Efficient Parallel Functional Programming with Hierarchical Memory Management

Sam Westrick
Carnegie Mellon University

Joint work with:
Ram Raghunathan, Adrien Guatto, Stefan Muller,
Rohan Yadav, Umut Acar, Guy Blelloch, Matthew Fluet

Setting the Stage

- functional programming is good for ***expressing*** parallelism
  (no side-effects, no concurrency, no race conditions)

- the point of parallelism is to make things ***faster***…

    - absolute efficiency is paramount
      (speedup w.r.t. fastest sequential solution)

- is parallel functional programming ***efficient***?

    - existing implementations achieve good scalability
      but not absolute efficiency

    - standard challenges:
      high rate of allocation, heavy reliance upon garbage collection

The Problem

we need
more efficient memory management
for ***parallel programs***

(not just functional)

Example: Mergesort

```
fun msort A =
  if length A < 2 then A else
  let
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msort [2,4,3,1]

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par (fn () => msort [2,4], fn () => msort [3,1])
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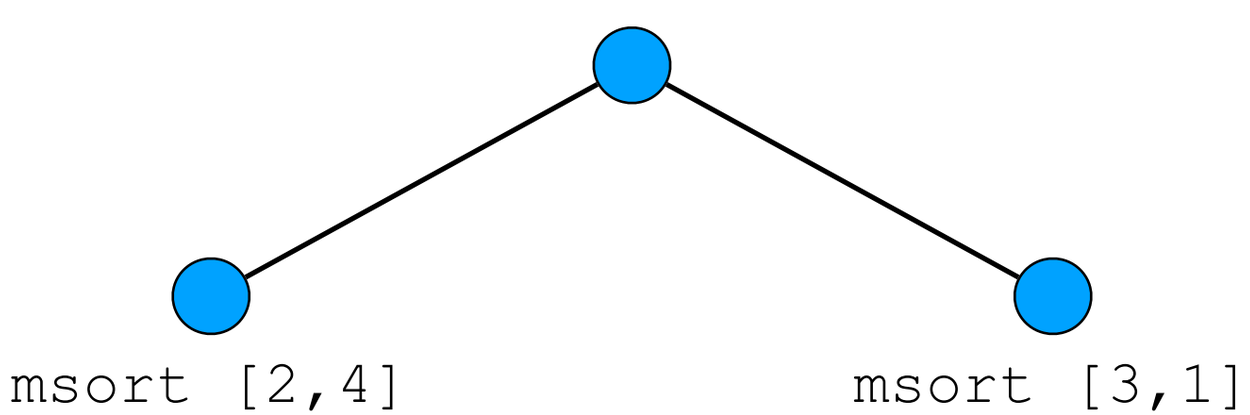

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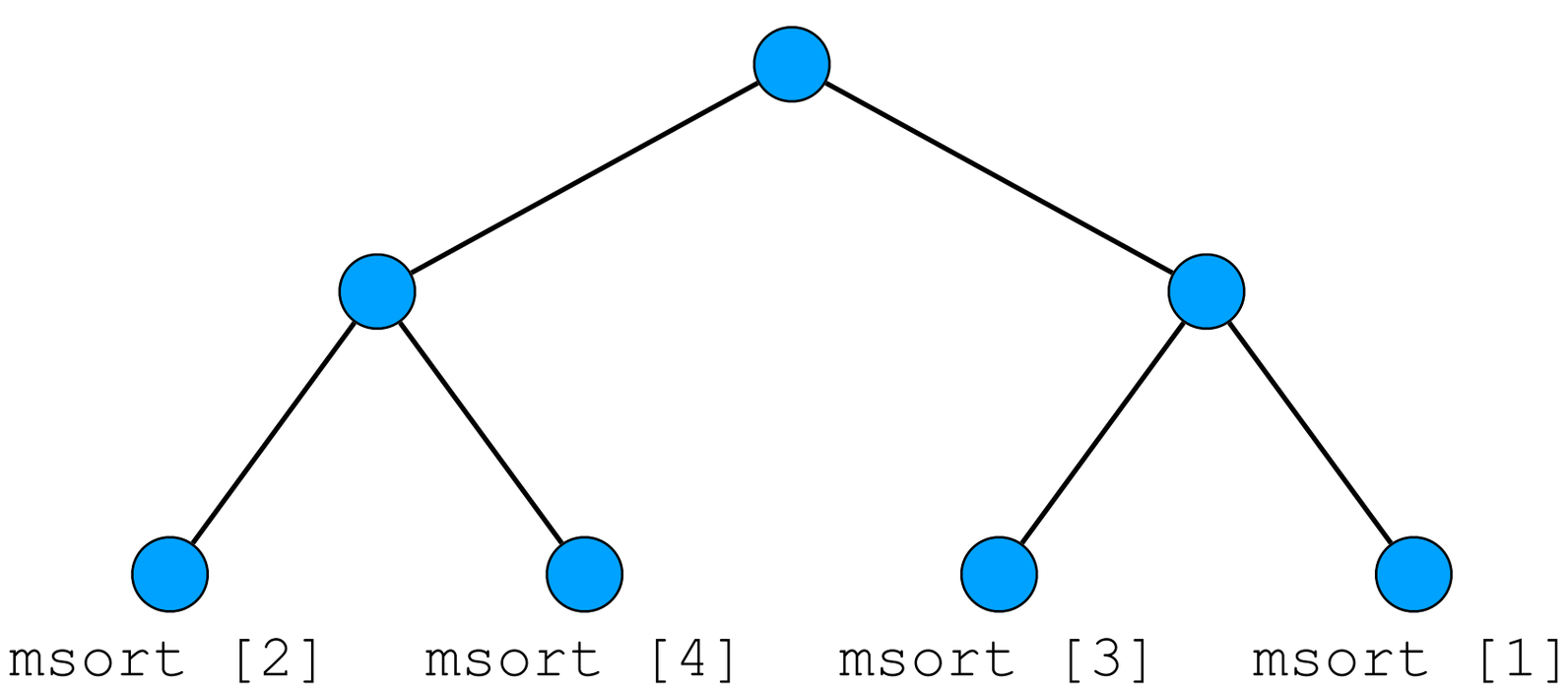

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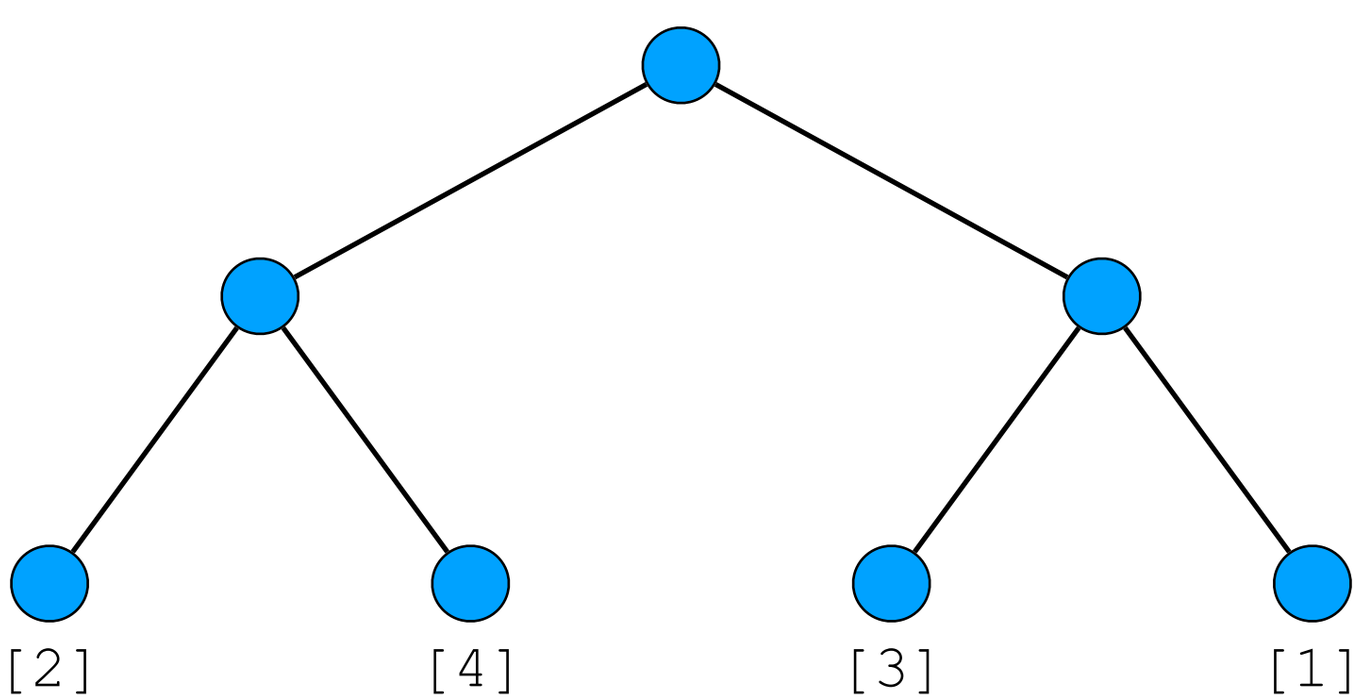

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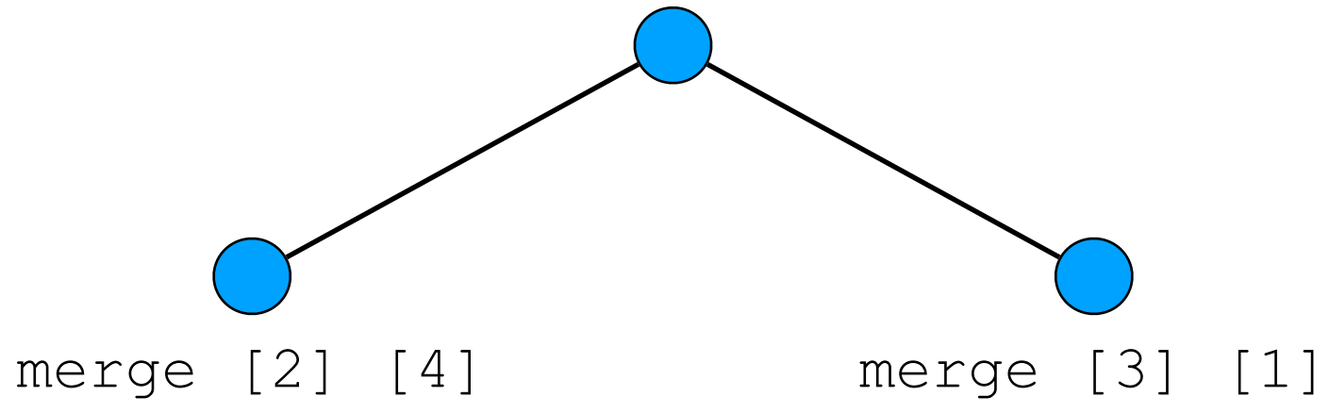

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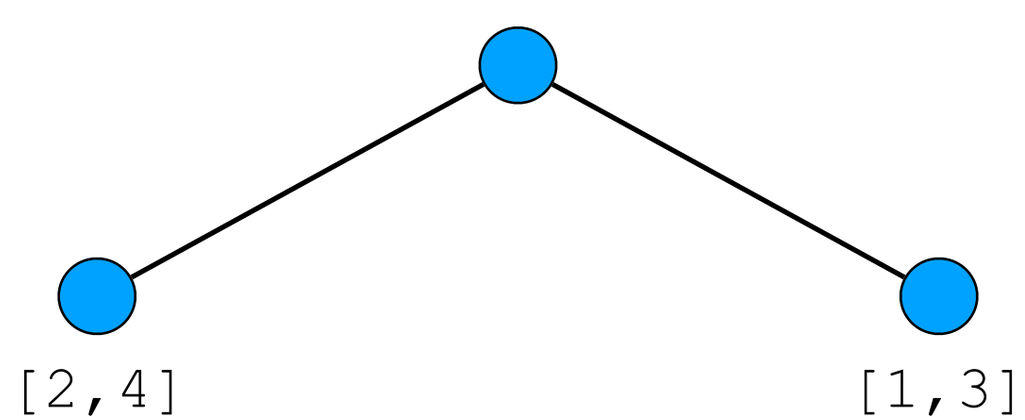

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merge [2,4] [1,3]

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[1,2,3,4]

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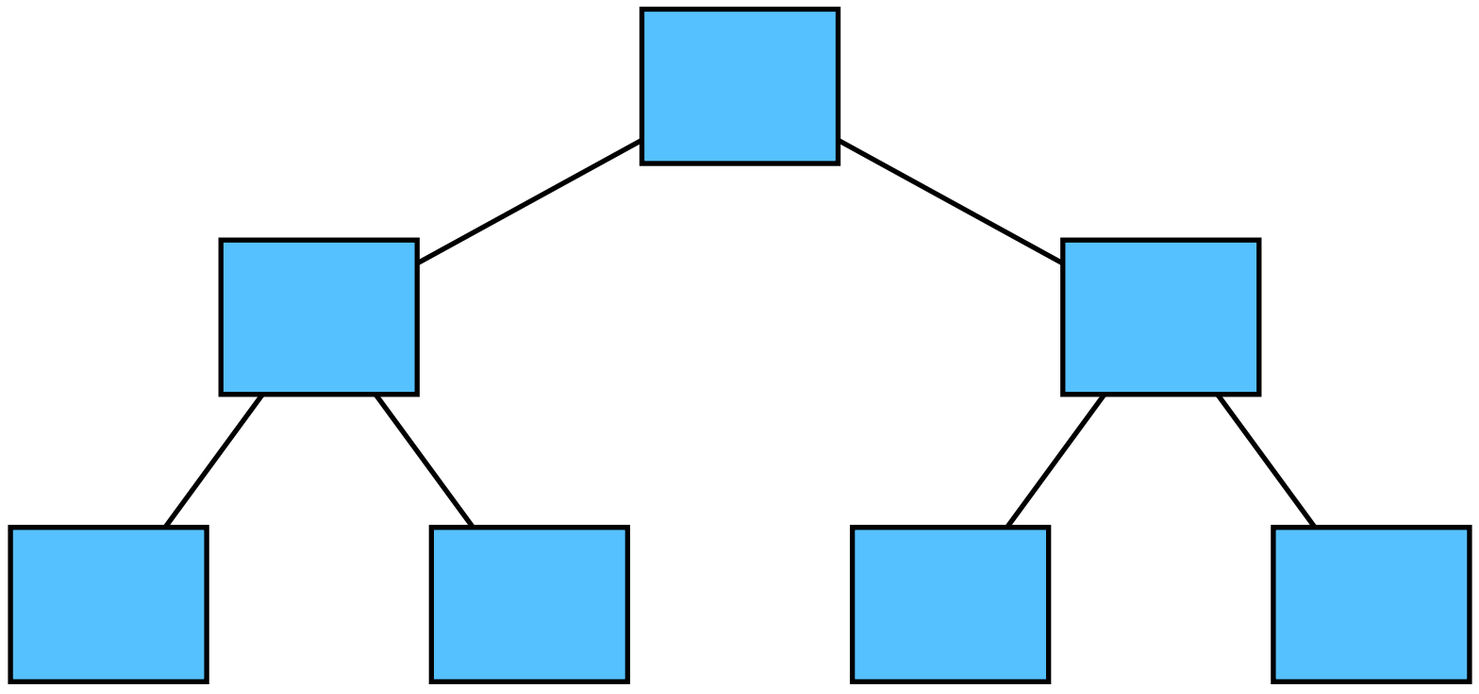

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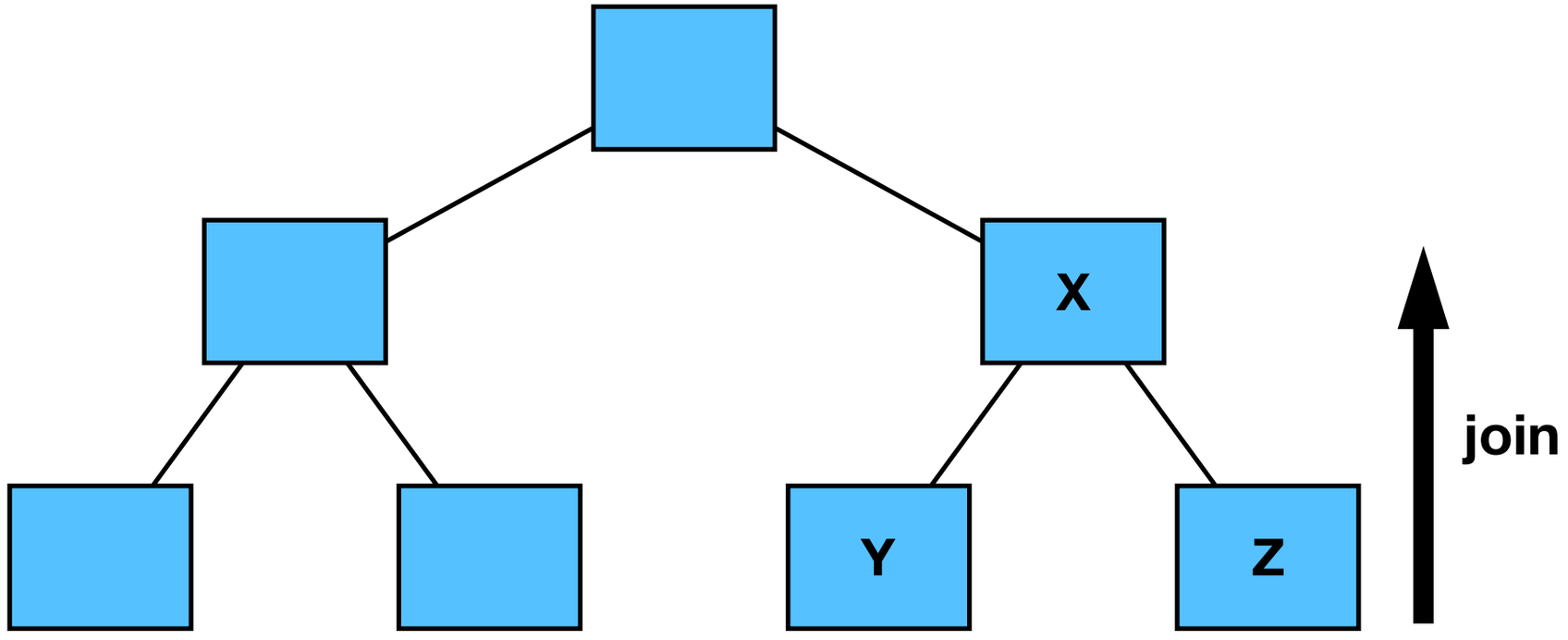

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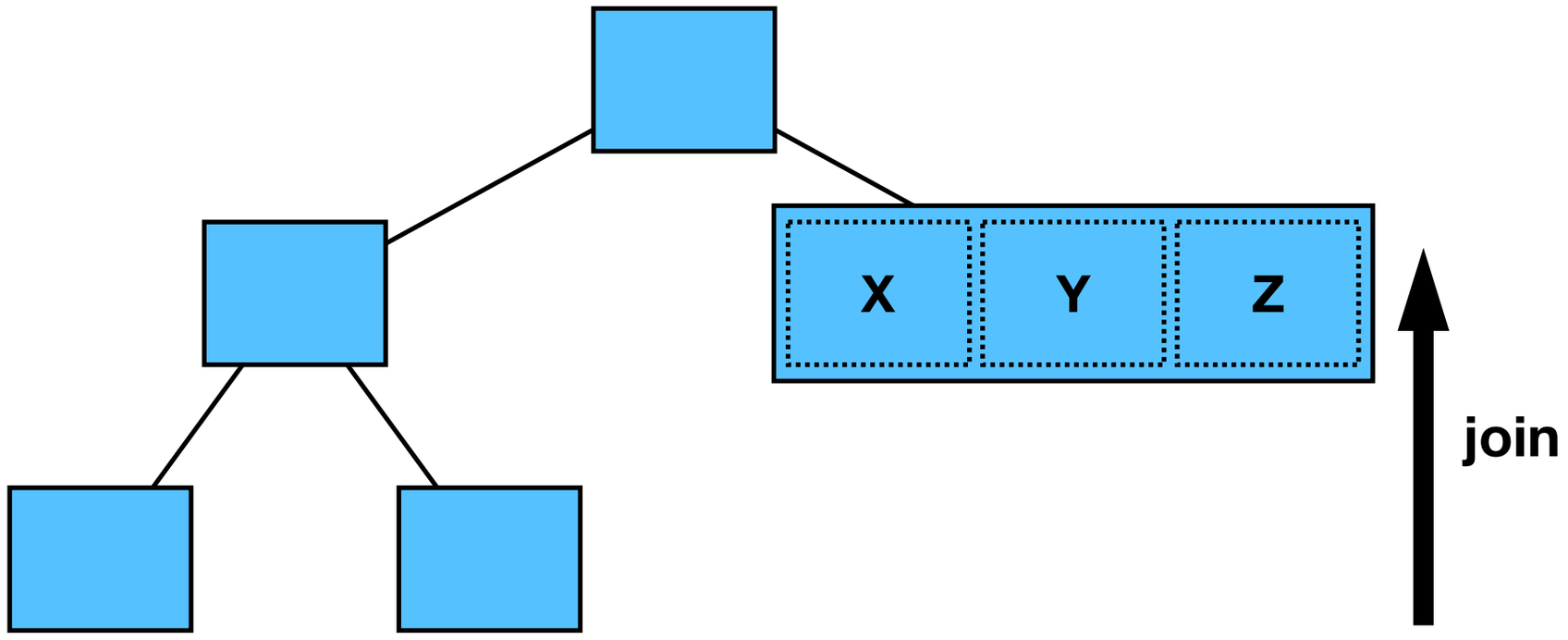

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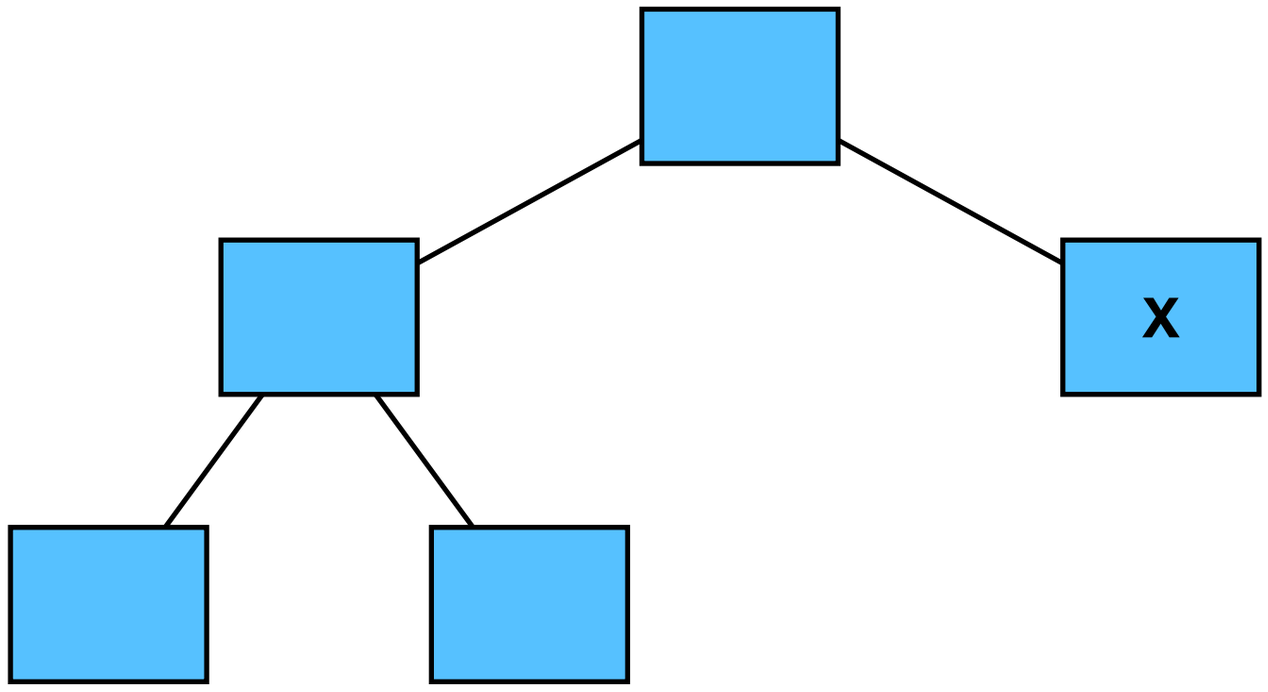

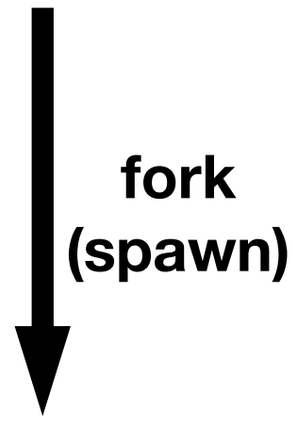

