Retrofitting a Concurrent GC onto OCaml

KC Sivaramakrishnan

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IIT MADRAS

OCaml

industrial-strength, pragmatic, functional programming language

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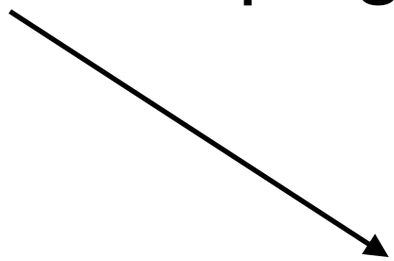

Hindley-Milner Type Inference

Powerful module system

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- Functional core with imperative and object-oriented features
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Jane Street

The Coq Proof Assistant

MIRAGE OS

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No multicore support!

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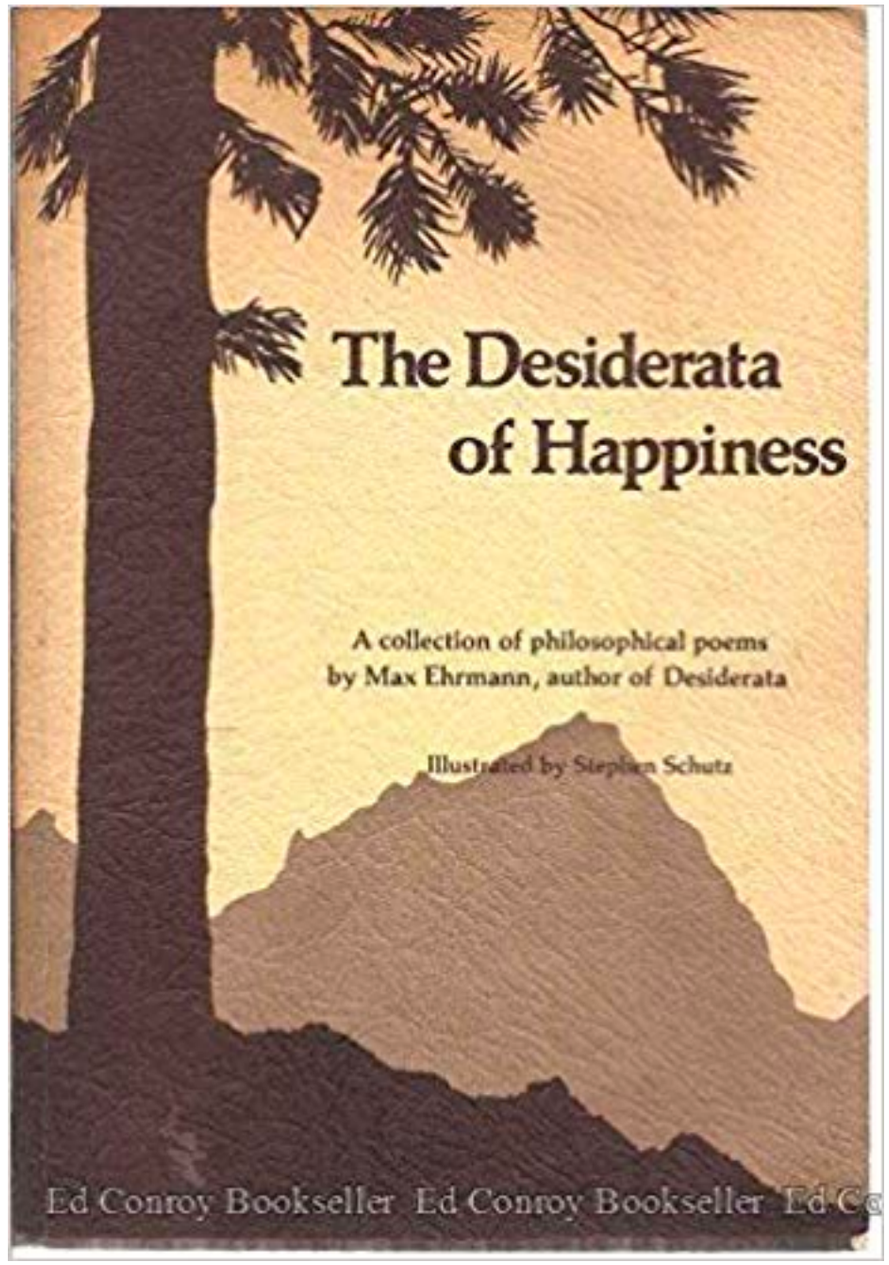
- In this talk,
  - Adding a concurrent GC to OCaml without destroying baseline performance
  - Opportunities and Impact of ***open*** (source) research

Multicore OCaml GC: Desiderata



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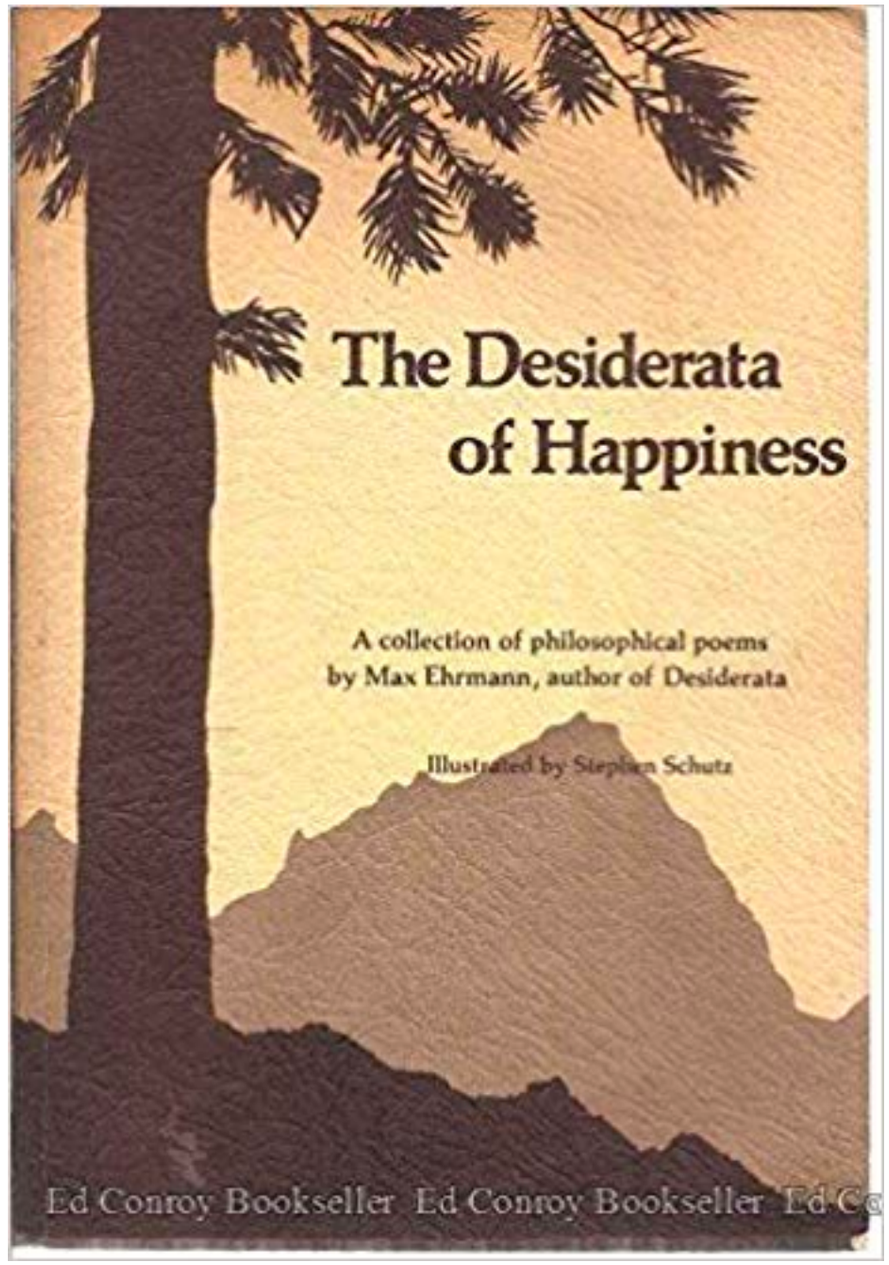

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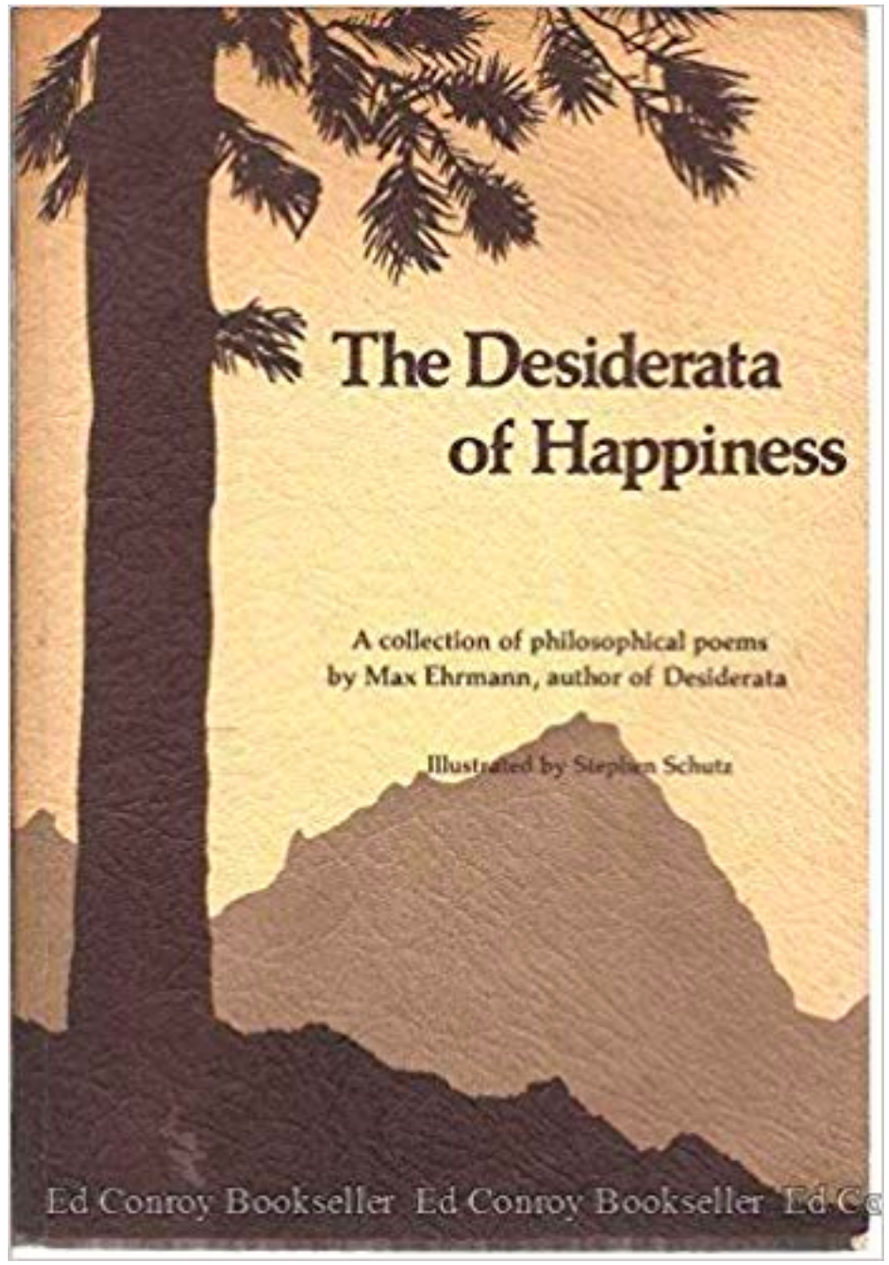

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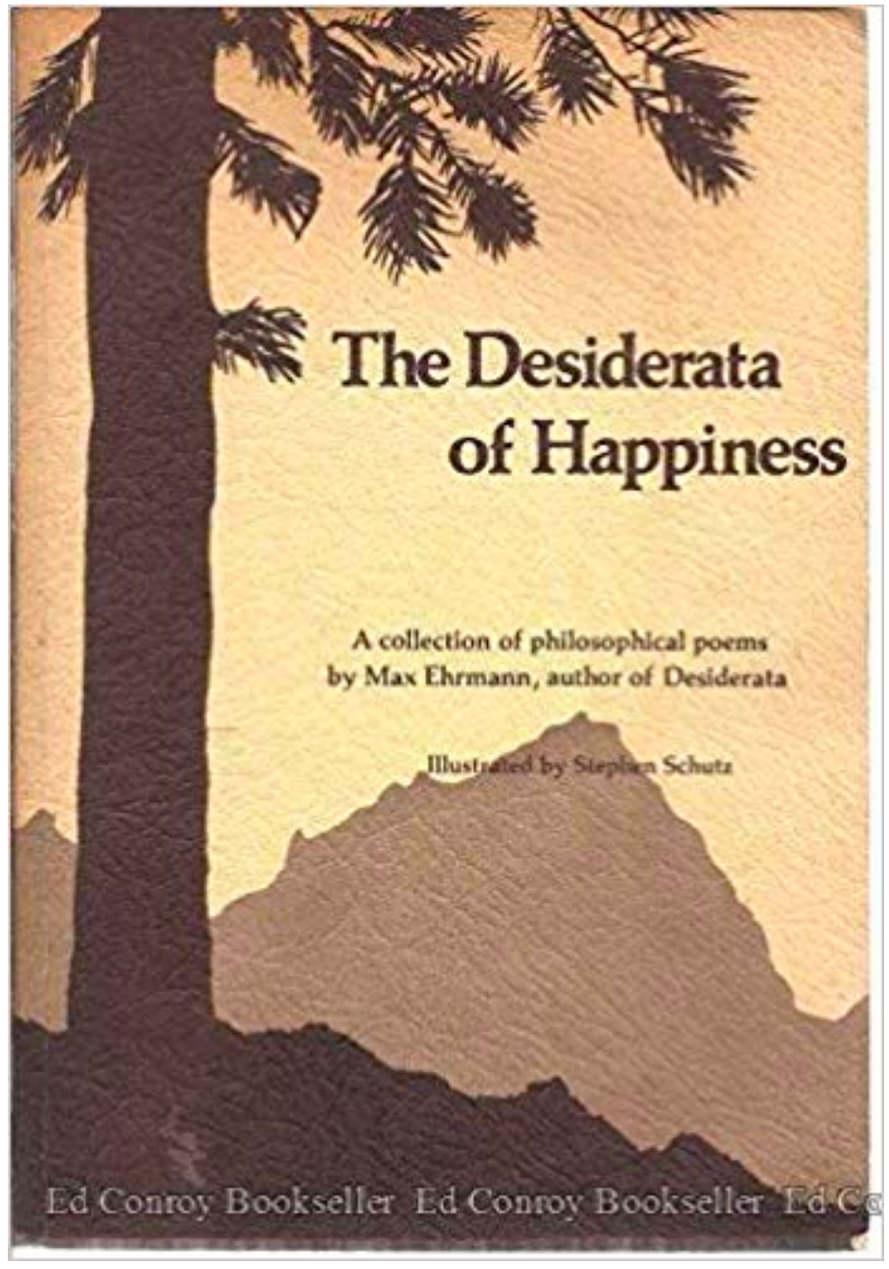

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- *Performance predictability and stability*
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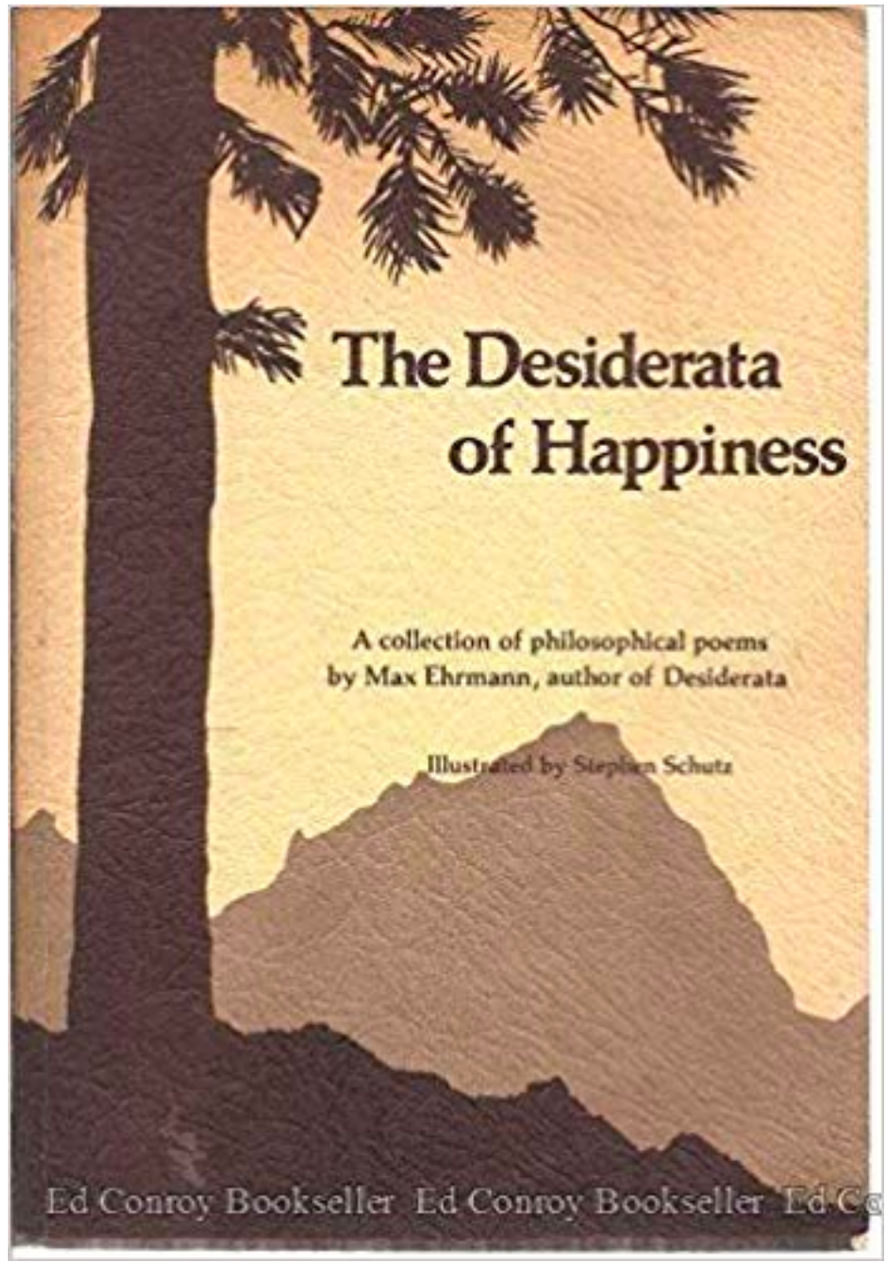

