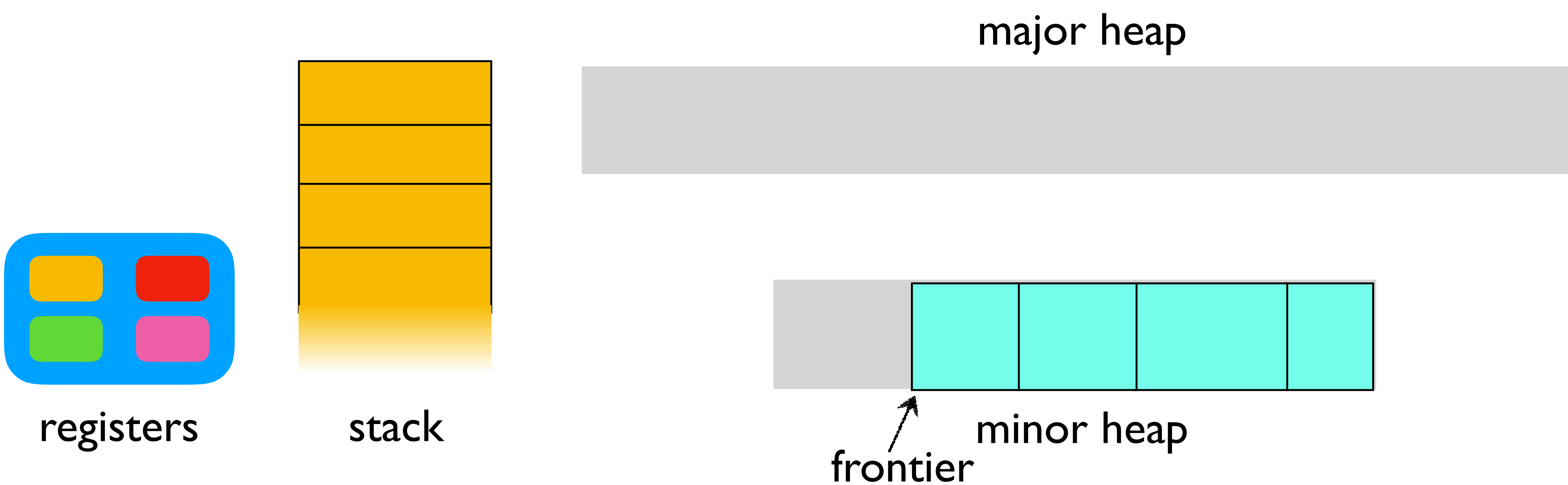

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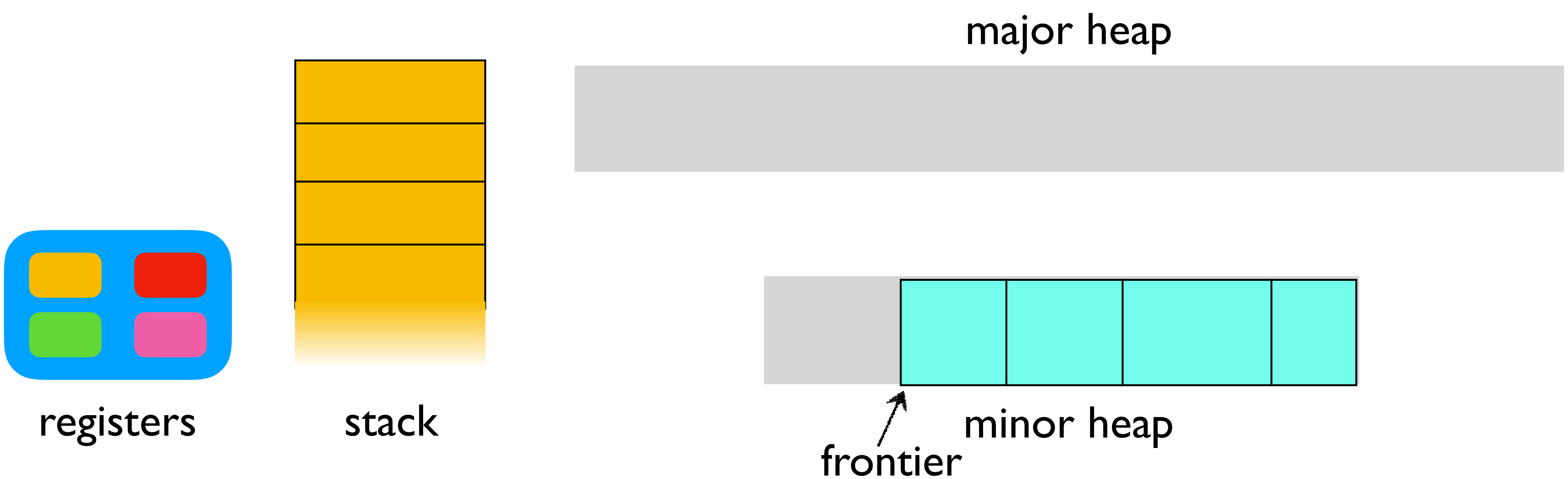

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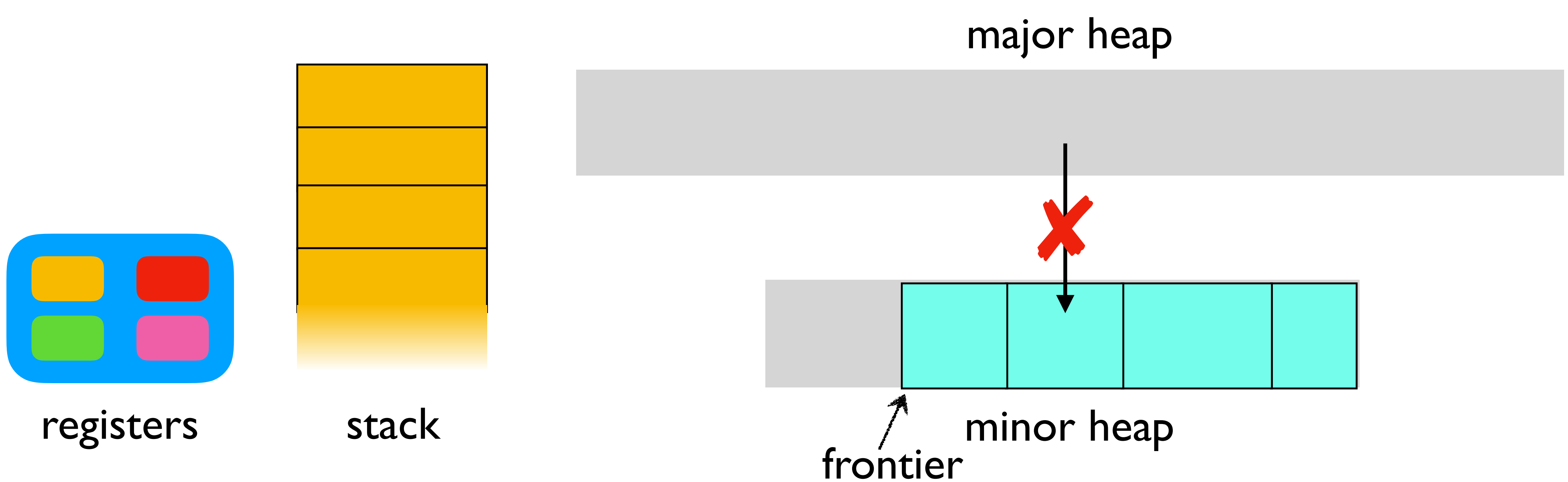

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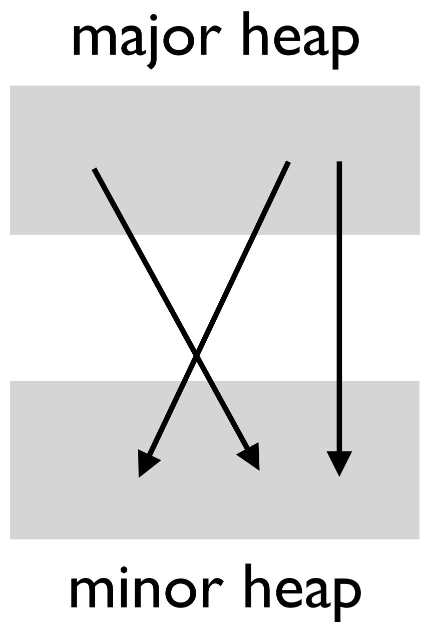
- Roots are registers and stack
  - ✦ purely functional => no pointers from major to minor

Mutations — Minor GC

- Old objects might point to young objects



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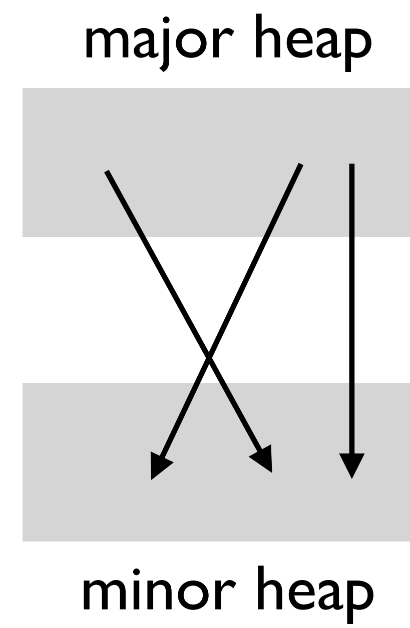

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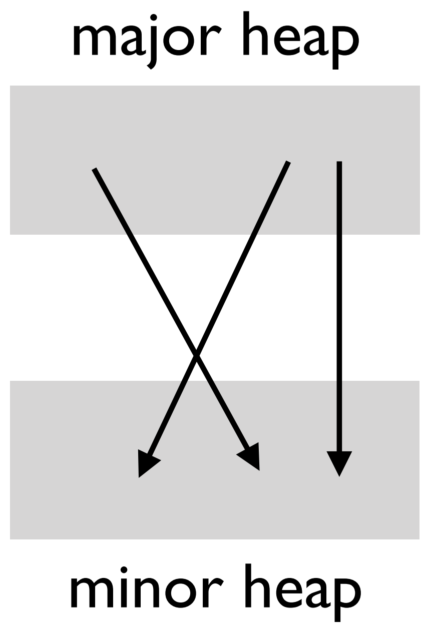

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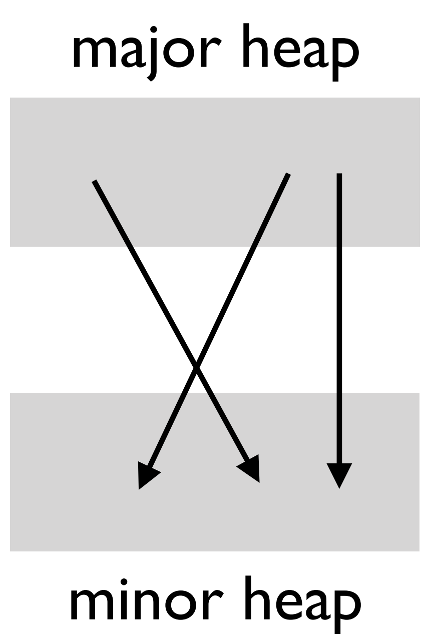
- *Remembered set*
  - ✦ Set of major heap addresses that point to minor heap
  - ✦ Used as root for minor collection
  - ✦ Cleared after minor collection.