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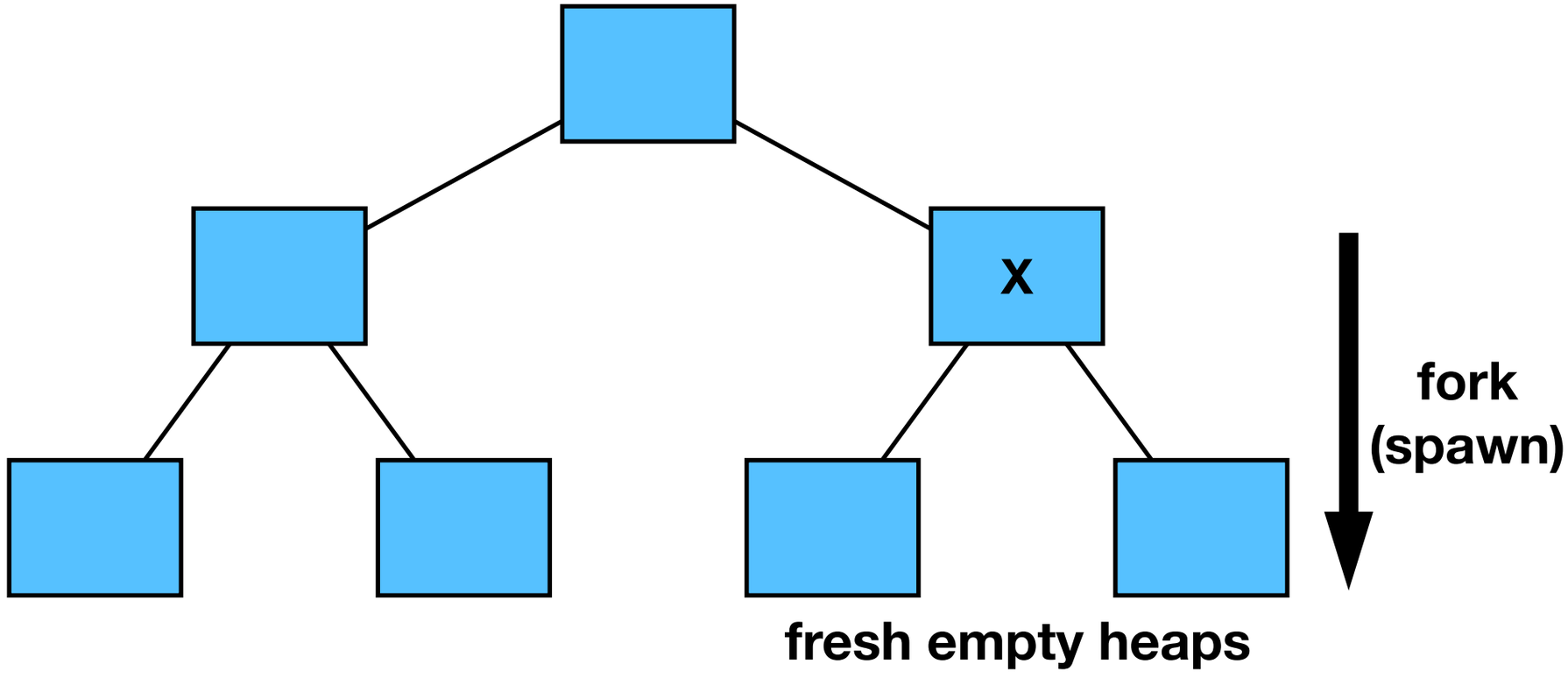

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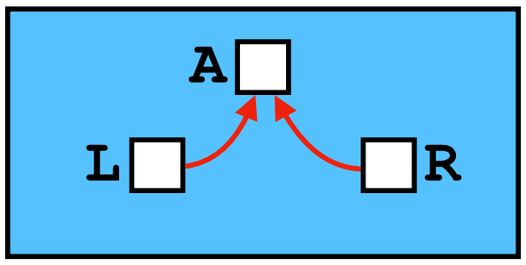

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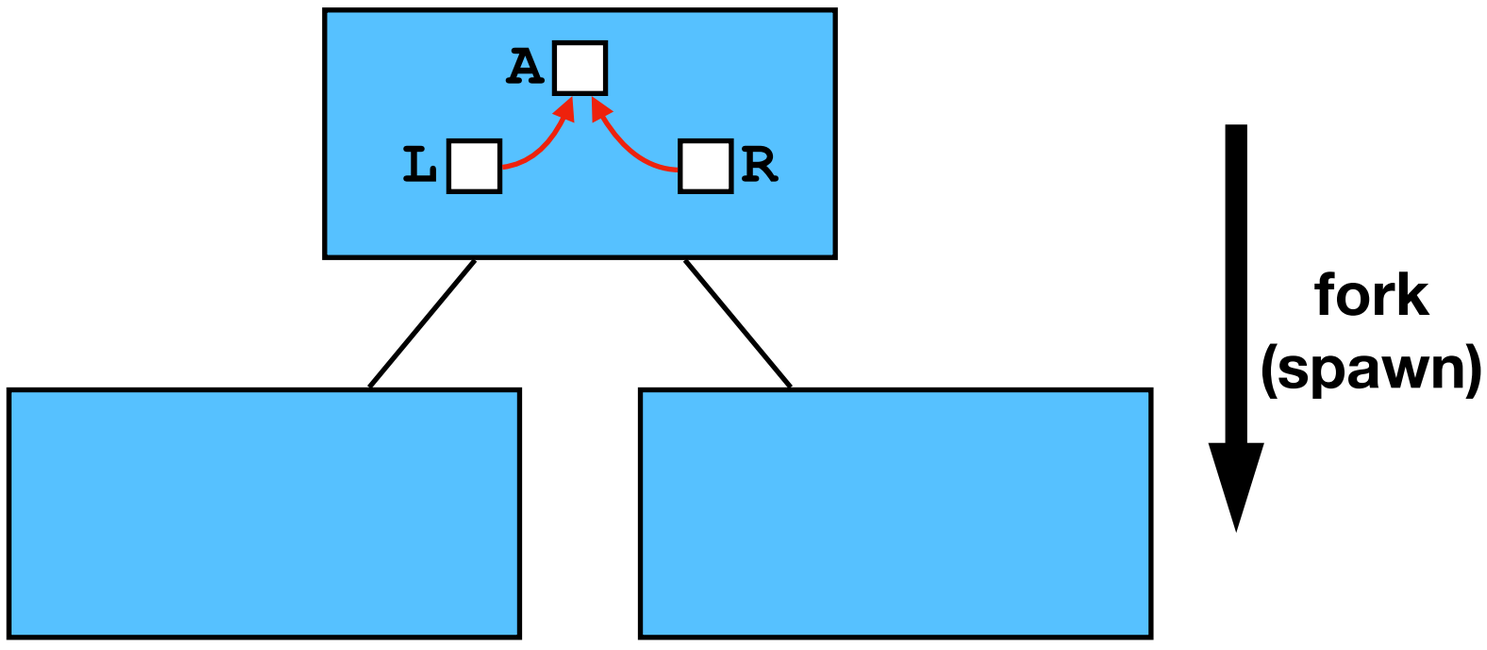

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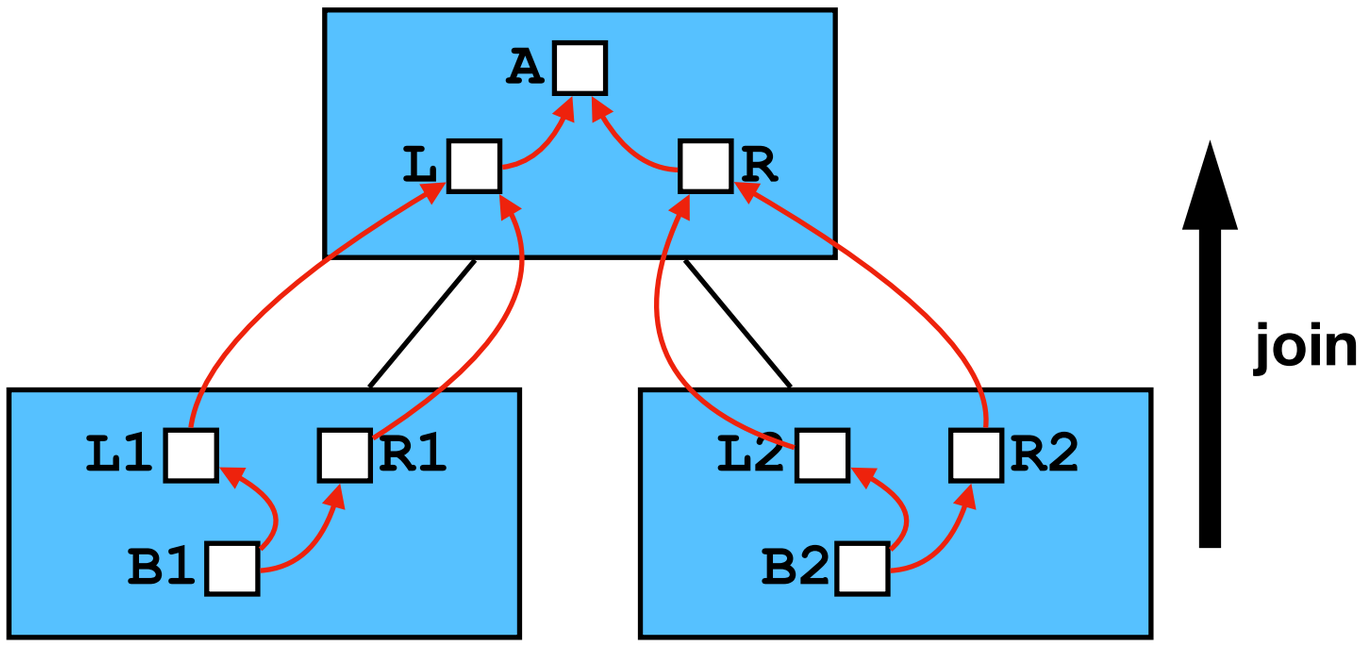

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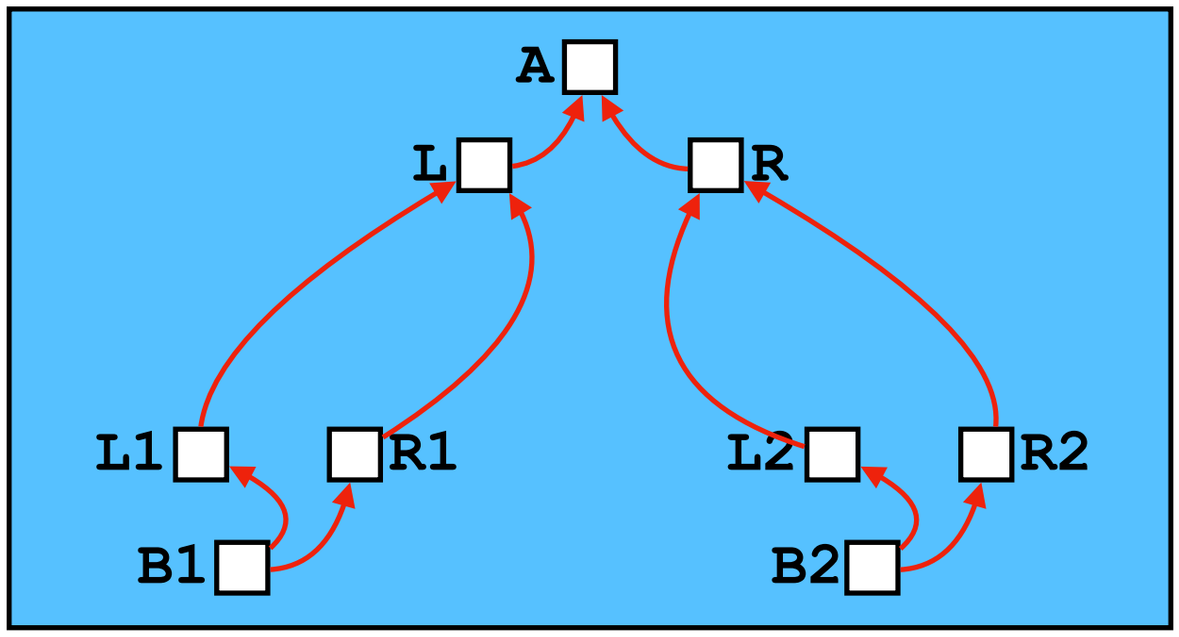

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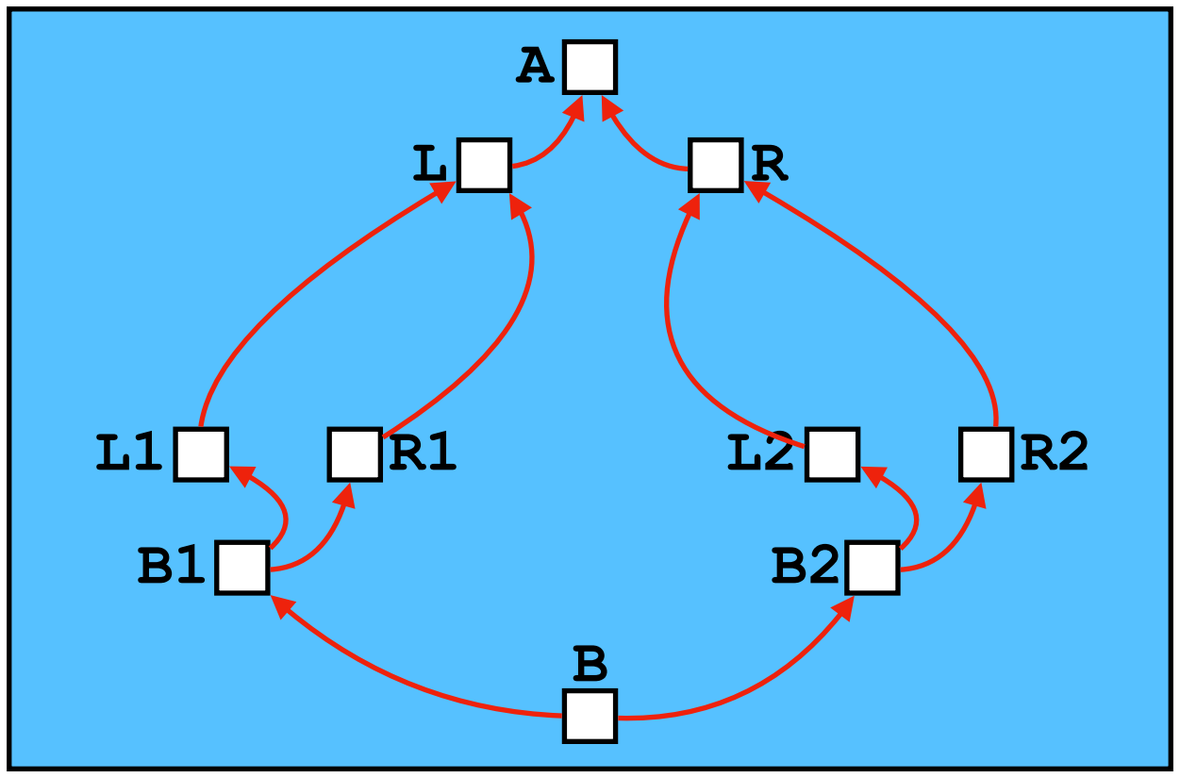
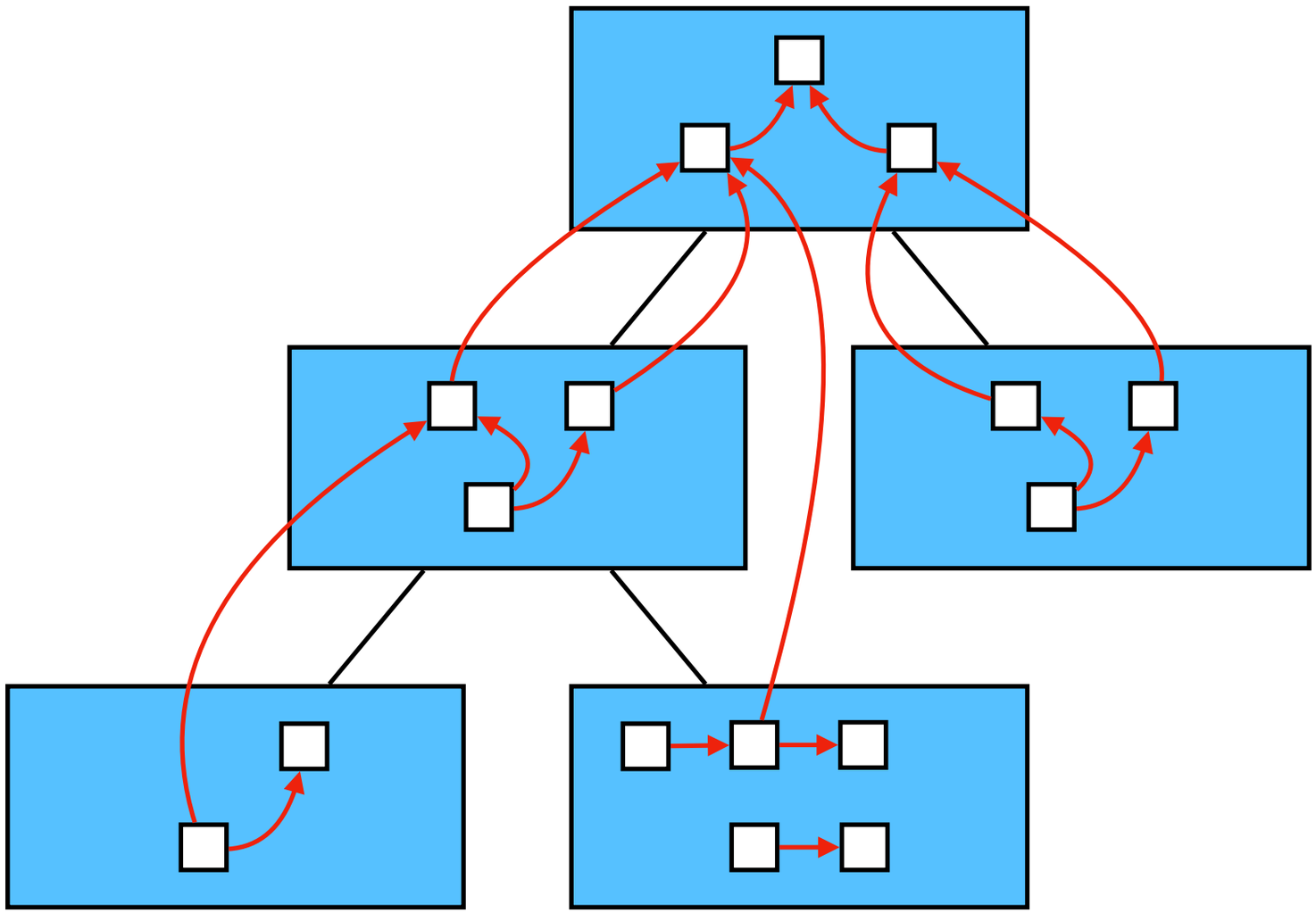


Hierarchical Memory Management

- give each ***task*** its own ***heap***
    - tasks allocate new data inside their own heaps
- organize heaps to mirror the ***nesting structure*** of tasks
    - fork (spawn, async, etc): fresh heaps for children
    - join (sync, finish, etc): merge heaps into parent

Disentanglement:

in strict purely functional programs,
all pointers either point up or are internal
[Raghunathan et al, ICFP'16]



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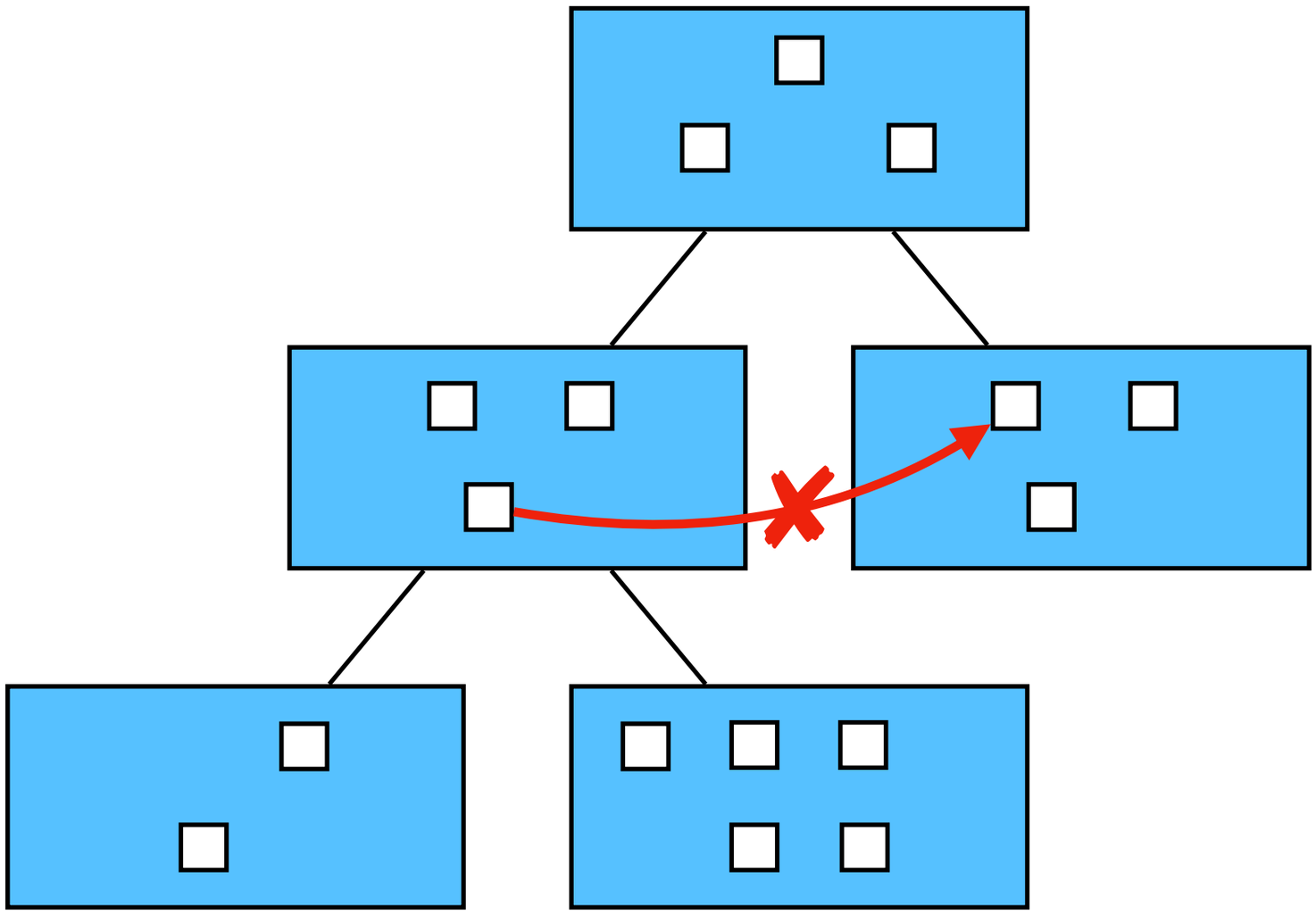

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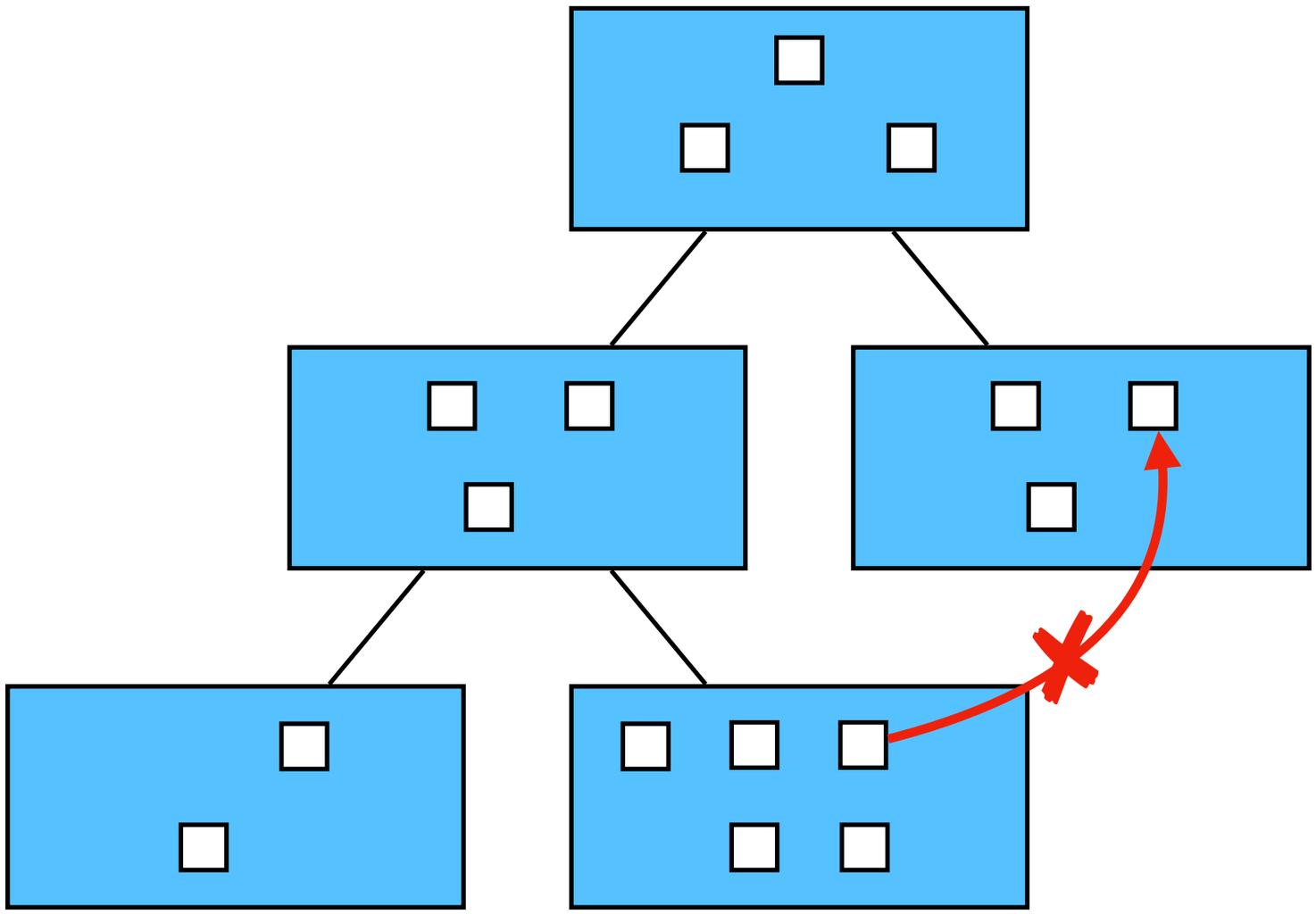

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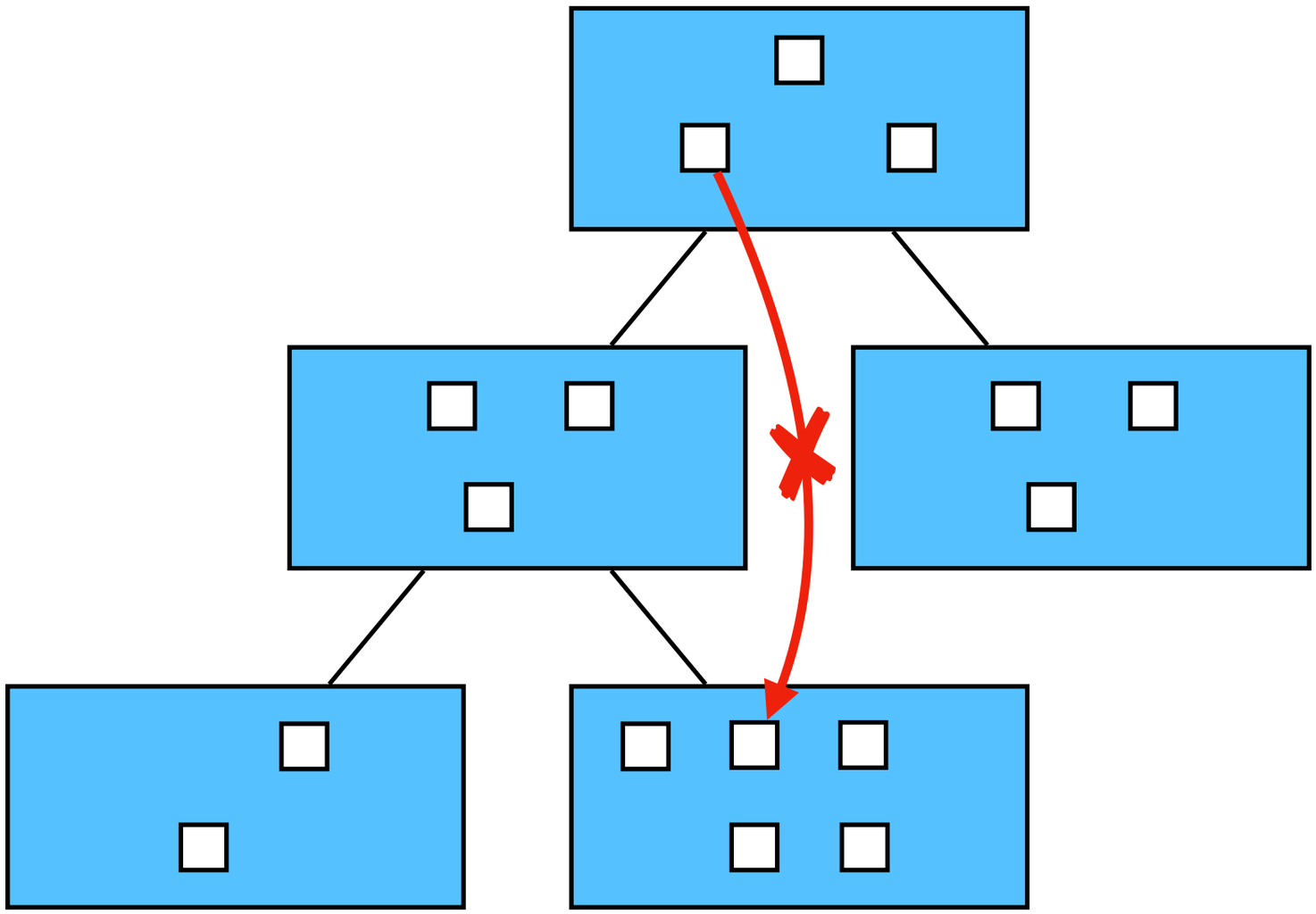
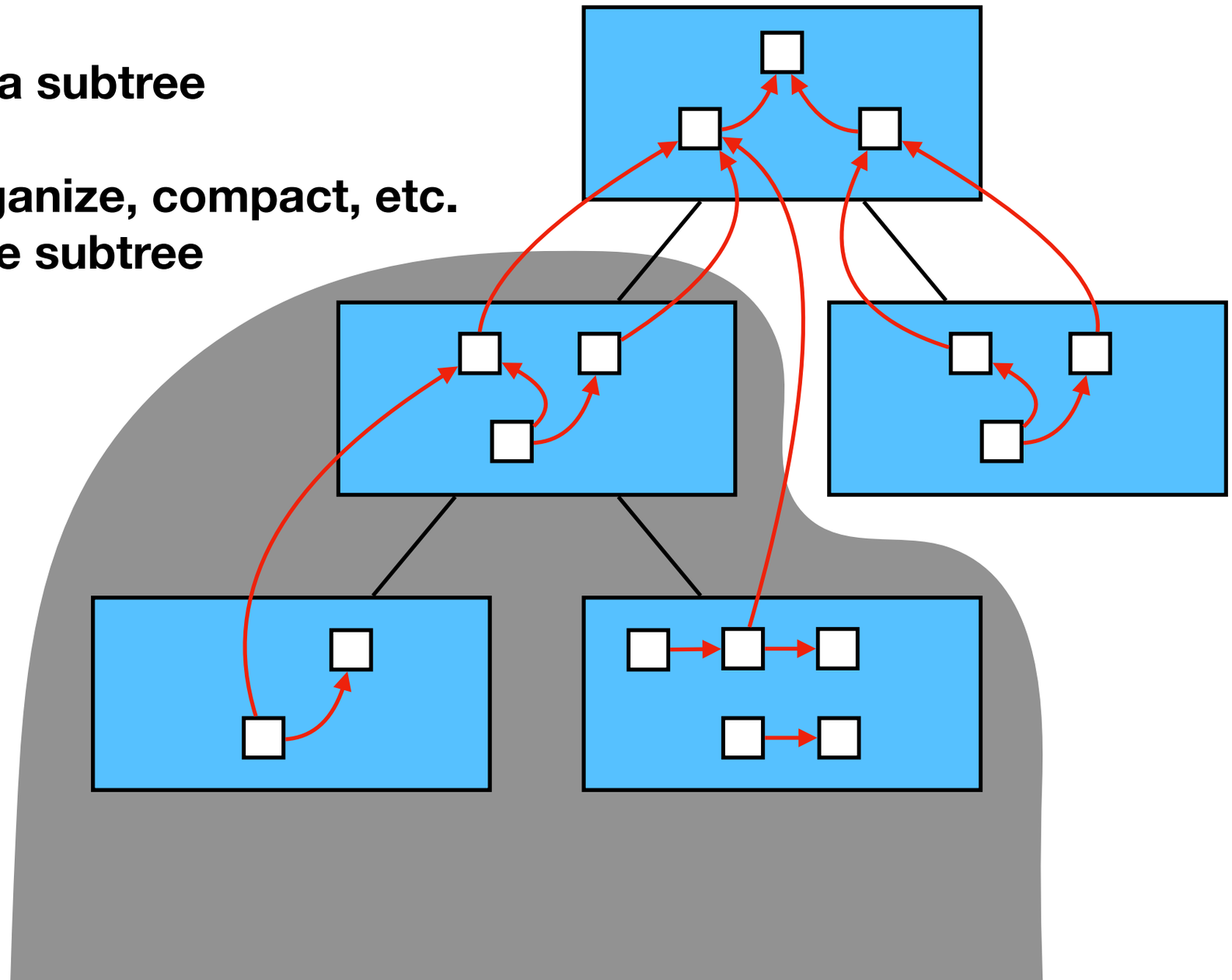


Local Garbage Collection

pick a subtree

reorganize, compact, etc. inside subtree



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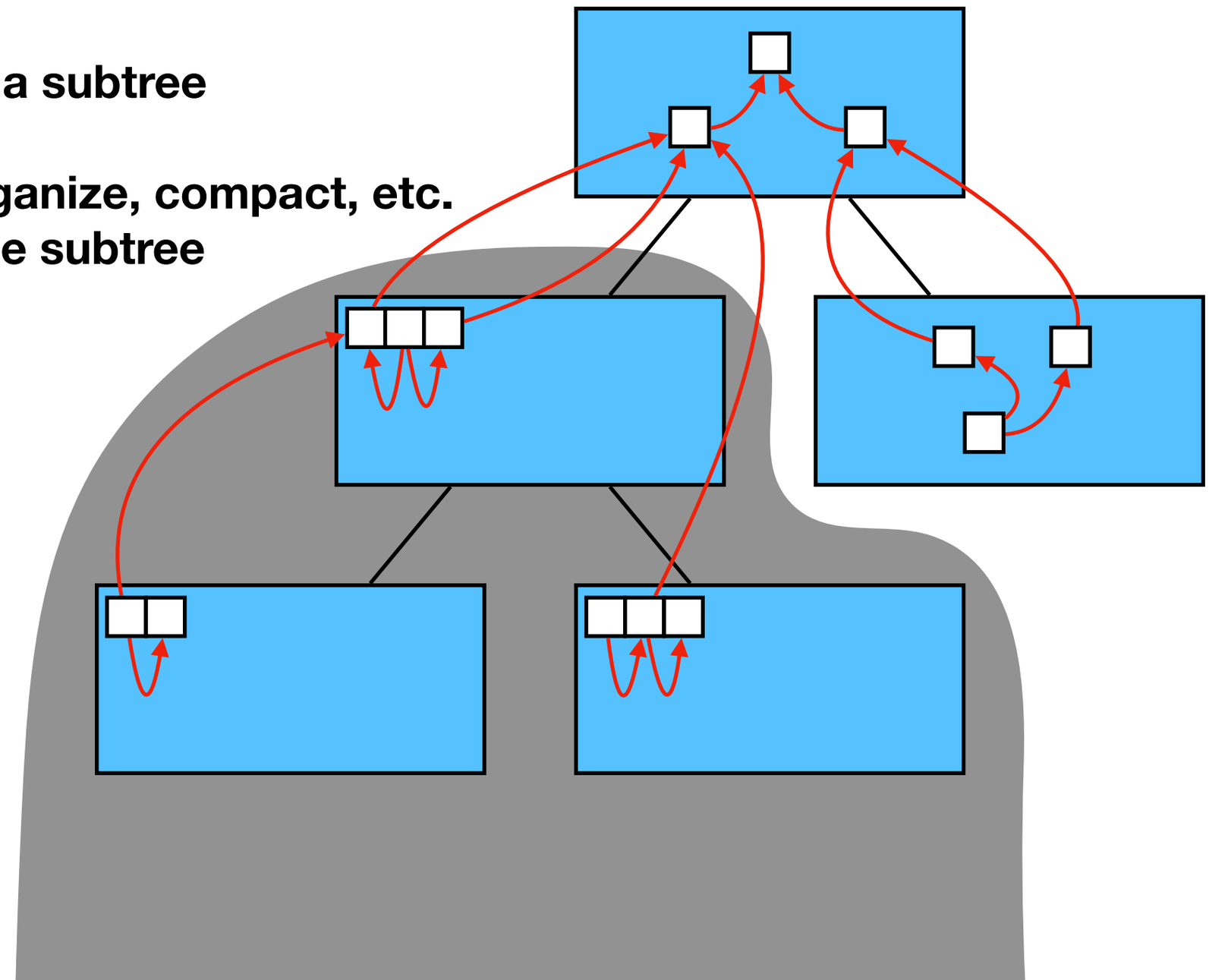

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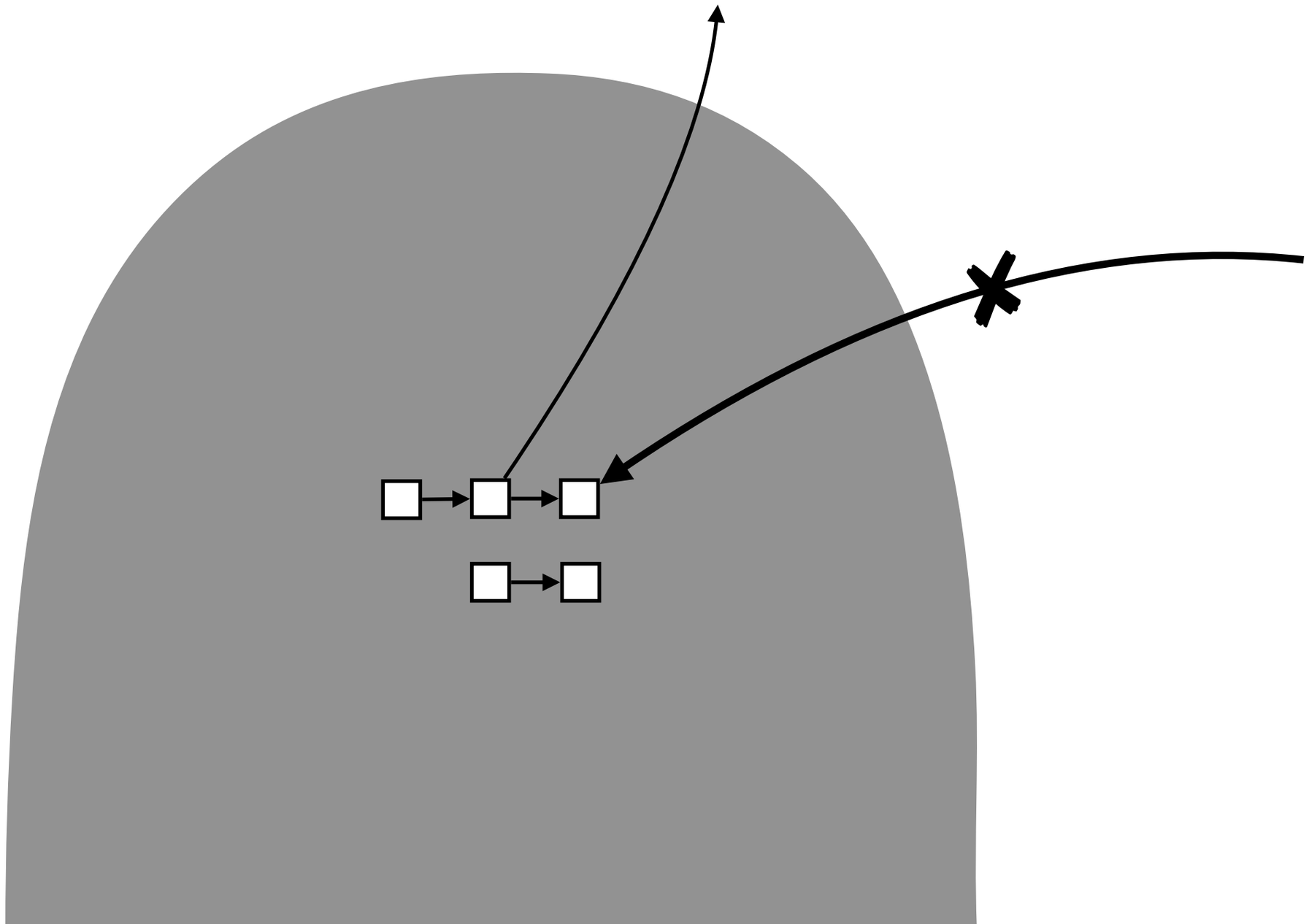

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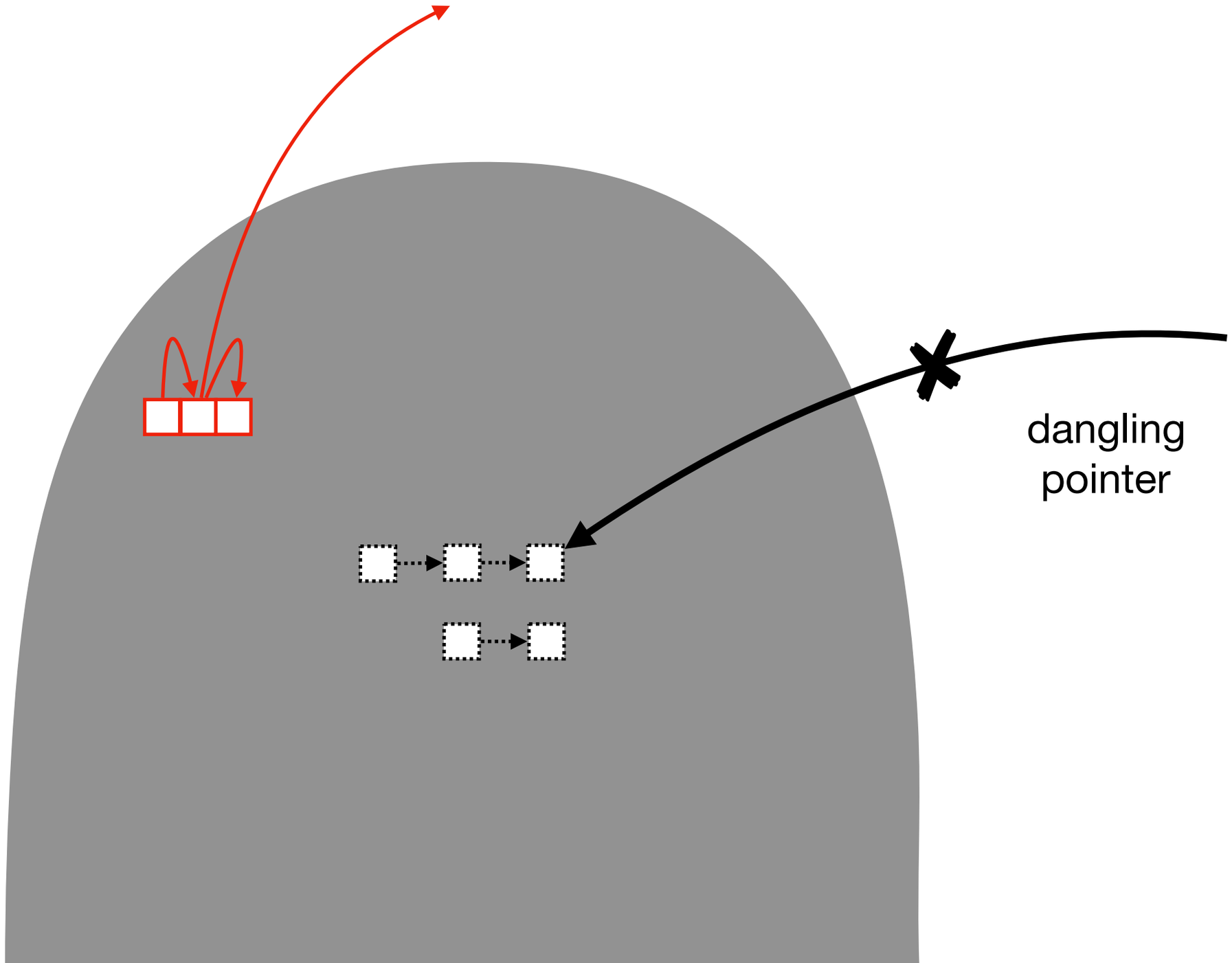

Local Garbage Collection

- localized within a subtree of heaps
- independent of
    - tasks whose heaps are outside the subtree
    - other local collections (on disjoint subtrees)
- can easily apply any existing GC algorithm
    - just ignore pointers that exit the subtree

In-place Updates

- often crucial for efficiency, especially under the hood
- but, ***can*** break disentanglement (not always)