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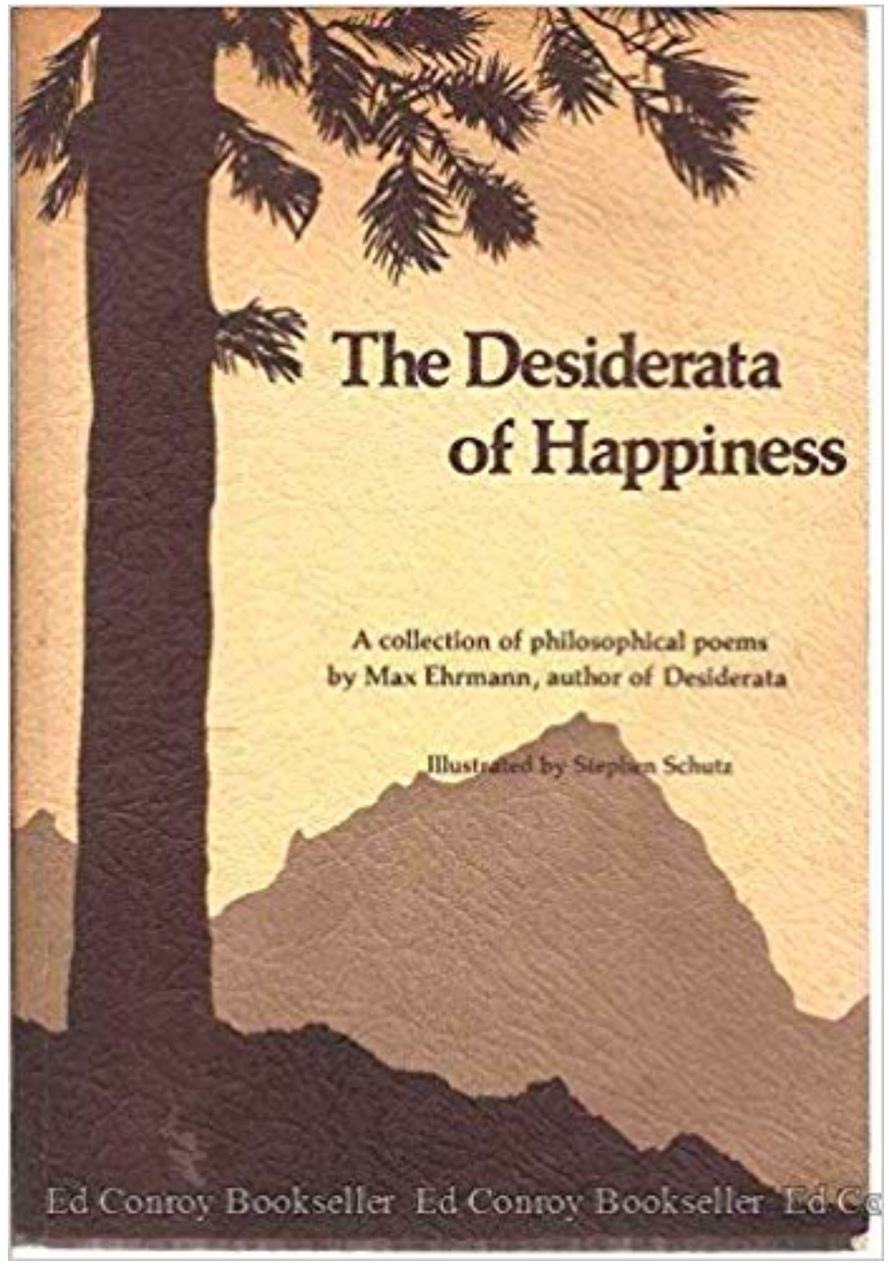
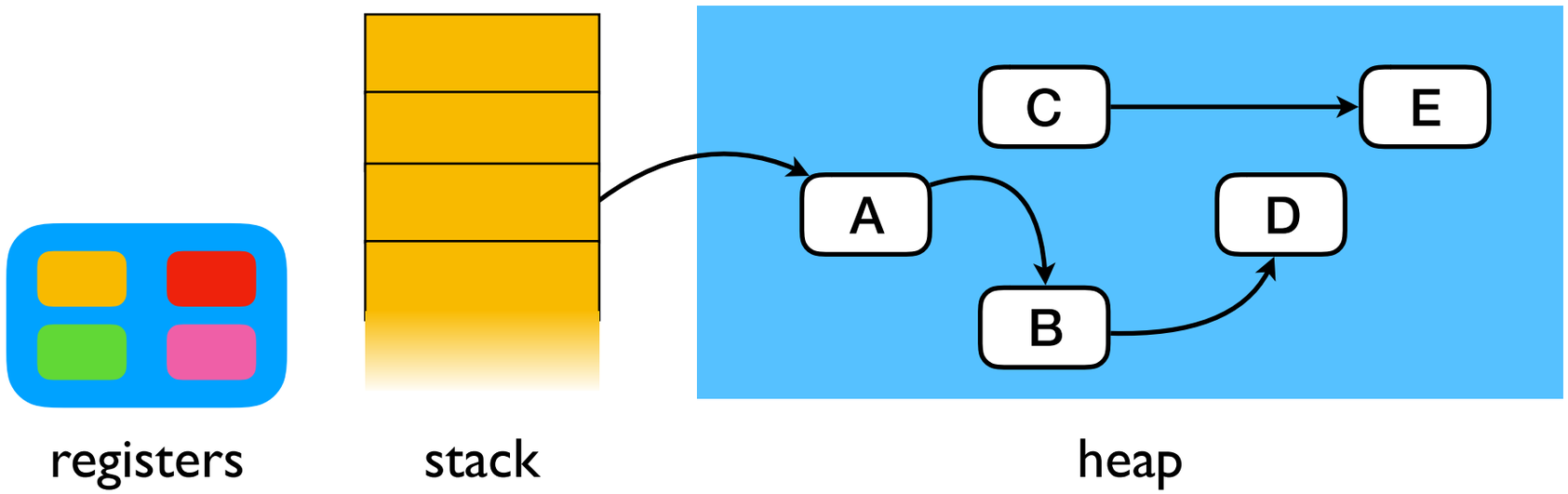
  - ✦ Slow and stable better than fast but unpredictable
- *Minimize knobs*
  - ✦ 90% of programs should run at 90% peak performance by default



Outline

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

Sequential purely functional



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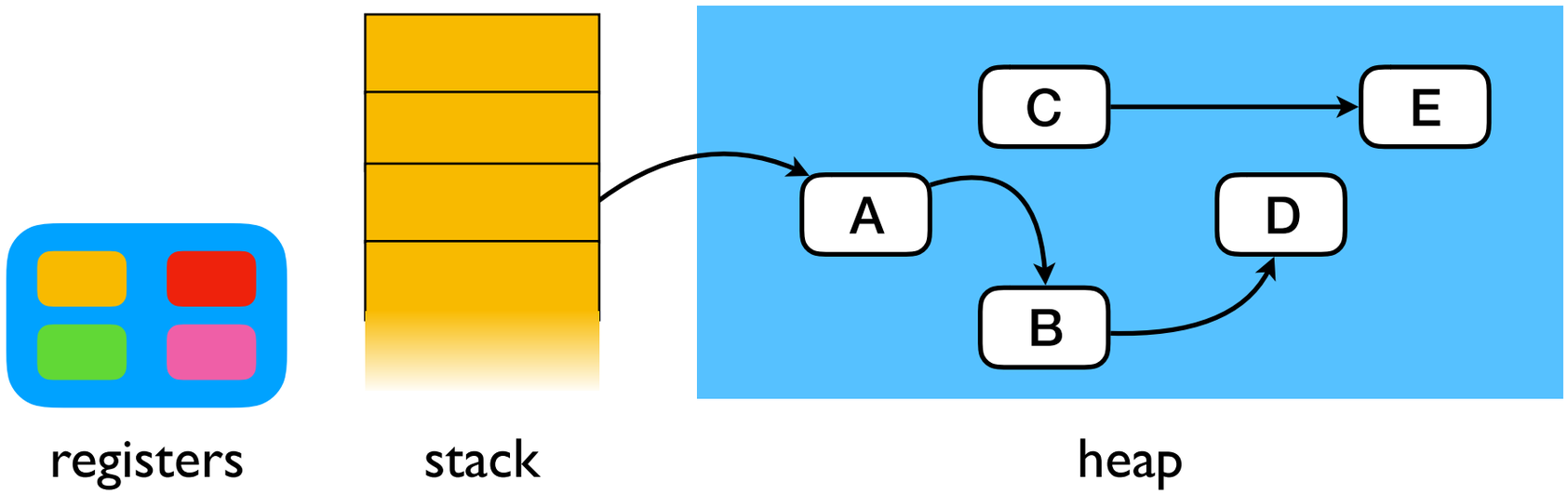

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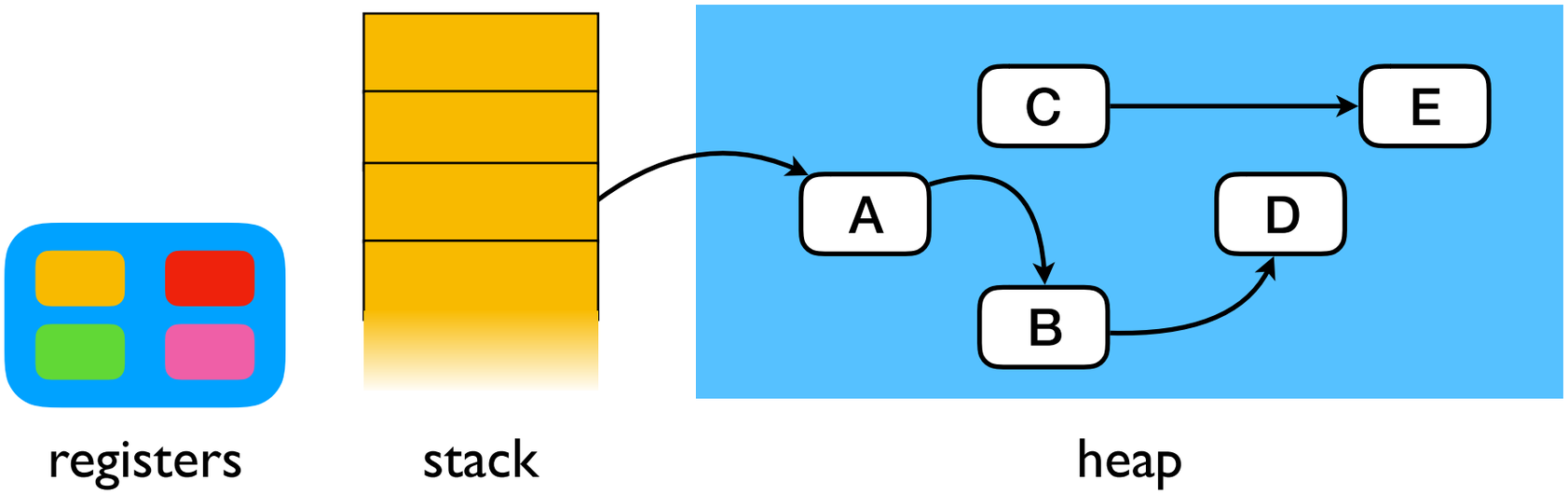

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  - ✦ States: White (Unmarked), Grey (Marking), Black (Marked)

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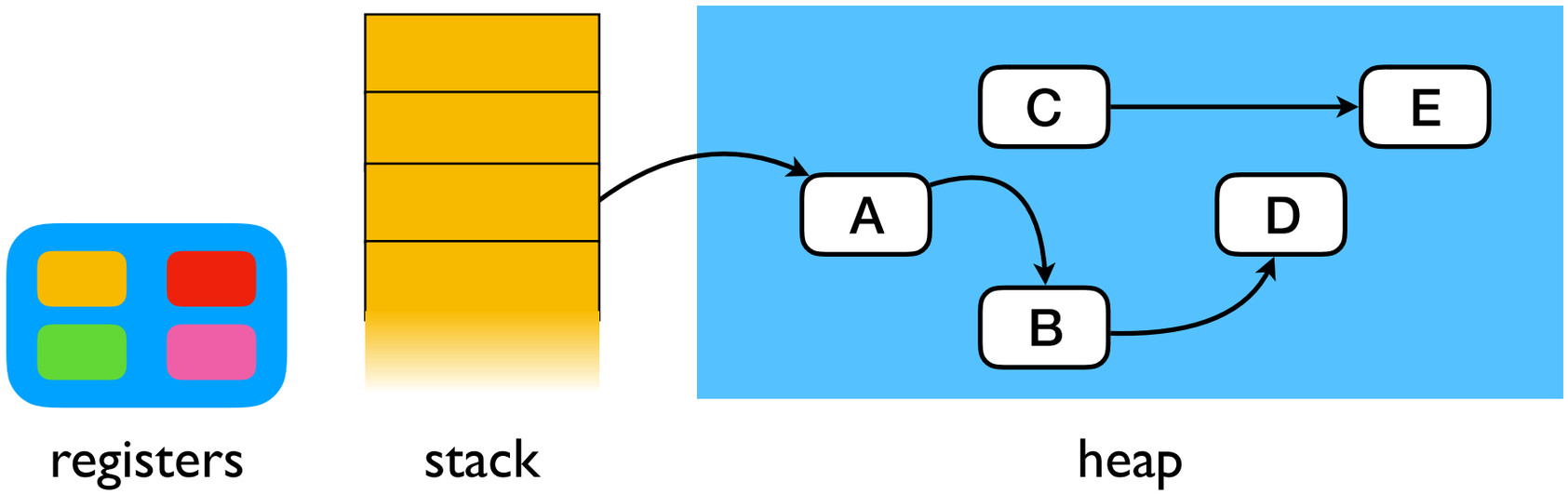

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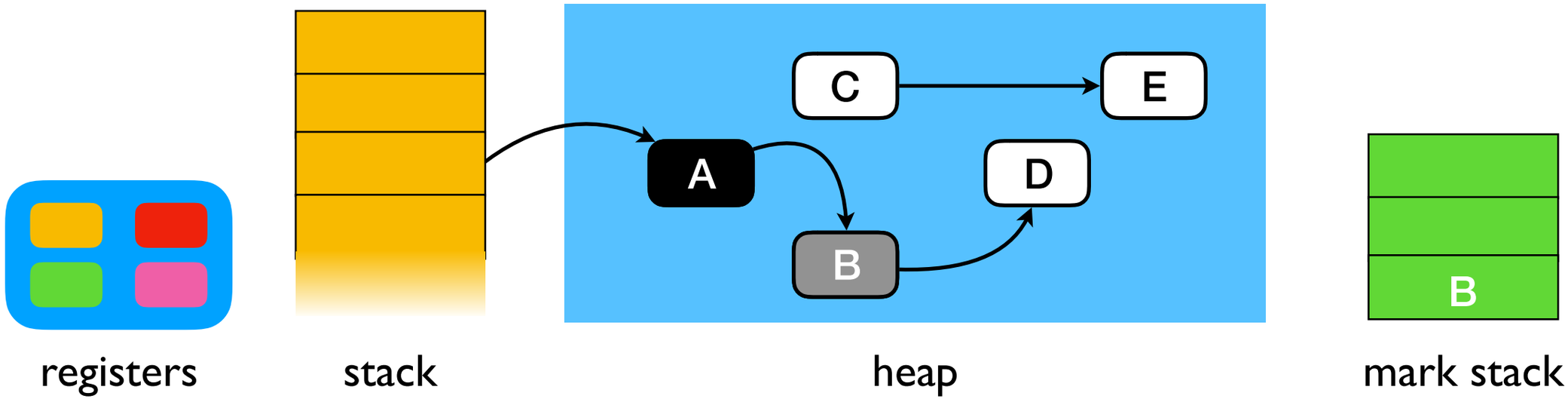

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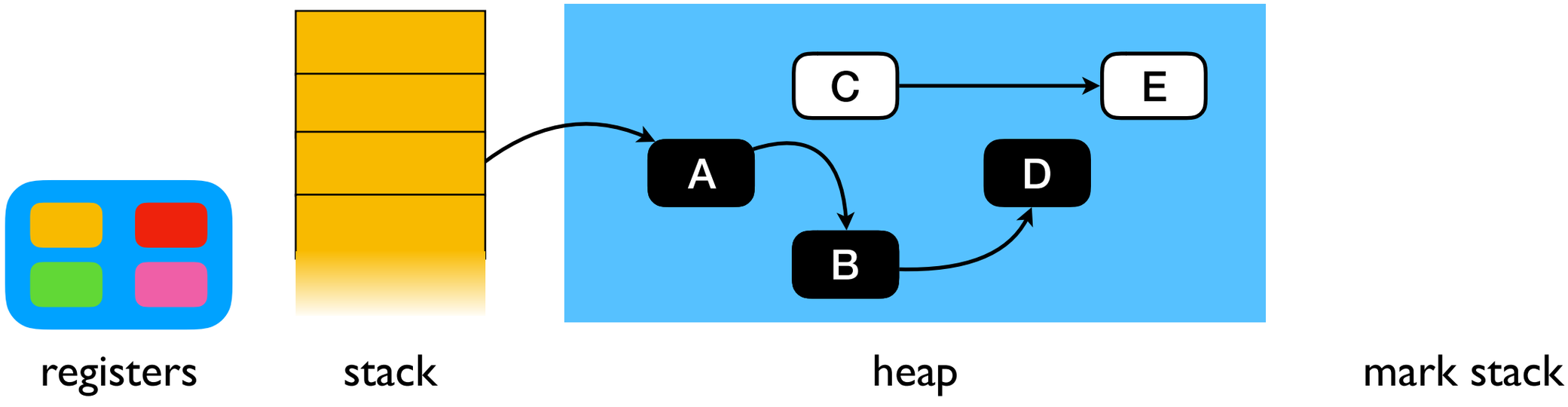

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  - ✦ Tri-color invariant: *No black object points to a white object*

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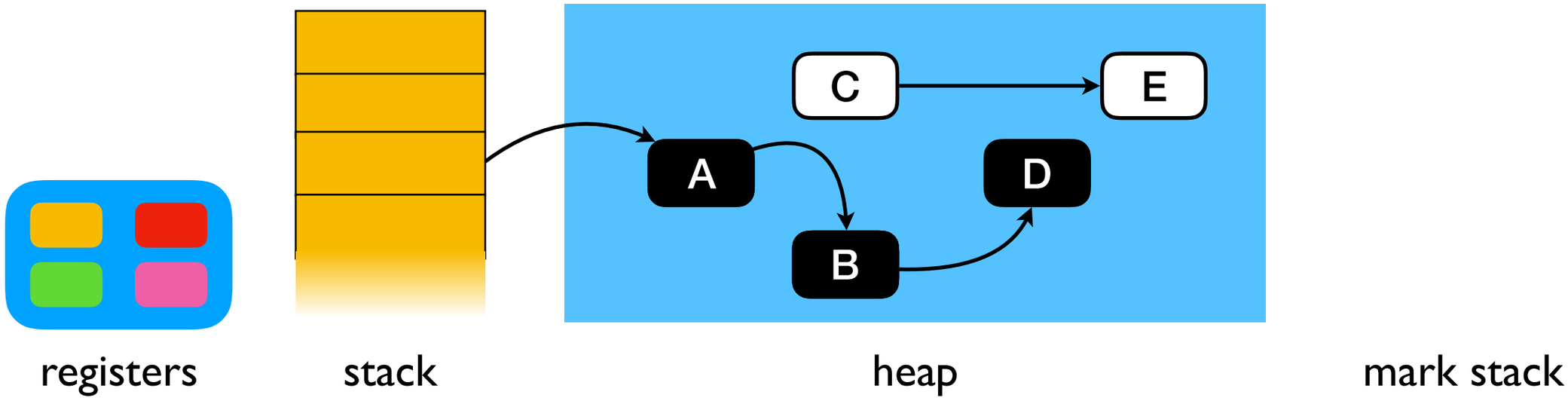

