Multicore OCaml

What's coming in 2021

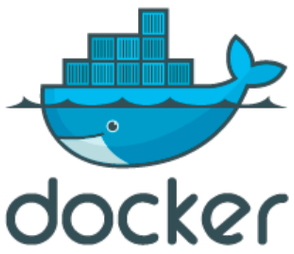
"KC" Sivaramakrishnan and Anil Madhavapeddy

OCaml Labs

IIT MADRAS

UNIVERSITY OF CAMBRIDGE

Industry



Tarides

Projects

The Astrée Static Analyzer

COMPCERT

Industry

Projects

ahrefs

Jane Street

FACEBOOK

docker

Tarides

Tezos

Bloomberg

The Astrée Static Analyzer

flow

hack

COMPCERT

No multicore support!

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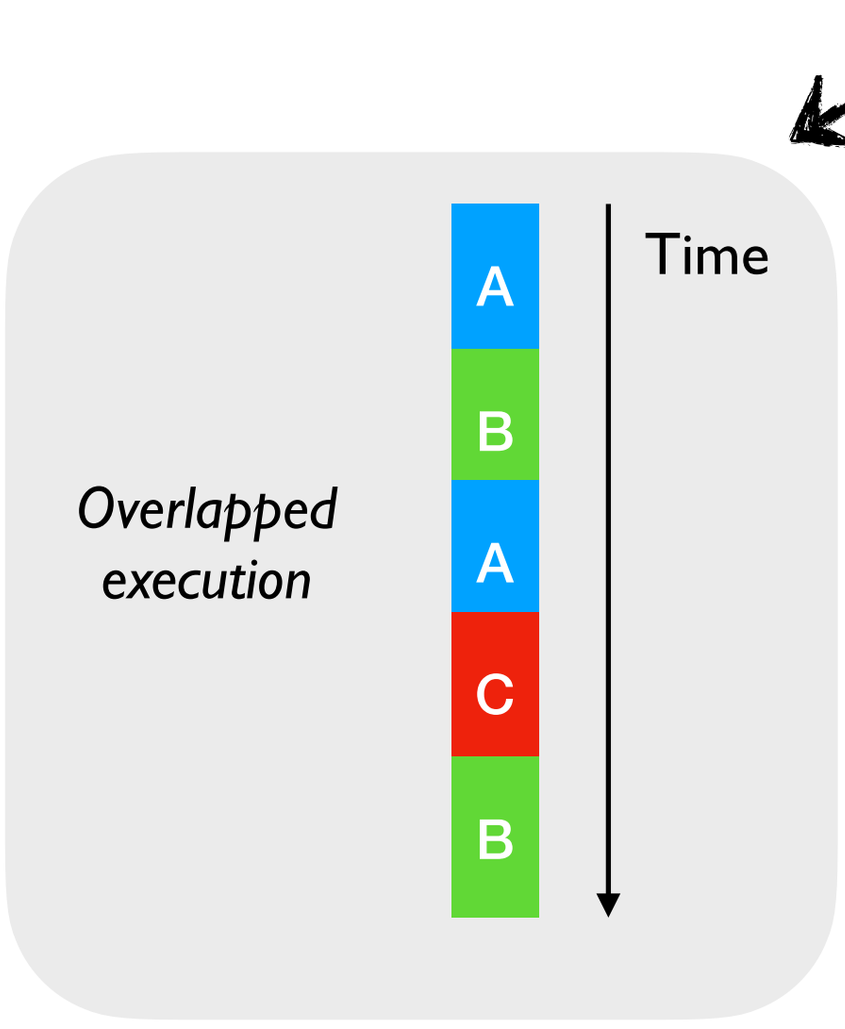

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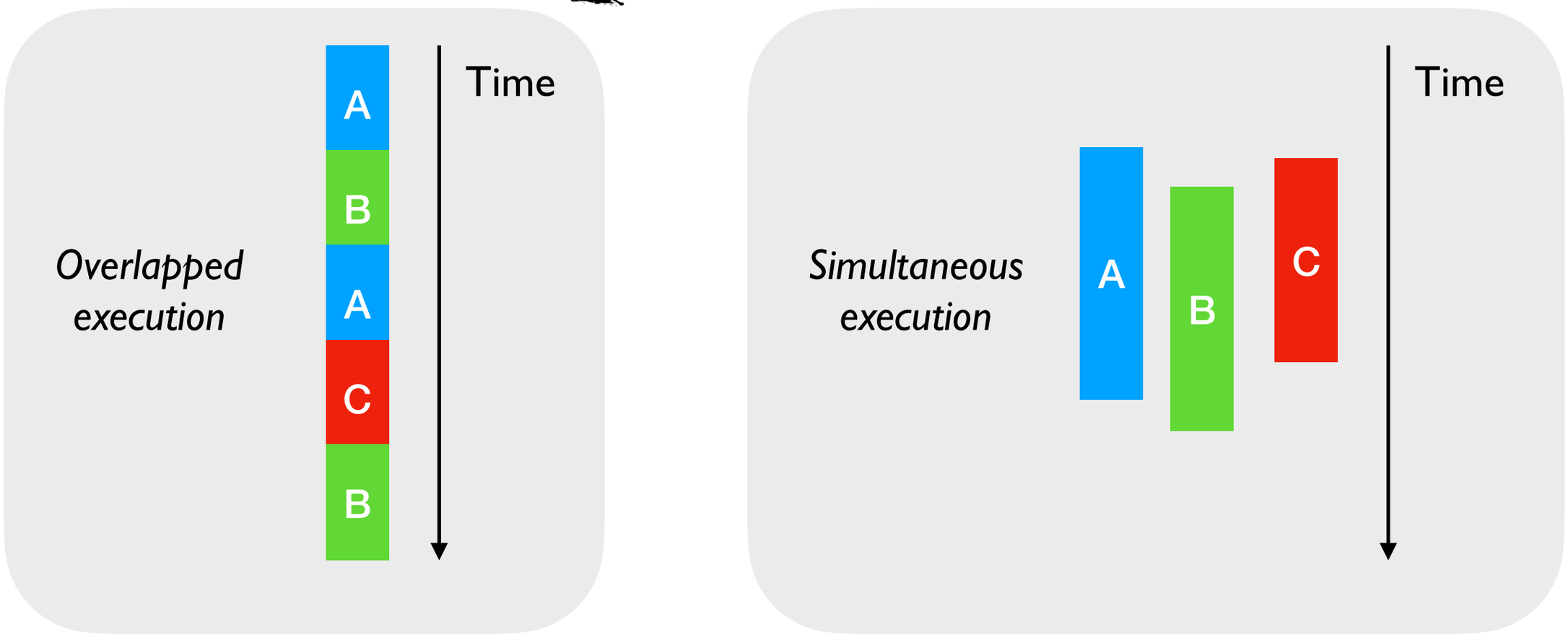

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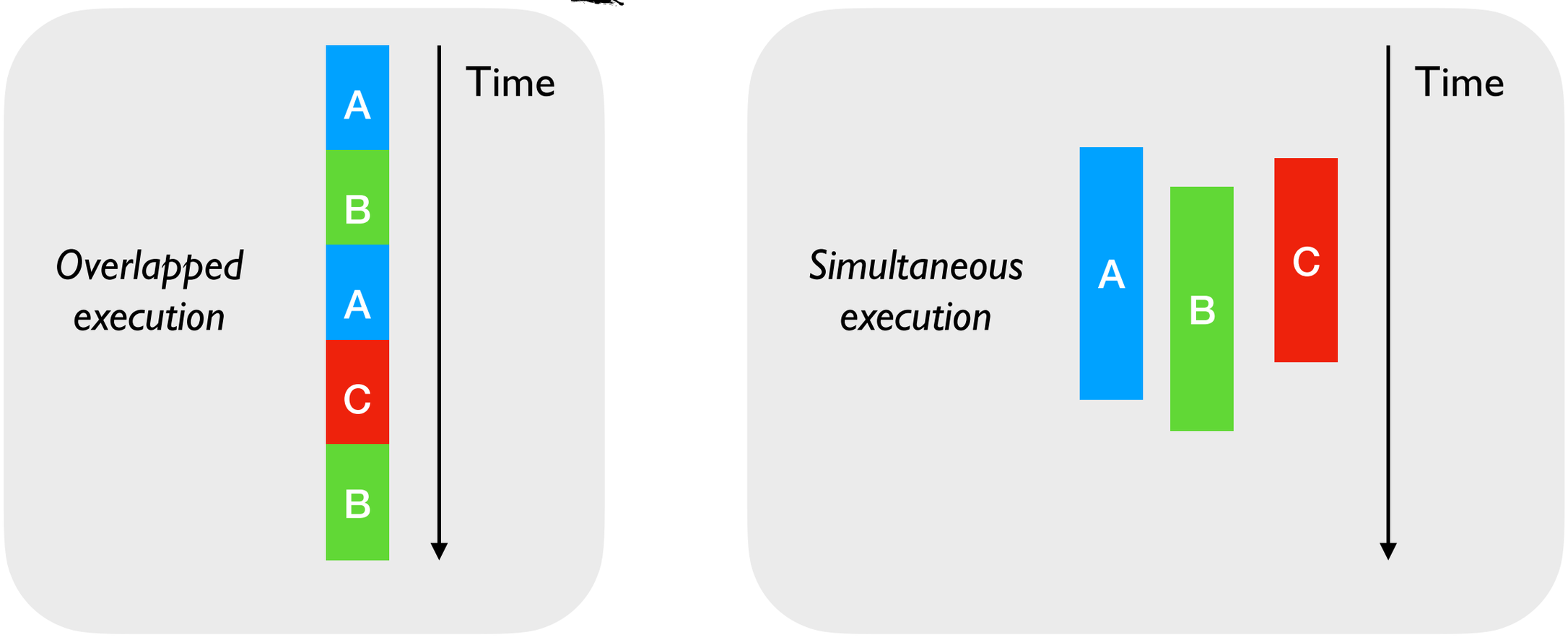

Effect Handlers

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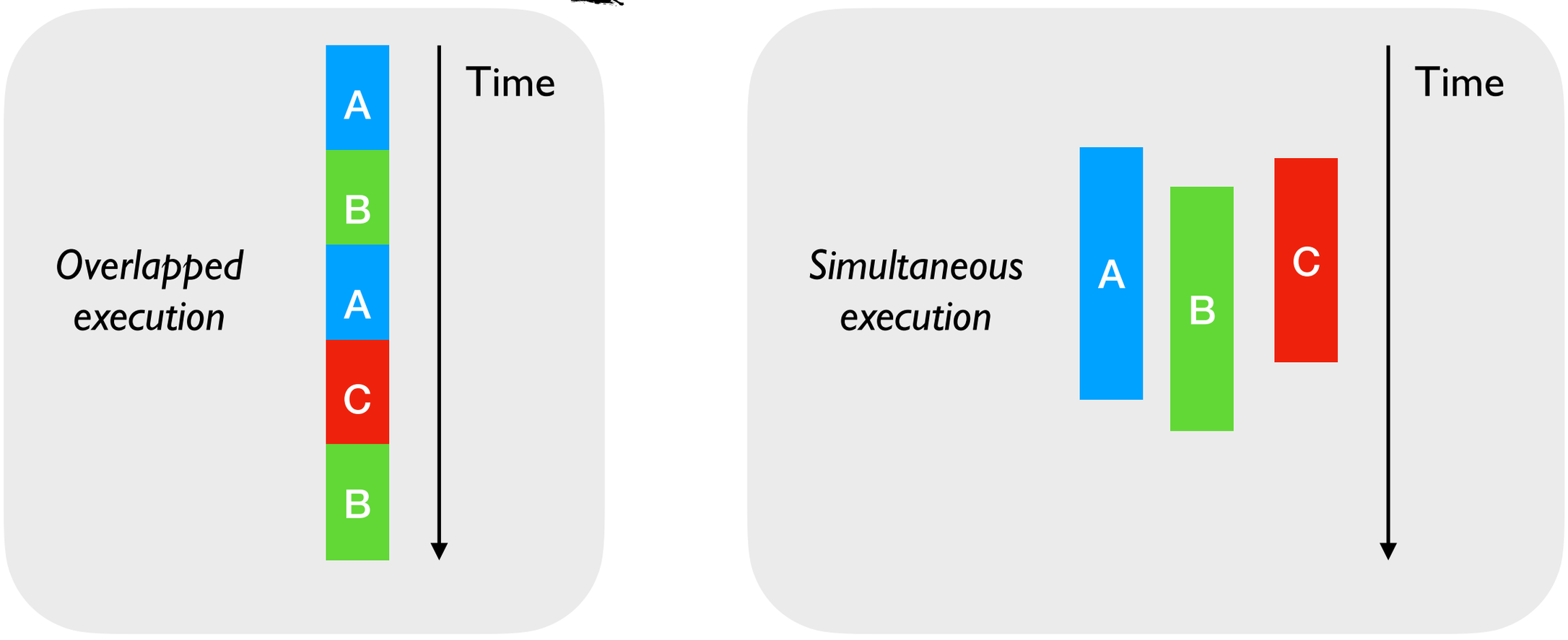