```
let
  val r = ref []
  fun f () = (r := 0 :: !r)
  fun g () = (r := 1 :: !r)
in
  par (f, g)
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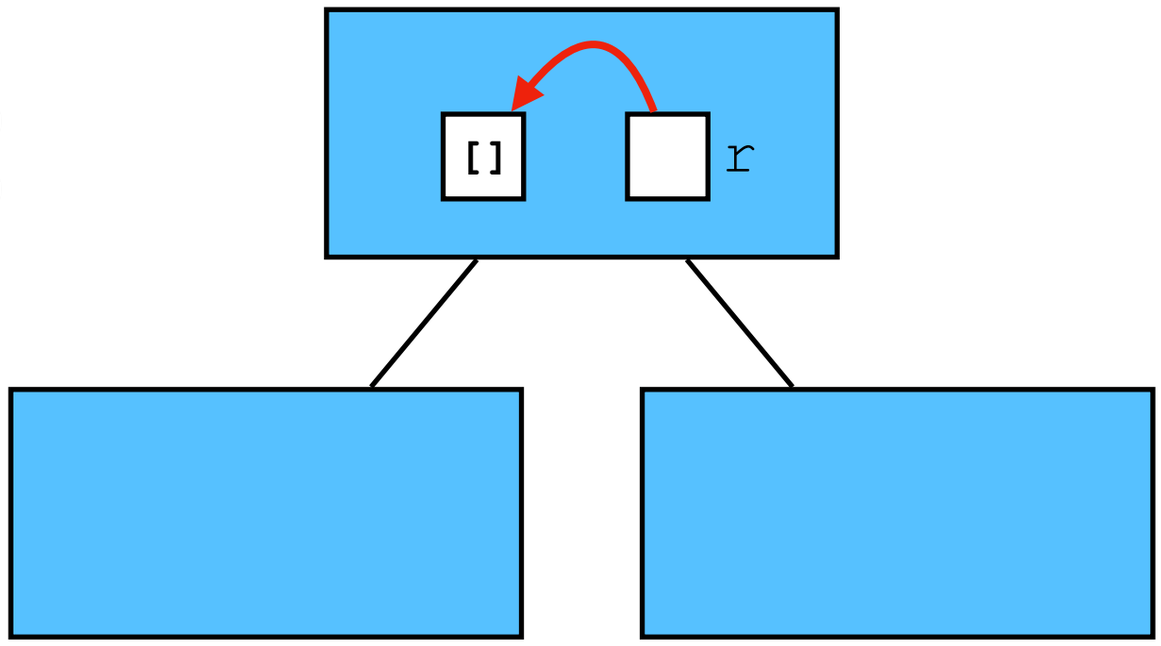