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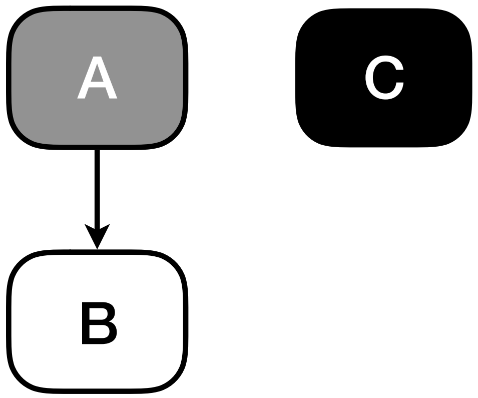

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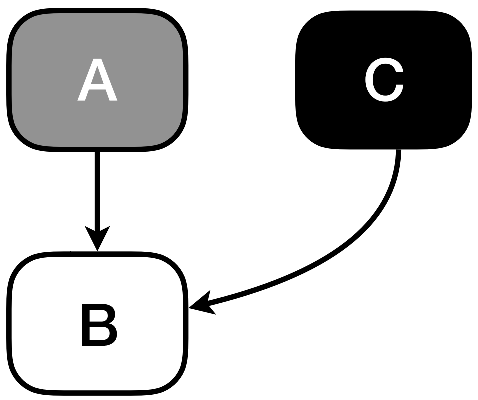

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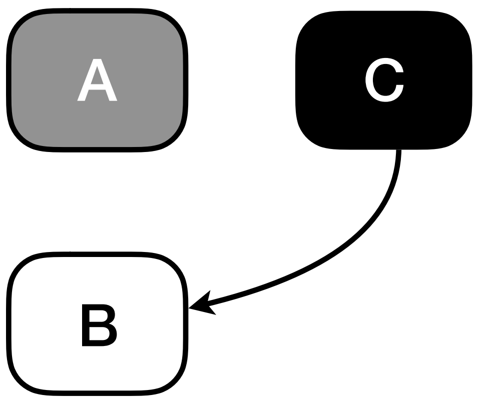

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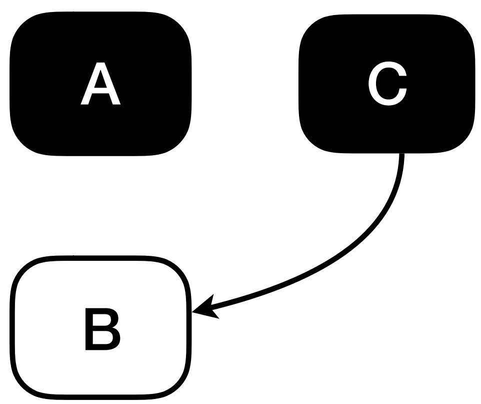

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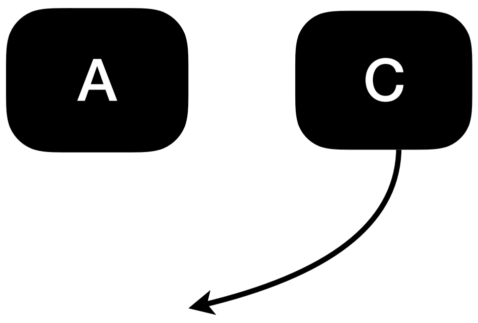

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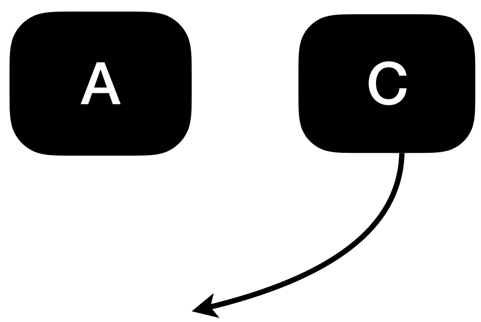

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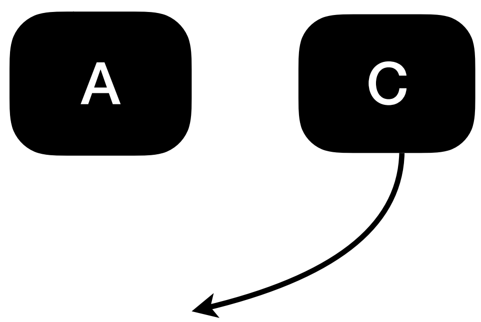

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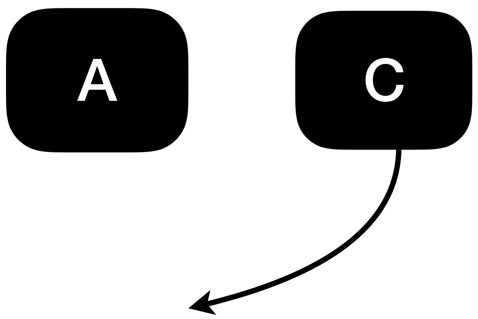

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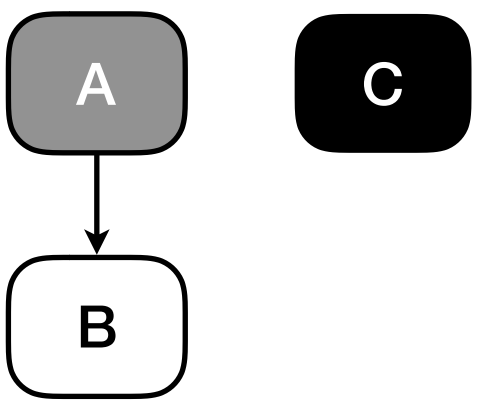

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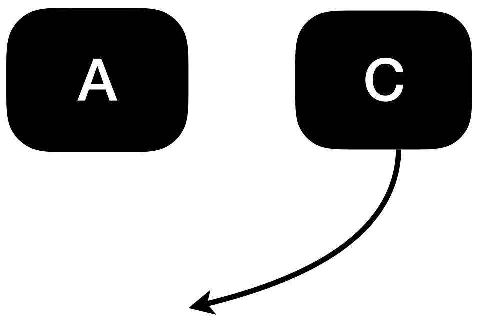

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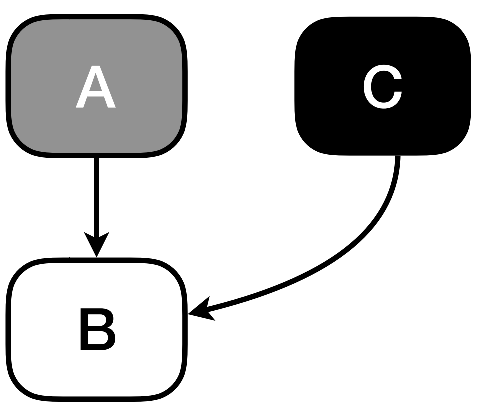

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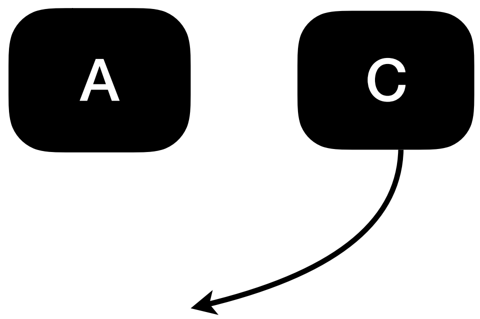

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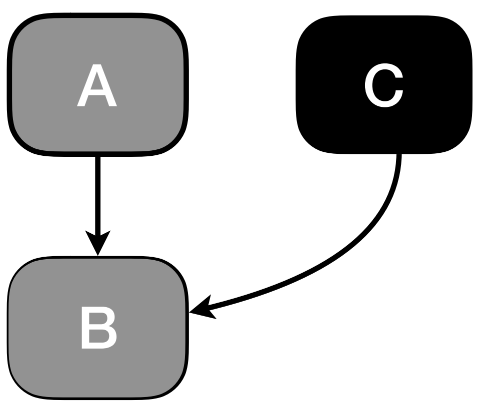

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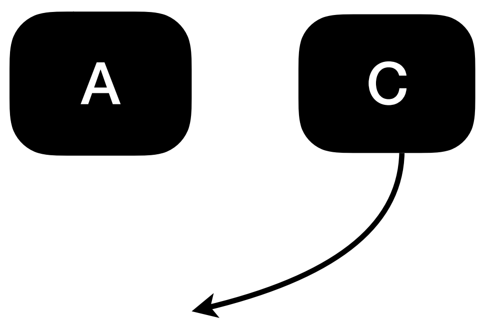

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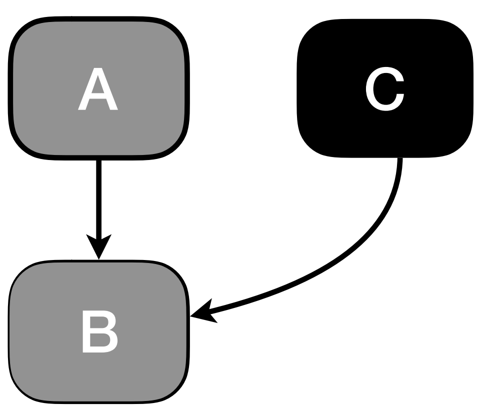

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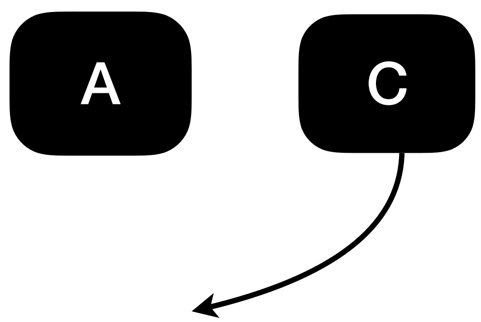

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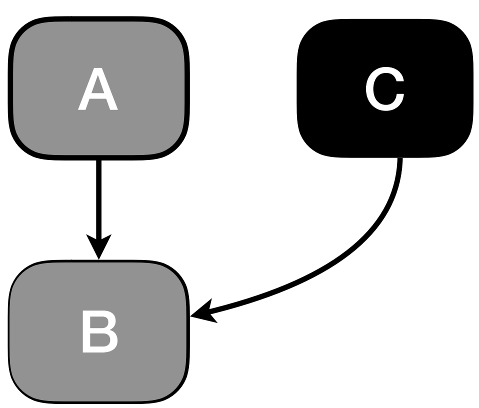

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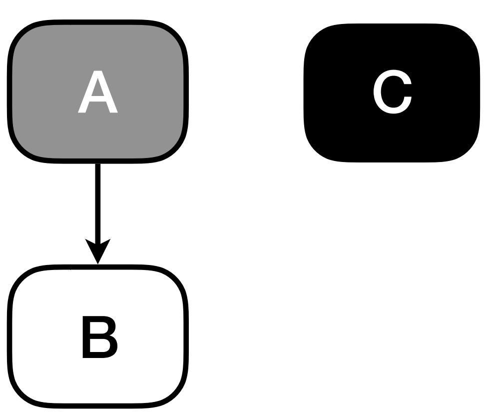

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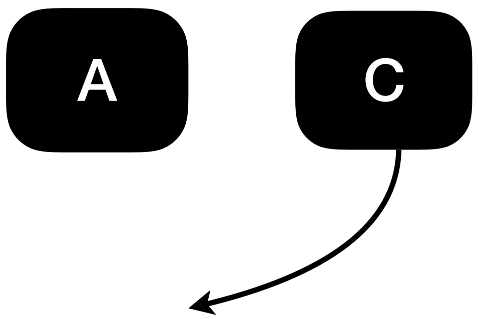

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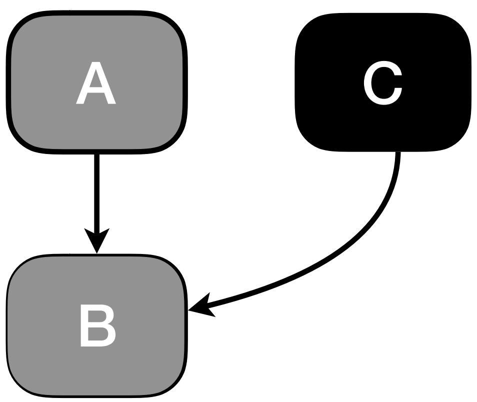

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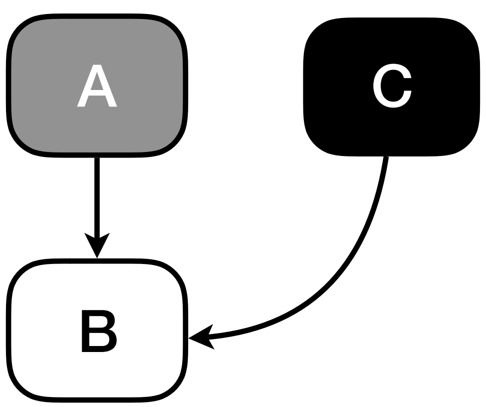

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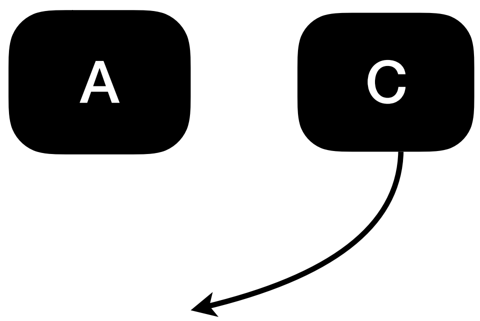

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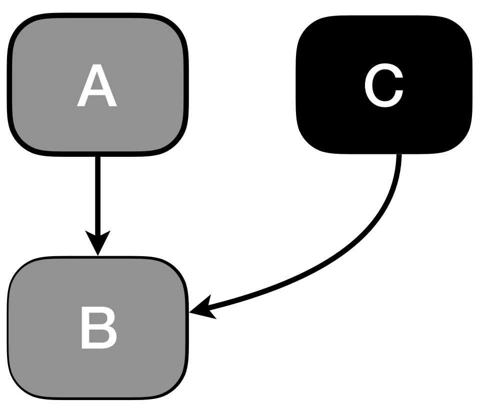

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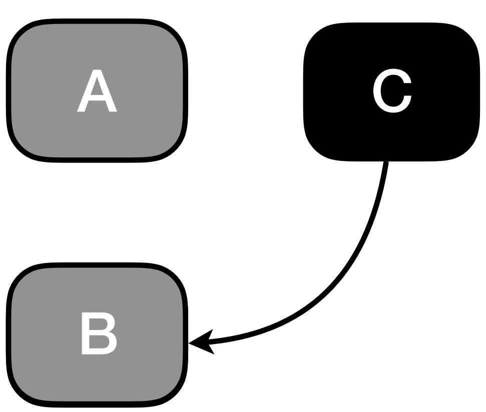