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Challenges

- Millions of lines of legacy code
  - ✦ Written without *concurrency* and *parallelism* in mind
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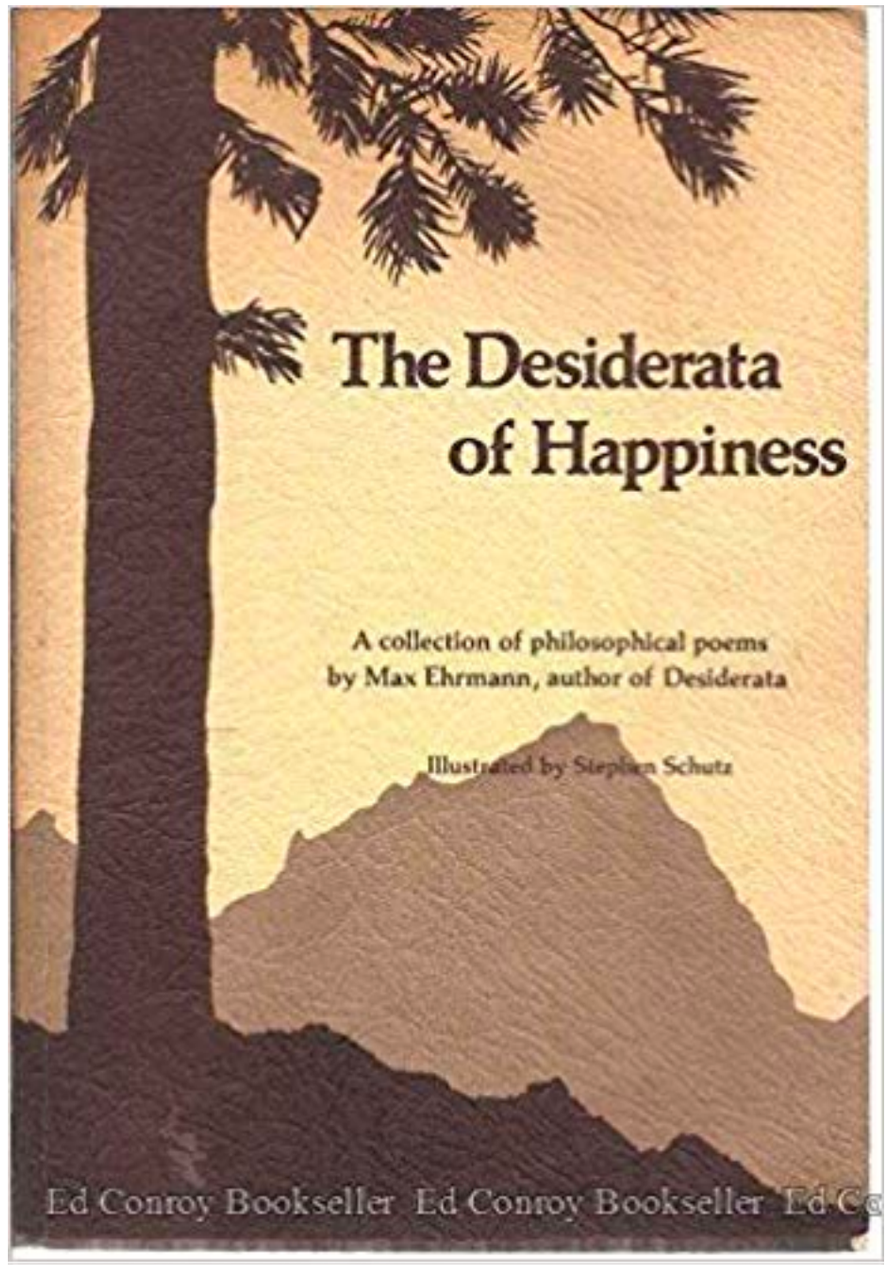
Backwards compatibility before scalability

Desiderata

- Feature backwards compatibility
  - ✦ Do not break existing code



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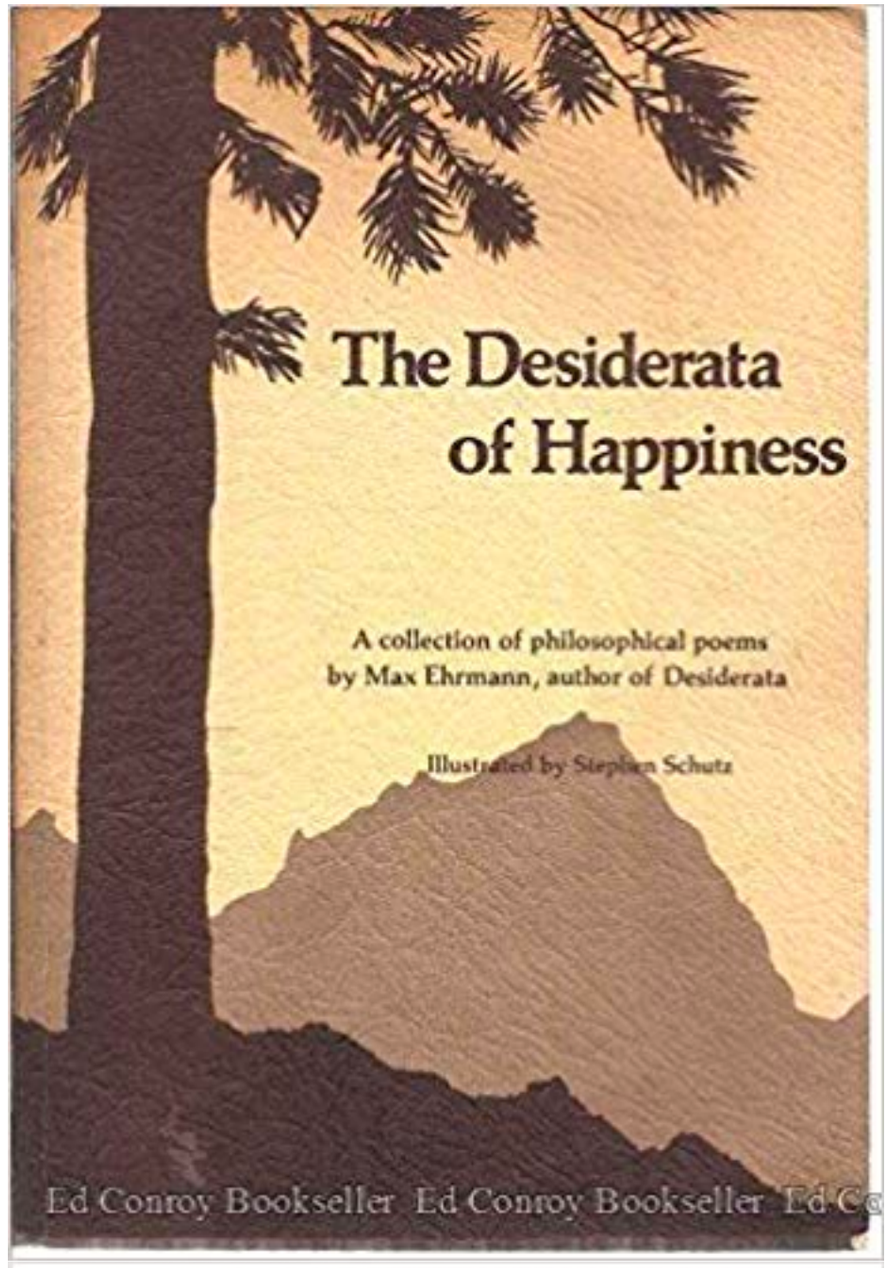
  - ✦ Existing programs run just as fast using just the same memory



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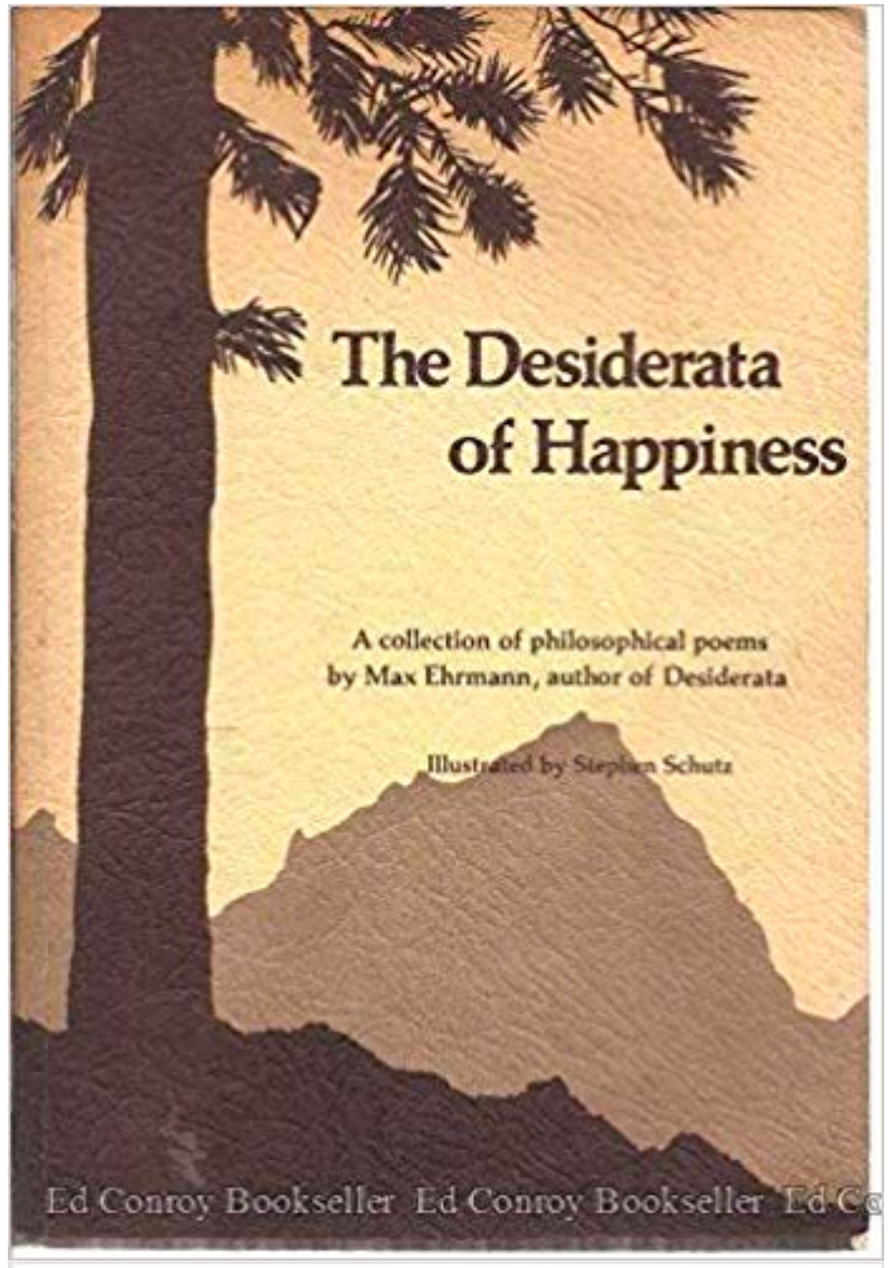

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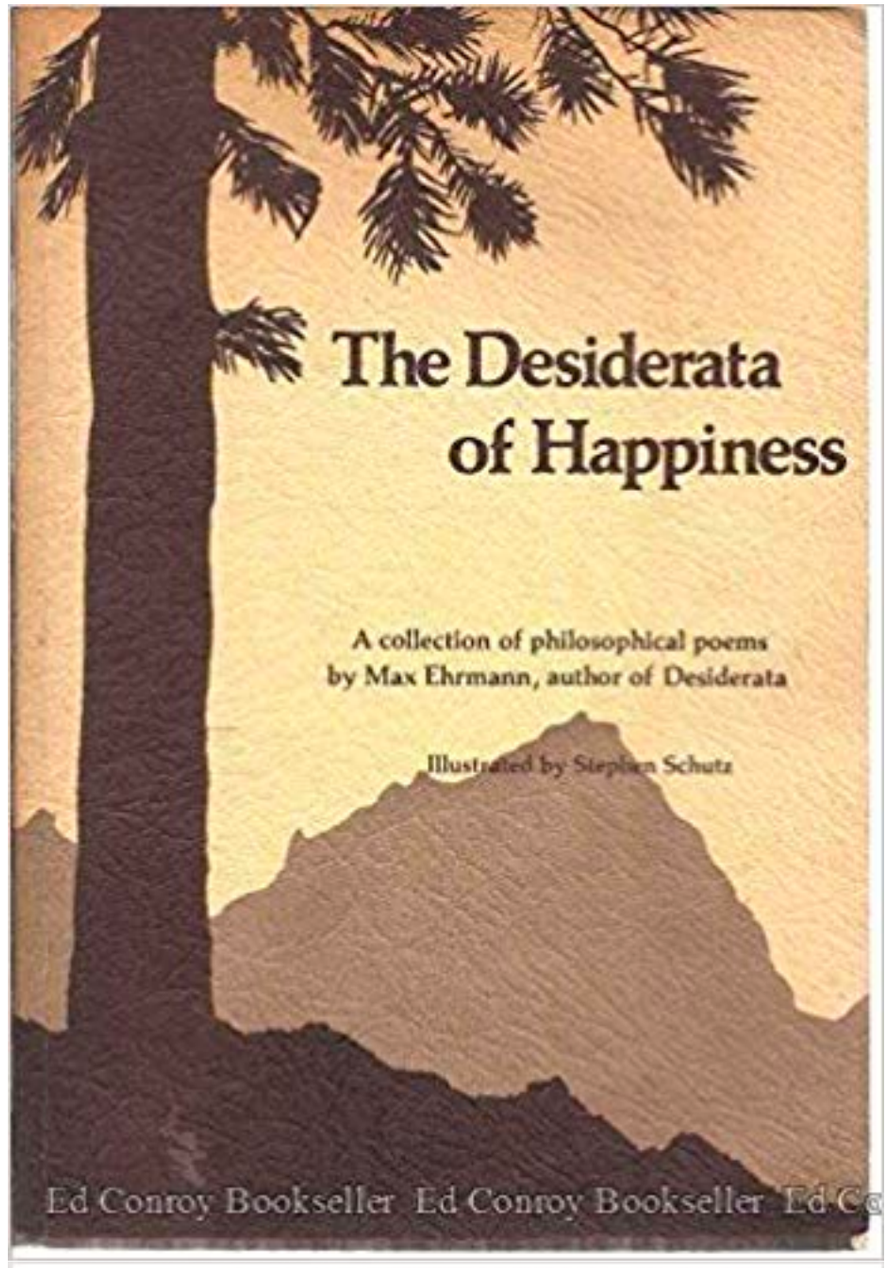