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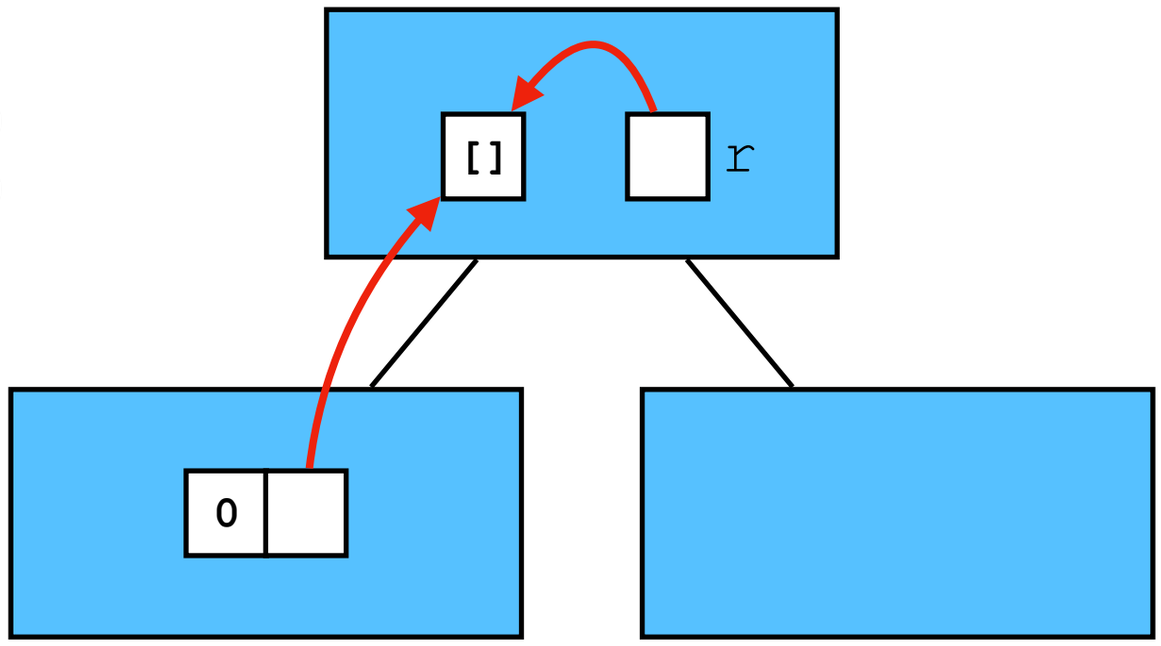