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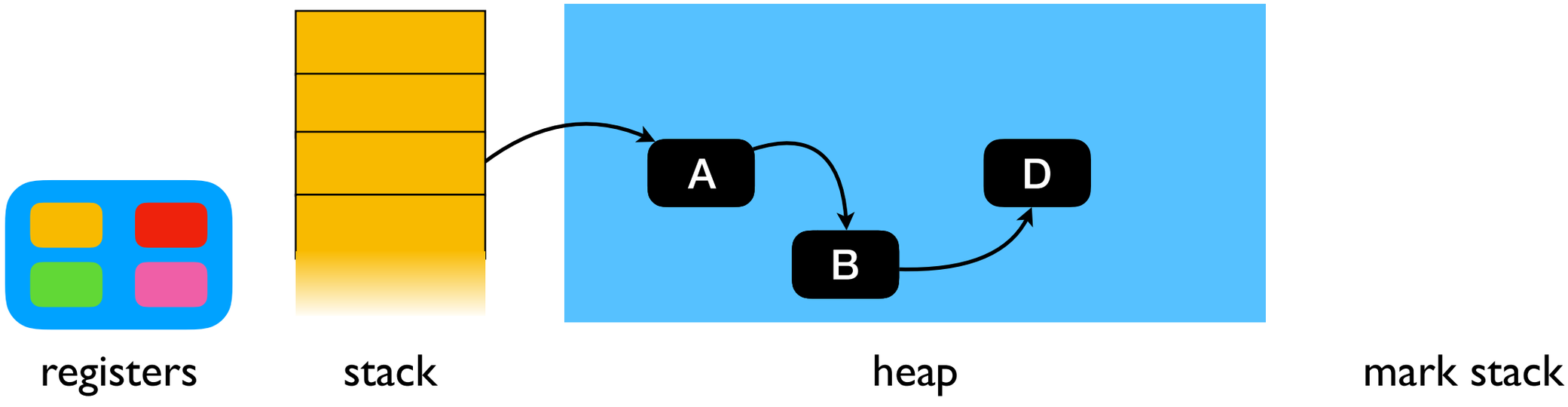

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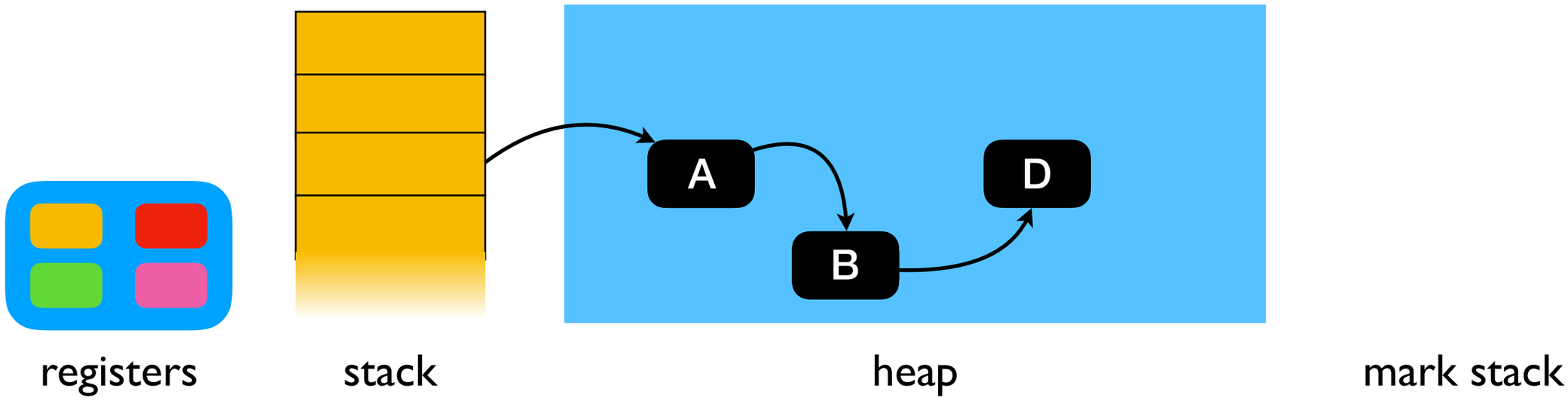

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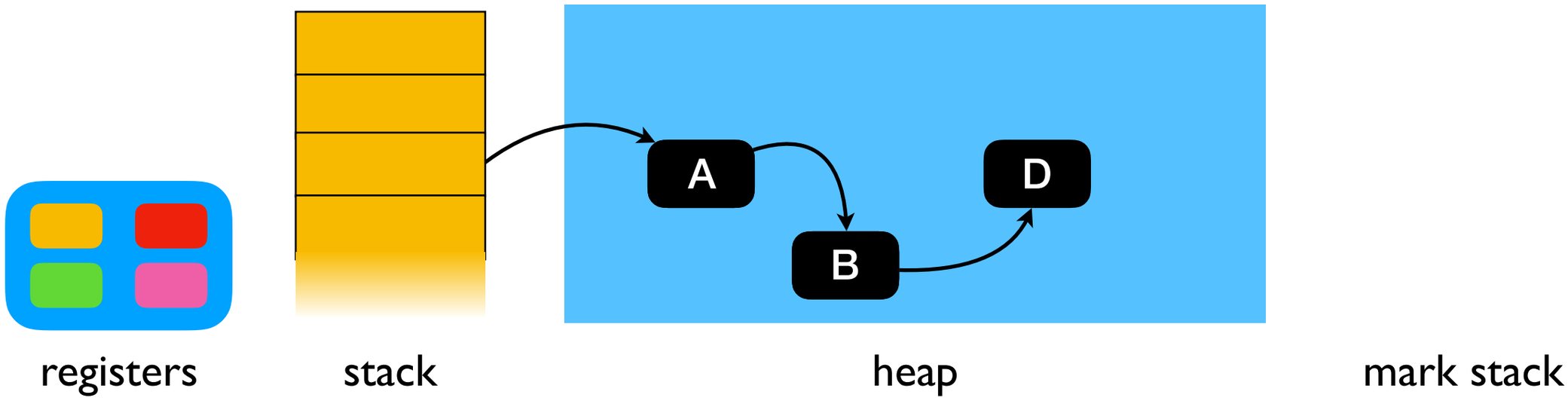

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  - ✦ Simple
  - ✦ Can perform the GC incrementally
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    - ✤ *Minimise GC pause times!*

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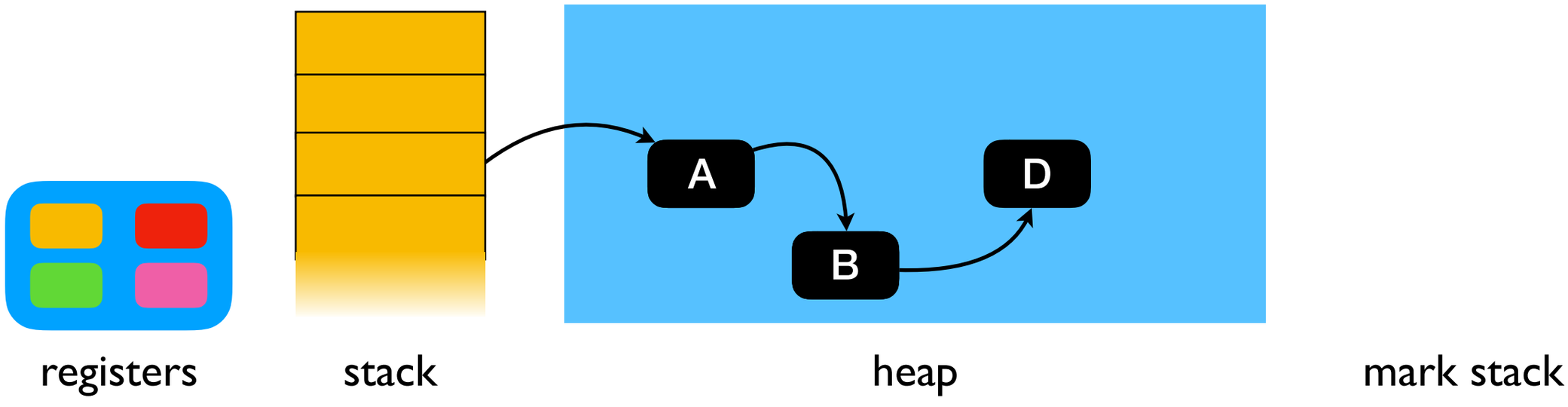

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- Cons
  - ✦ Need to maintain free-list of objects => allocations overheads + fragmentation

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  - ✦ Young objects are much more likely to die than old objects

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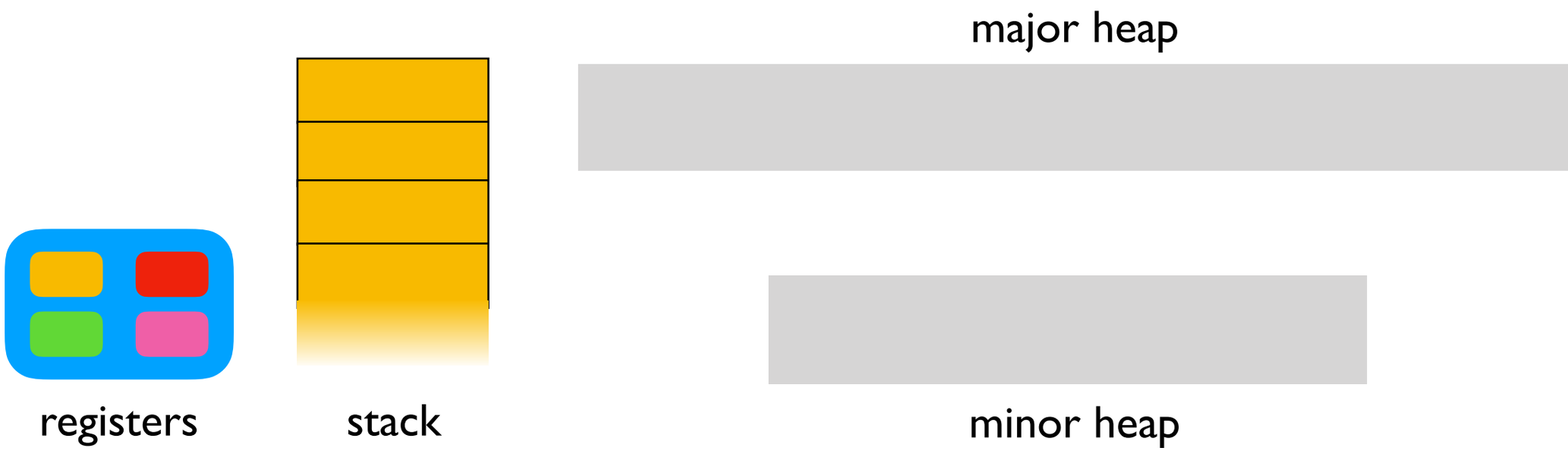

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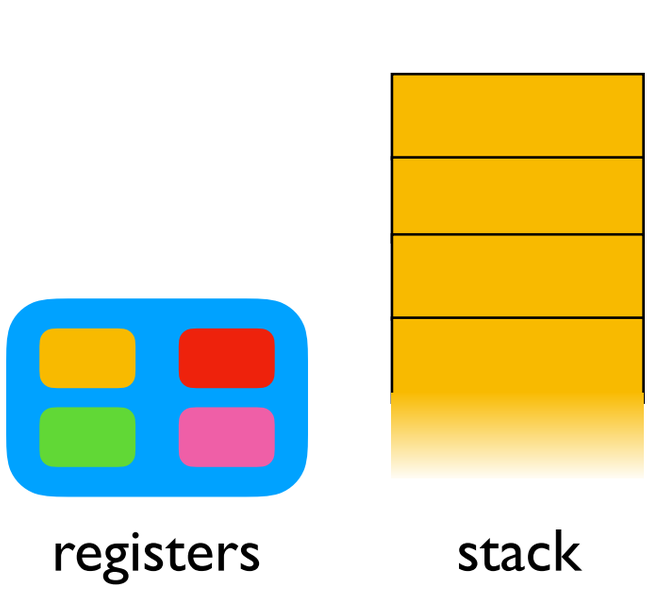

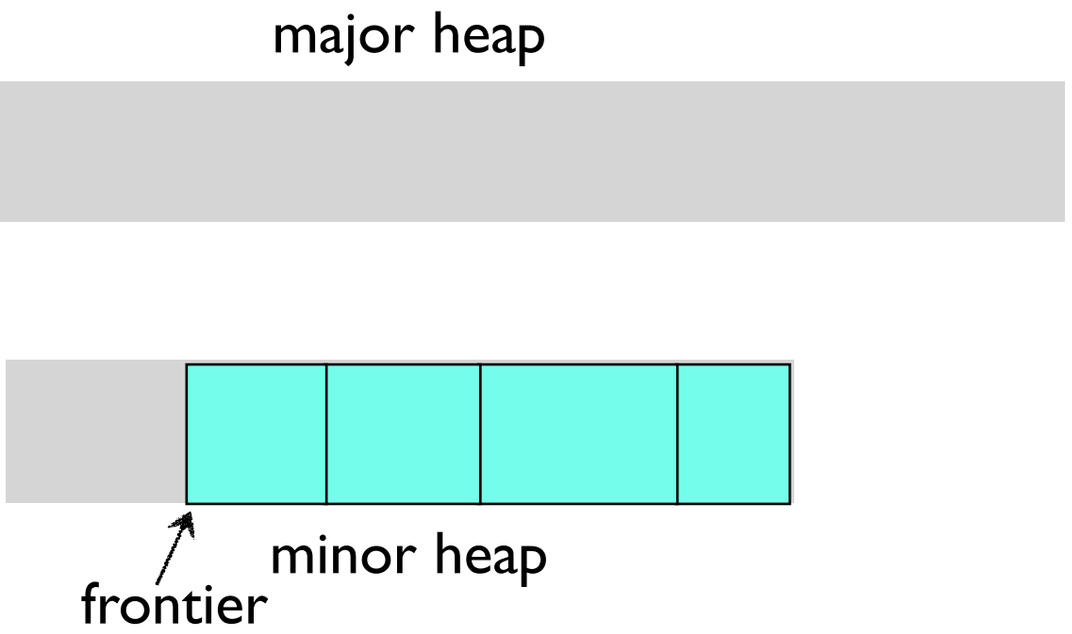

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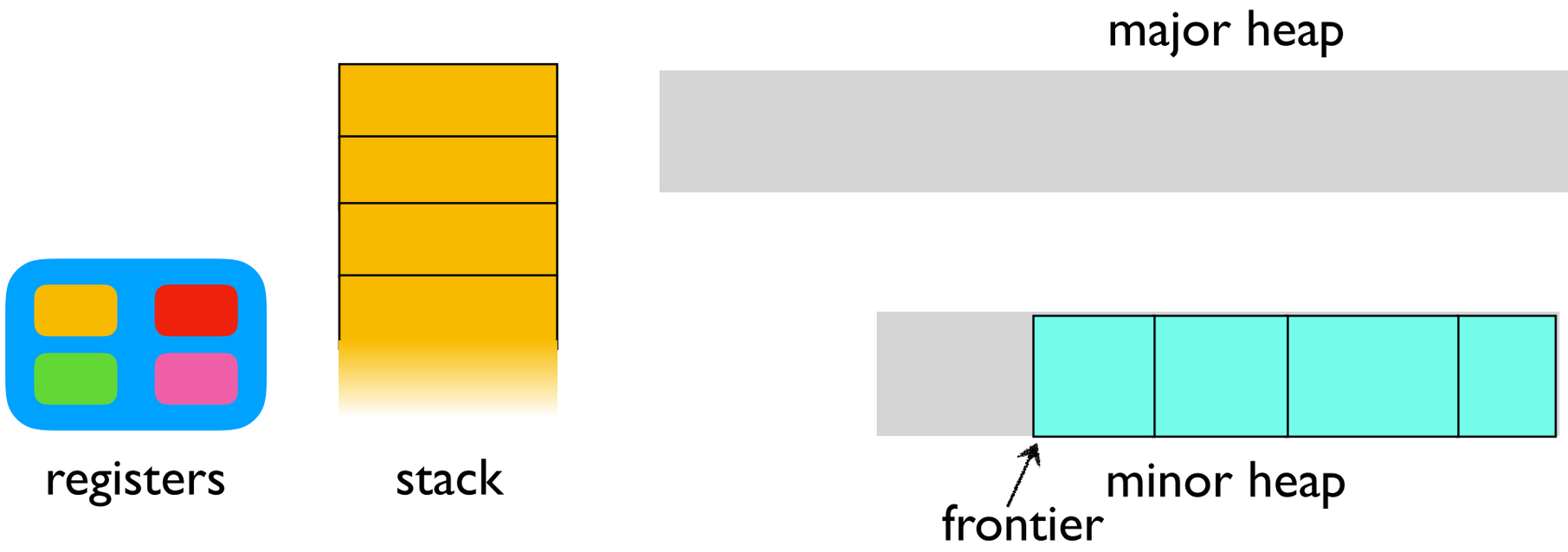

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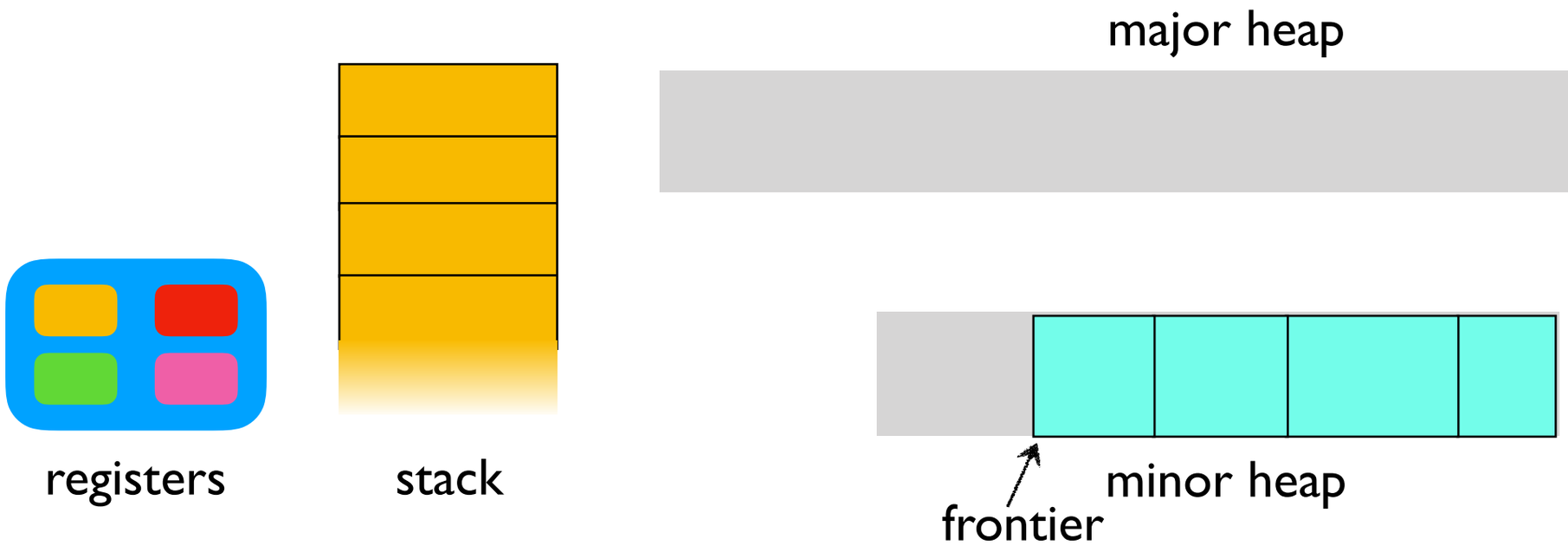