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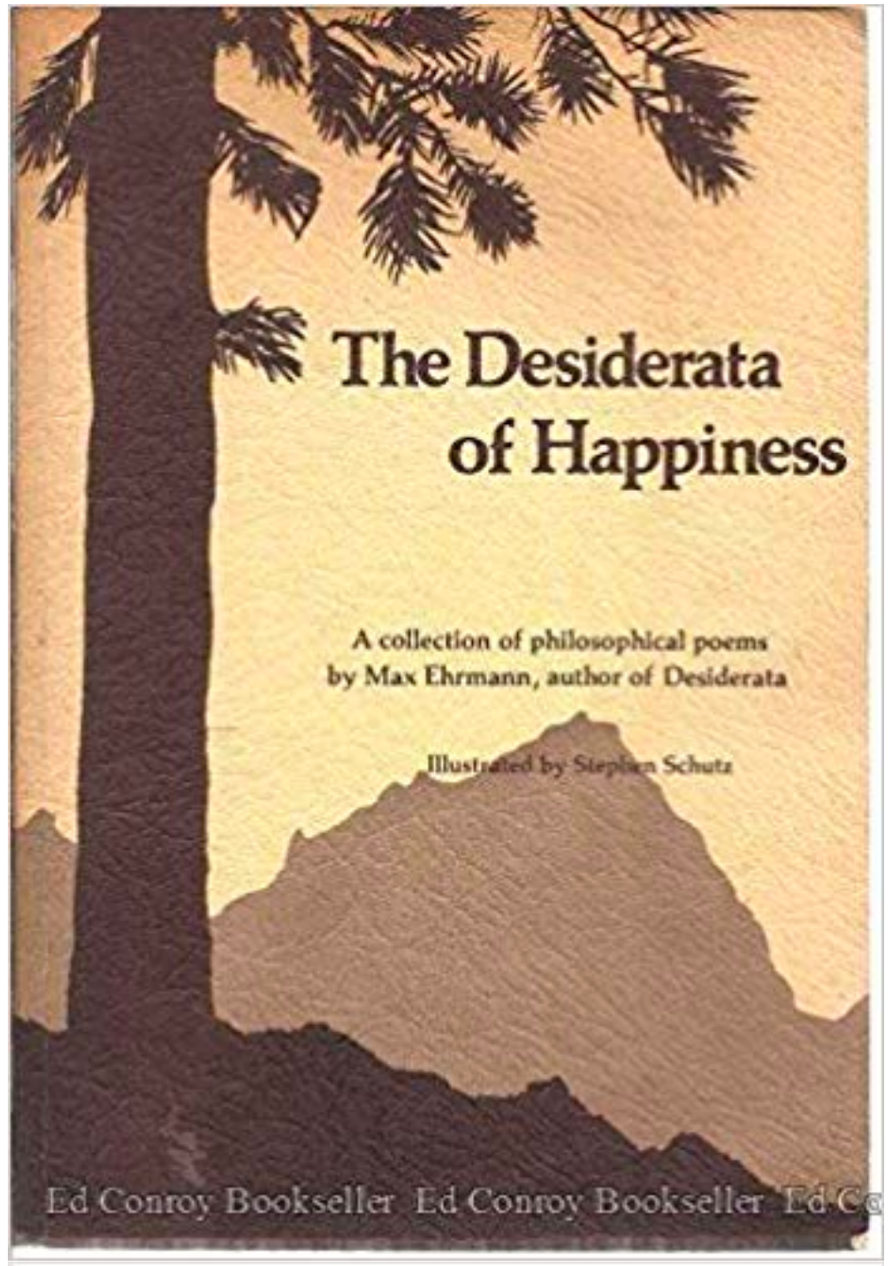
- Performant concurrent and parallel programming abstractions



Rest of the talk

- *Domains* for shared memory parallelism
- *Effect handlers* for concurrent programming

Domains for Parallelism

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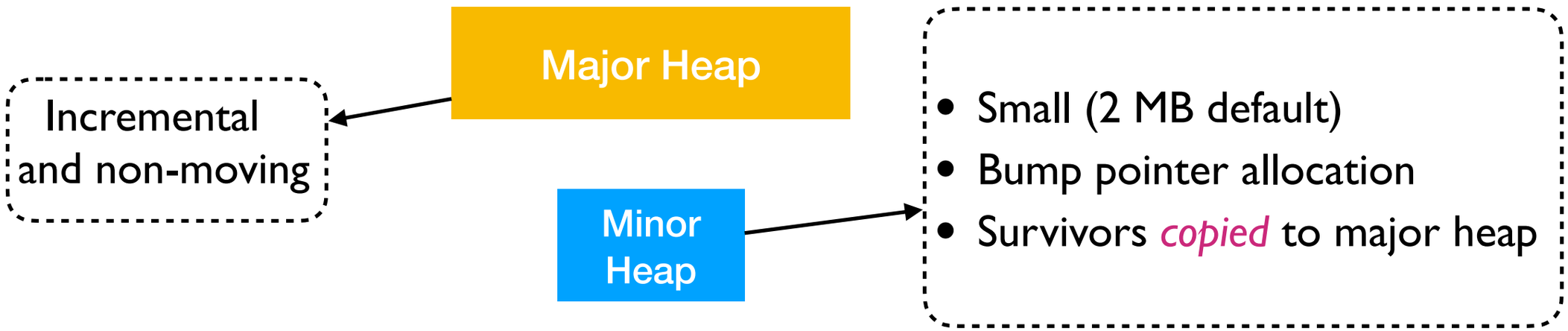
    - ✤ Dolan et al, "Bounding Data Races in Space and Time", PLDI'18
- No restrictions on sharing objects between domains
  - ✦ But how does it work?

Stock OCaml GC

- A generational, non-moving, incremental, mark-and-sweep GC



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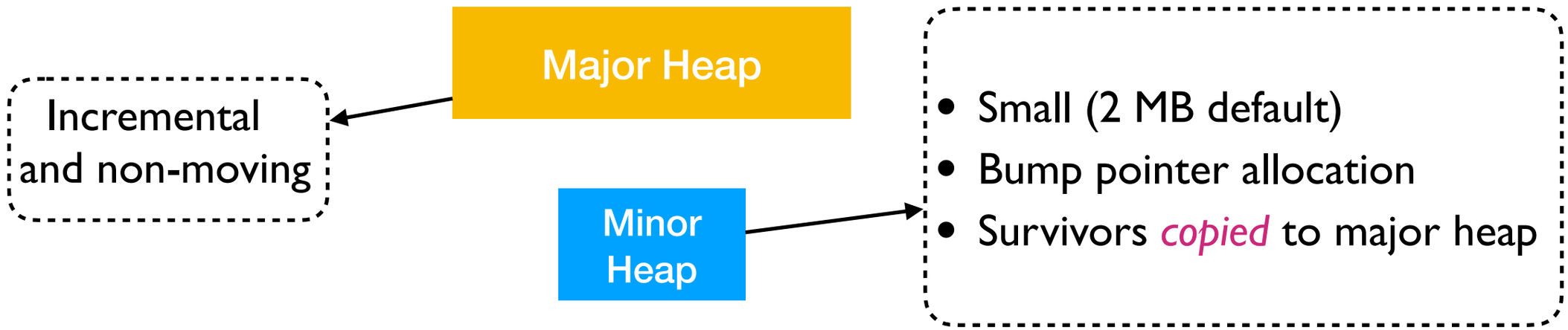

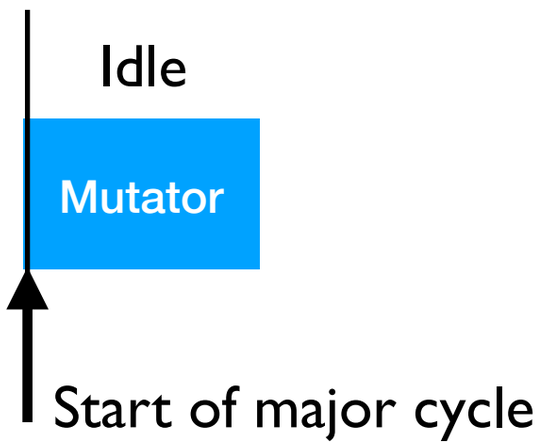

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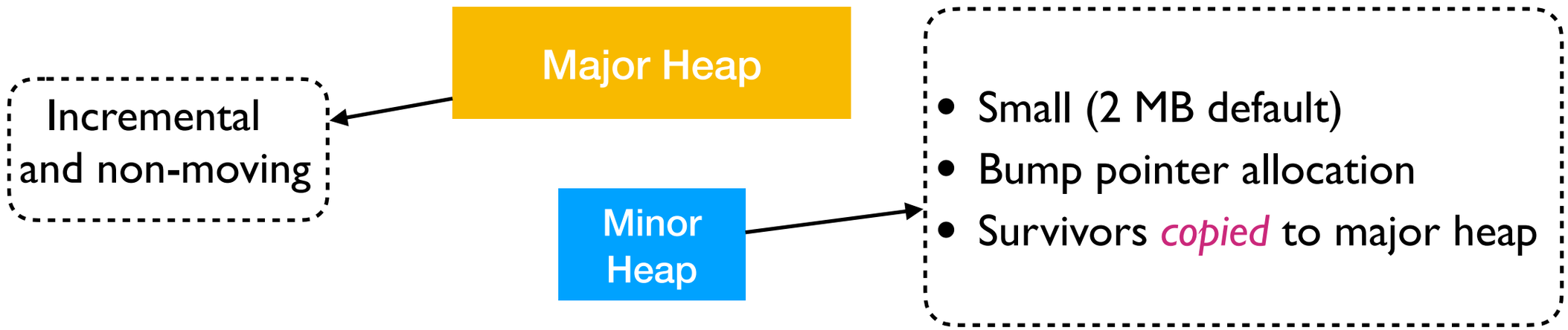

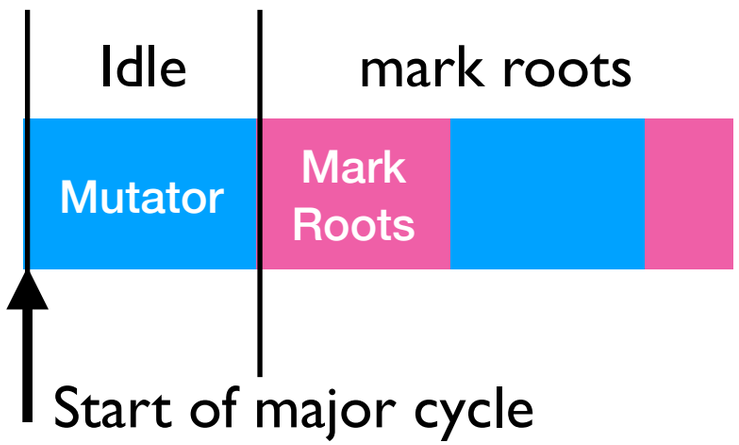

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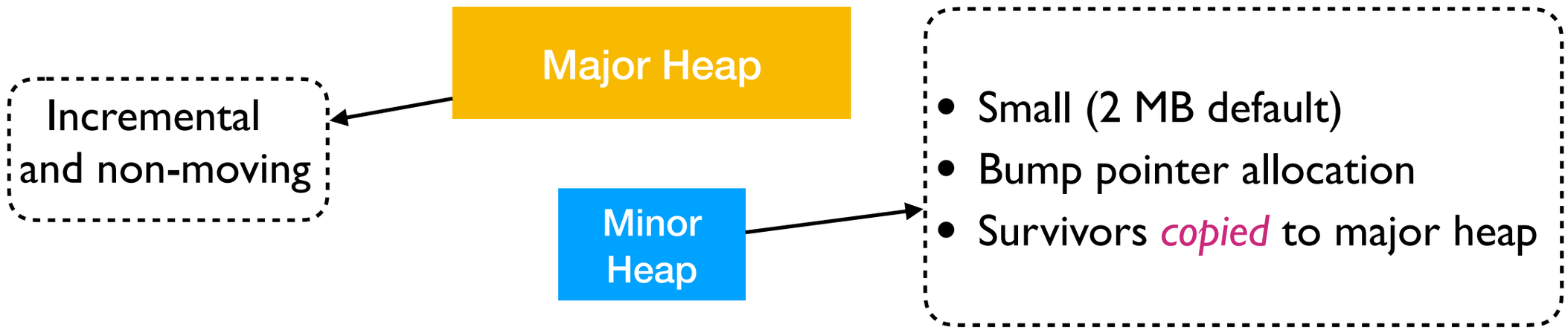

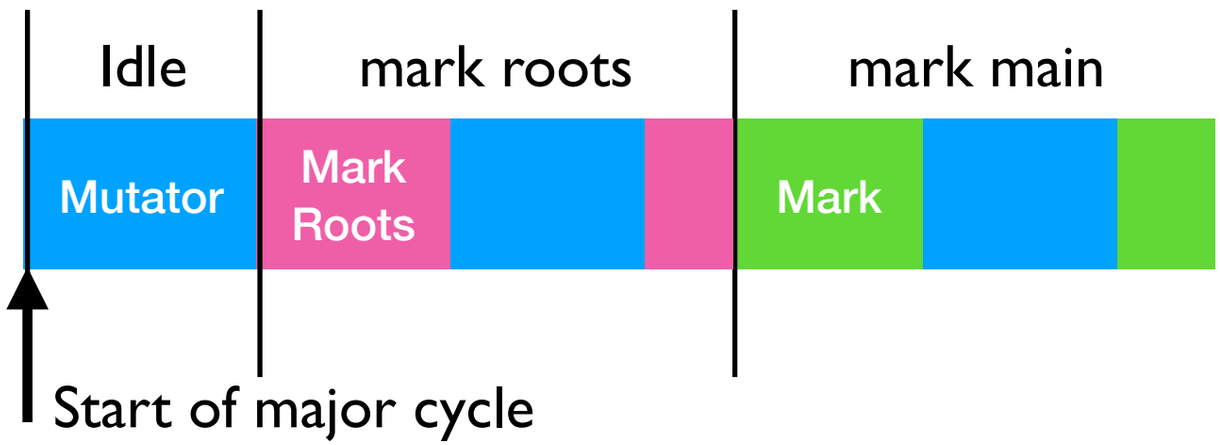

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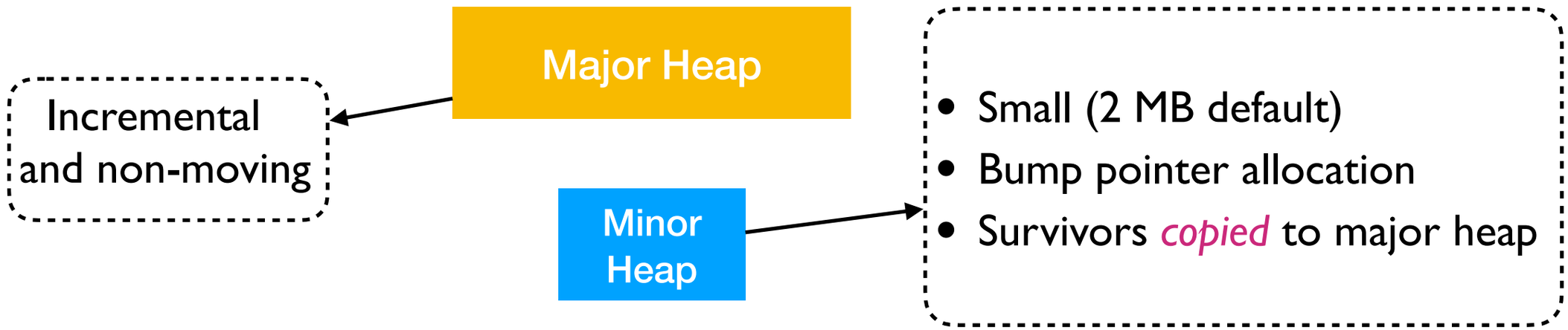