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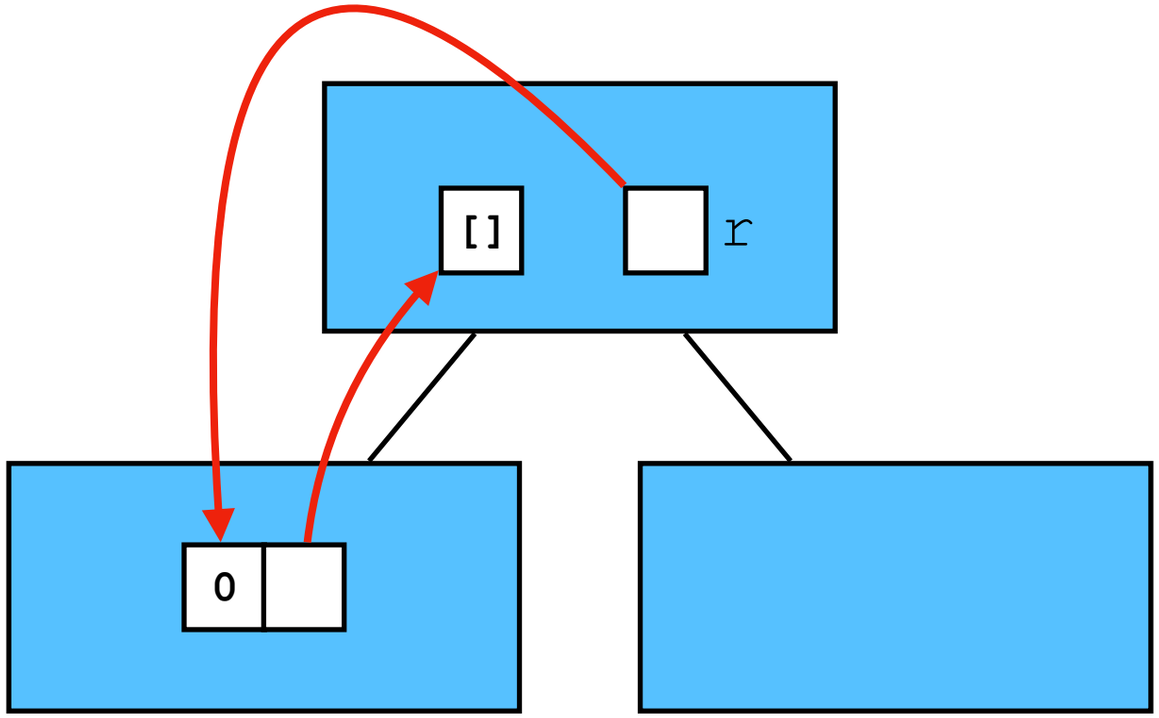