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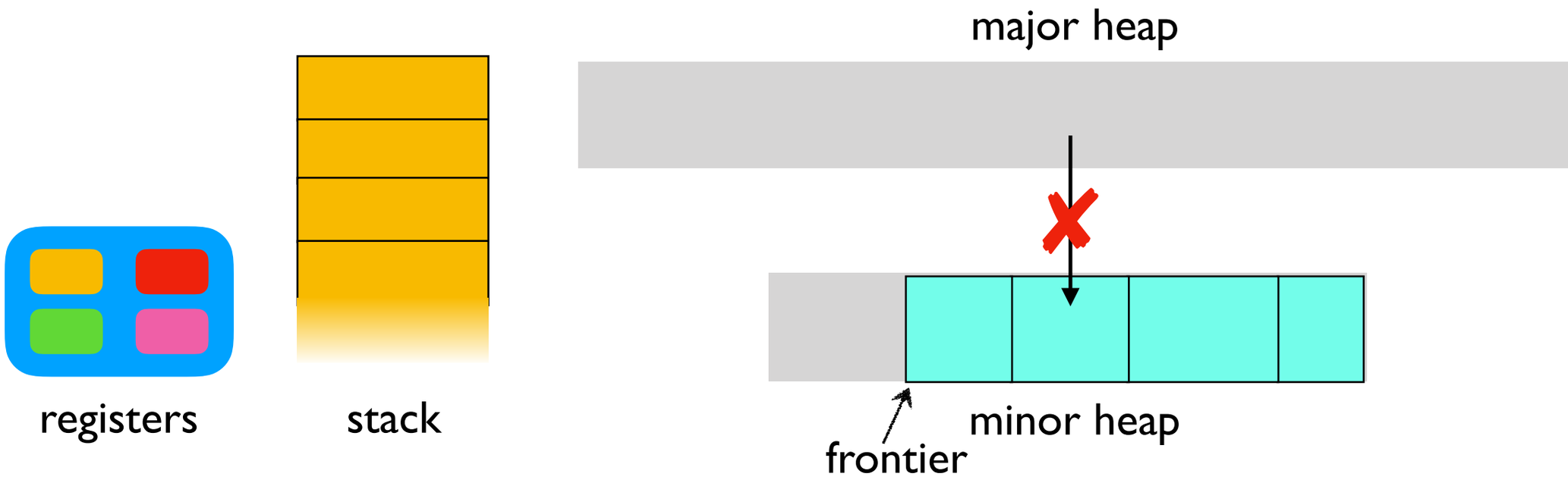

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- Purely functional => no major to minor pointers

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  - ✦ Mutations are pervasive in real-world code

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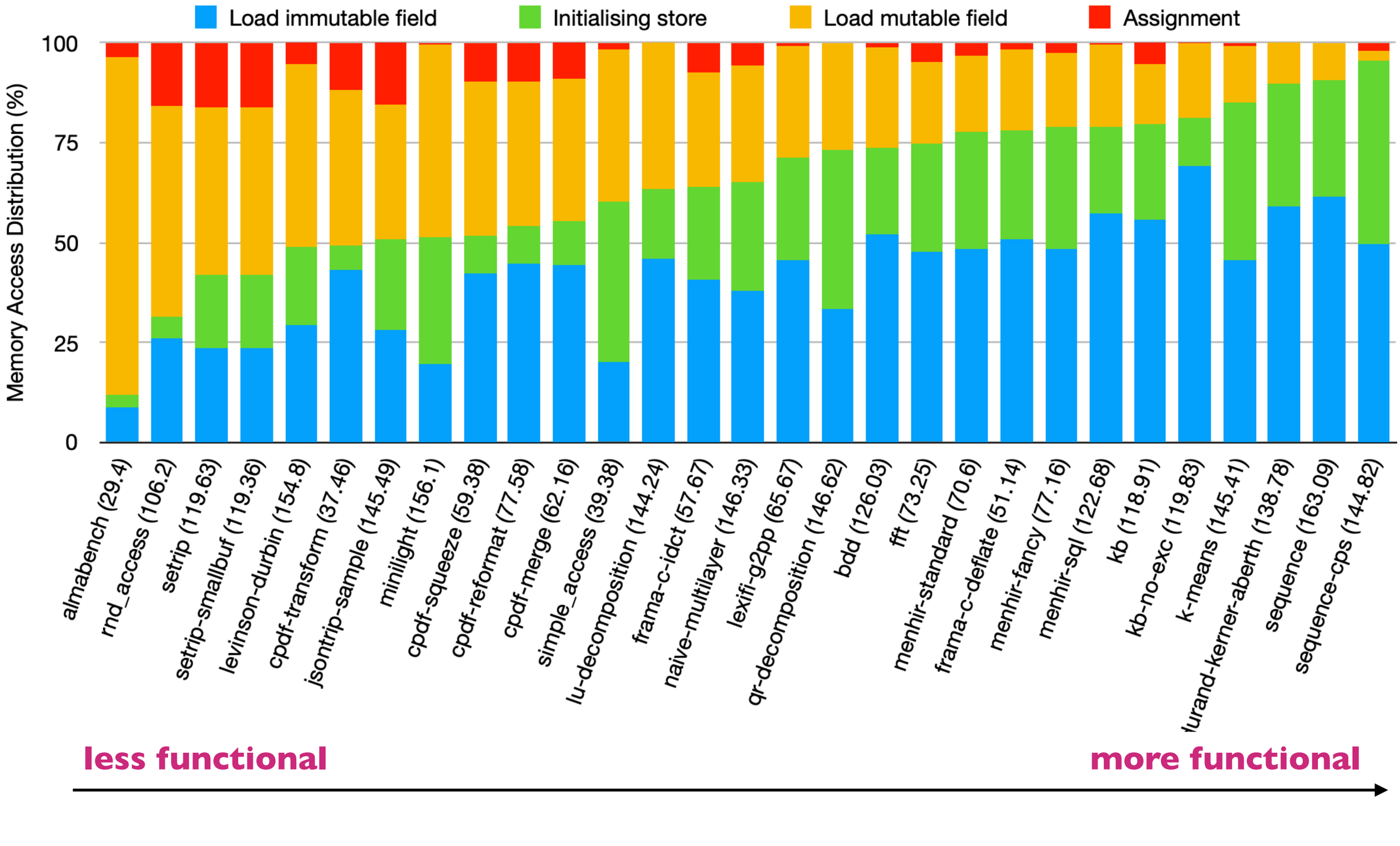
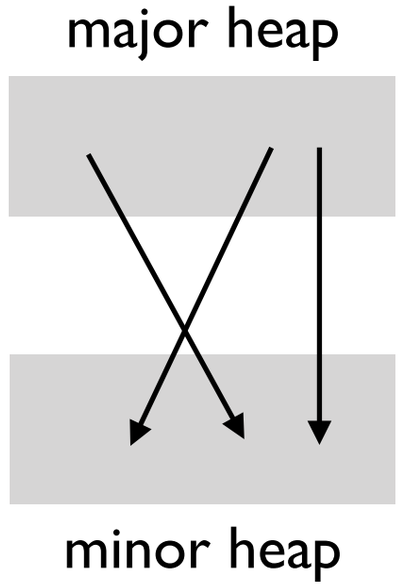

Load immutable field
Initialising store
Load mutable field
Assignment
Memory Access Distribution (%)
100
75
50
25
0
almabench (29.4)
rnd_access (106.2)
setrip (119.63)
setrip-smallbuf (119.36)
levinson-durbin (154.8)
cpdf-transform (37.46)
jsontrip-sample (145.49)
minilight (156.1)
cpdf-squeeze (59.38)
cpdf-reformat (77.58)
cpdf-merge (62.16)
simple_access (39.38)
lu-decomposition (144.24)
frama-c-idct (57.67)
naive-multilayer (146.33)
lexifi-g2pp (65.67)
qr-decomposition (146.62)
bdd (126.03)
fft (73.25)
menhir-standard (70.6)
frama-c-deflate (51.14)
menhir-fancy (77.16)
menhir-sql (122.68)
kb (118.91)
kb-no-exc (119.83)
k-means (145.41)
lurand-kerner-aberth (138.78)
sequence (163.09)
sequence-cps (144.82)
less functional
more functional

Mutations — Minor GC

- Old objects might point to young objects



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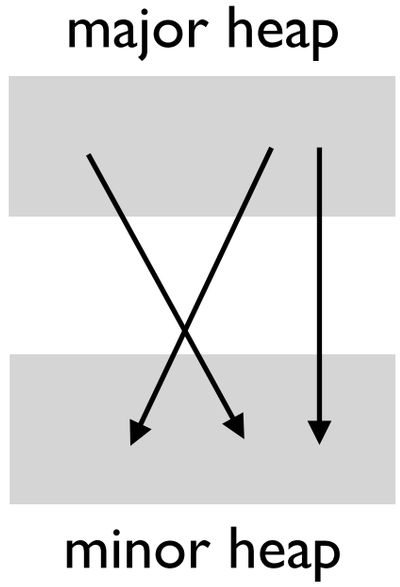

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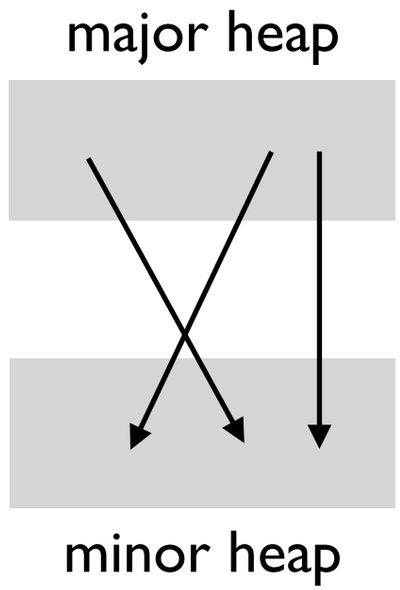


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(* Before r := x *)
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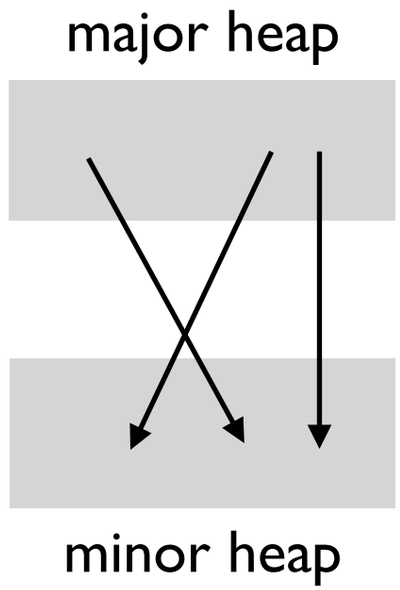


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- *Remembered set*
  - ✦ Set of major heap addresses that point to minor heap
  - ✦ Used as root for minor collection
  - ✦ Cleared after minor collection.

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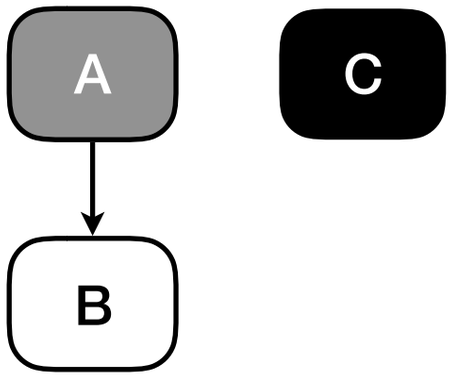

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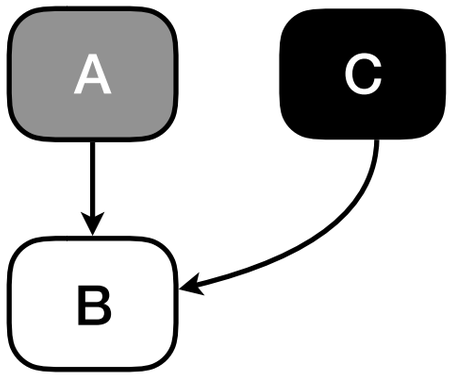

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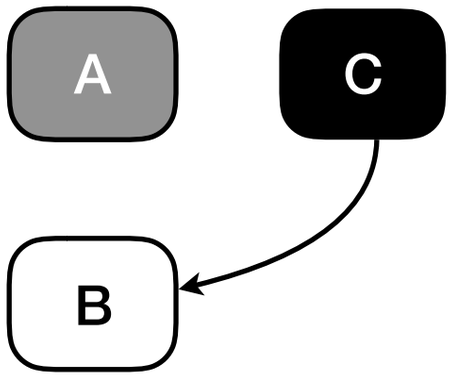

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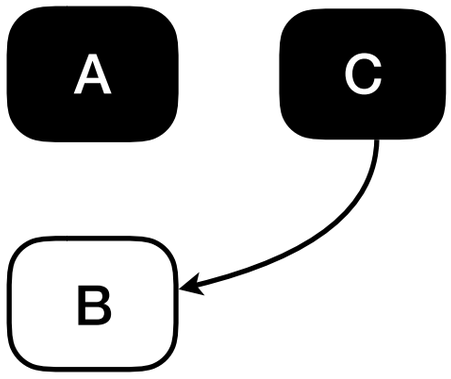

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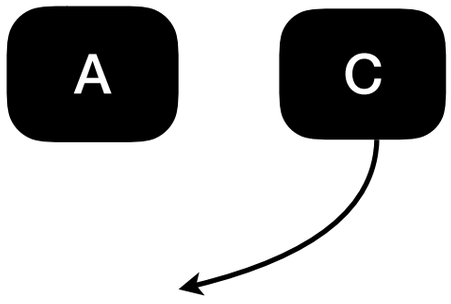

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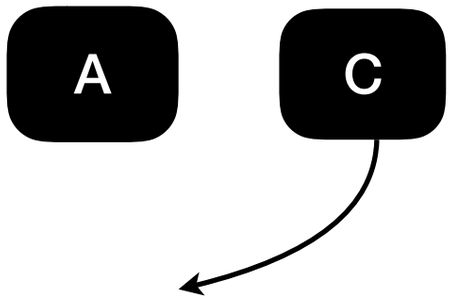

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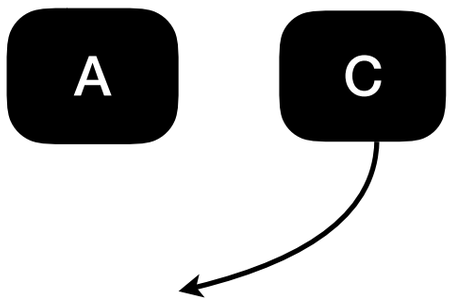

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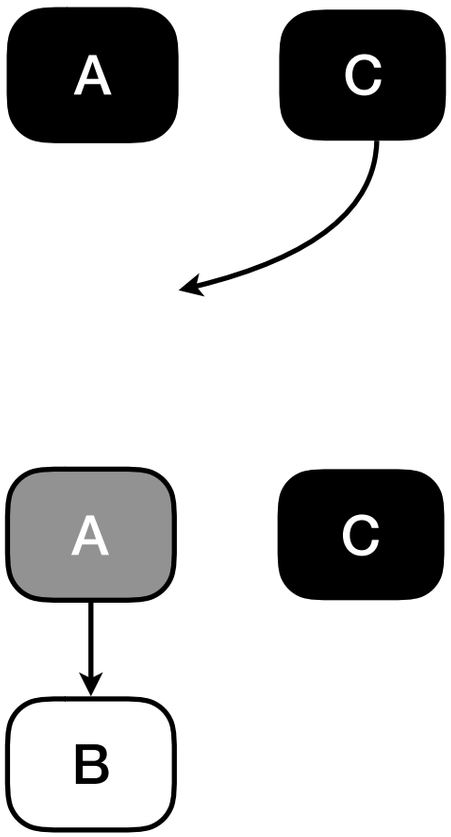

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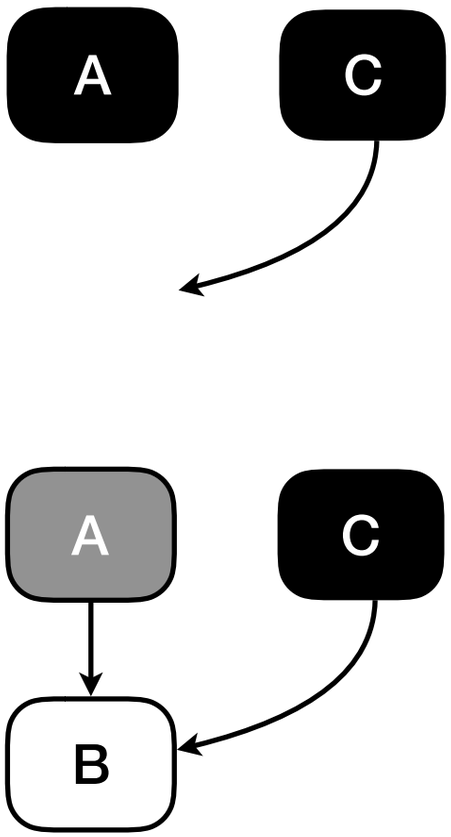

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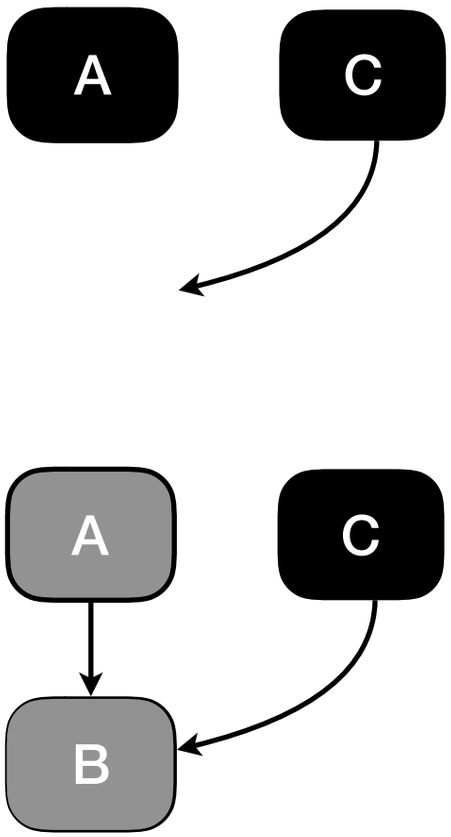

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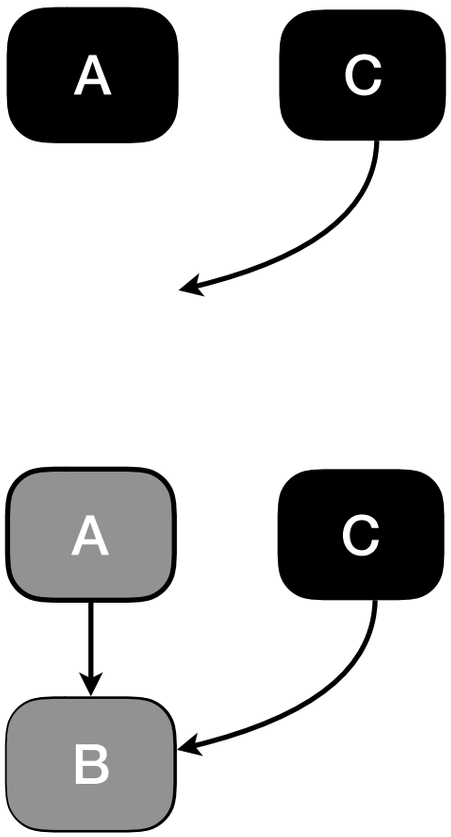

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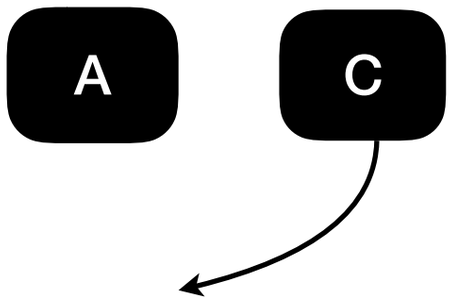

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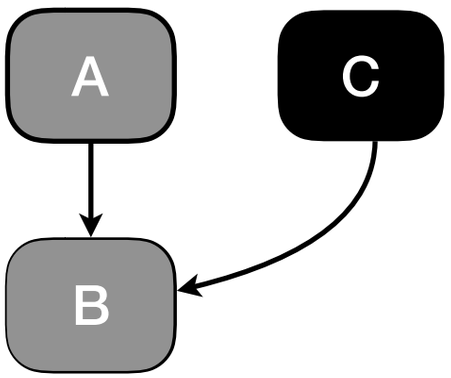