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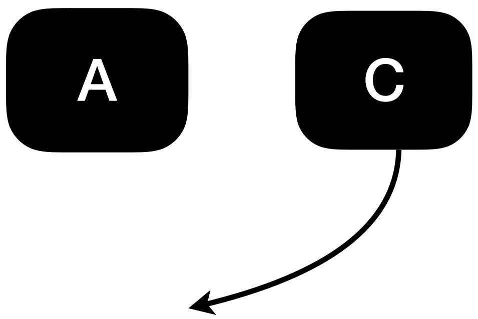

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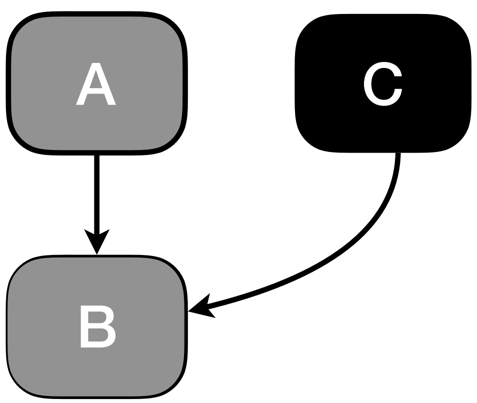

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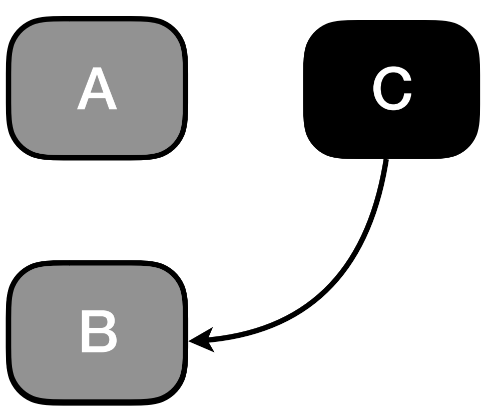

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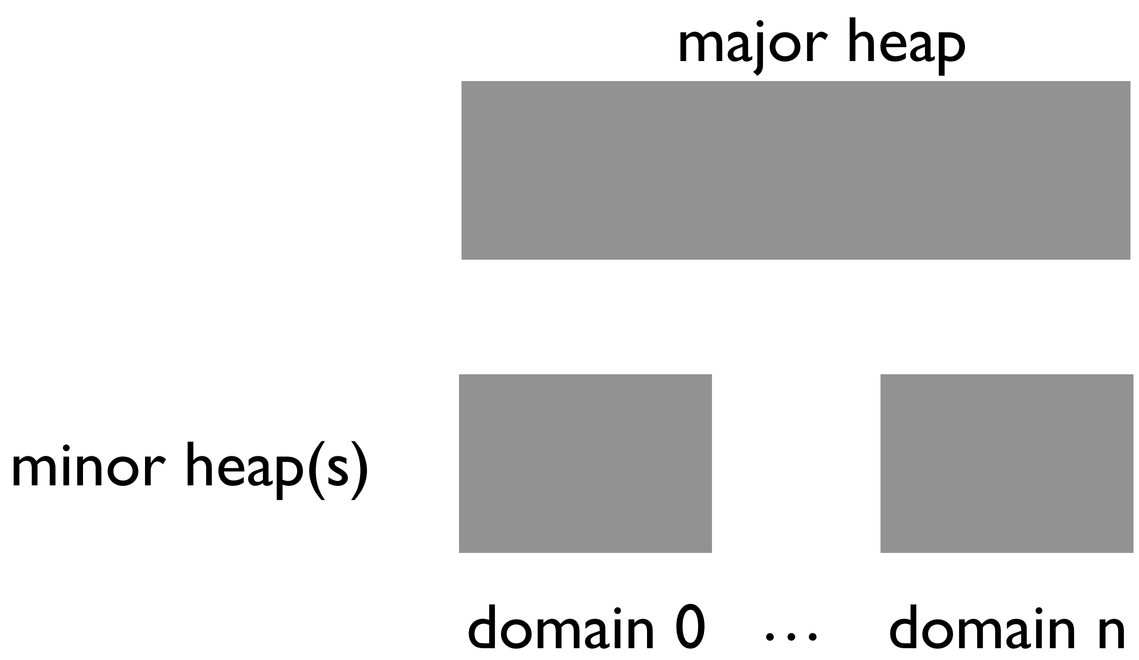

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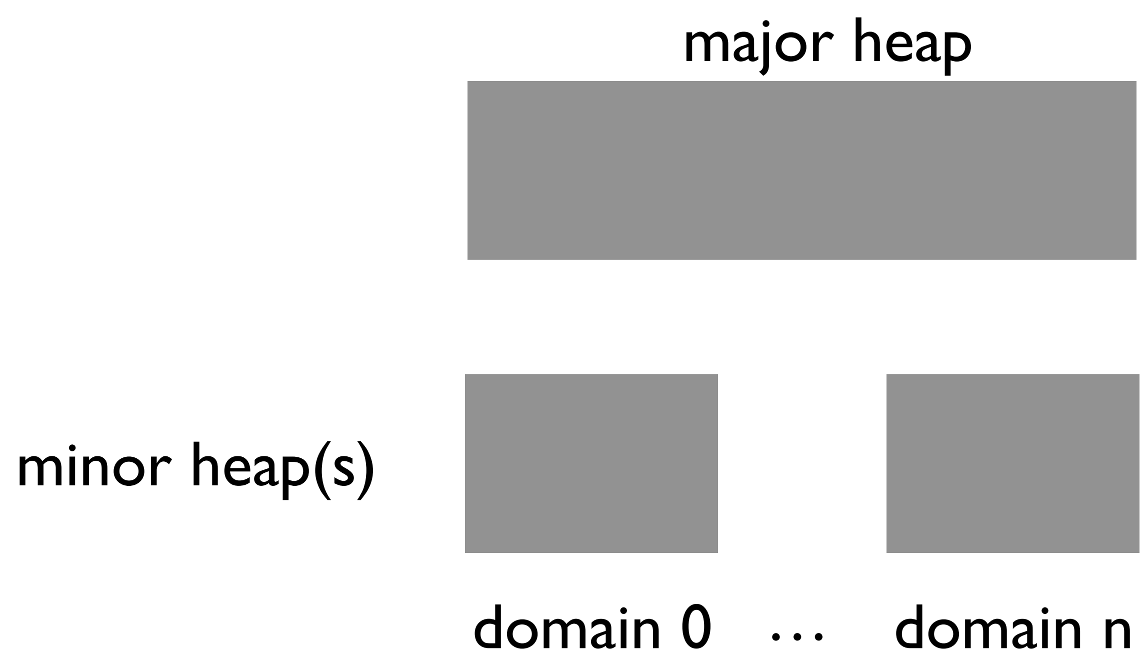

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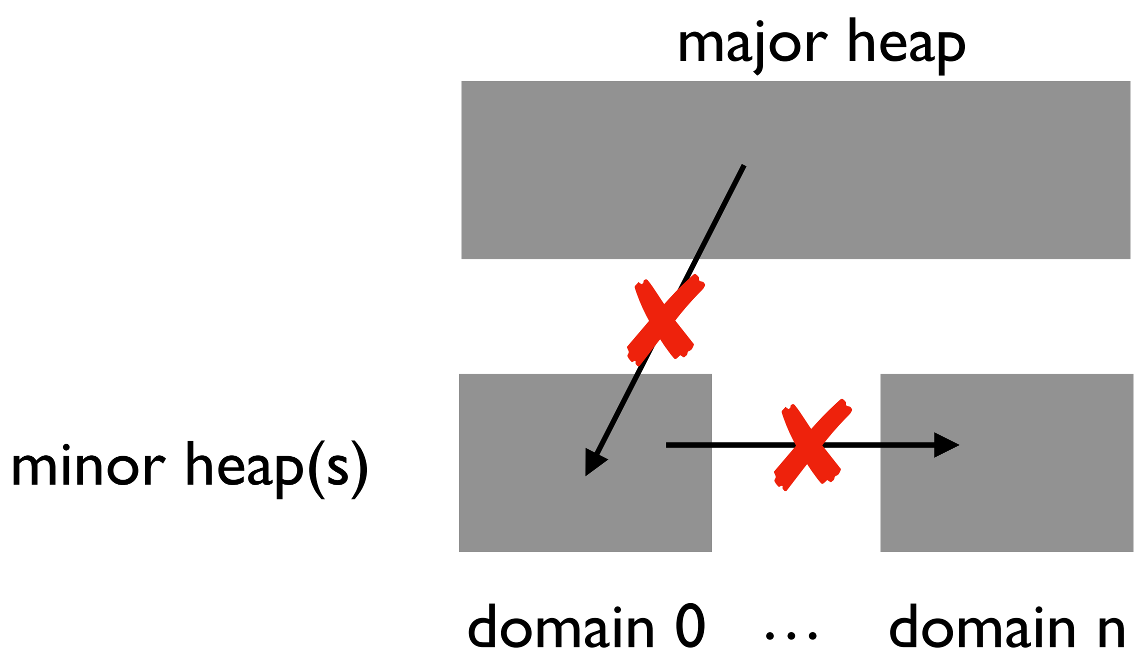

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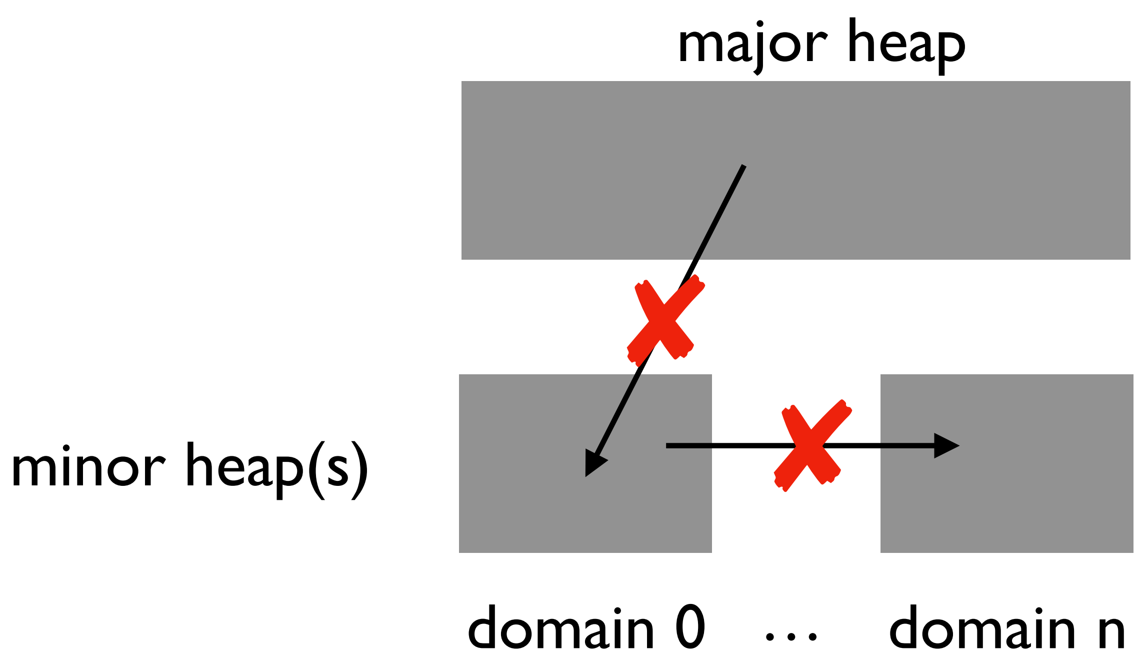

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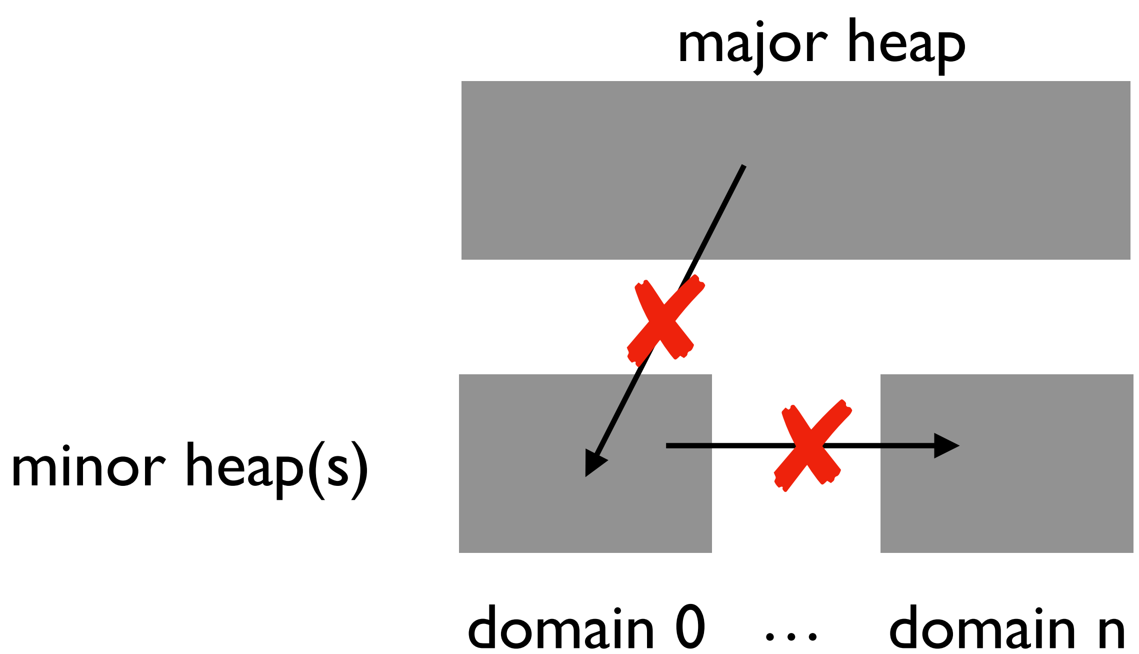