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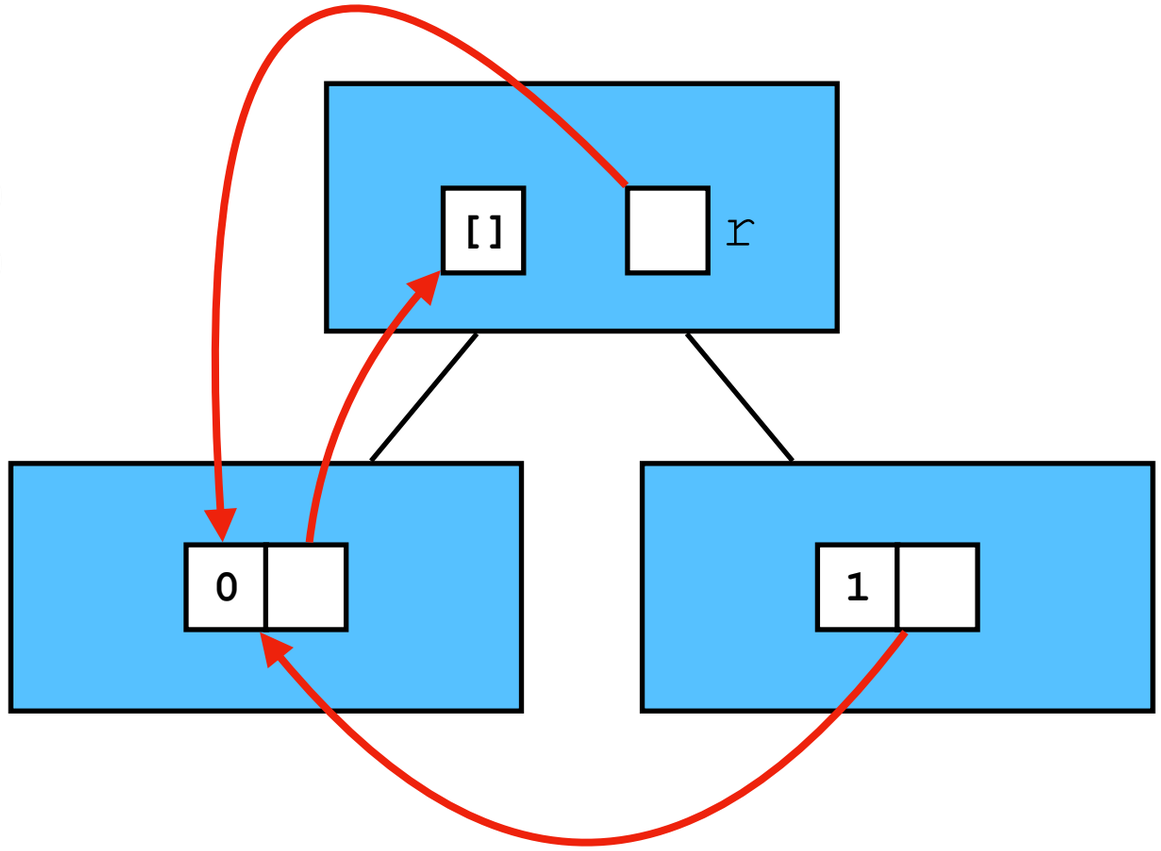