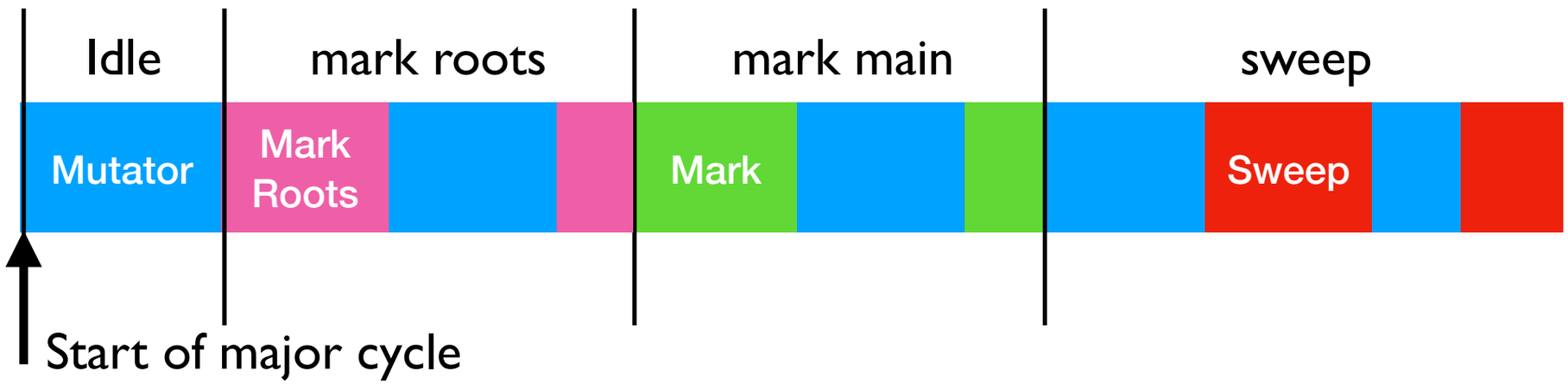

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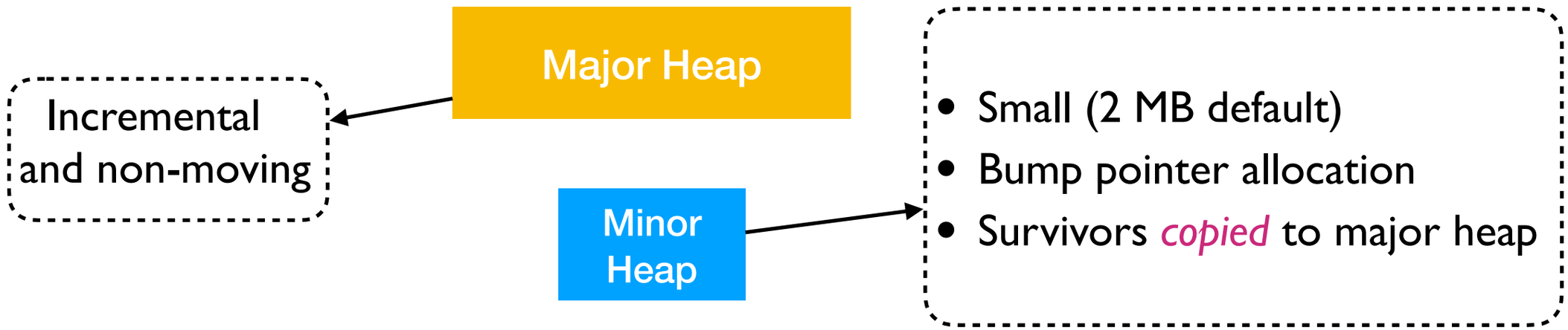

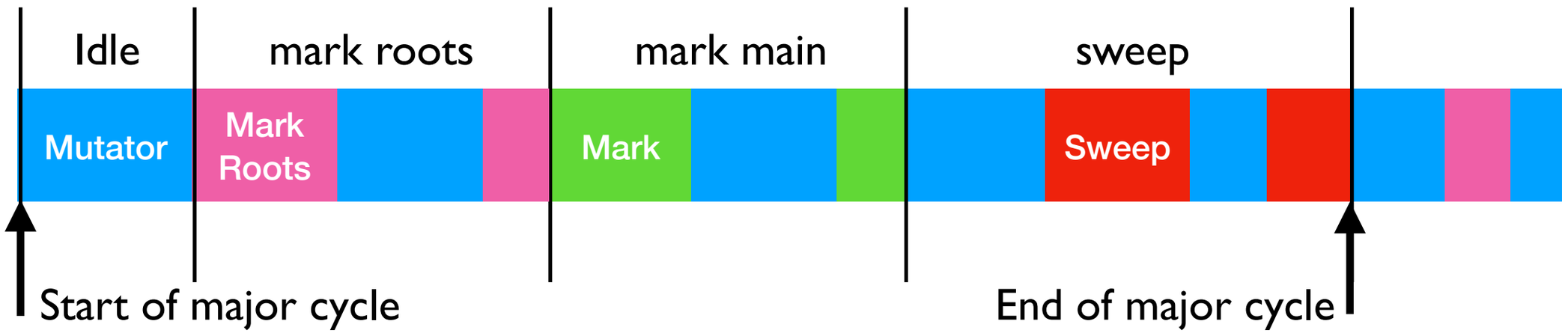

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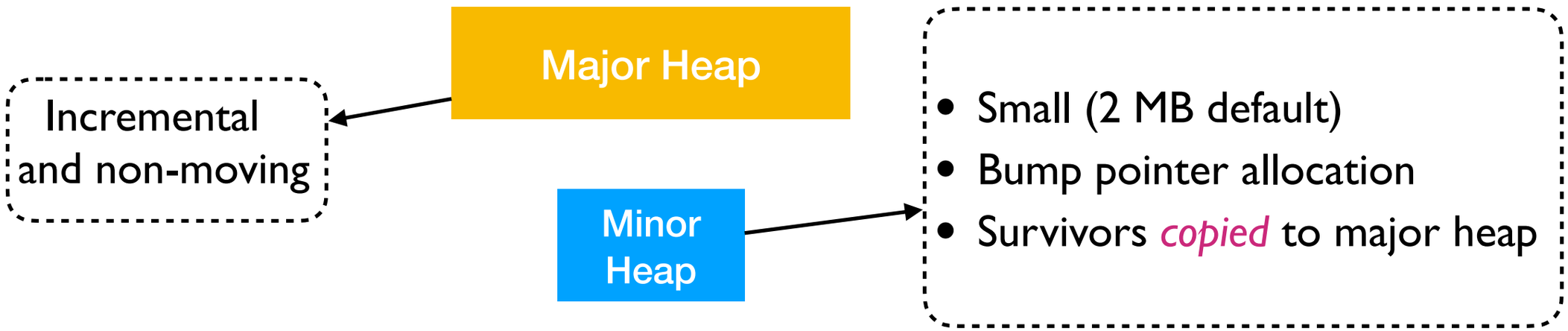

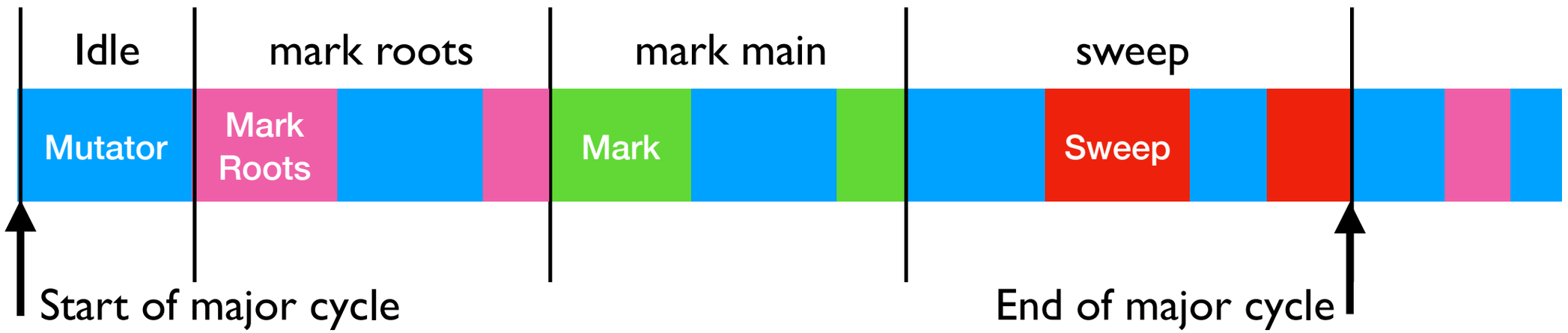

- Fast allocations

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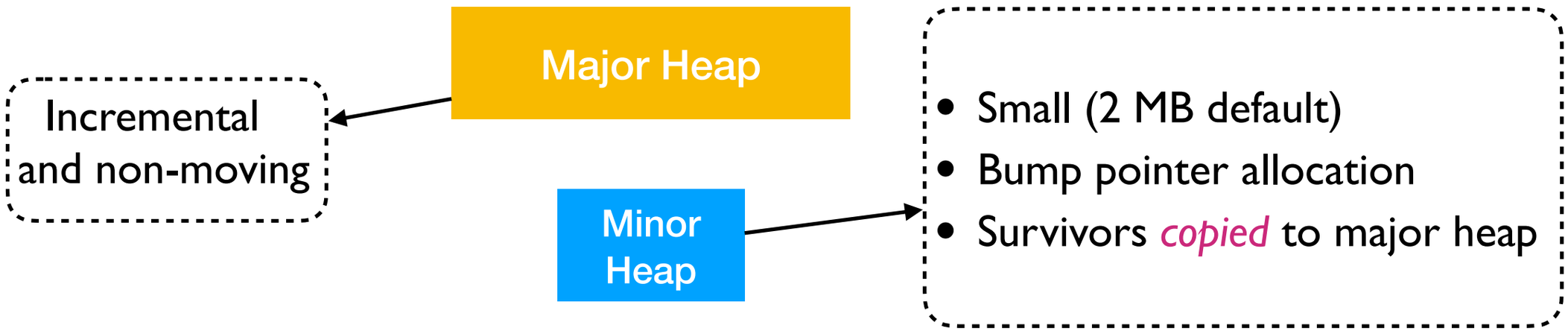
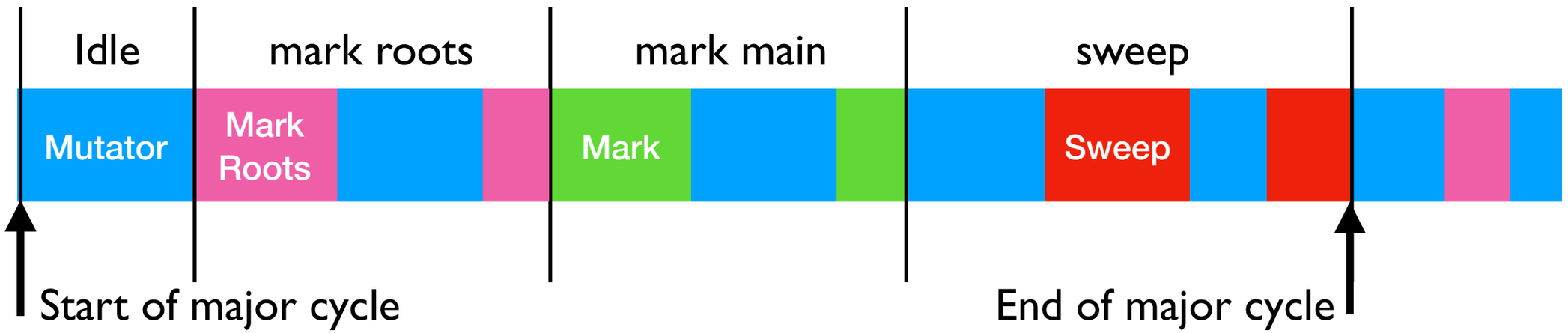
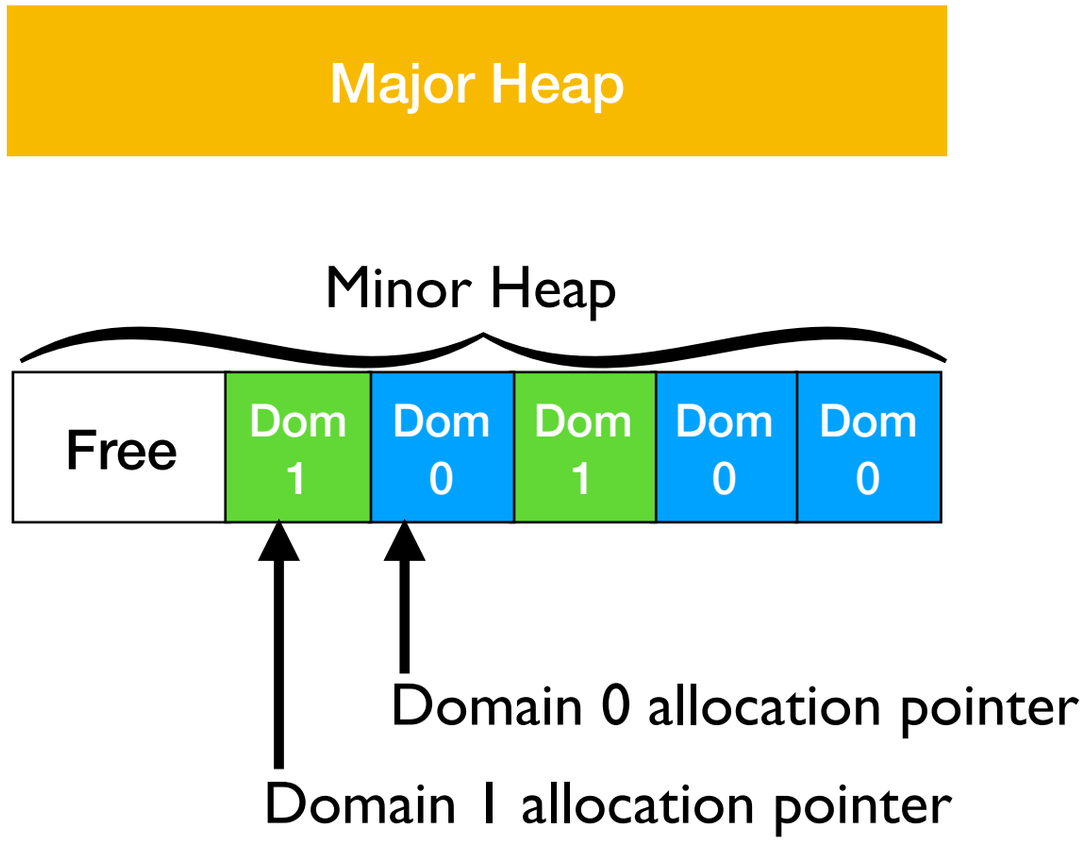