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- *Too much promotion.* Ex: work-stealing queue

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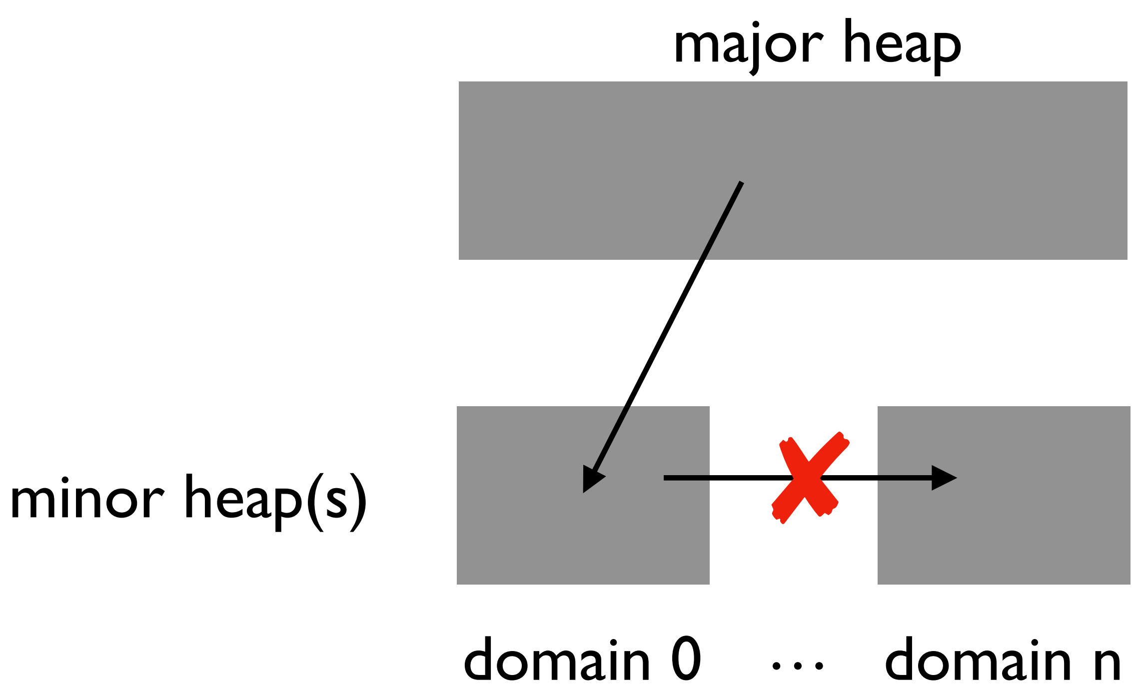

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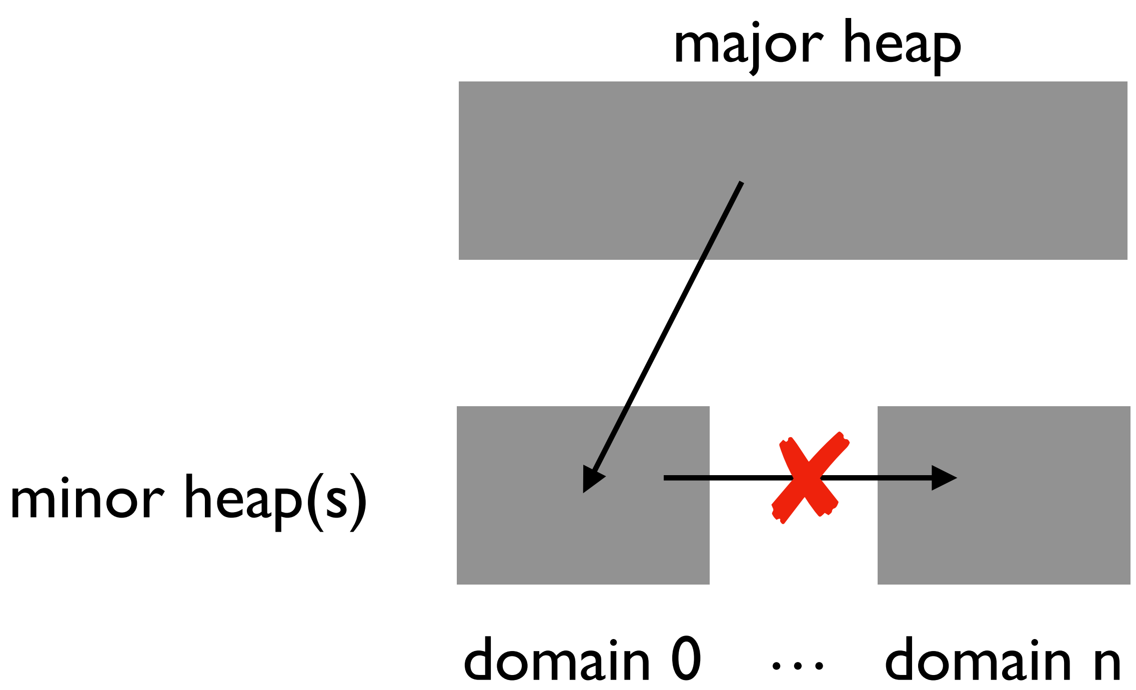
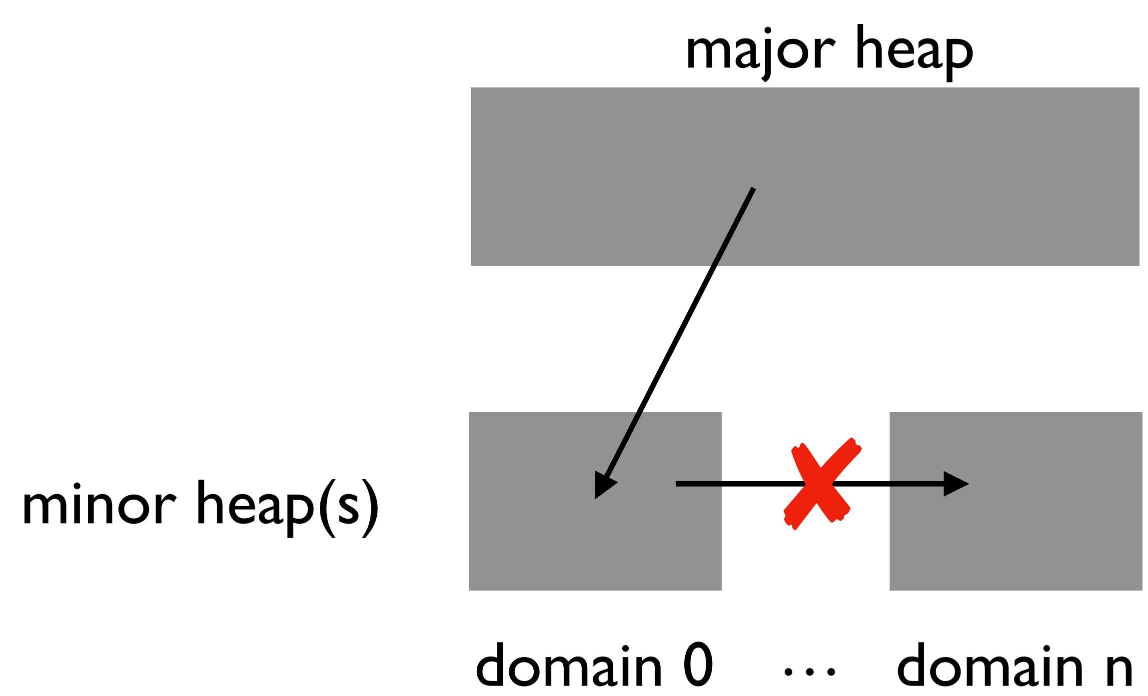


- Weaker invariant
  - ✦ No pointers between minor heaps
  - ✦ *Objects in foreign minor heap are not accessed directly*

Parallelism — Minor GC



- Weaker invariant
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  - ✦ *Objects in foreign minor heap are not accessed directly*
- Read barrier. If the value loaded is
  - ✦ integers, object in shared heap or own minor heap => continue
  - ✦ object in foreign minor heap => *Read fault (Interrupt + promote)*

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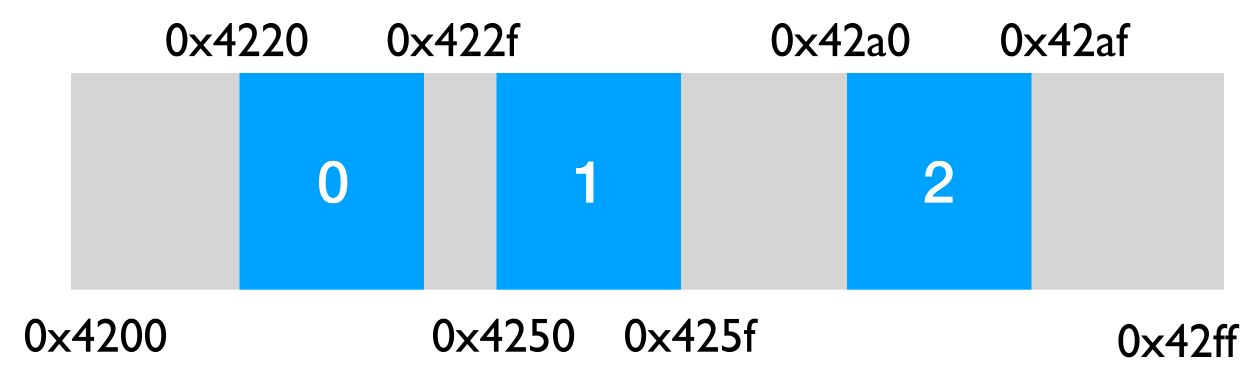

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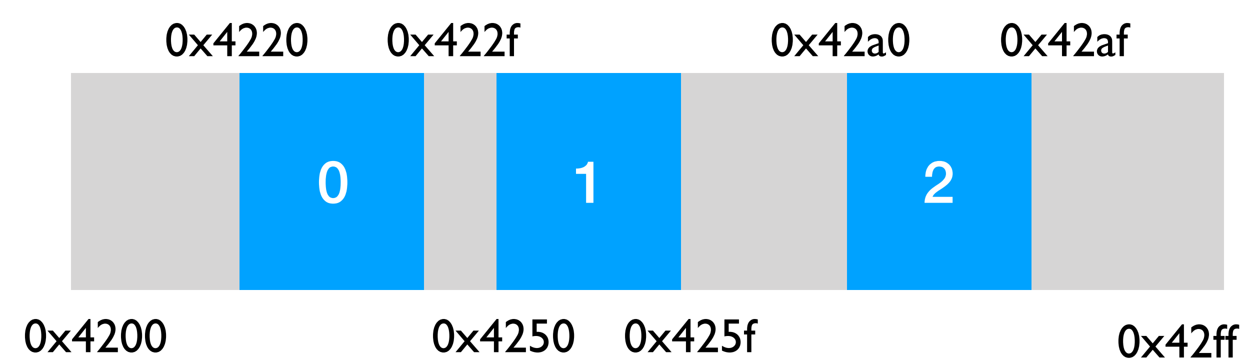

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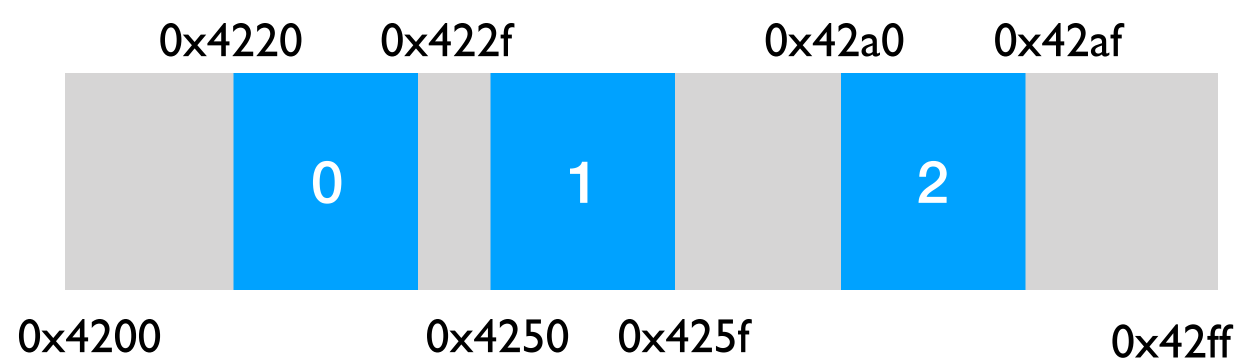