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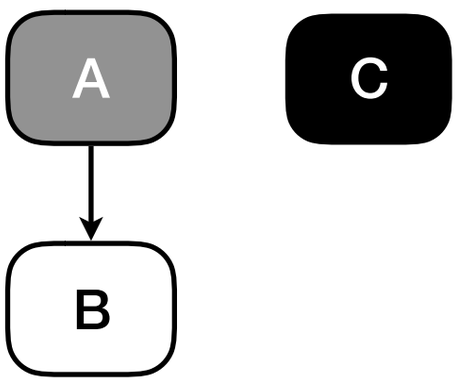

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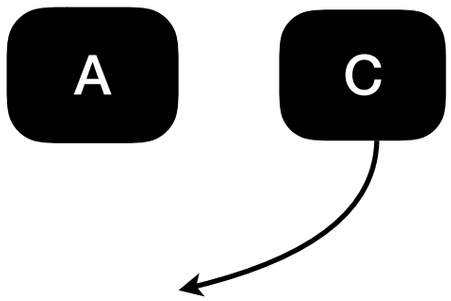

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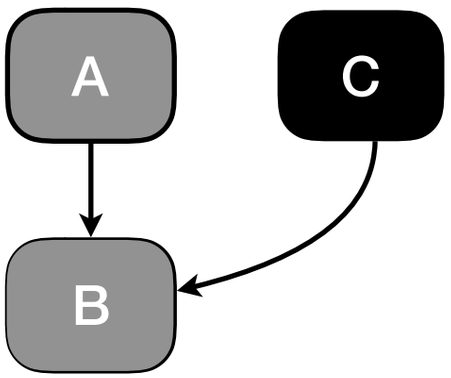

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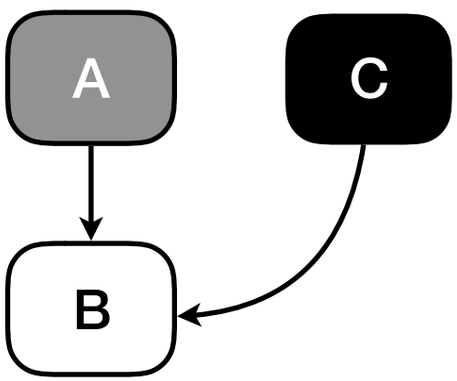

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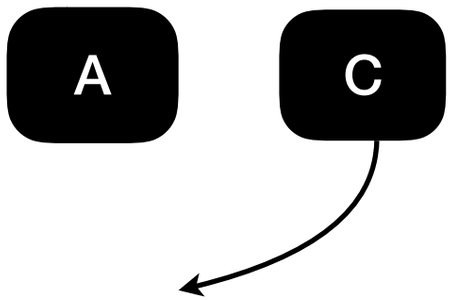

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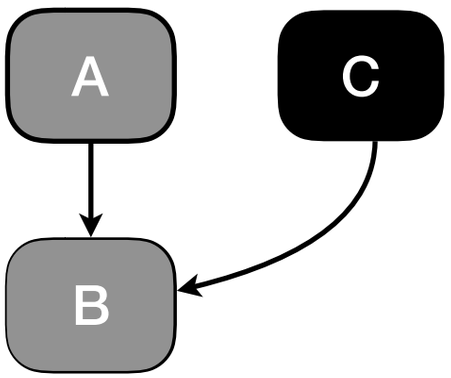

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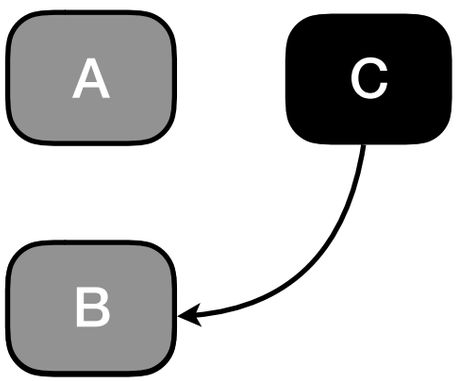

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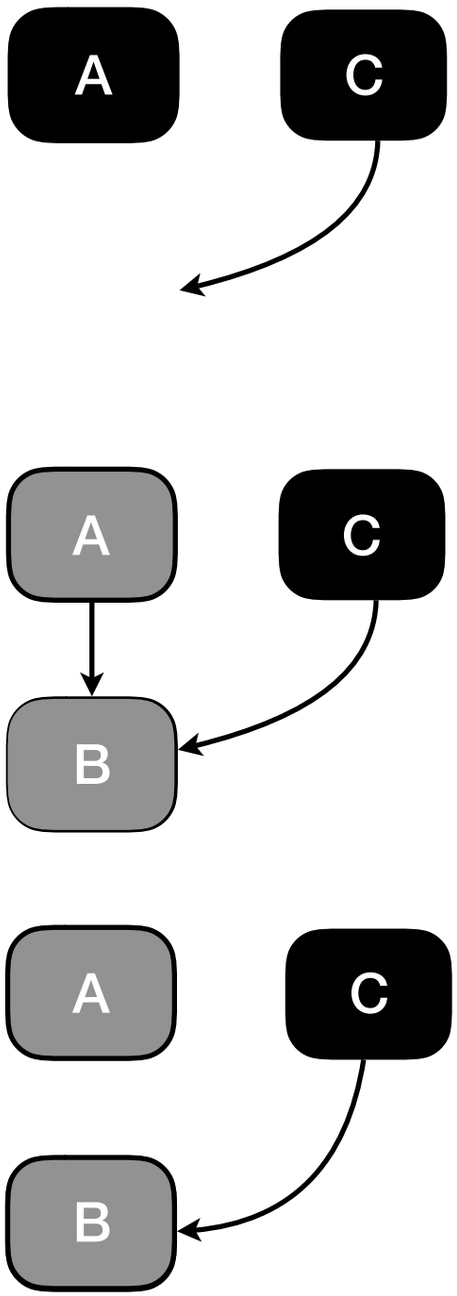

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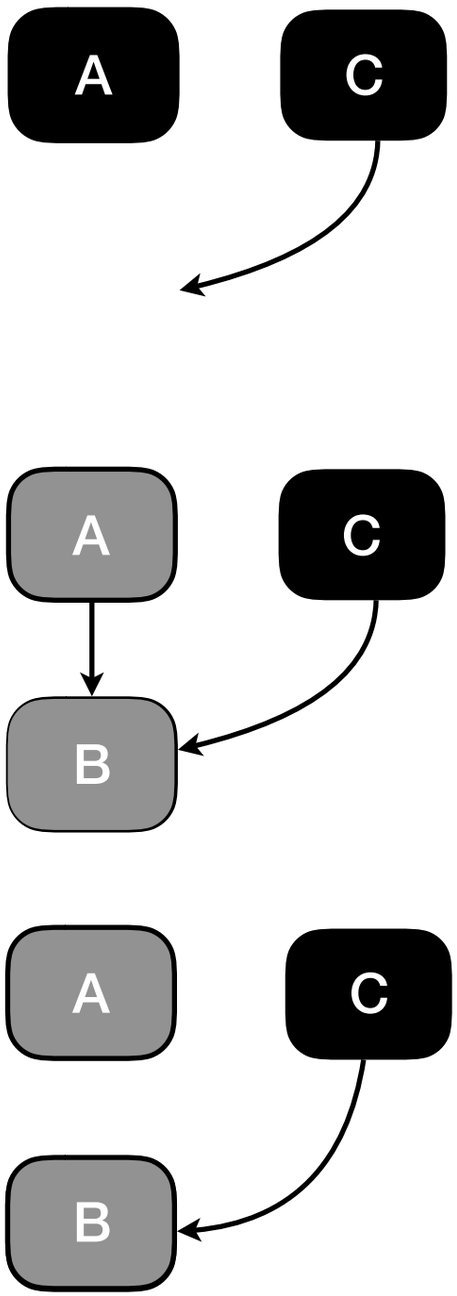