- Fast allocations
- Max GC latency **< 10 ms**, 99th percentile latency **< 1 ms**

Multicore OCaml GC



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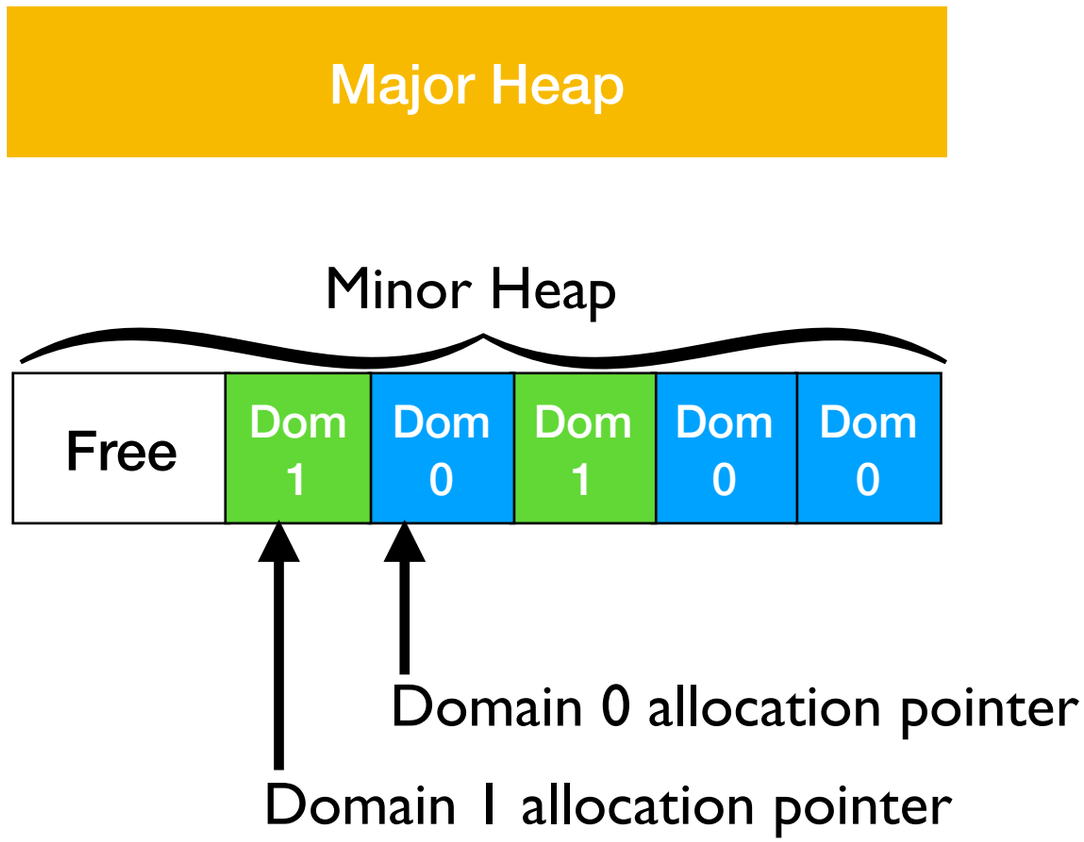
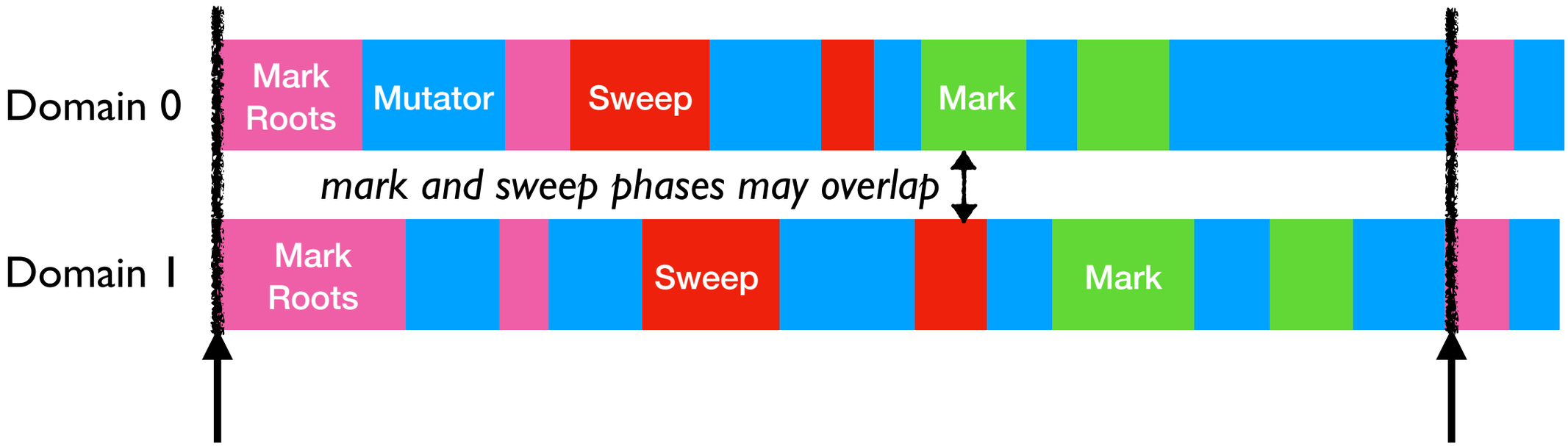


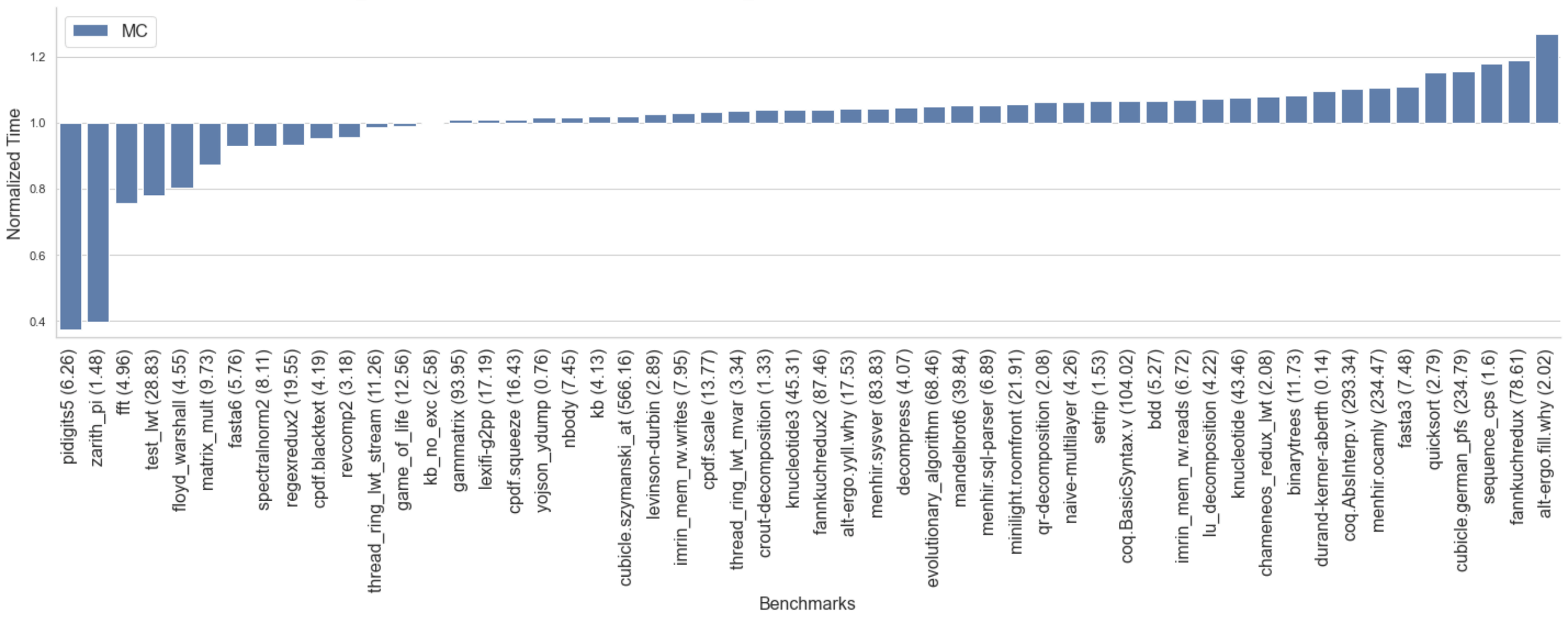
- *Stop-the-world parallel minor collection* for minor heap
  - ✦ 2 global barriers / minor gc
  - ✦ On 24 cores, ~10 ms pauses

Multicore OCaml GC



- *Mostly-concurrent mark-and-sweep* for major collection
  - ✦ All the marking and sweeping work done *without synchronization*
  - ✦ 3 barriers per cycle (worst case) to agree end of GC phases
    - ✤ 2 barriers for the two kinds of finalisers in OCaml
  - ✦ ~5 ms pauses on 24 cores

Sequential performance



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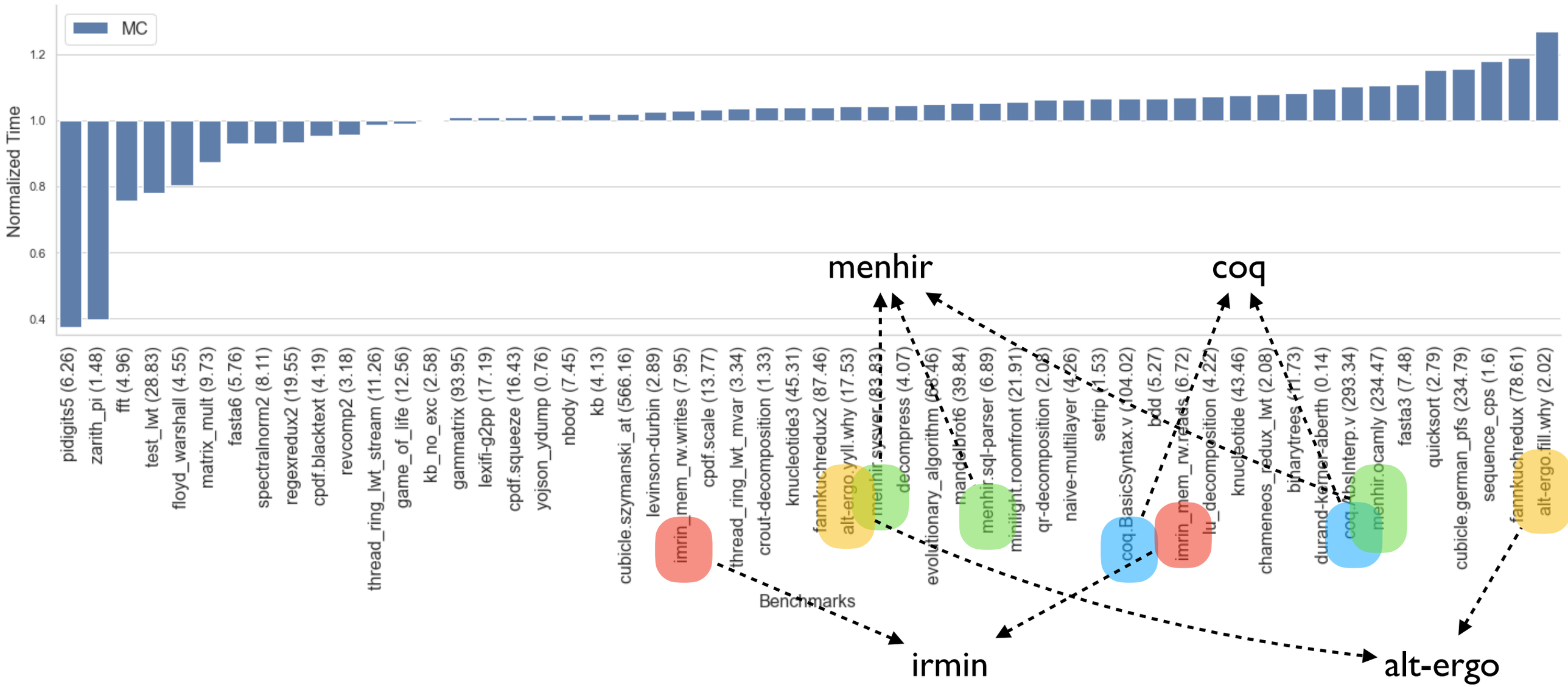