- Integer low_bit(S) = `0x1`, Minor PQ = `0x42`, R determines domain
- Compare with y, where y lies within domain => *allocation pointer!*
  - ✦ On amd64, allocation pointer is in `r15` register

Efficient read barrier check

```
# %rax holds x (value of interest)
xor %r15, %rax
sub 0x0010, %rax
test 0xff01, %rax
# Any bit set => ZF not set => not foreign minor
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Shared heap

```
# PQ(%r15) != PQ(%rax)
xor %r15, %rax
# PQ(%rax) is non-zero
sub 0x0010, %rax
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Own minor heap

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# PQR(%rax) is zero
sub 0x0010, %rax
# PQ(%rax) is non-zero
test 0xff01, %rax
# ZF not set
```

Foreign minor heap

```
# PQ(%r15) = PQ(%rax)
# S(%r15) = S(%rax) = 0
# R(%r15) != R(%rax)
xor %r15, %rax
# R(%rax) is non-zero, rest 0
sub 0x0010, %rax
# rest 0
test 0xff01, %rax
# ZF set
```

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- Combine 2 & 3

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```
(* r := x *)
let write_barrier (r, x) =
  if is_major r && is_minor x then
    remembered_set.add r
  else if is_major r && is_major x then
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  else if is_minor r && is_minor x && addr r > addr x then
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- Otherwise, move + minor GC

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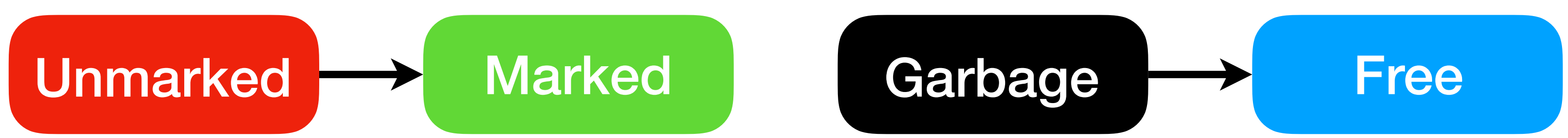

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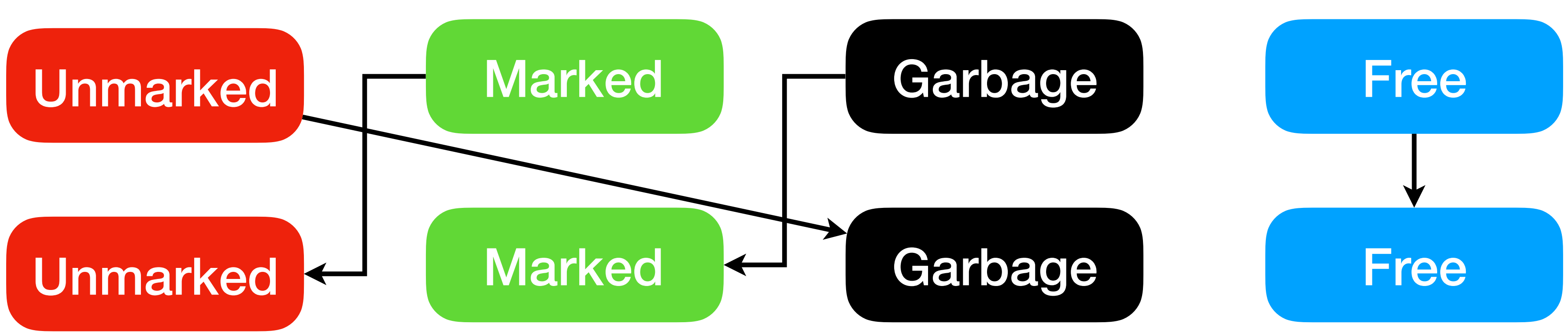

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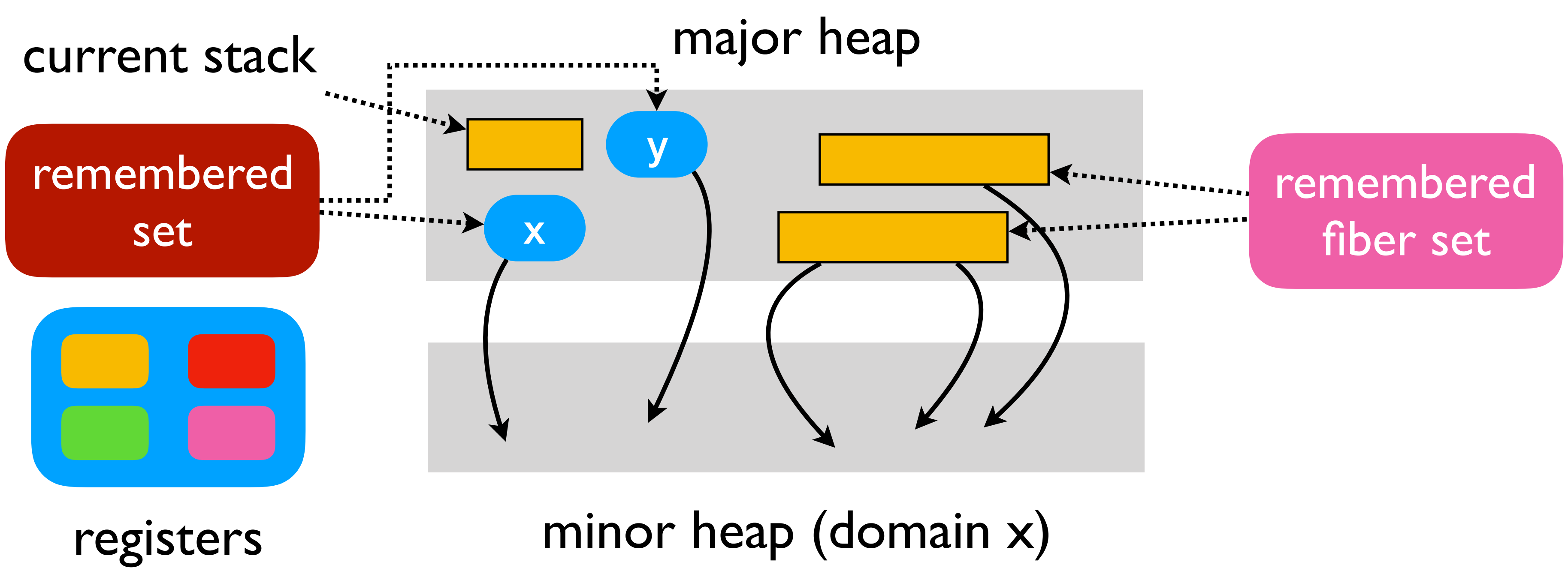

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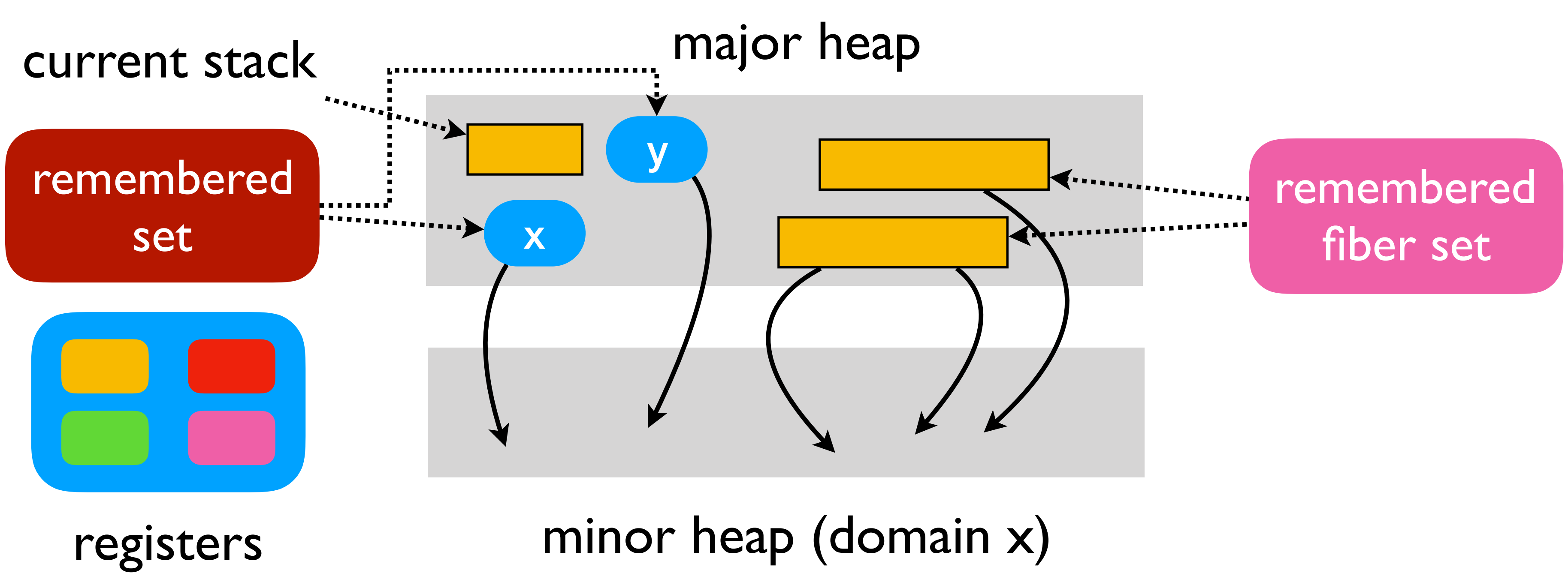
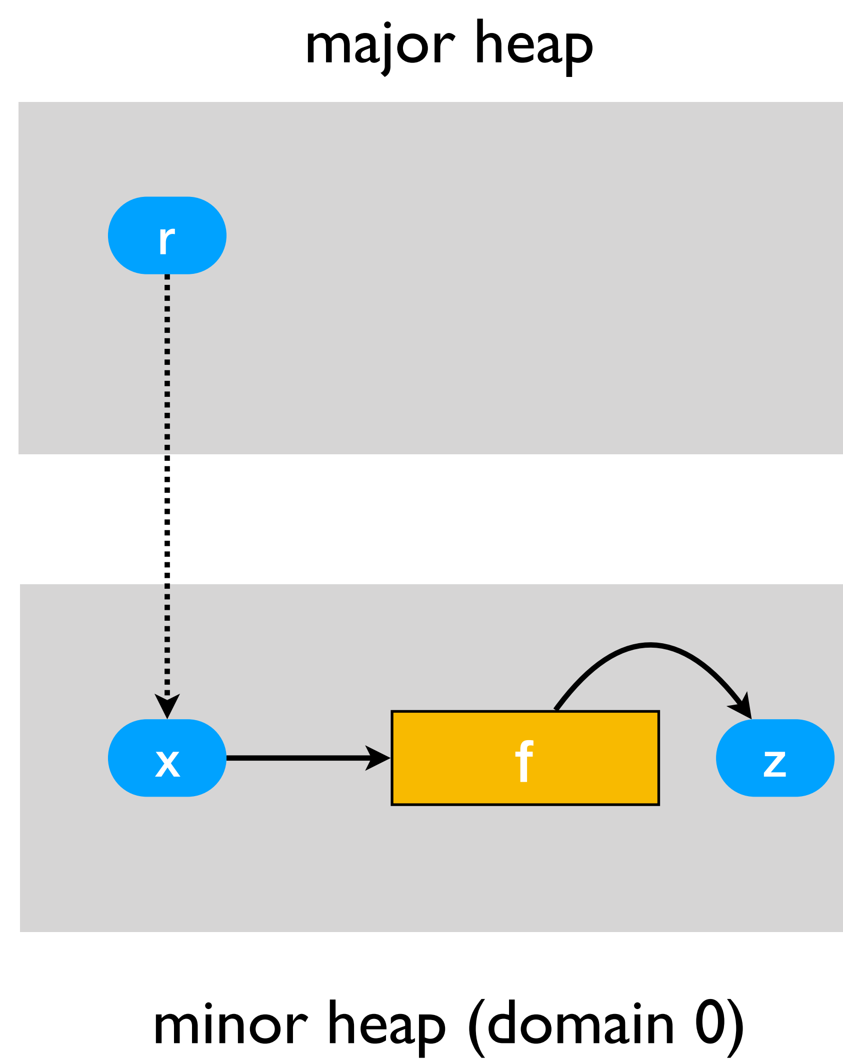


- Remembered fiber set
  - Set of fibers in major heap that were ran in the current cycle of domain x
  - Cleared after minor GC

Concurrency — Promotions

- Fibers transitively reachable are not promoted automatically
  - Avoids false promotions



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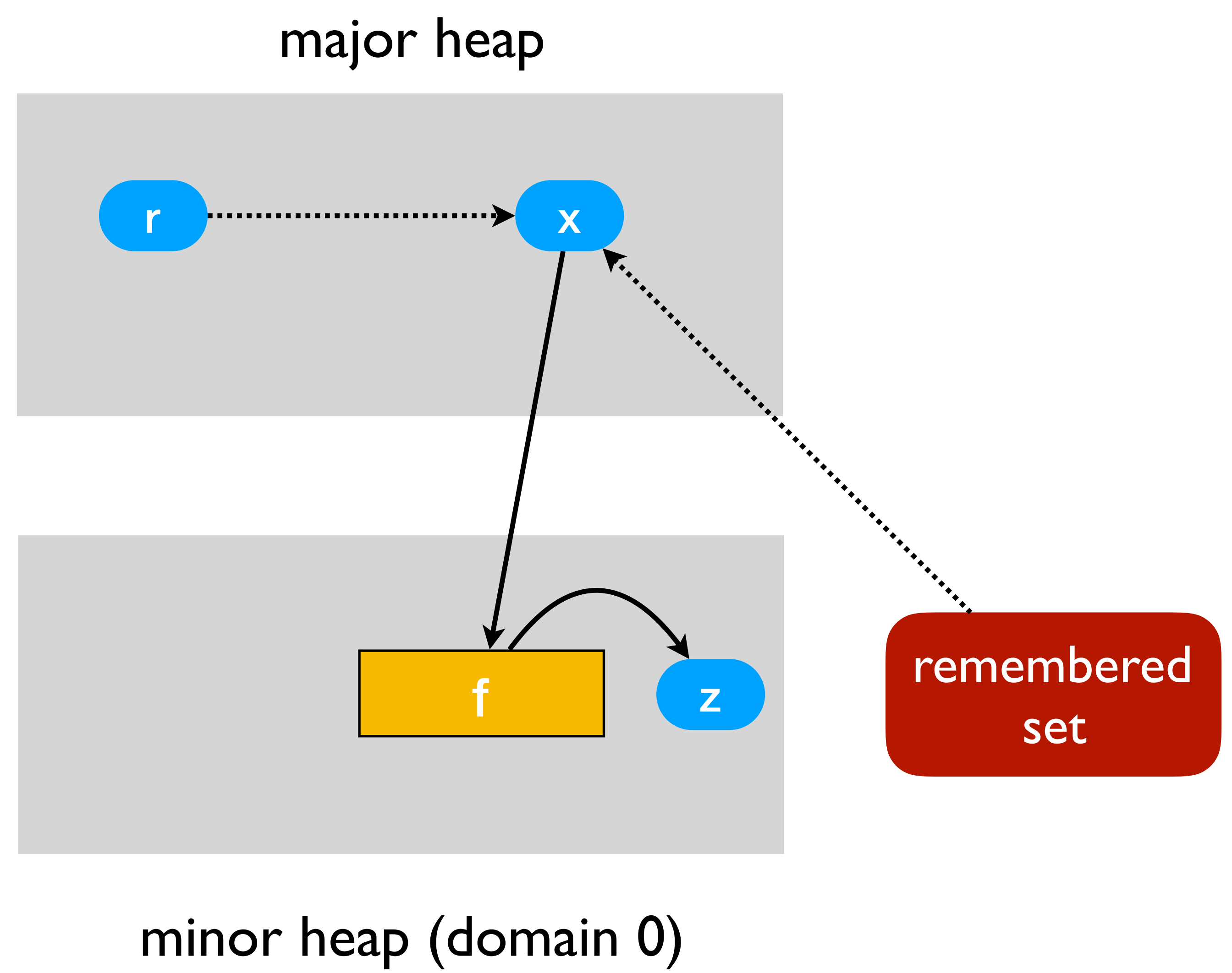

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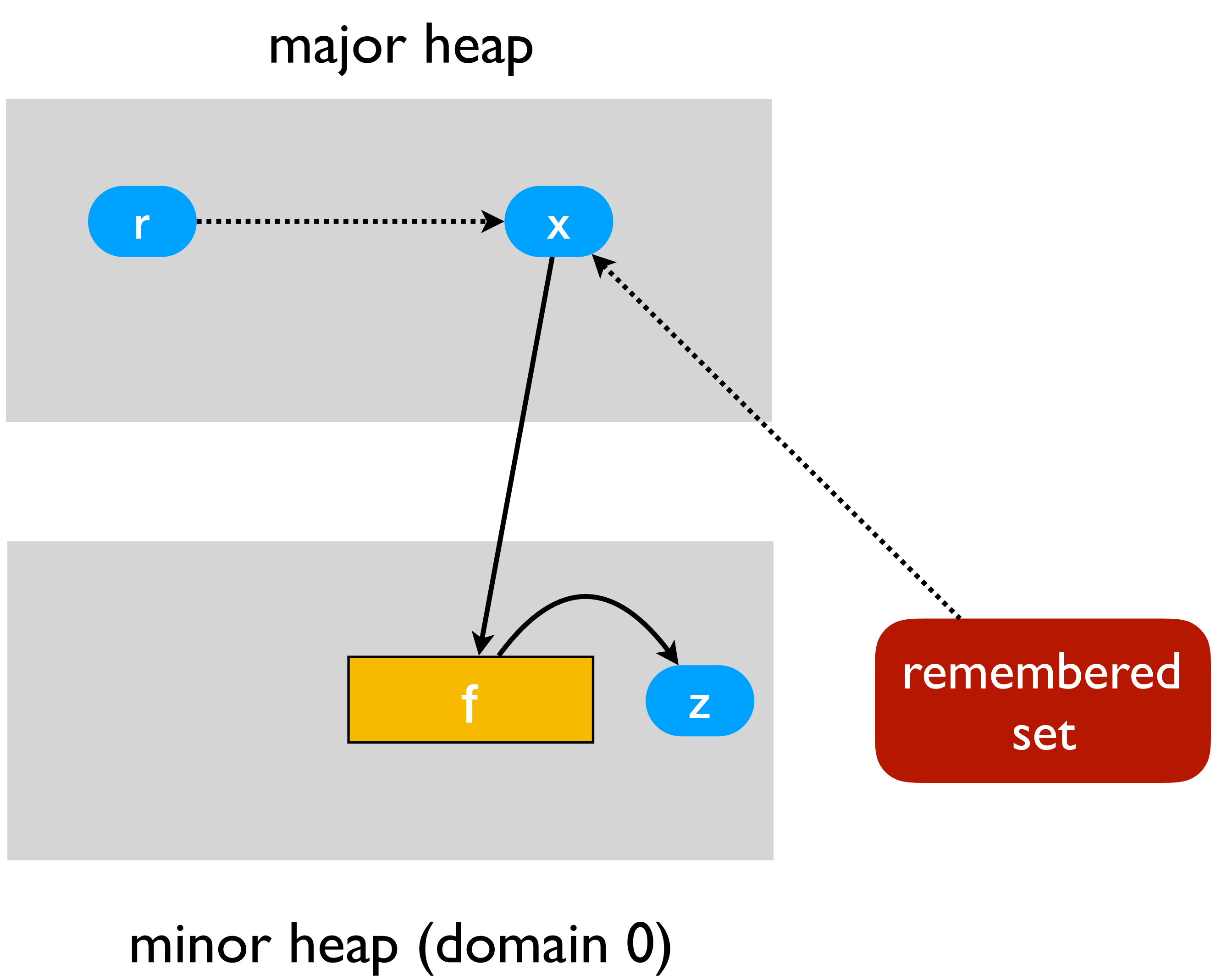

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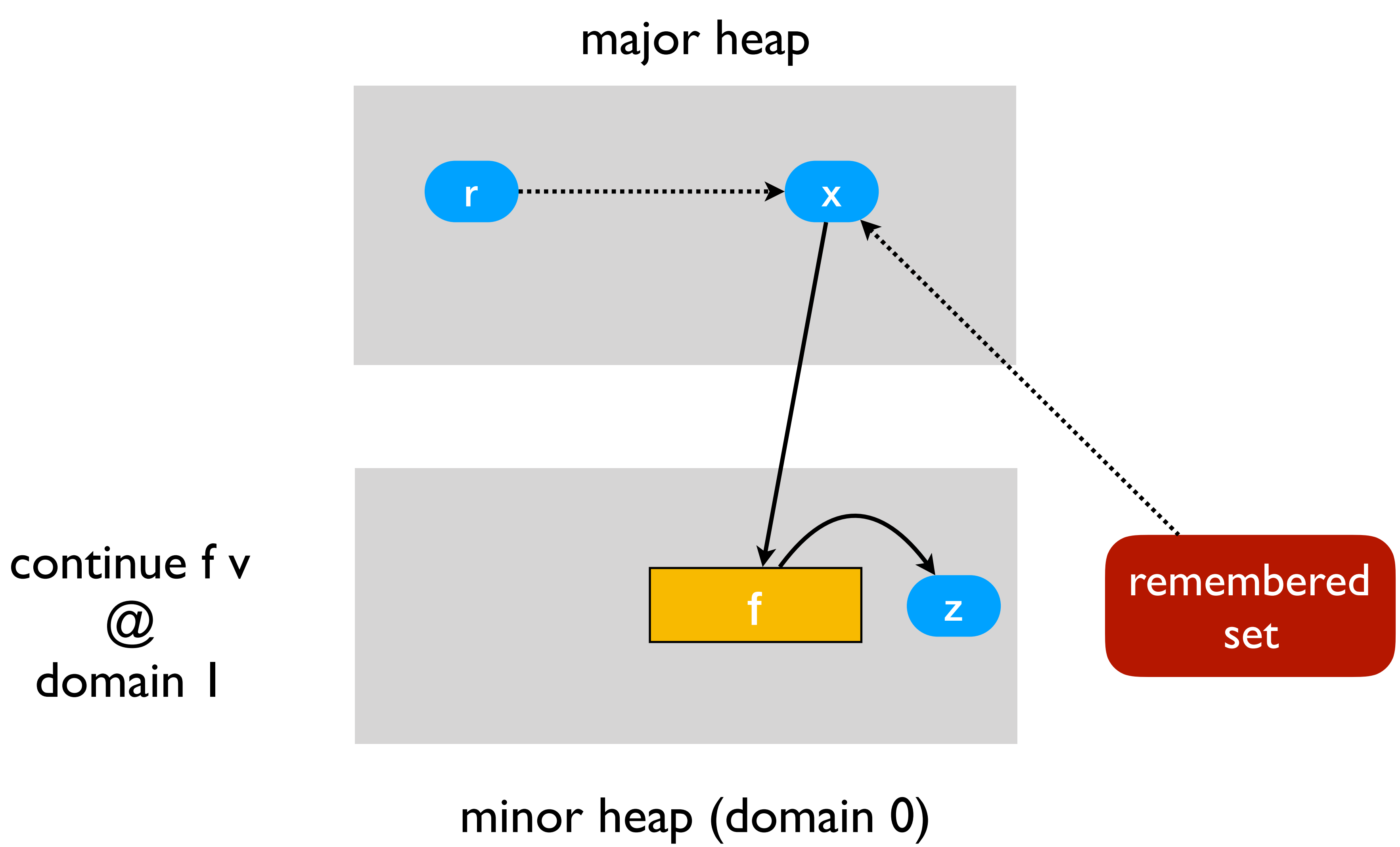

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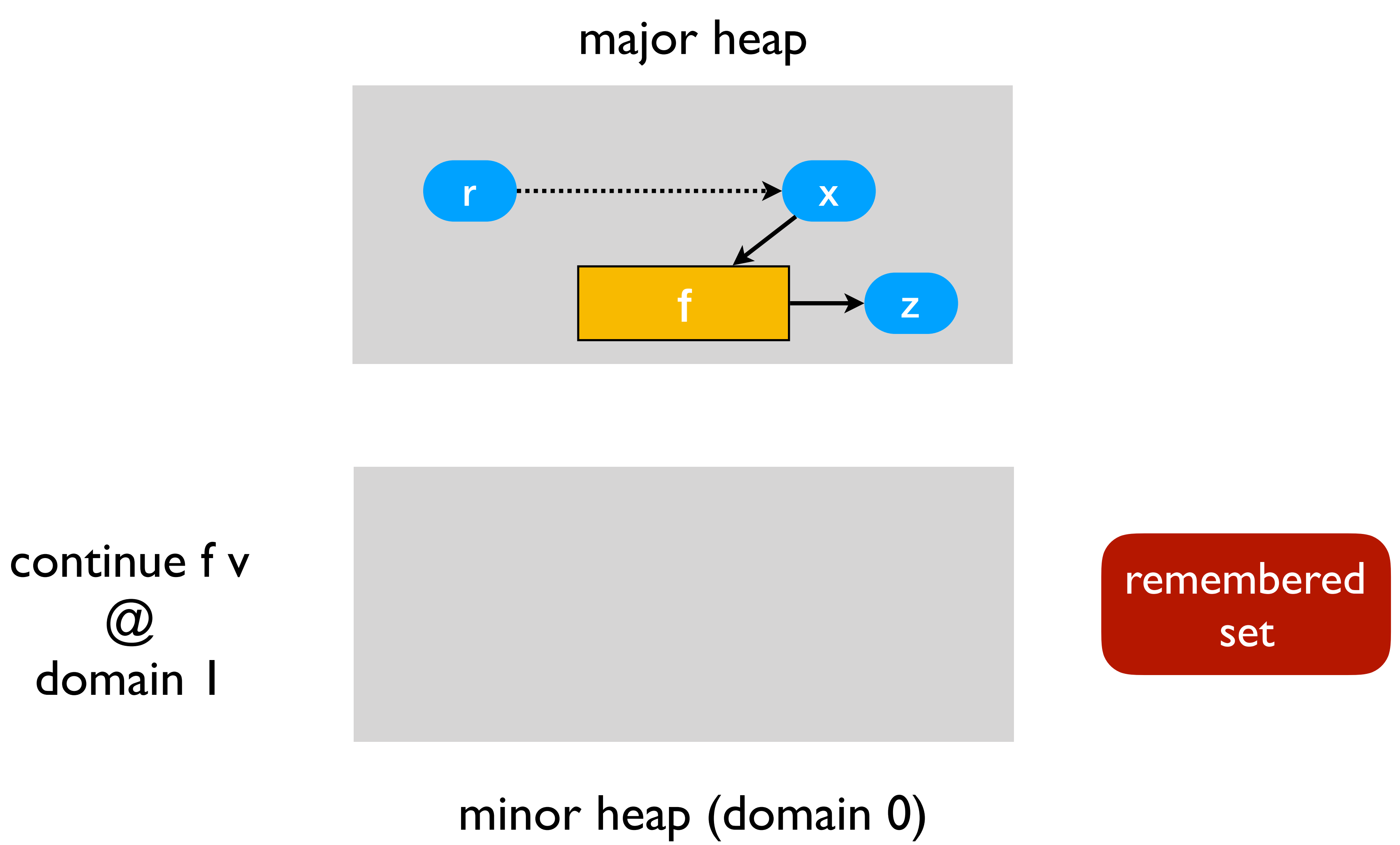