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```
(* Before r := x *)
let write_barrier (r, x) =
  if is_major r && is_minor x then
    remembered_set.add r
  else if is_major r && is_major x then
    mark(!r)
```

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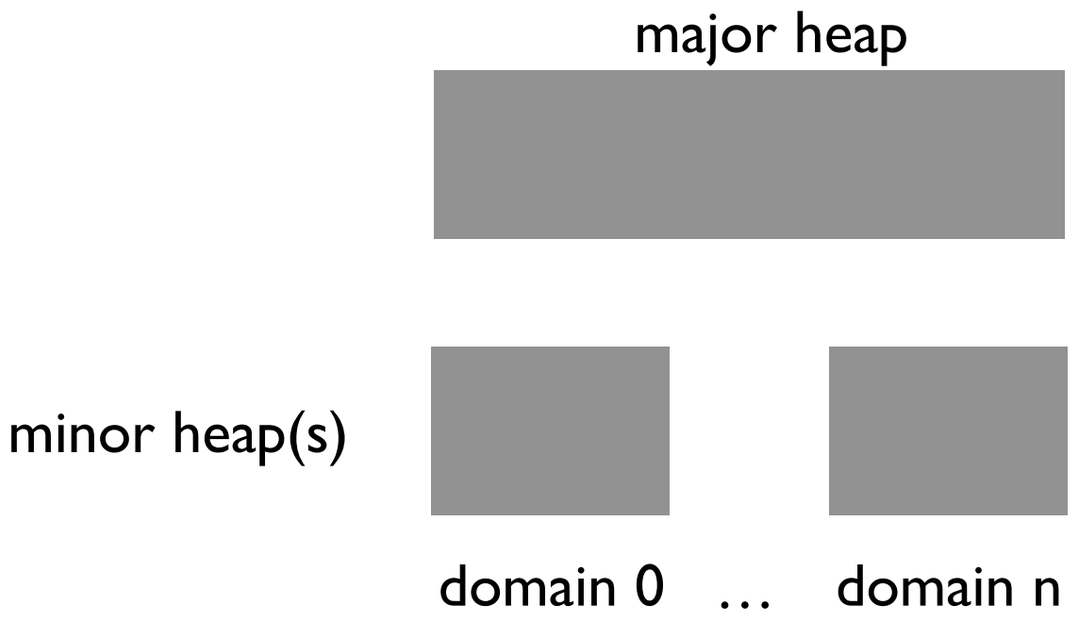

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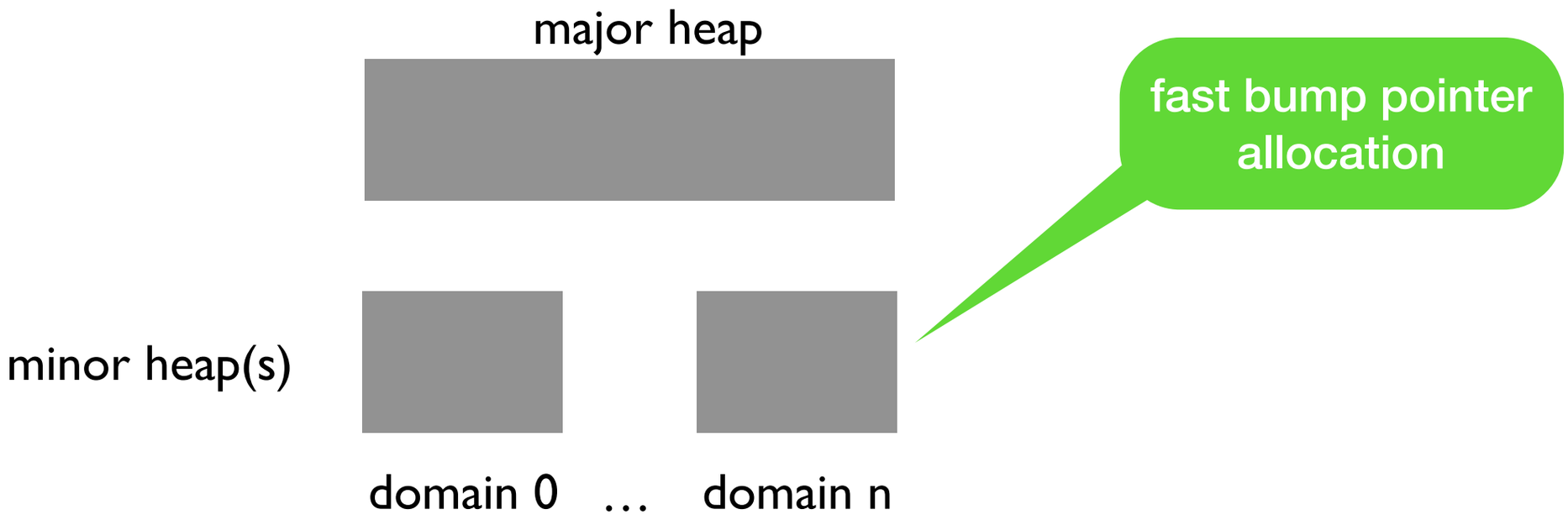

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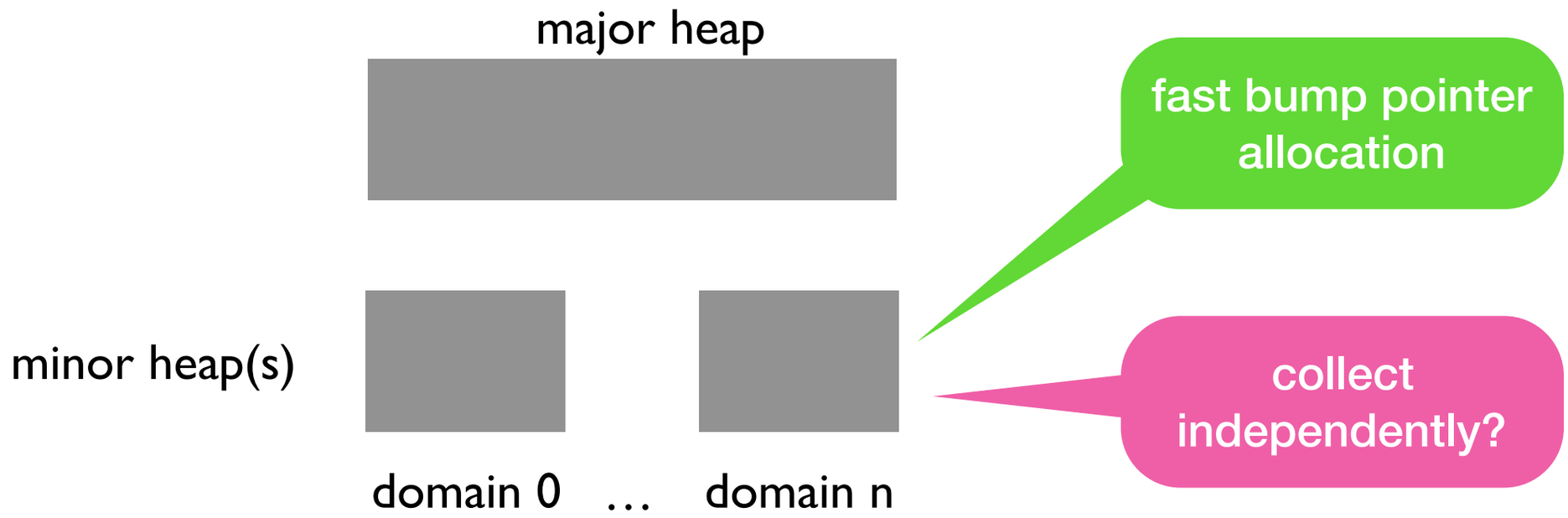

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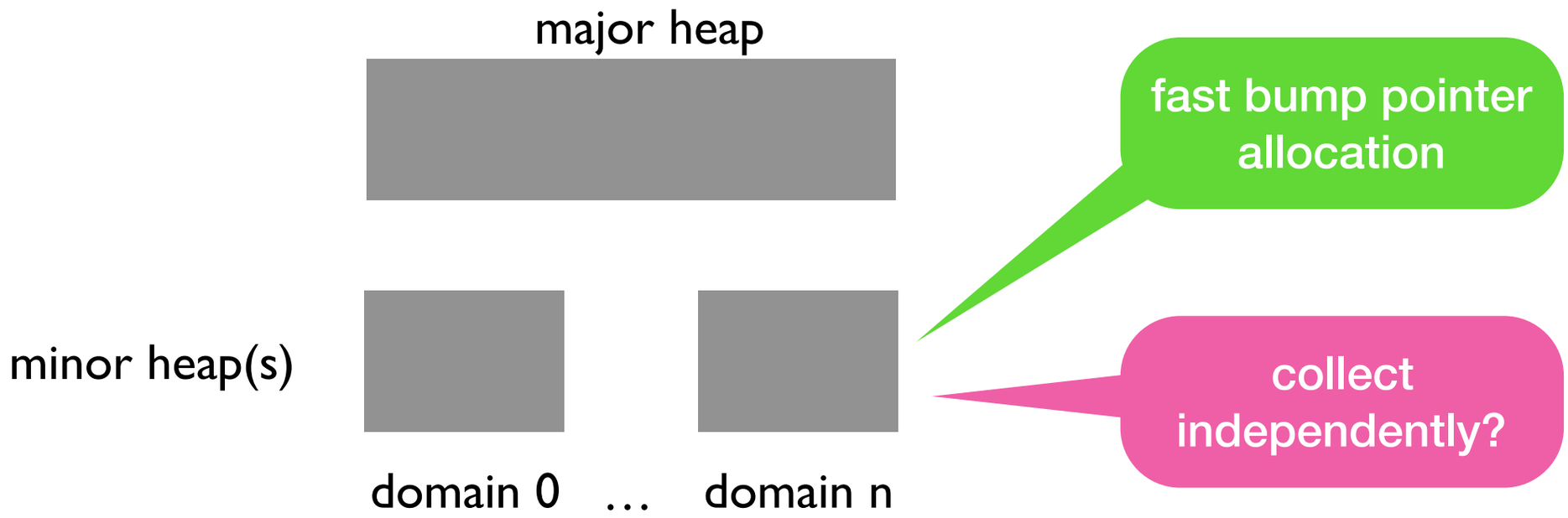

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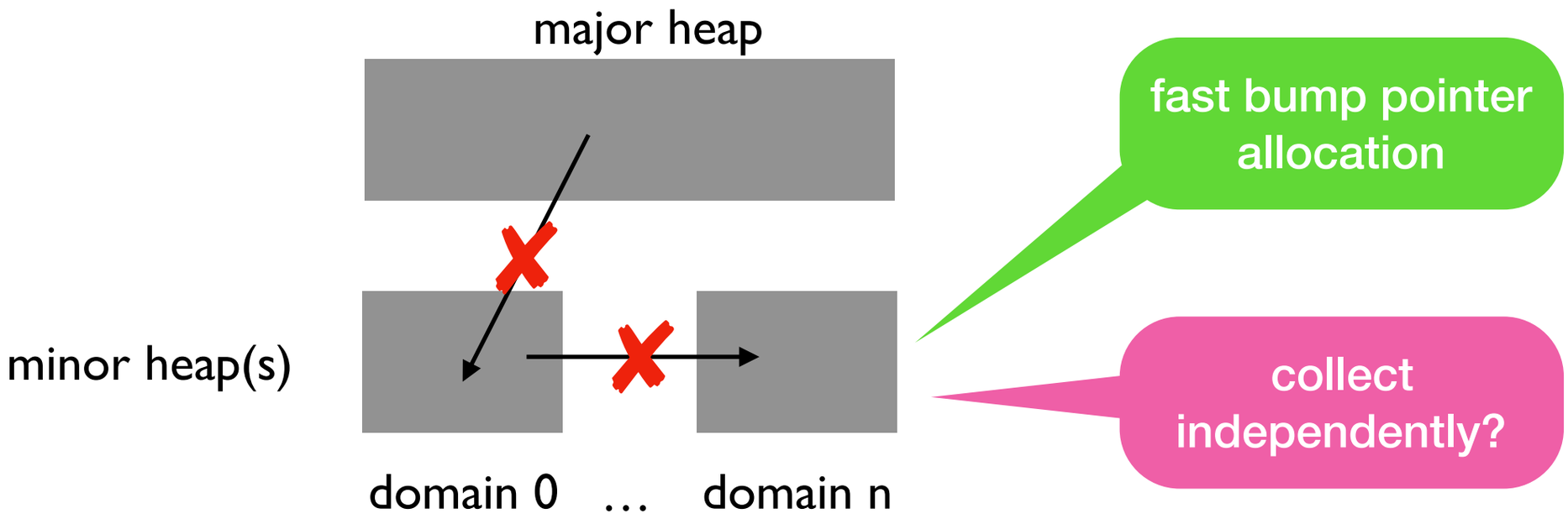

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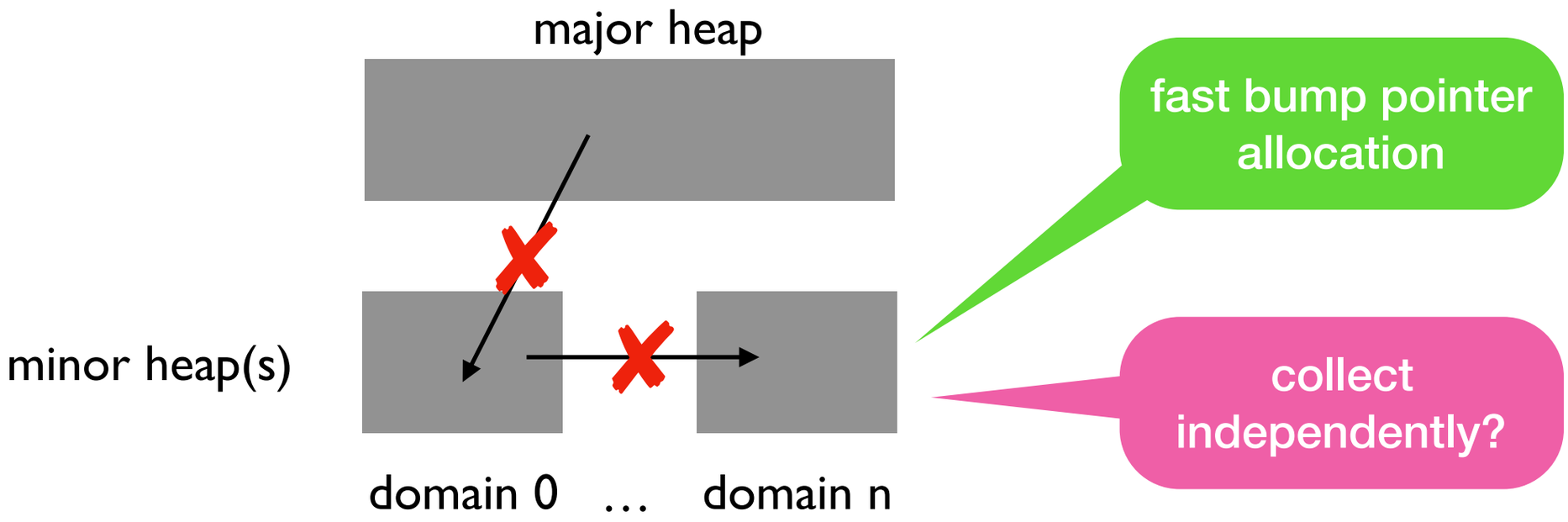

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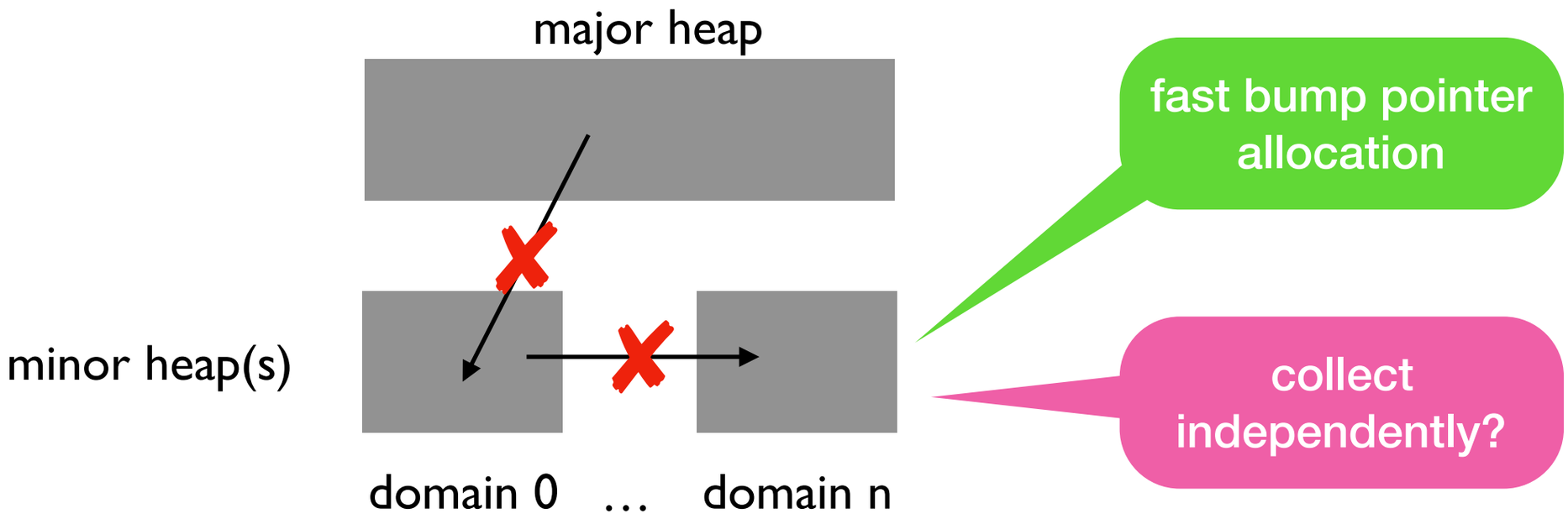

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- *Too much promotion.* Ex: work-stealing queue

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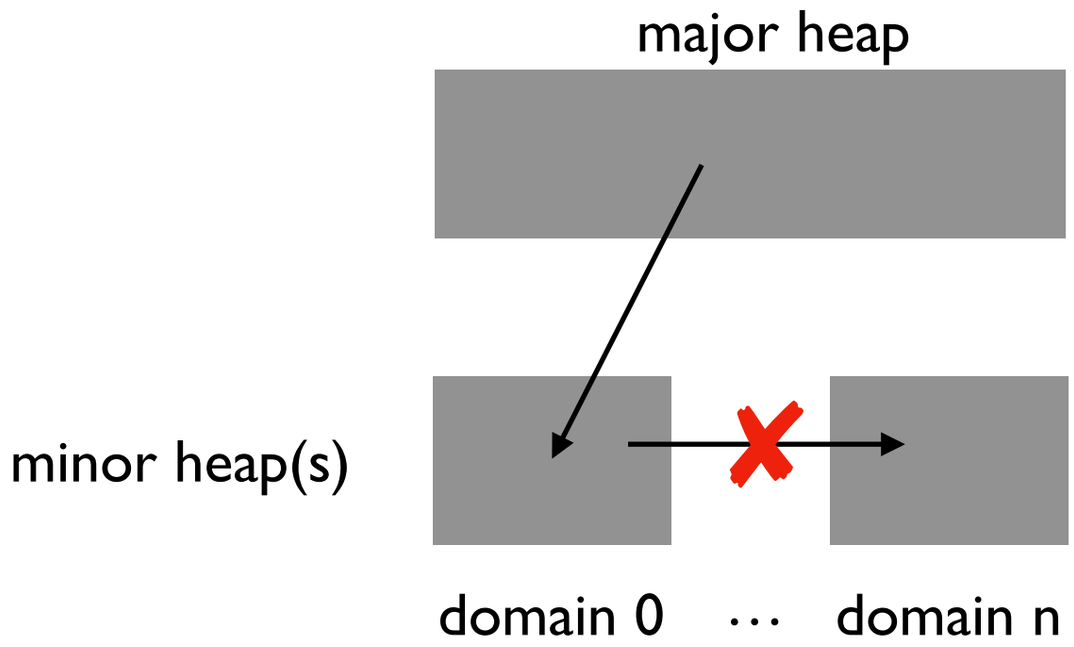

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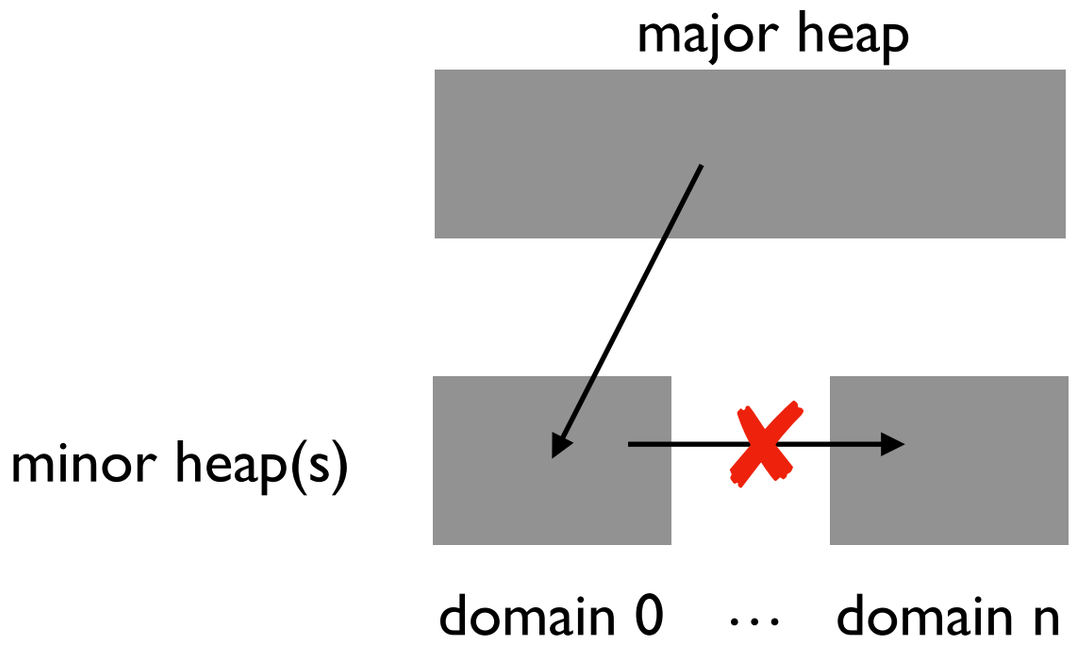

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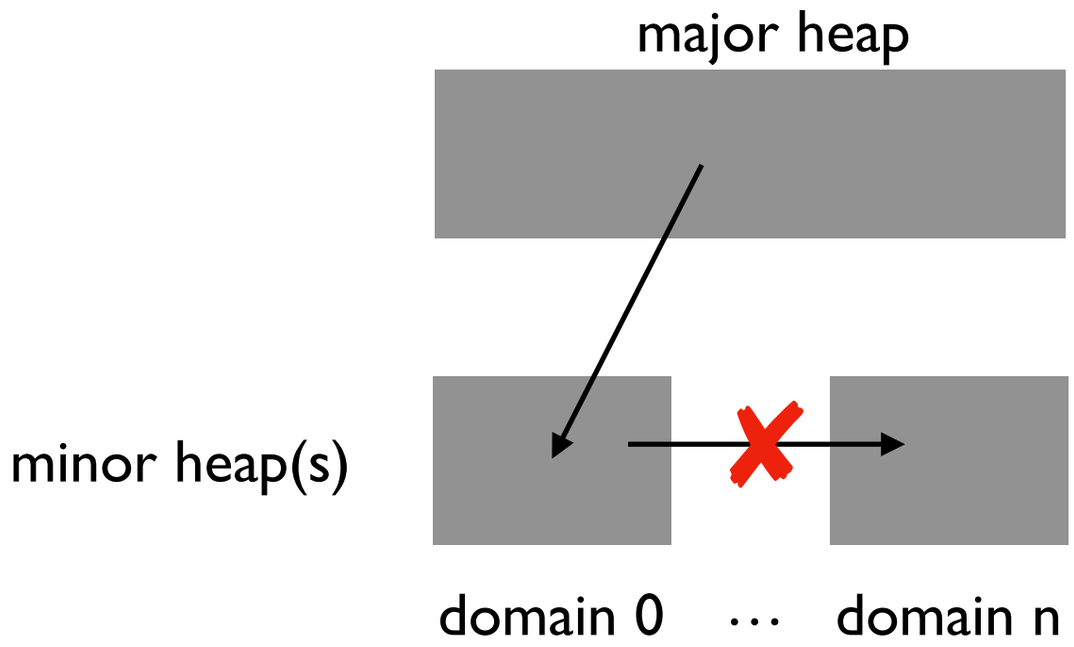

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- Read barrier. If the value loaded is