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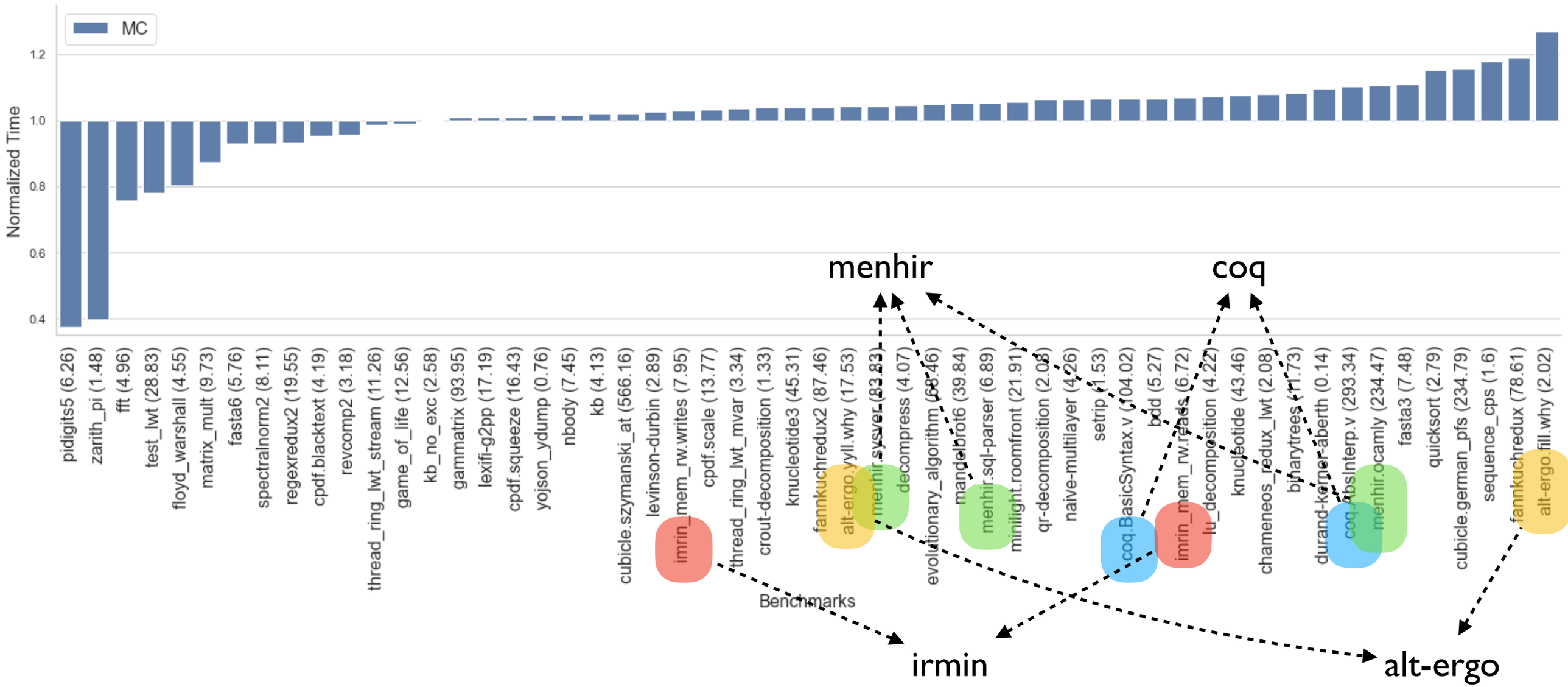

- ~1% faster than stock (geomean of normalised running times)
  - ✦ Difference under measurement noise mostly
  - ✦ Outliers due to difference in allocators

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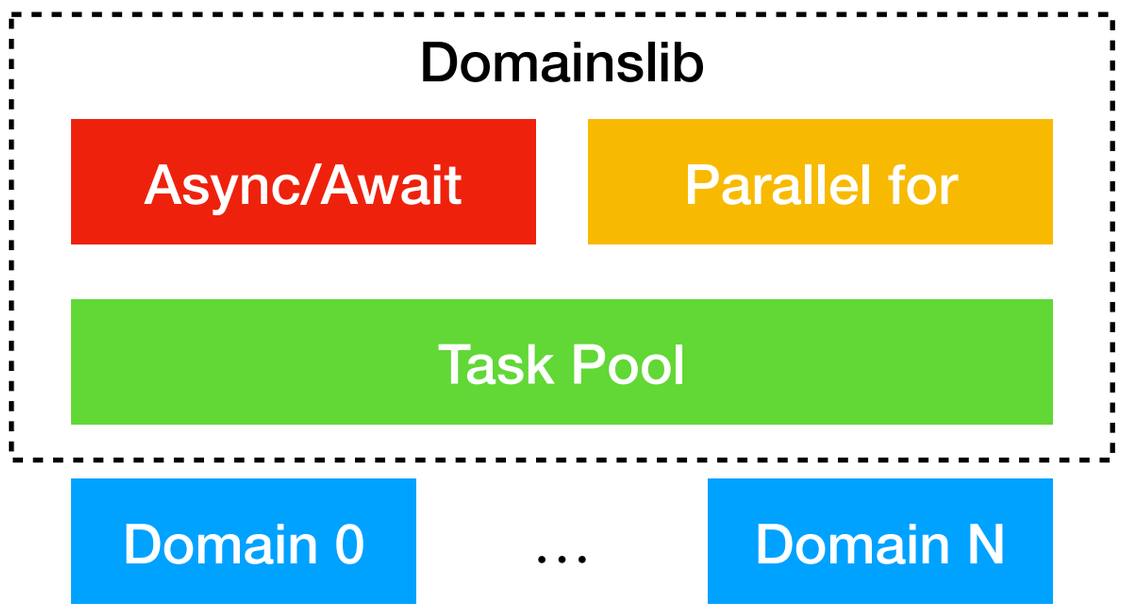

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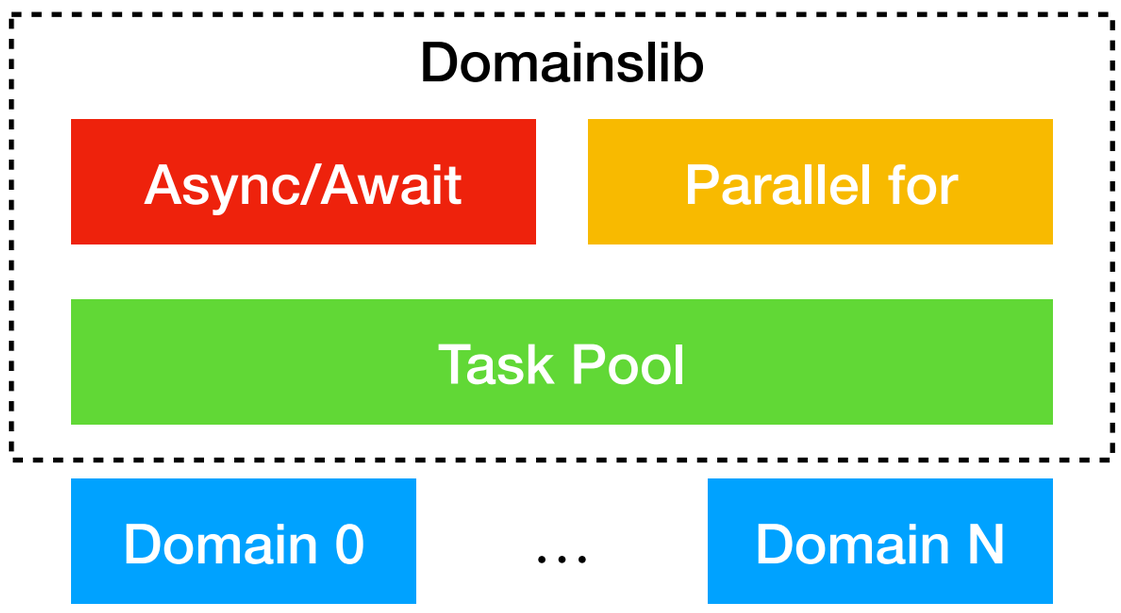

Let's look at examples!

Recursive Fibonacci - Sequential

```
let rec fib n =
  if n < 2 then 1
  else fib (n-1) + fib (n-2)
```

Recursive Fibonacci - Parallel

```
module T = Domainslib.Task
```

```
let fib n =
  let pool = T.setup_pool ~num_domains:(num_domains - 1) in
  let res = fib_par pool n in
  T.teardown_pool pool;
  res
```

Recursive Fibonacci - Parallel

```
module T = Domainslib.Task



let rec fib_par pool n =
  if n <= 40 then fib_seq n
  else
    let a = T.async pool (fun _ -> fib_par pool (n-1)) in
    let b = T.async pool (fun _ -> fib_par pool (n-2)) in
    T.await pool a + T.await pool b

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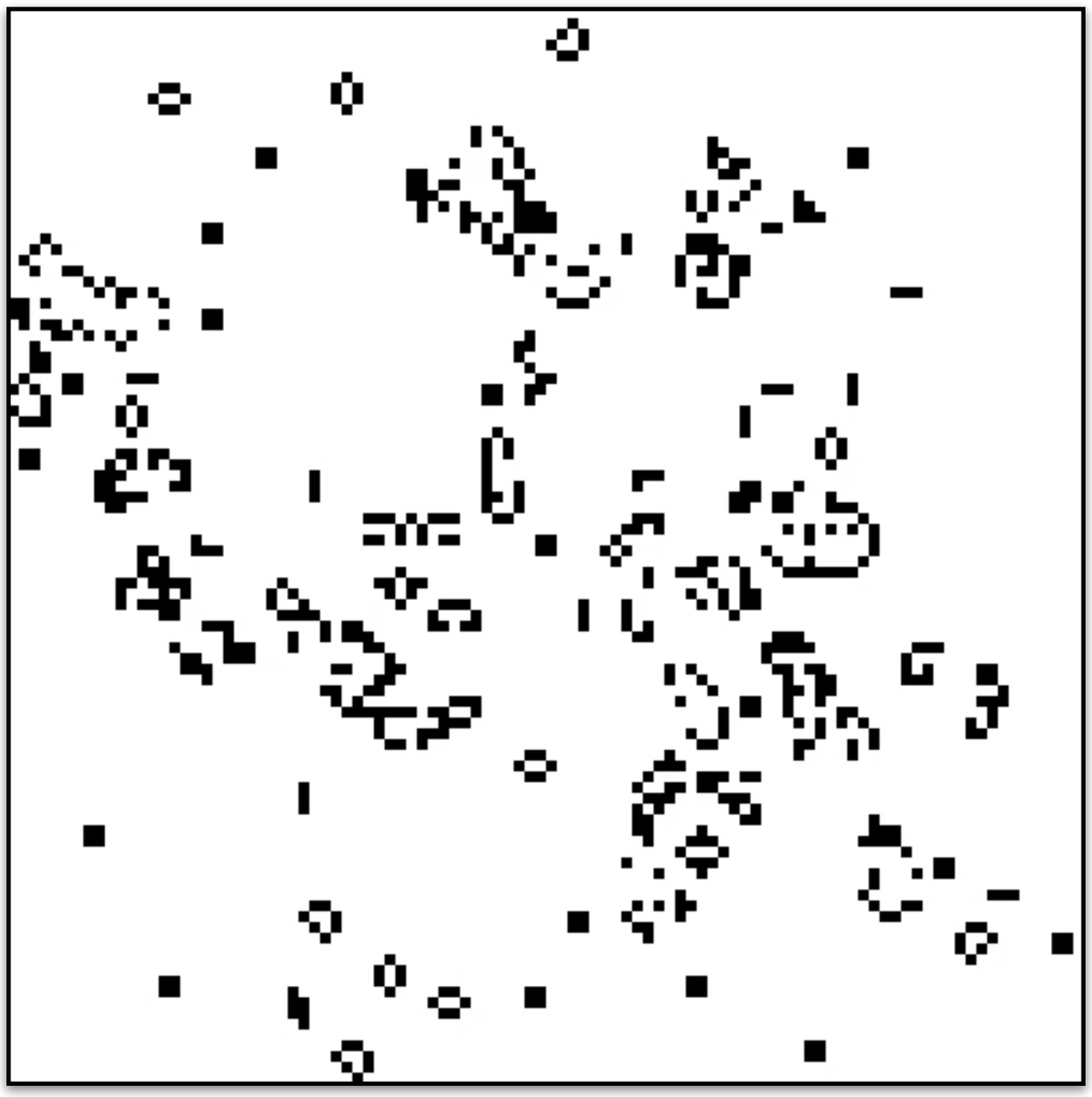
```

Performance: fib(48)

Cores	Time (Seconds)	Vs Serial	Vs Self
1	37.787	0.98	1
2	19.034	1.94	1.99
4	9.723	3.8	3.89
8	5.023	7.36	7.52
16	2.914	12.68	12.97
24	2.201	**16.79**	**17.17**

Conway's Game of Life



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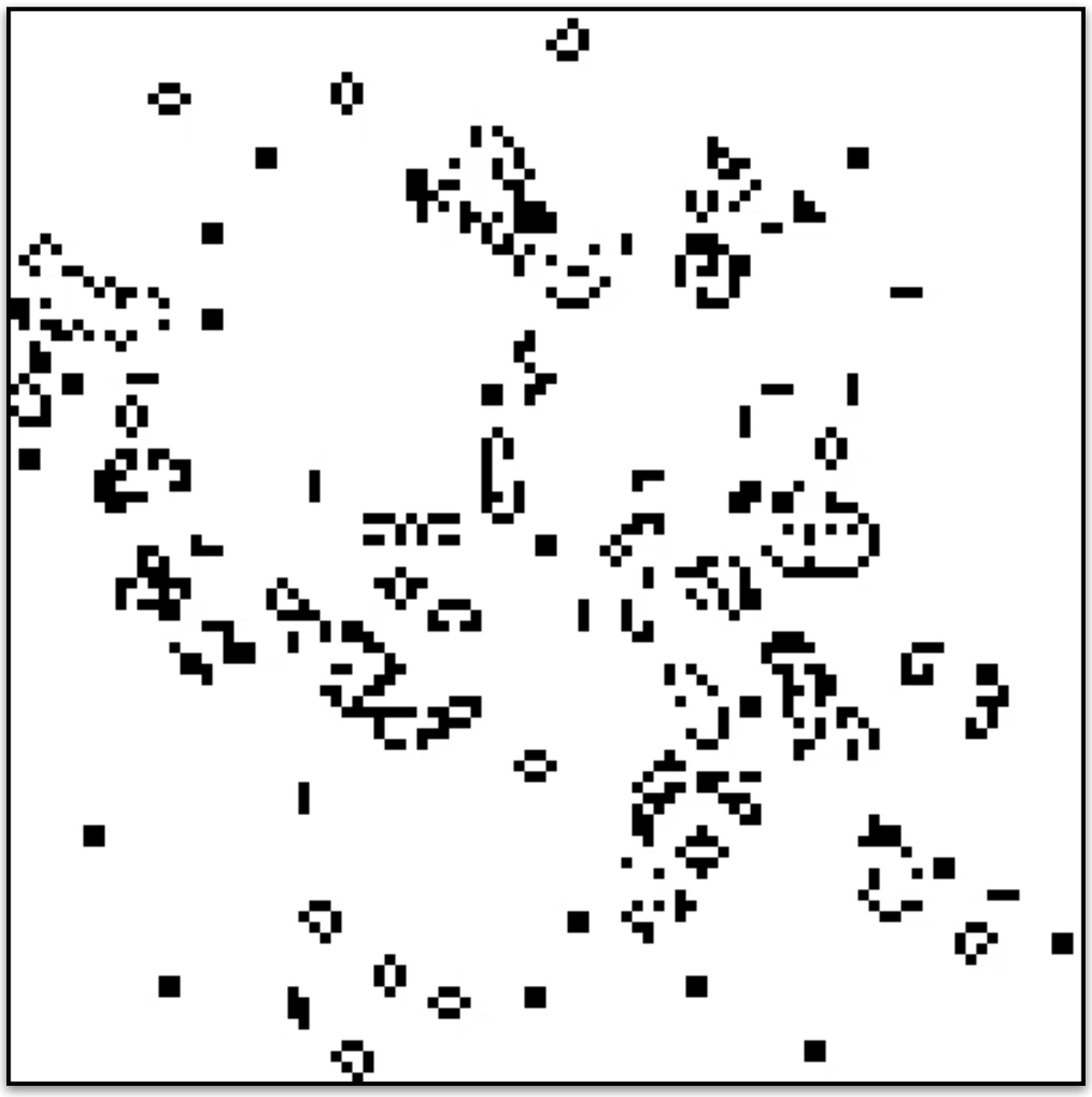