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    - Context switches <<< promotions
- Scan lazily before context switch
  - Only once per fiber per promotion
  - In practice, scans a fiber per a batch of promotions

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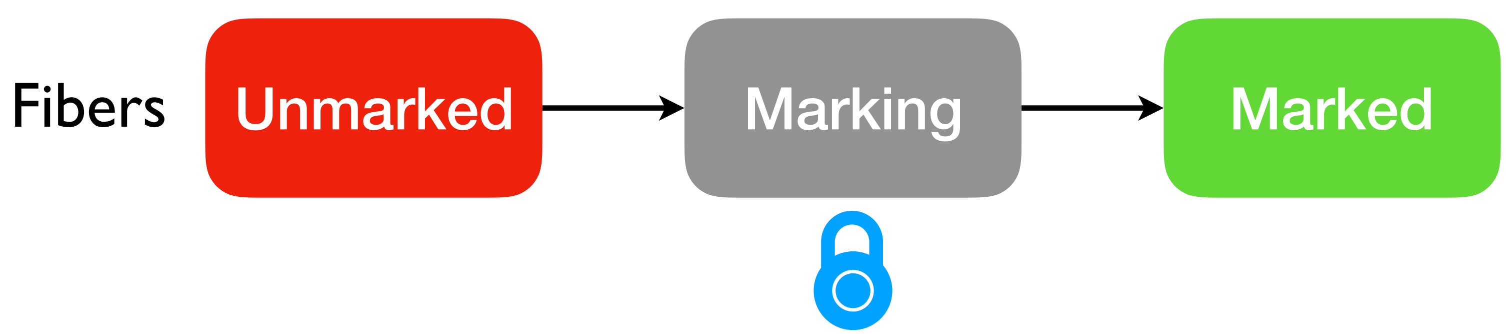

Summary

- Multicore OCaml GC
  - Optimize for latency
  - Independent minor GCs + mostly-concurrent mark-and-sweep

	Mutations	Concurrency	Parallelism
Minor GC	rem set	rem fiber set	local heaps
Promotions	o2y rem set	lazy scanning	read faults
Major GC	deletion barrier	mark & switch	MCGC

Questions?

Backup Slides

Purely functional GC

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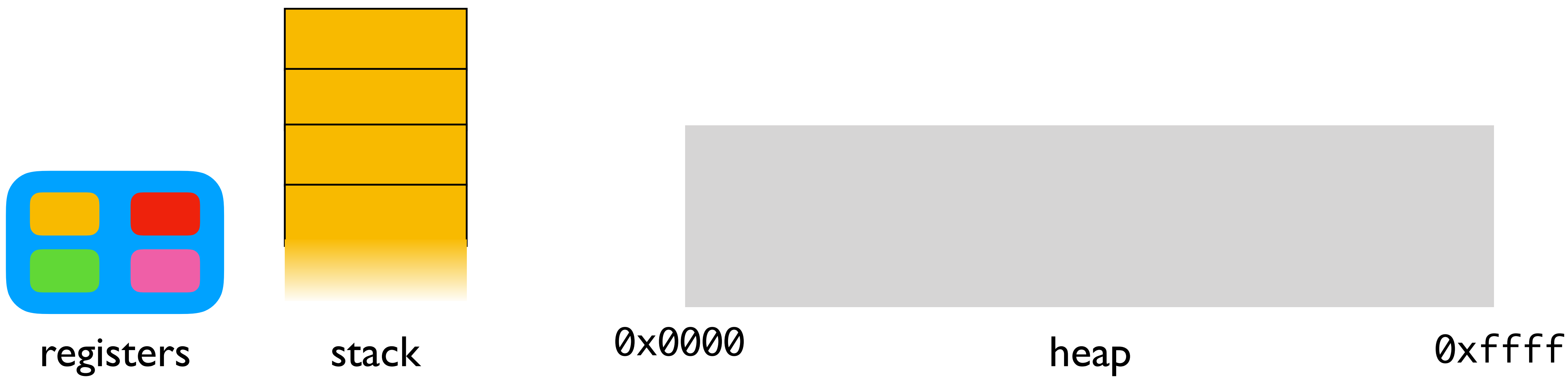
- Stop-the-world mark and sweep

Purely functional GC



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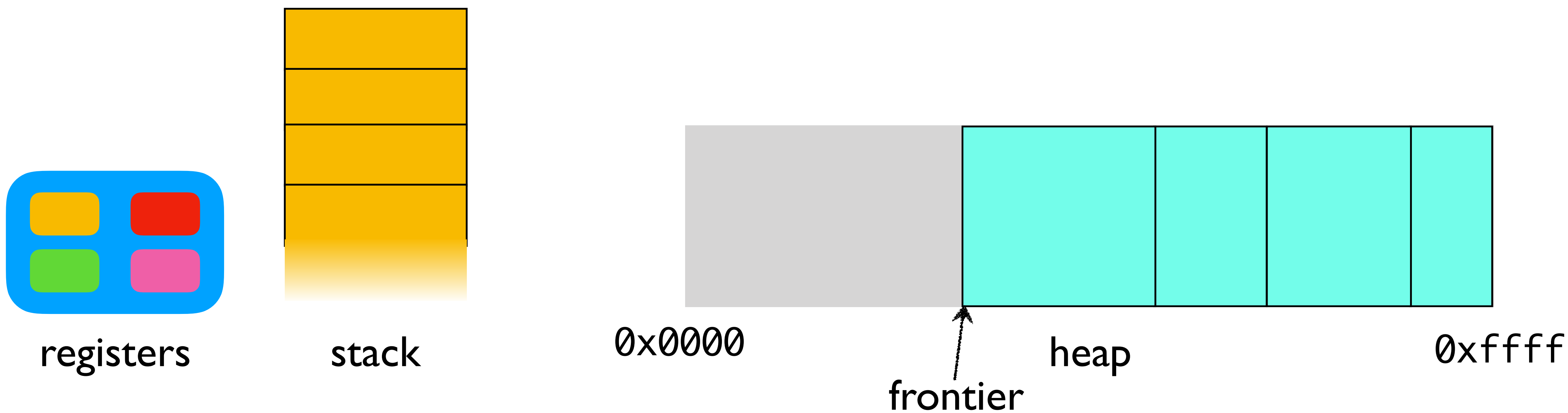

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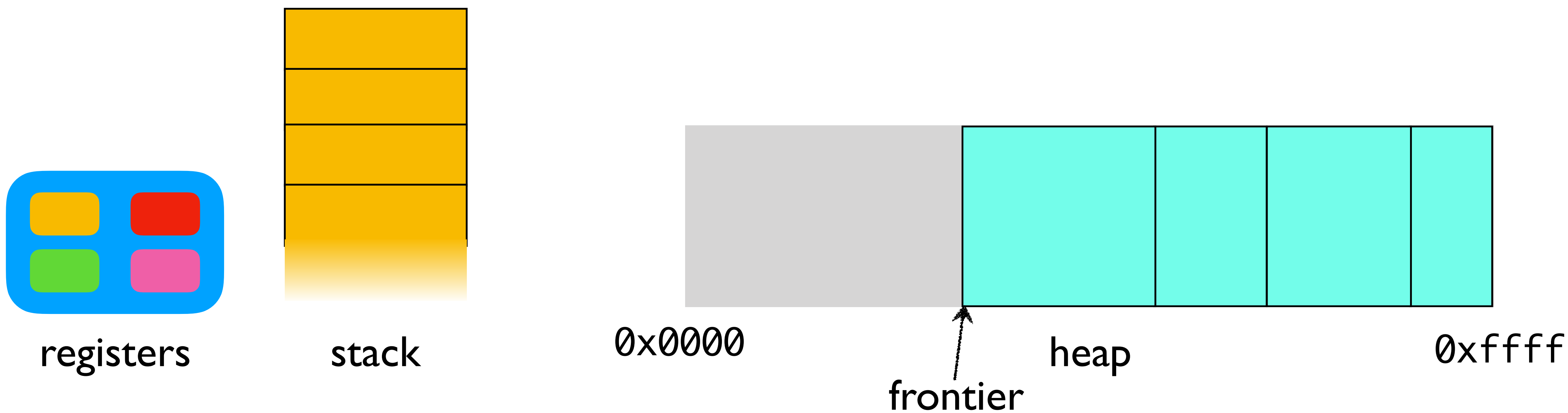

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- 2-pass mark compact
  - ✦ Fast allocations by bumping the frontier

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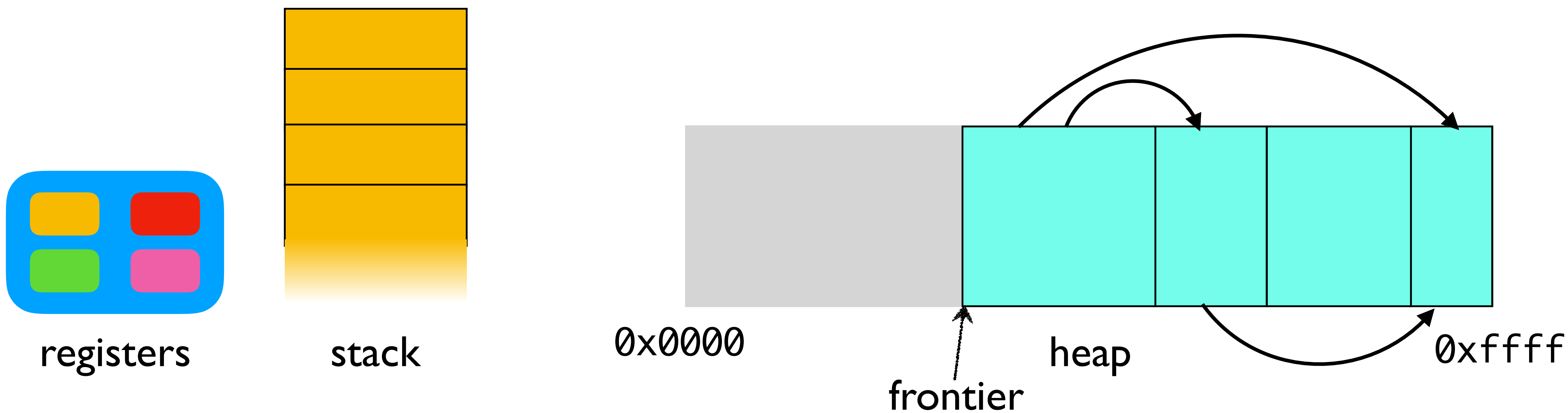