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  - ✦ object in foreign minor heap => *Read fault (Interrupt + promote)*

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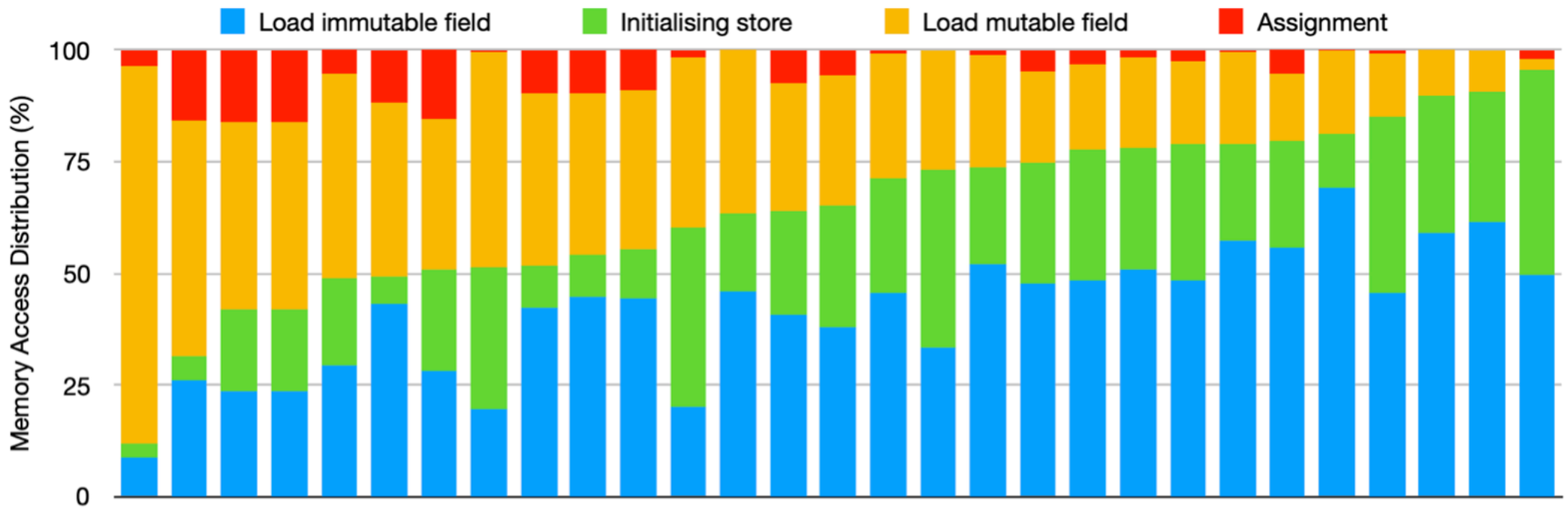

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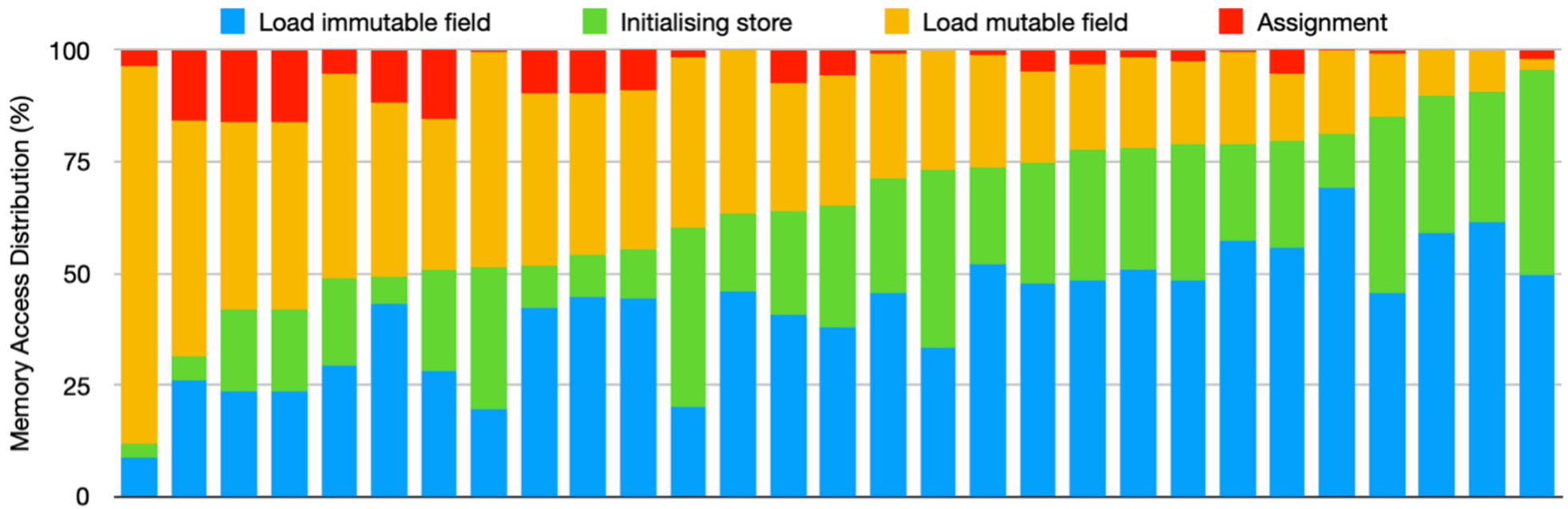


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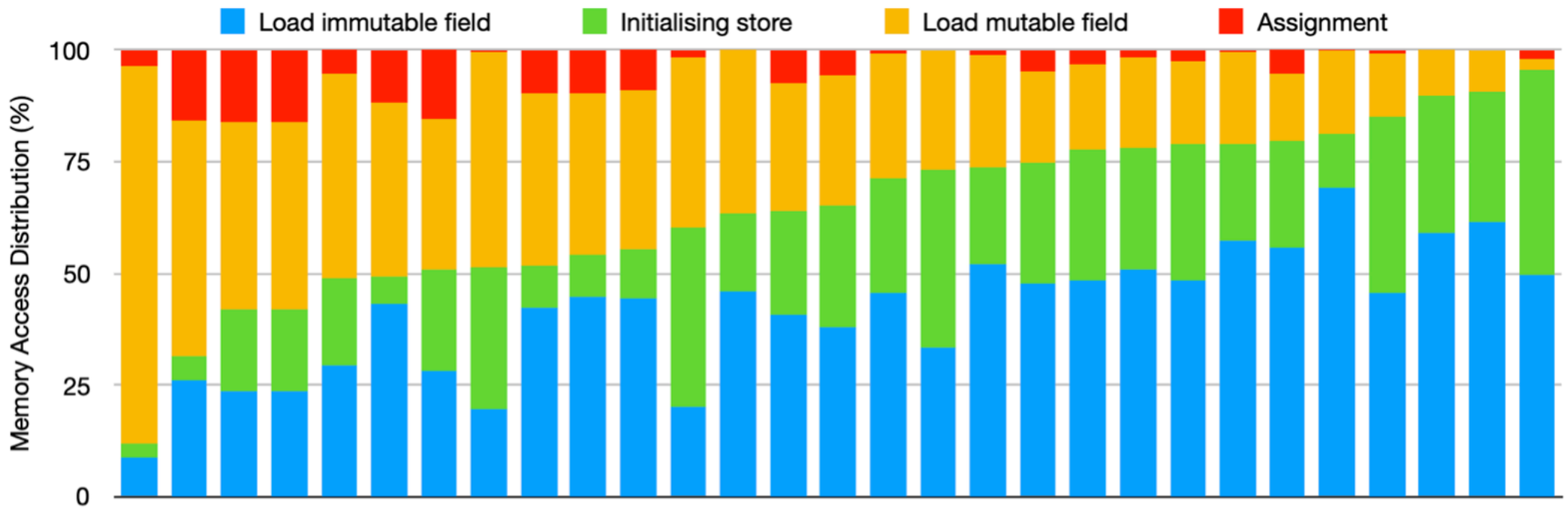


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Deep dive into Multicore OCaml Garbage Collector
http://kcsrk.info/multicore/gc/2017/07/06/multicore-ocaml-gc/

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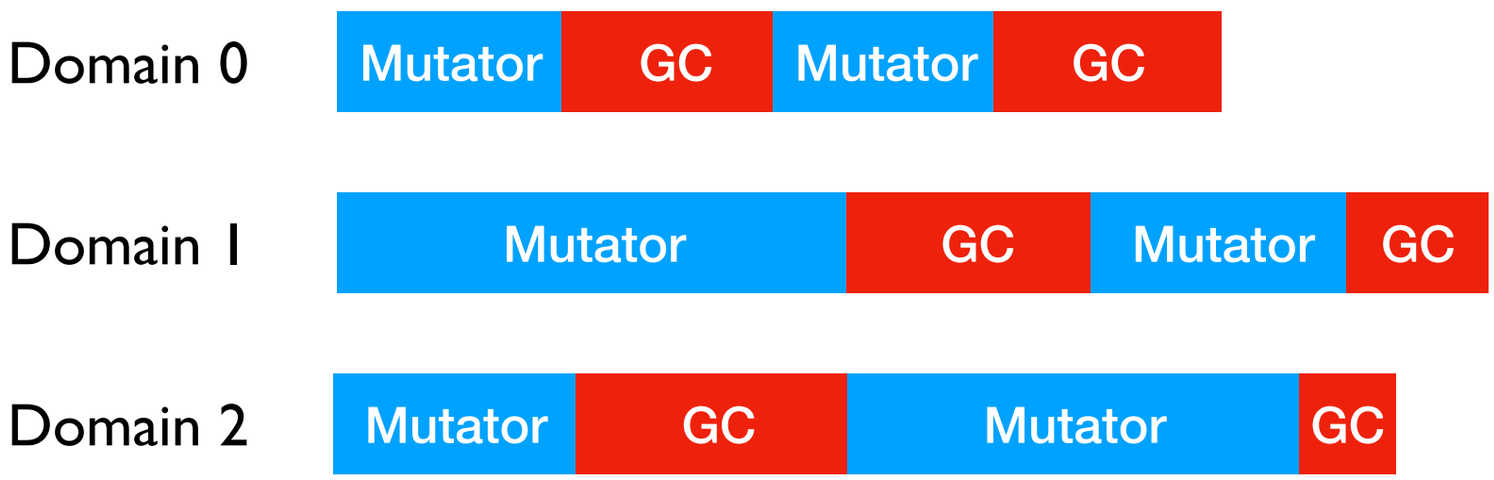
- Multicore OCaml's GC should be *concurrent (and incremental)*



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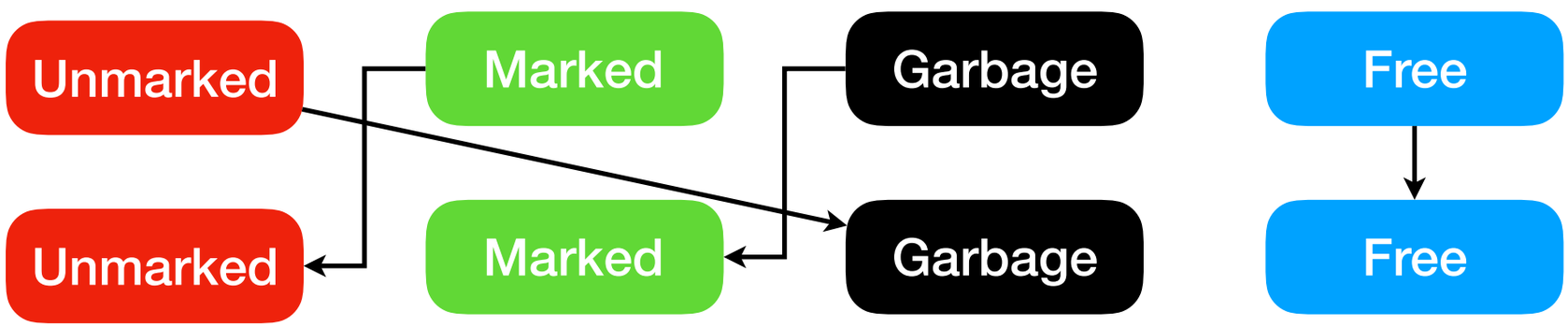
Yuasa!



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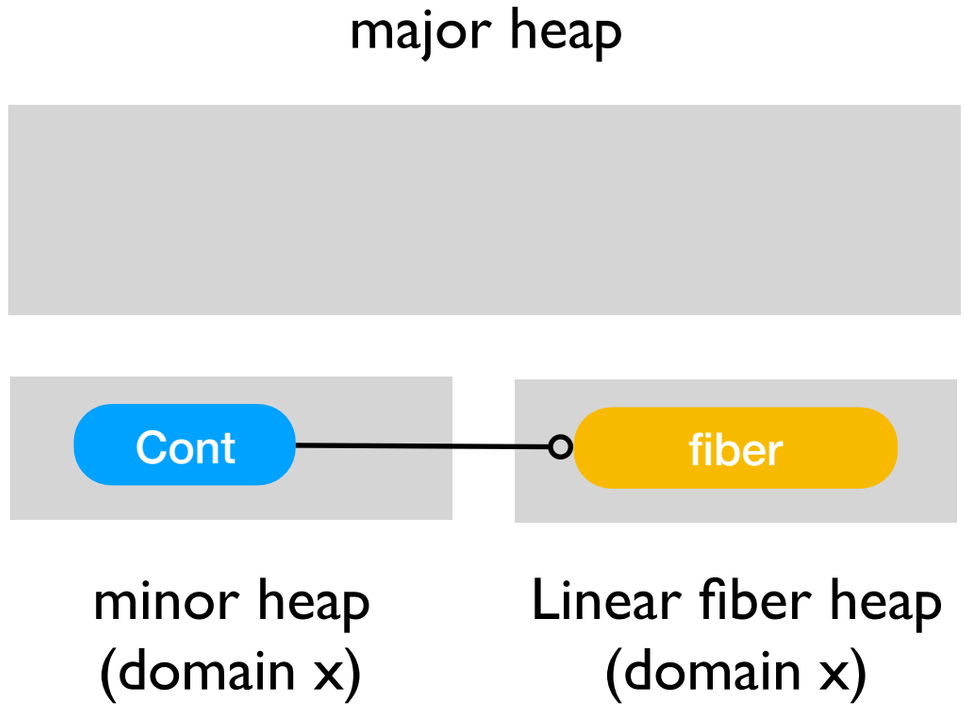

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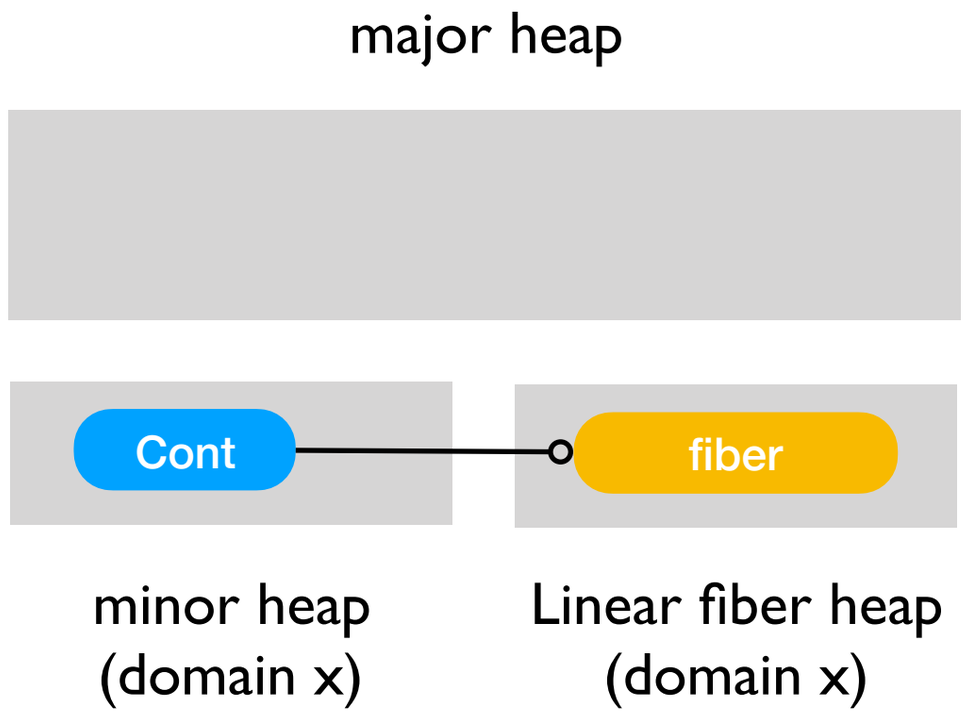

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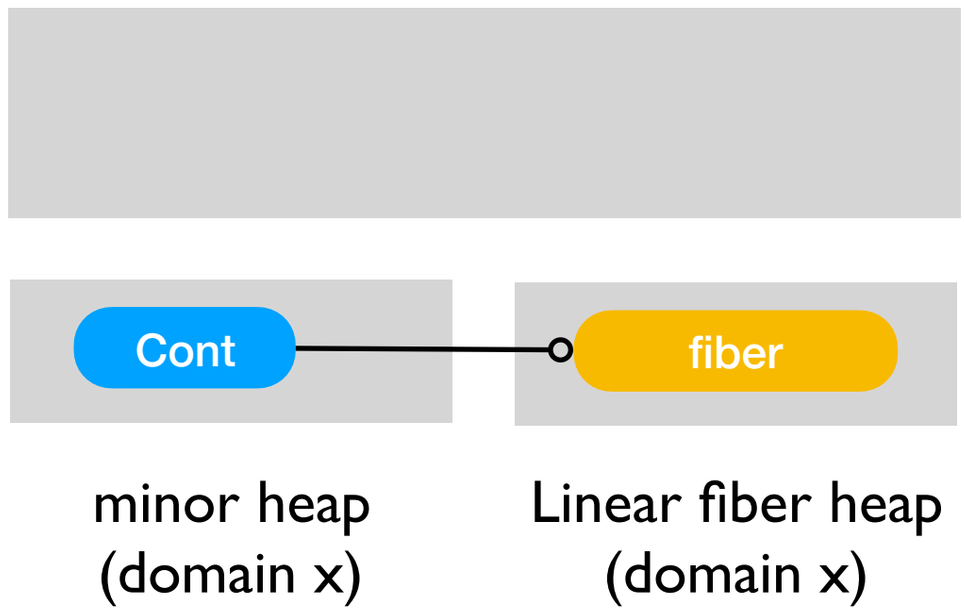

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- *No write barriers on fiber stack operations (push & pop)*
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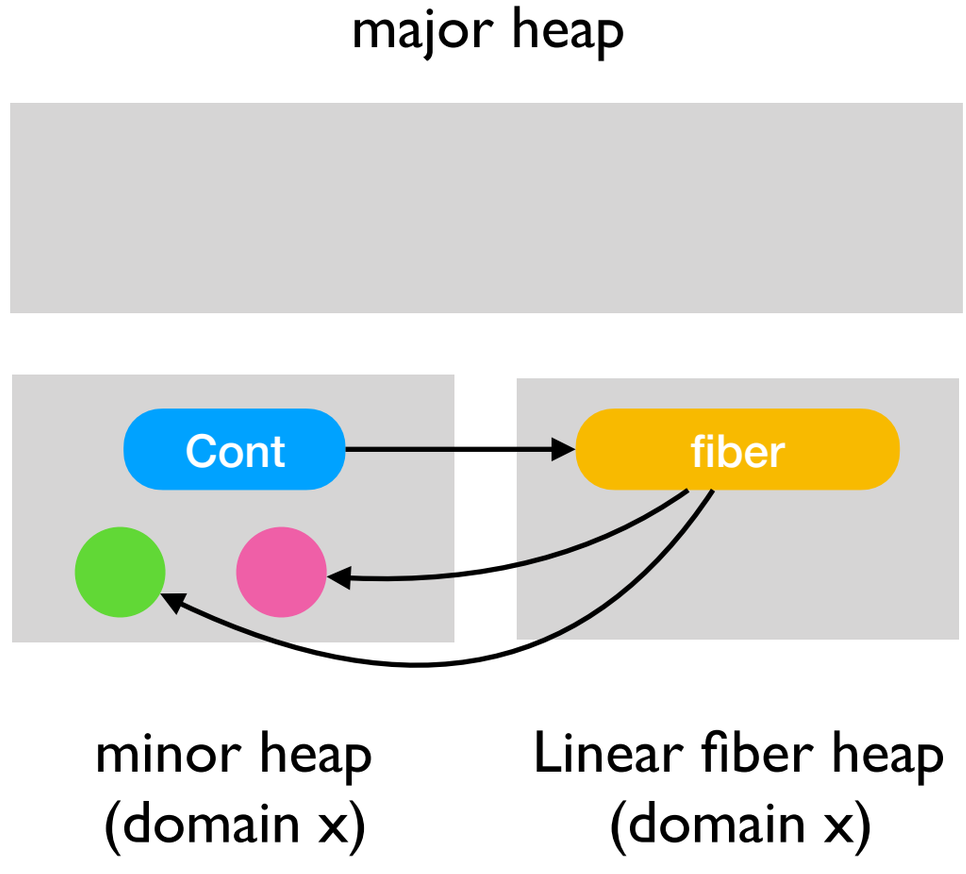