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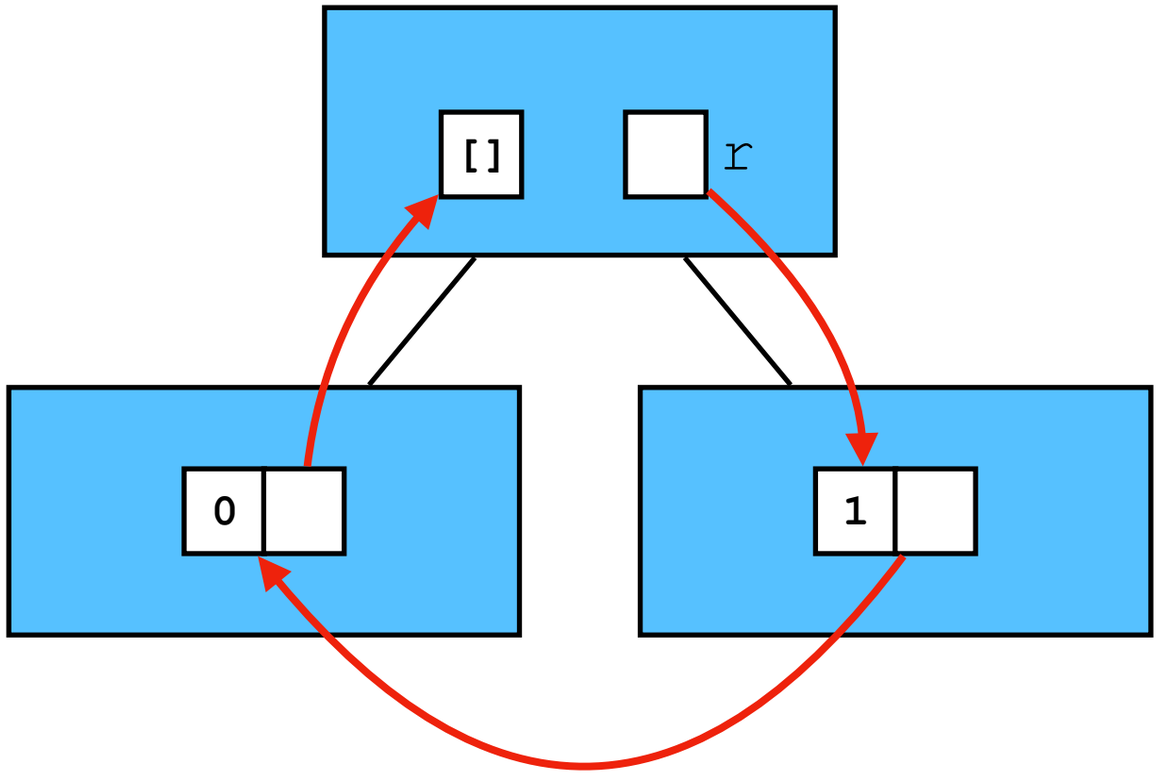