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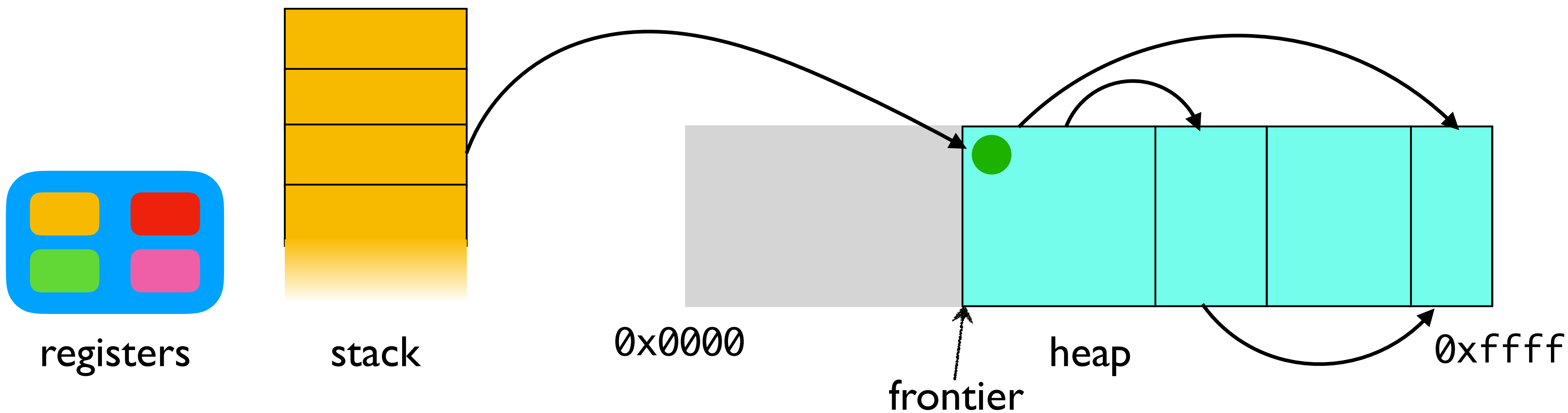
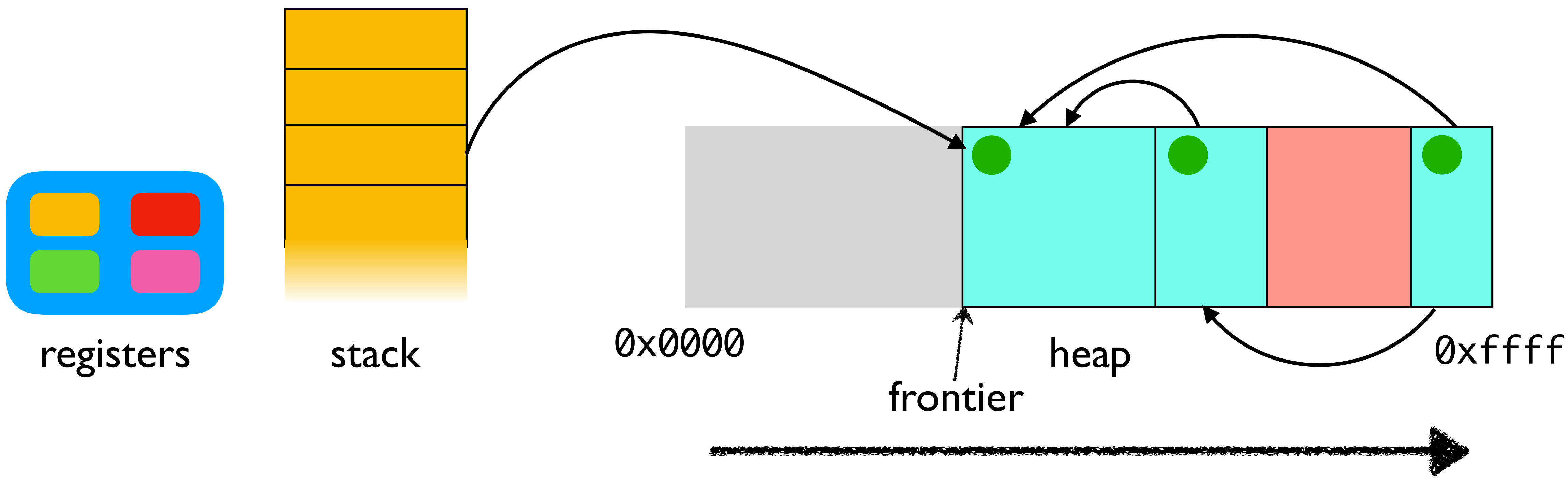
  - ✦ Fast allocations by bumping the frontier
- *All heap pointers go right*

Purely functional GC



- Mark roots

Purely functional GC



- Mark roots
- Scan from *frontier* to *start*. For each marked object,
  - Mark reachable object & *reverse pointers*

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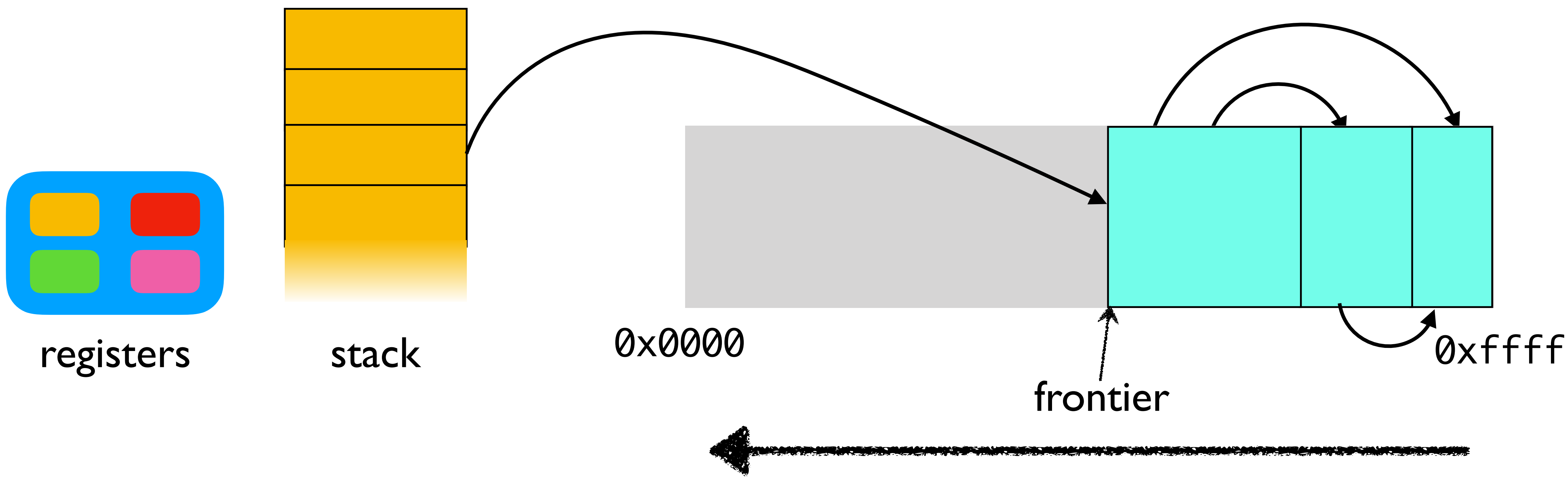

- Mark roots
- Scan from *frontier* to *start*. For each marked object,
  - Mark reachable object & *reverse pointers*
- Scan from *start* to *frontier*. For each marked object,
  - Copy to next available free space & *reverse pointers pointing left*

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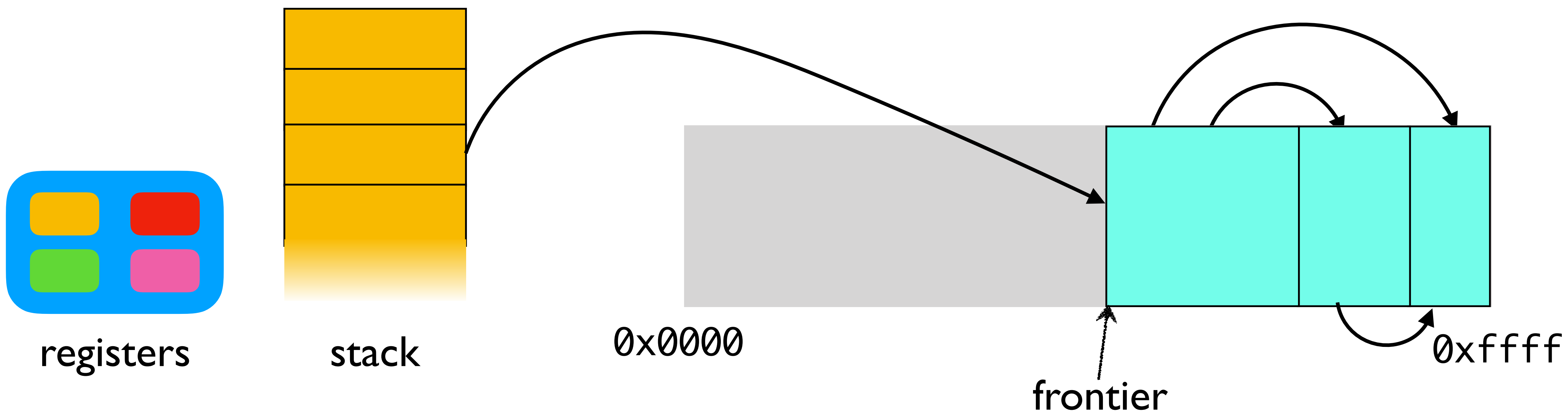

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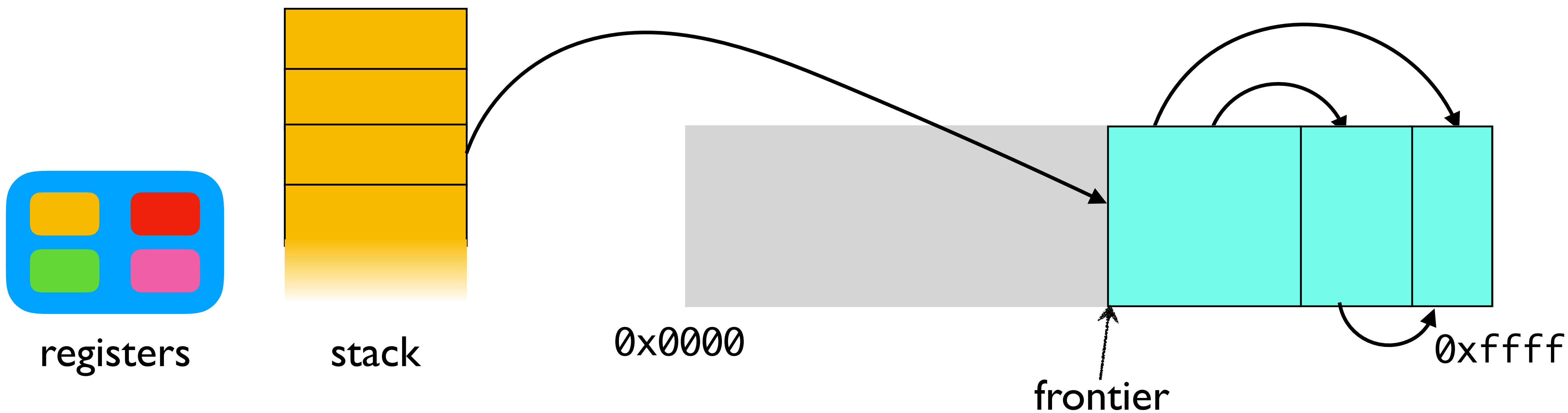

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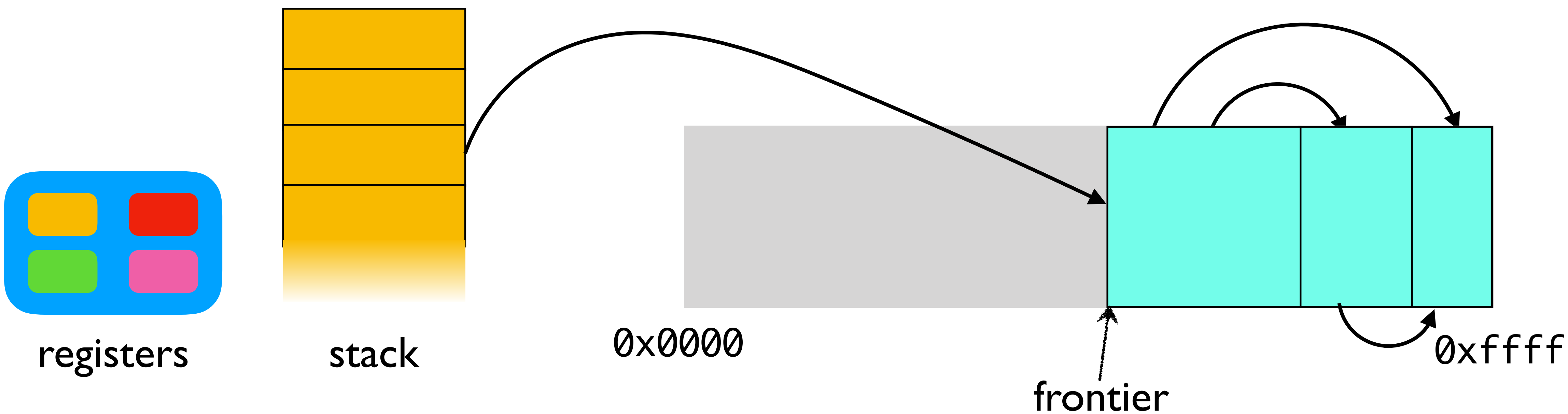

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- Cons
  - ✦ Need to touch all the objects on the heap
  - ✦ Compaction as default is leads to long pause times