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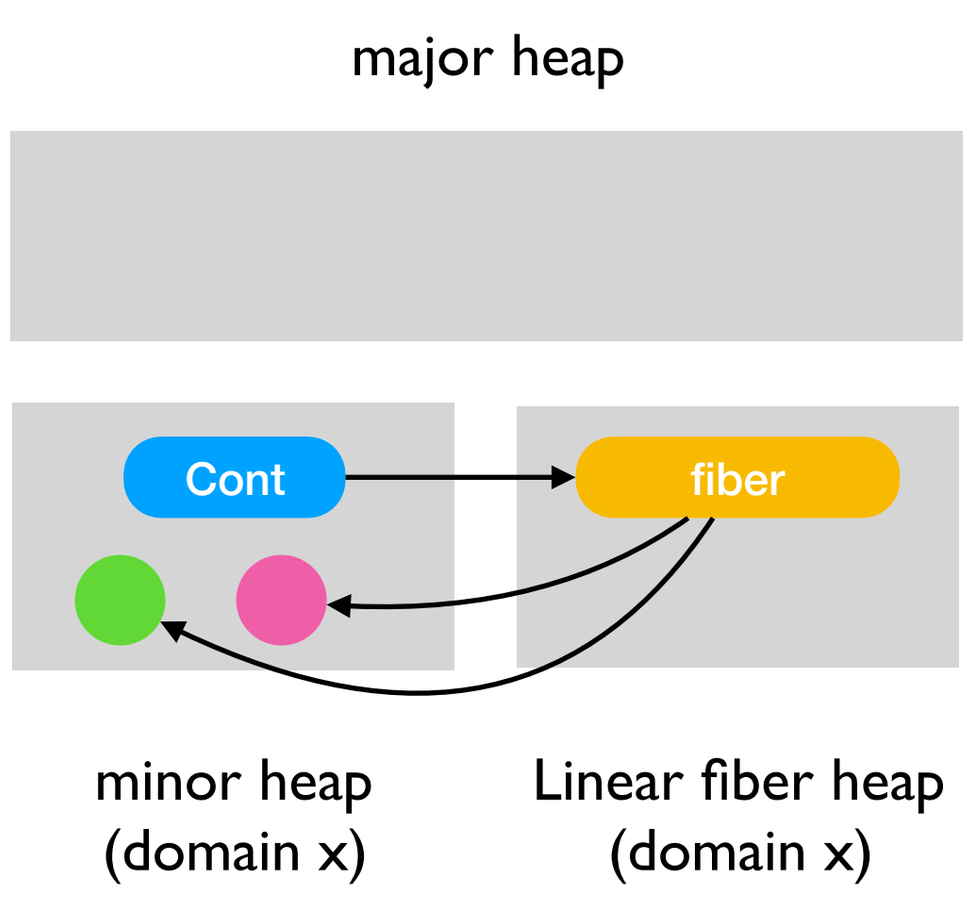

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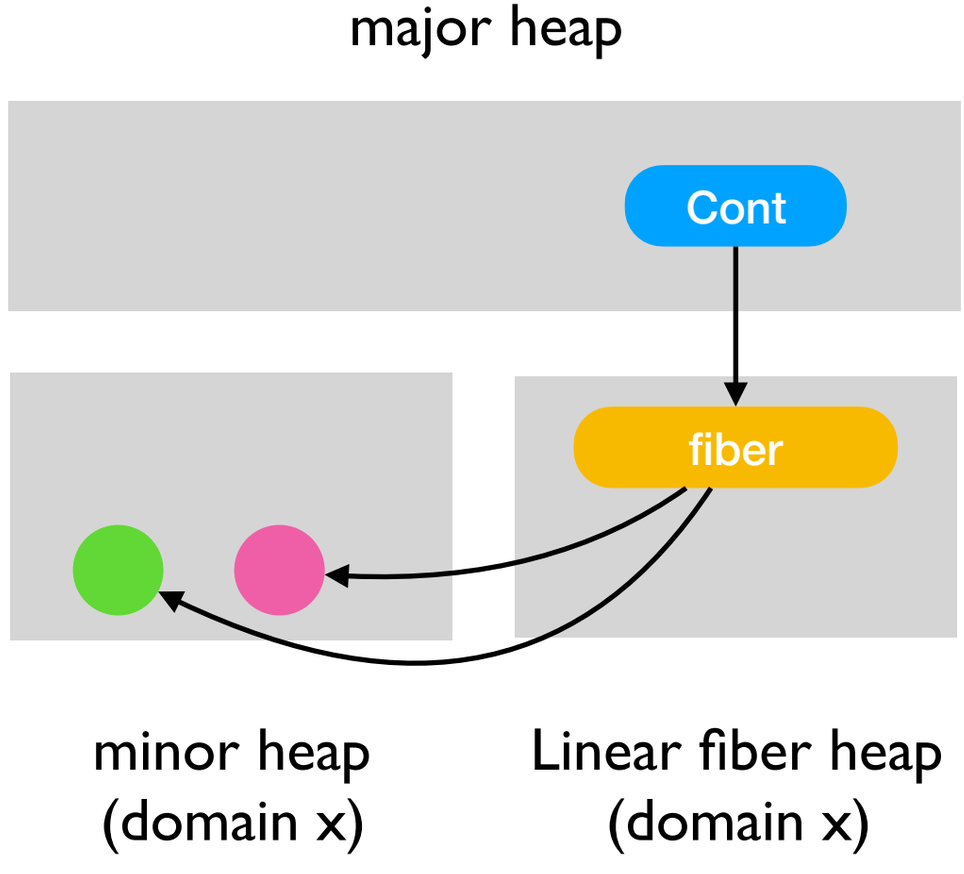

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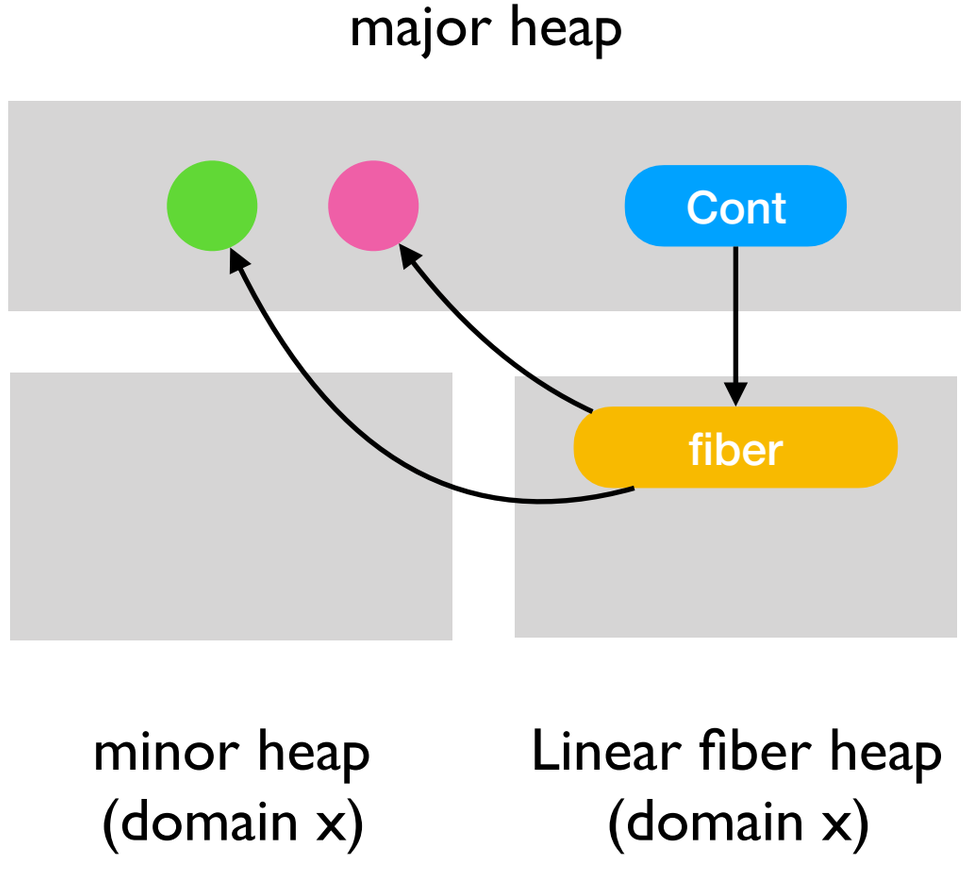

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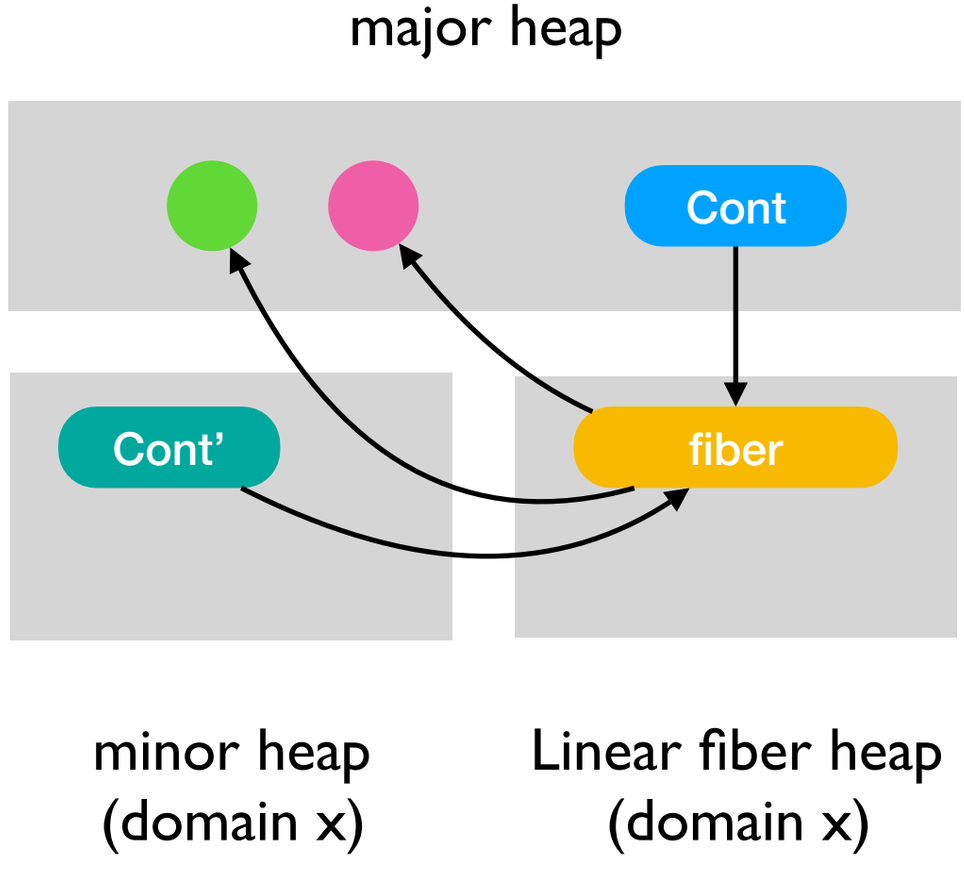

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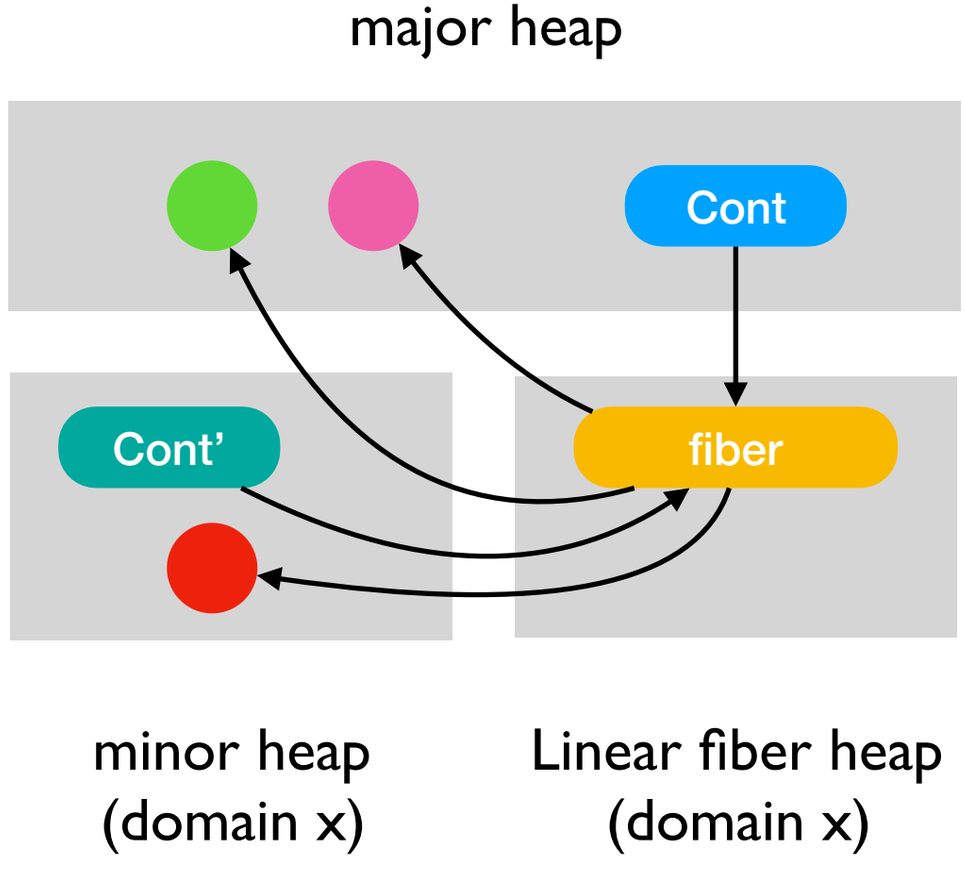

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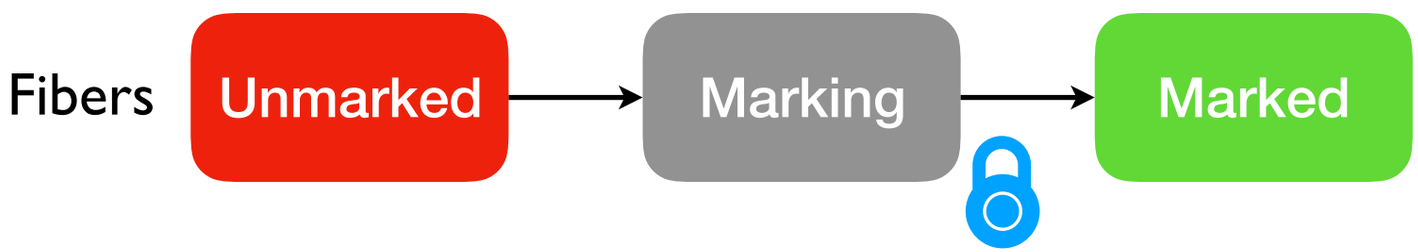

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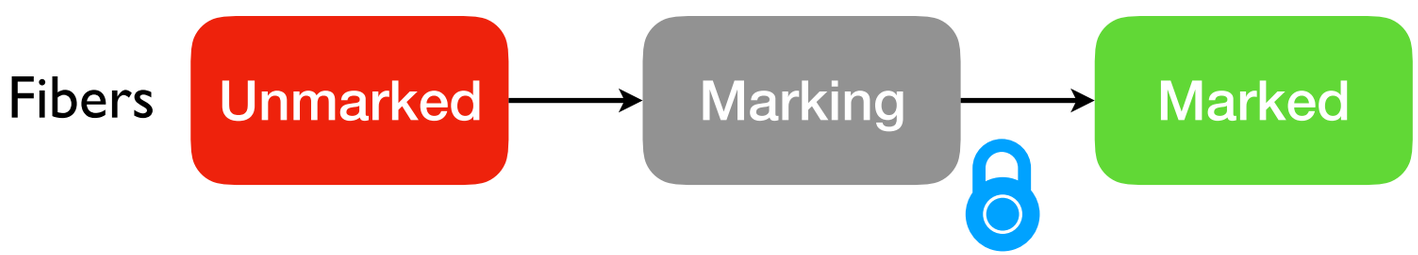

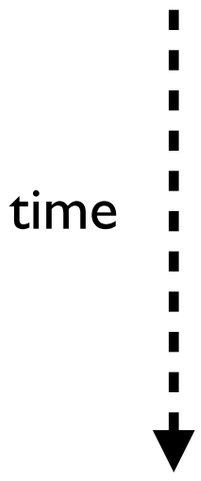

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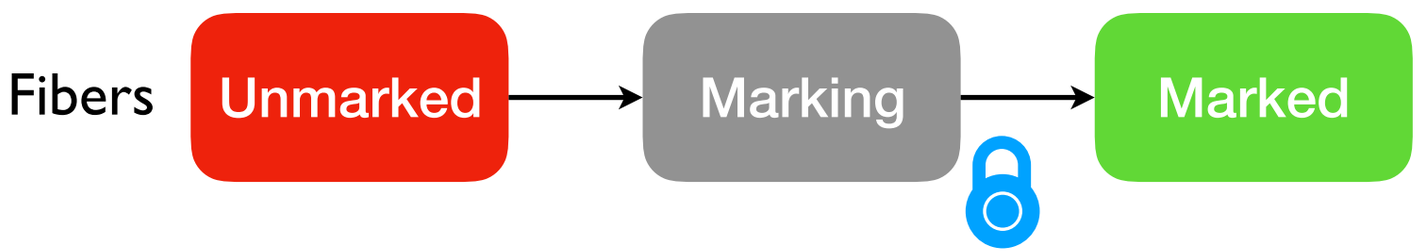

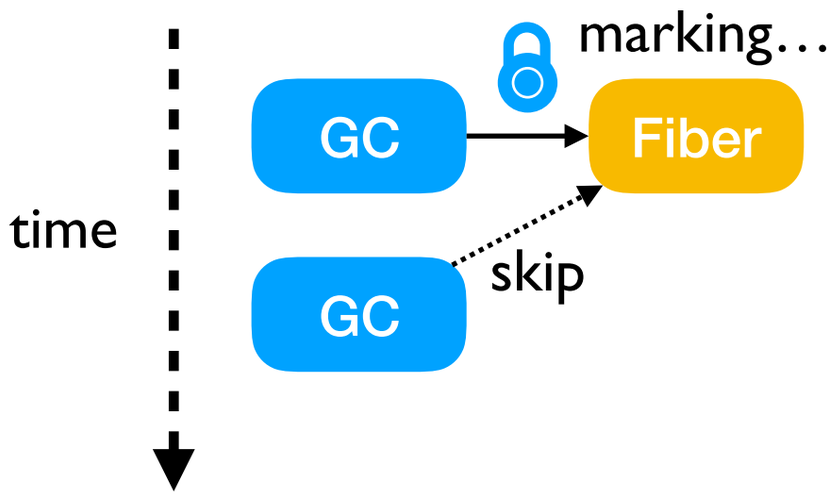

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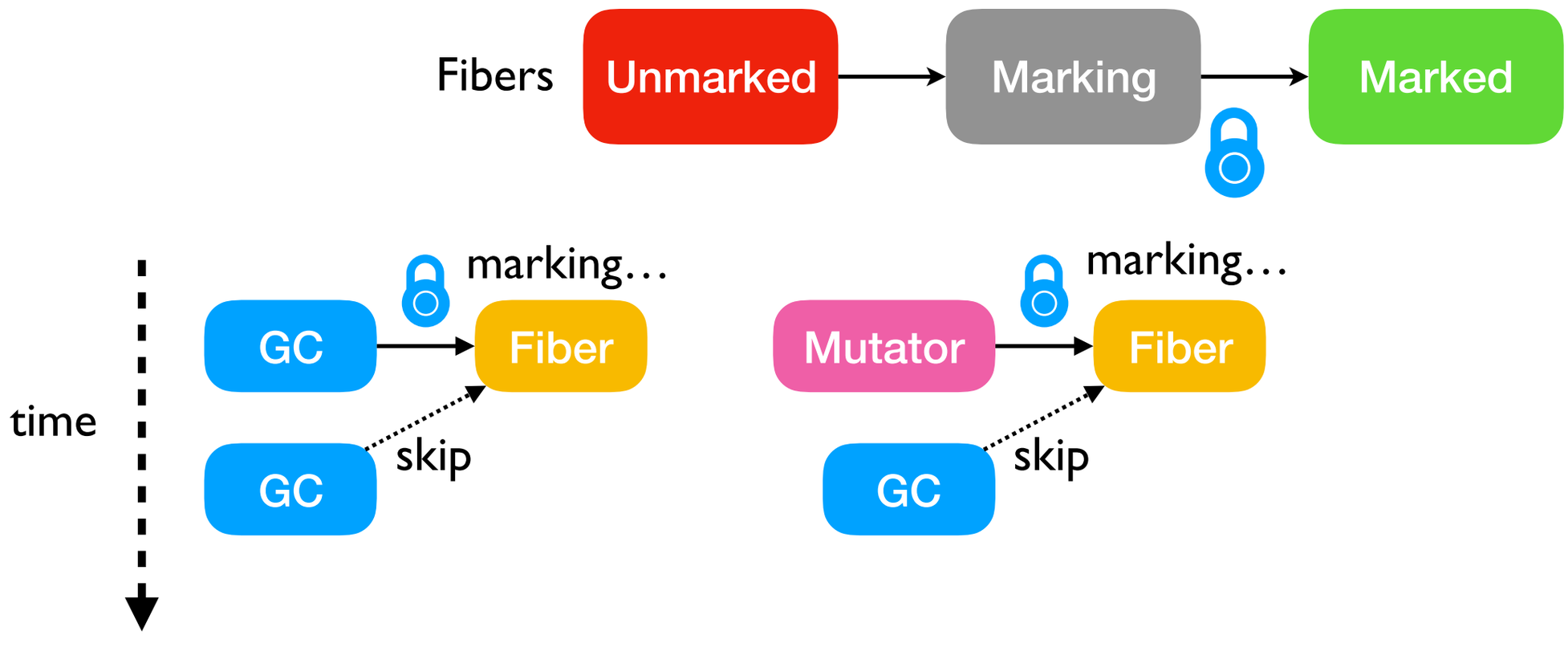

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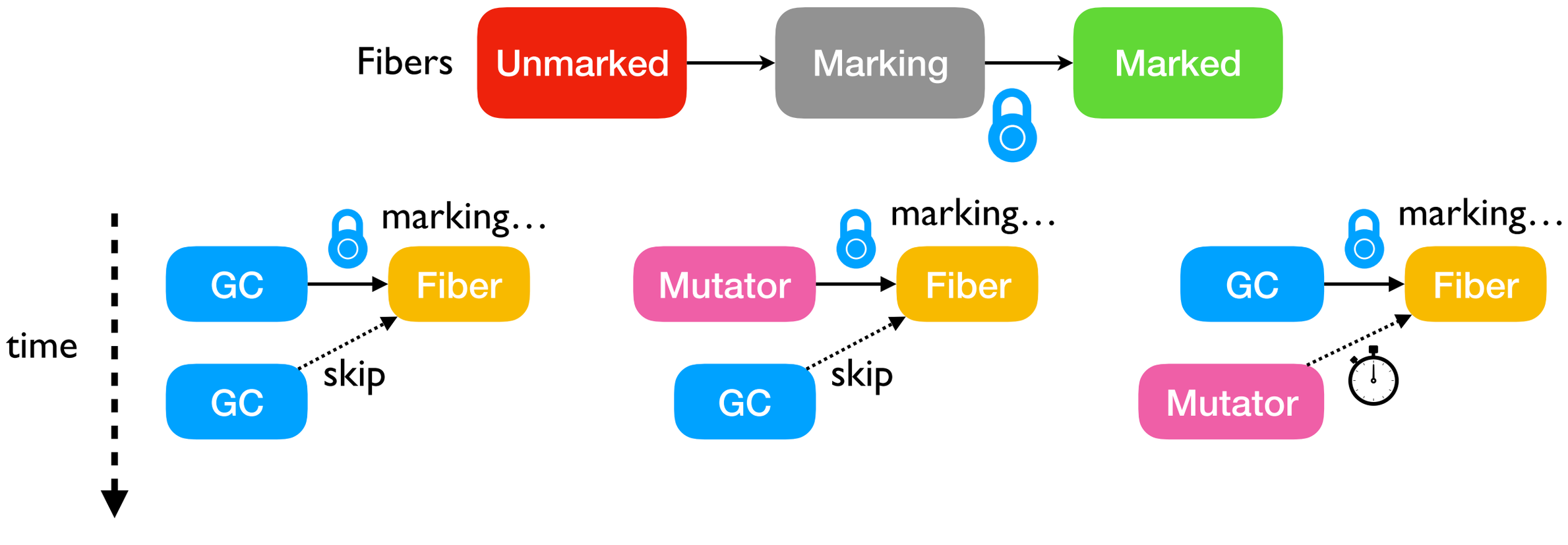

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Inria
INVENTEURS DU MONDE NUMÉRIQUE

Jane Street

Multicore OCaml

Microsoft Research

Tezos

UNIVERSITY OF CAMBRIDGE

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Questions?

https://github.com/ocamllabs/ocaml-multicore

http://kcsrk.info