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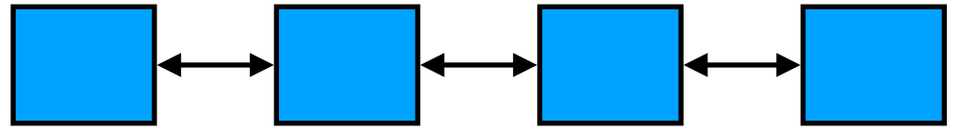
- options:
  - enforce disentanglement dynamically with promotion
    [Guatto et al, PPoPP'18]
  - weaken to permit important classes of effects
    [Westrick et al, work in progress]

Implementation

- extend MLton compiler with fork-join library
  `val par : (unit -> 'a) * (unit -> 'b) -> 'a * 'b`

- block-structured heaps
  - heaps are lists of blocks:
    merge heaps in O(1) time



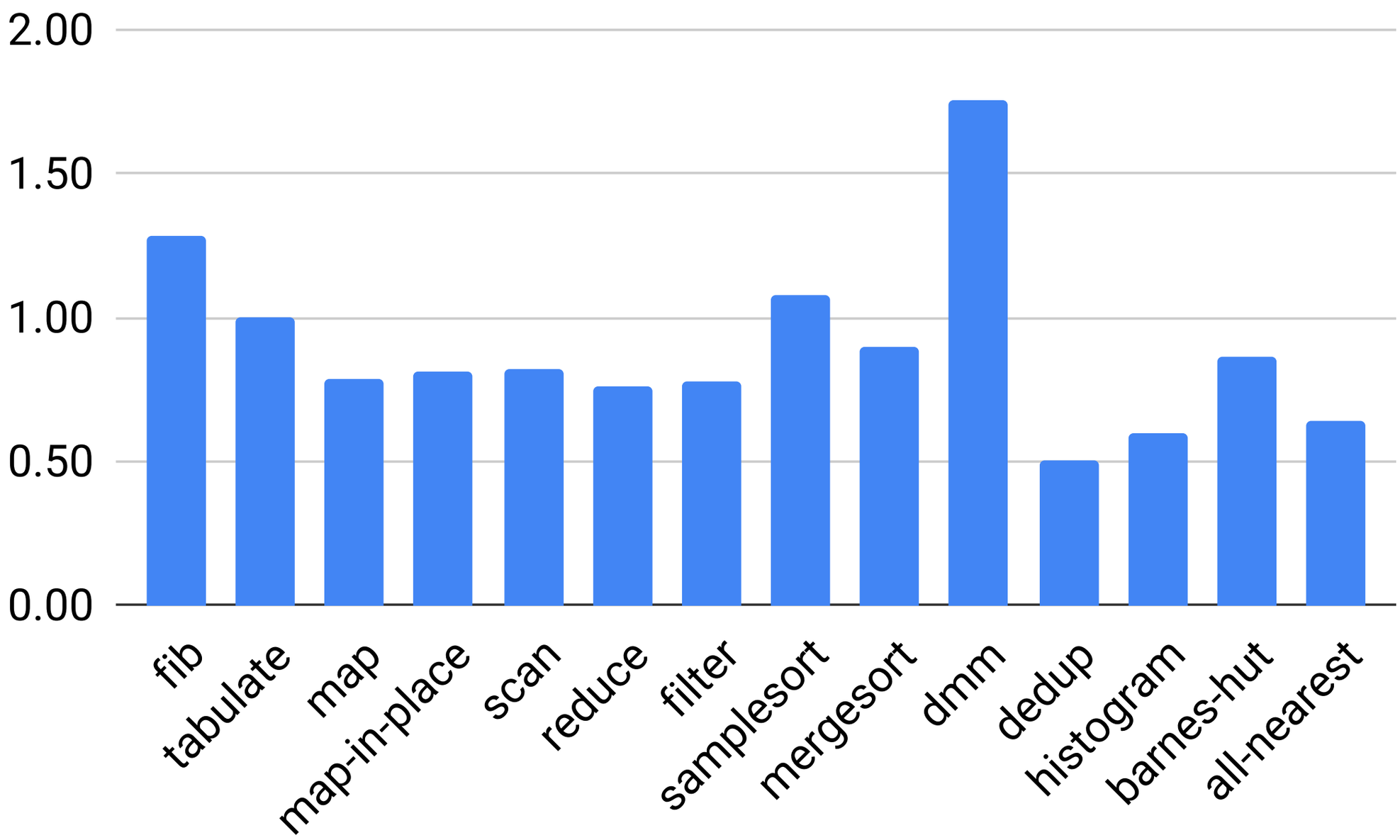
- no read barrier. write barrier only on mutable pointer data

- local collections: sequential Cheney-style copying/compacting

- work-stealing scheduler
  - GC policy influenced by scheduler decisions

Runtime Overhead

Ours / MLton, 1 core



Speedups

MLton / Ours, 72 cores