Conway's Game of Life

```
let next () =
  ...
  for x = 0 to board_size - 1 do
    for y = 0 to board_size - 1 do
      next_board.(x).(y) <- next_cell cur_board x y
    done
  done;
  ...
```

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  done;
  ...
```

```
let next () =
  ...
  T.parallel_for pool ~start:0 ~finish:(board_size - 1)
    ~body:(fun x ->
       for y = 0 to board_size - 1 do
         next_board.(x).(y) <- next_cell cur_board x y
       done);
  ...
```

Performance: Game of Life

Board size = 1024, Iterations = 512

Cores	Time (Seconds)	Vs Serial	Vs Self
1	24.326	1	1
2	12.290	1.980	1.98
4	6.260	3.890	3.89
8	3.238	7.51	7.51
16	1.726	14.09	14.09
24	1.212	**20.07**	**20.07**

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Should we add lightweight threads to OCaml?

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- Effect *declaration* separate from *interpretation* (c.f. exceptions)

```
effect E : string

let comp () =
  print_string "0 ";
  print_string (perform E);
  print_string "3 "

let main () =
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Effect Handlers

- A mechanism for programming with *user-defined effects*
- Modular basis of non-local control-flow mechanisms
  - ✦ Exceptions, generators, lightweight threads, promises, asynchronous IO, coroutines
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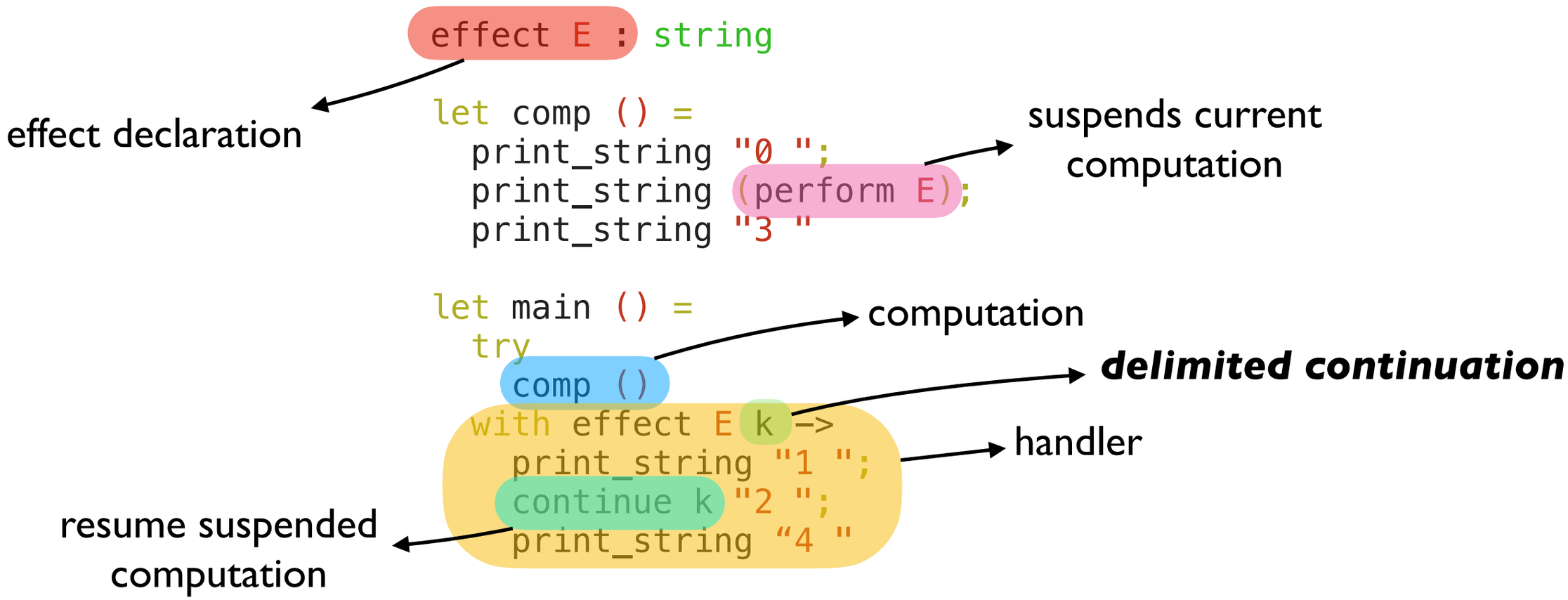

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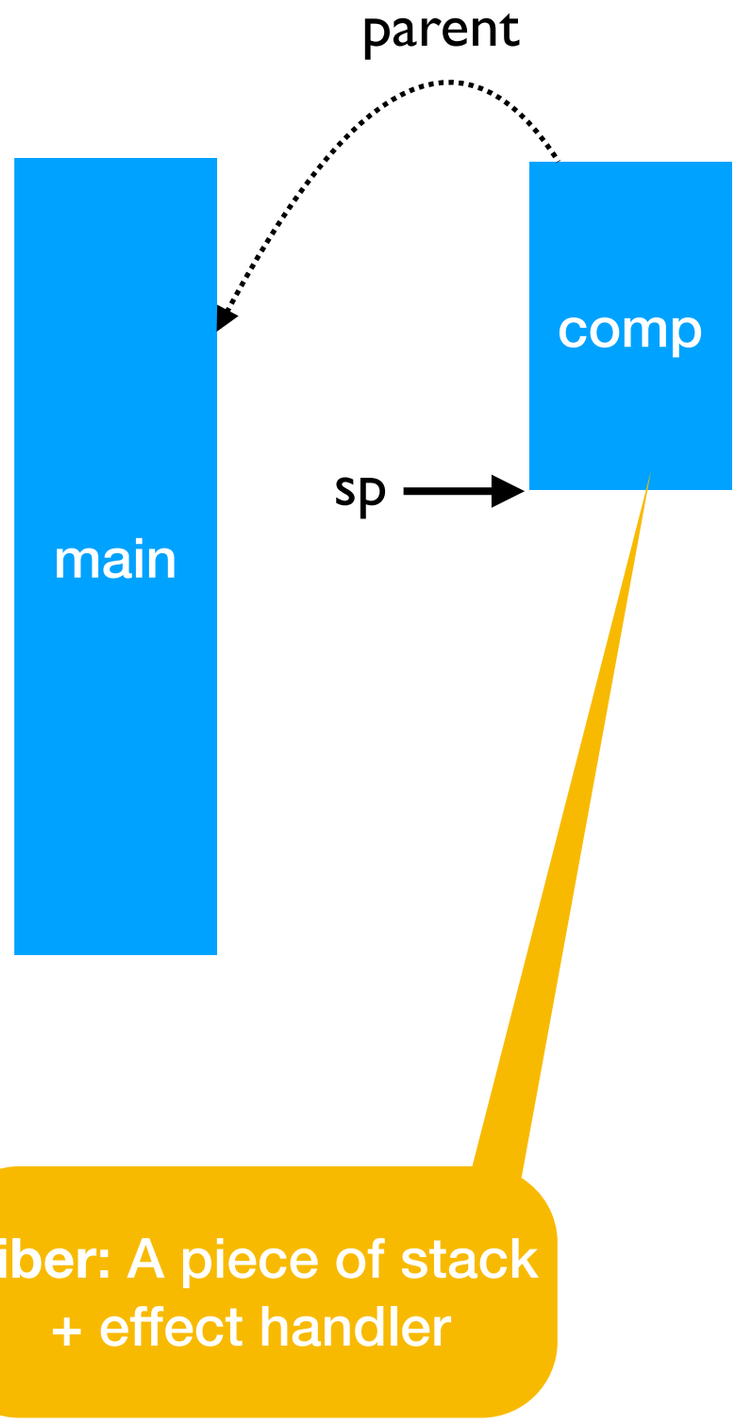

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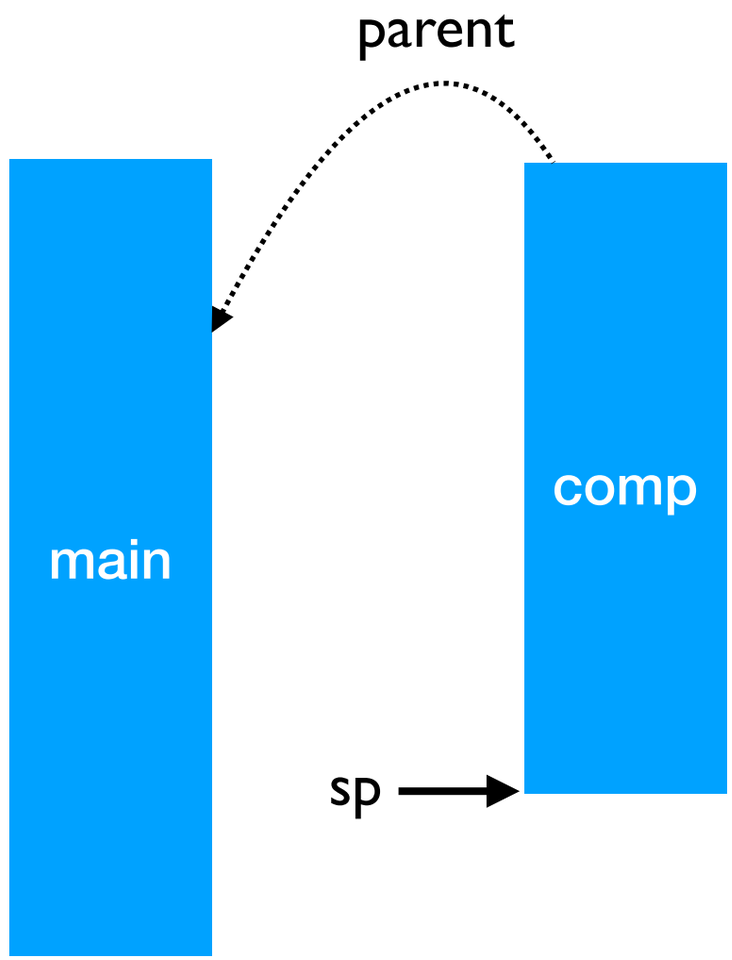

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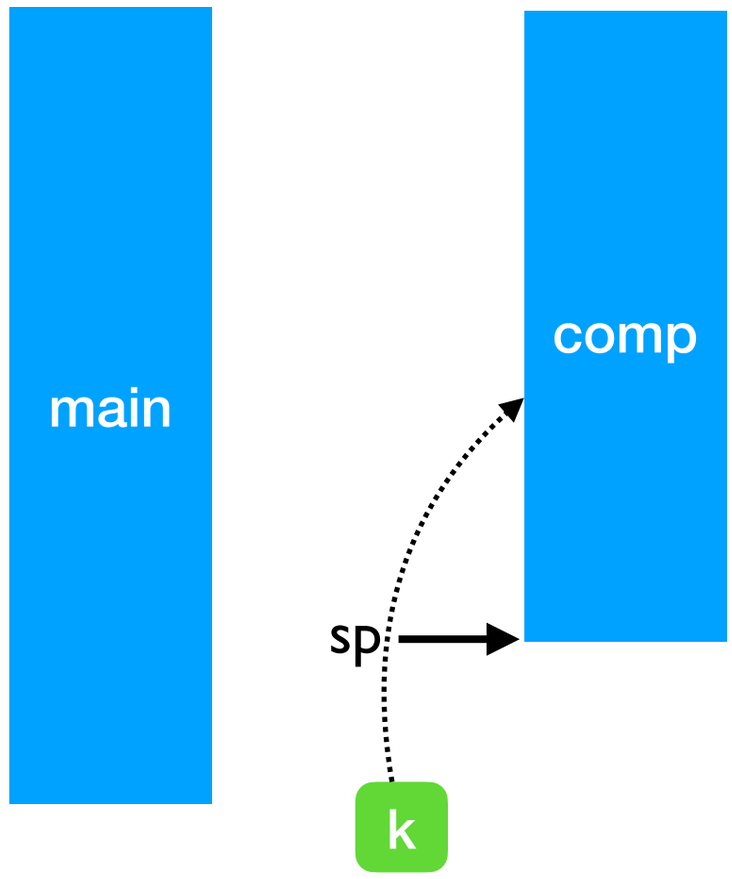

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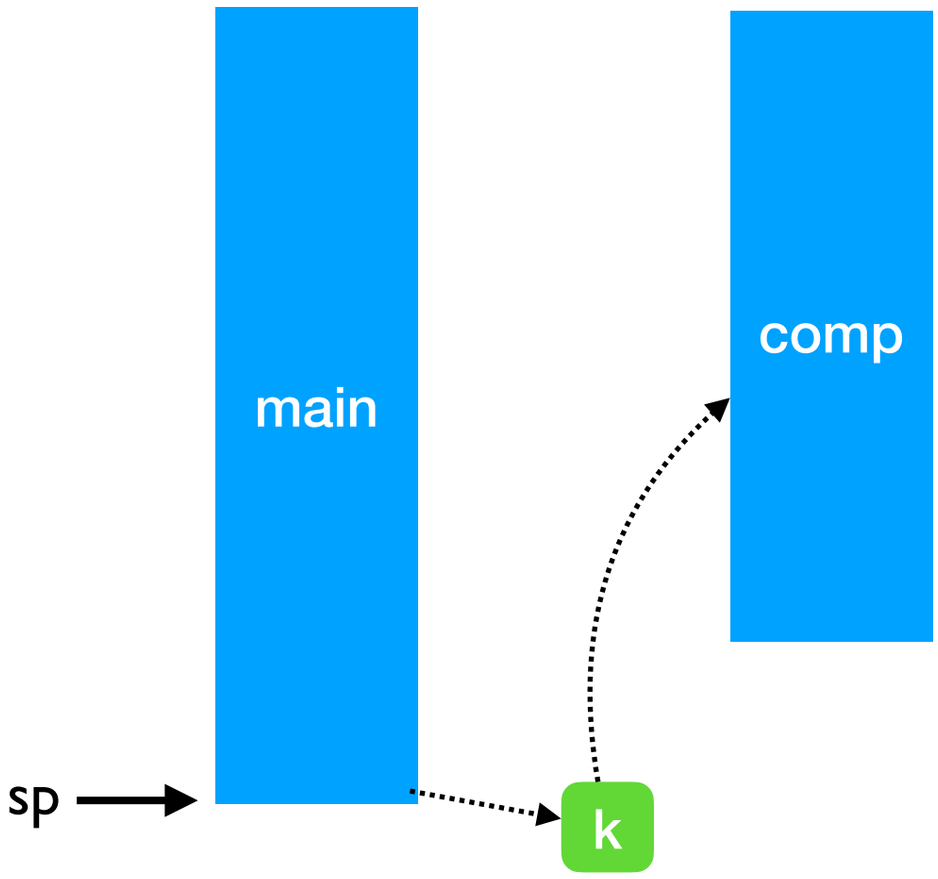

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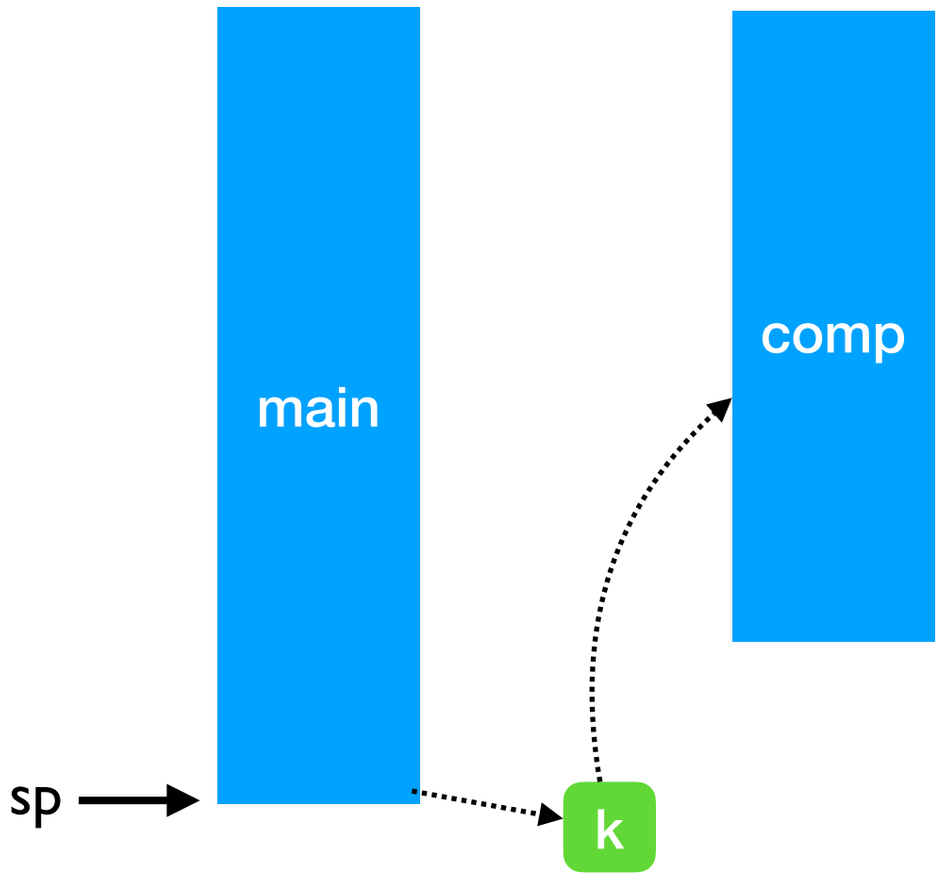

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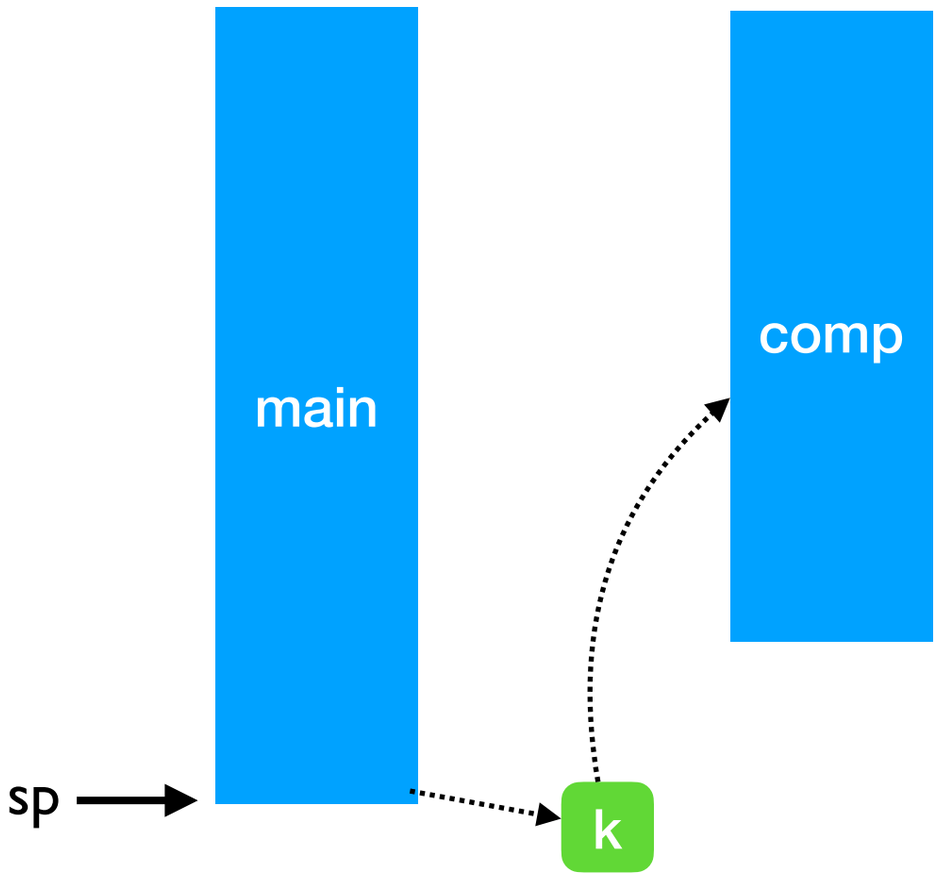

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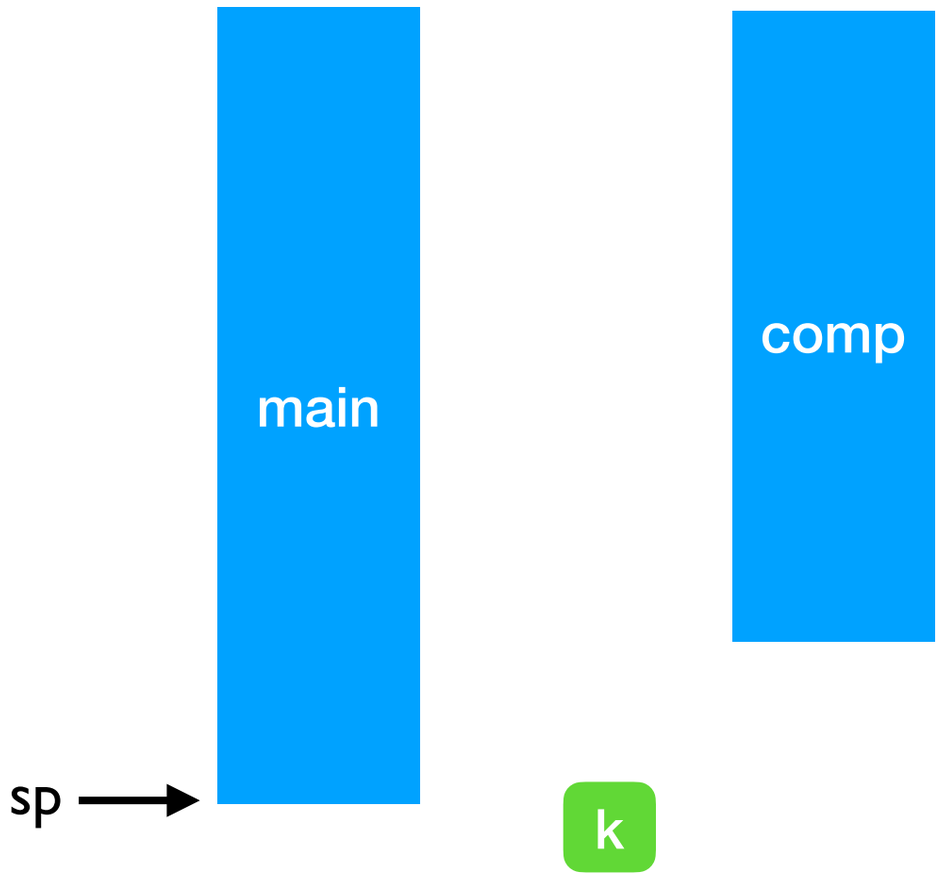

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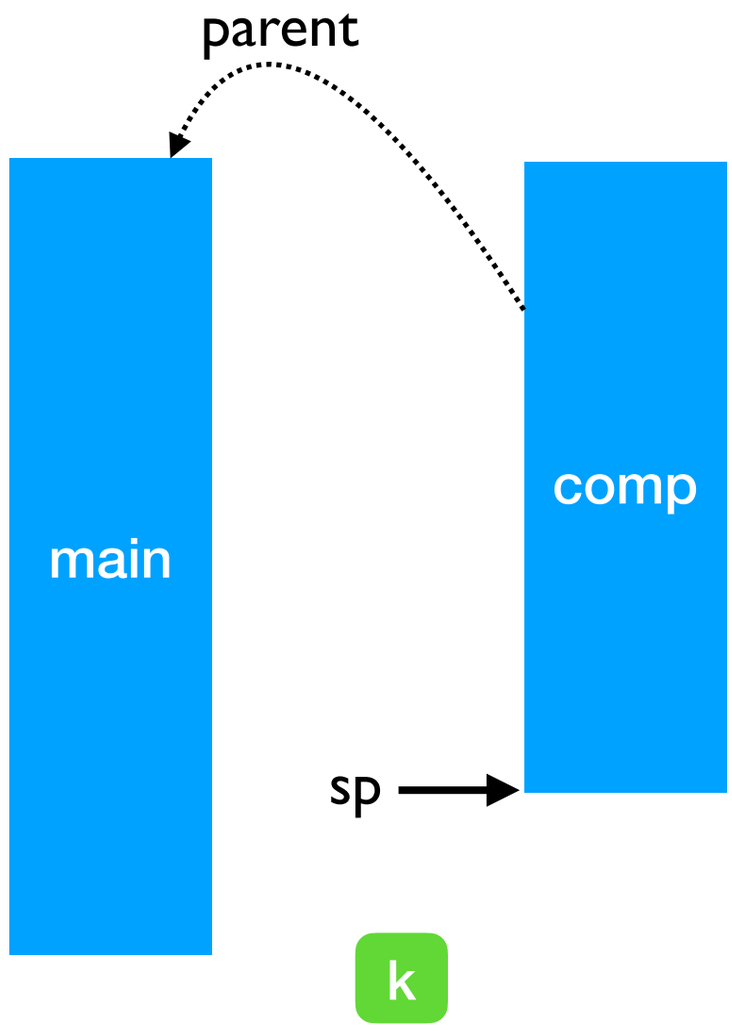

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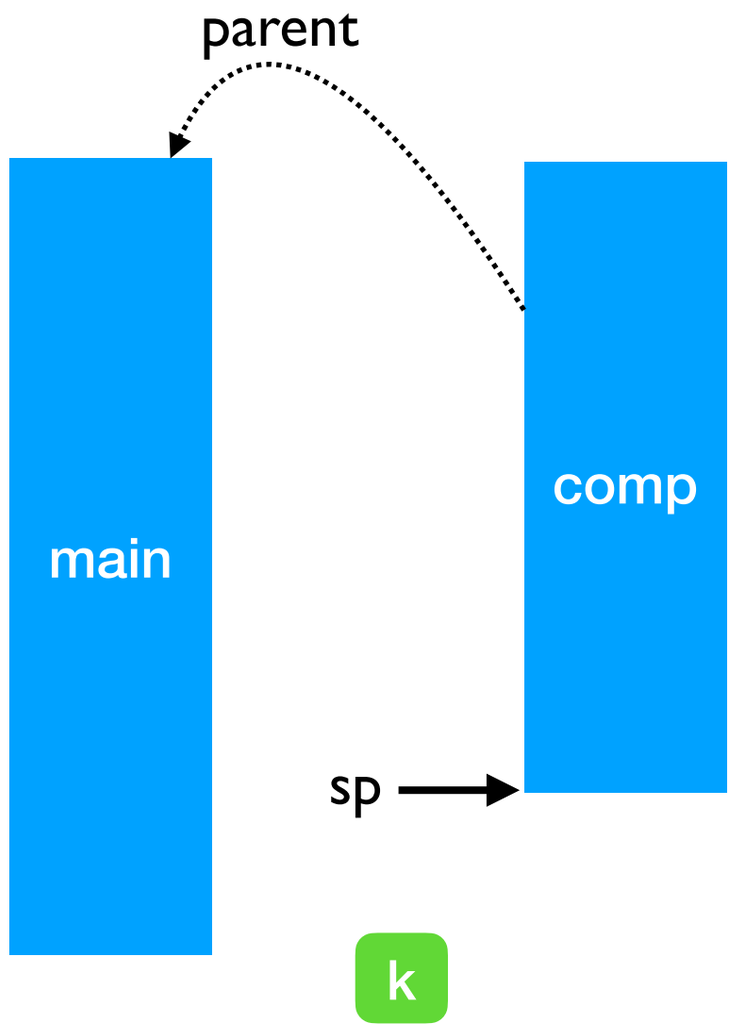

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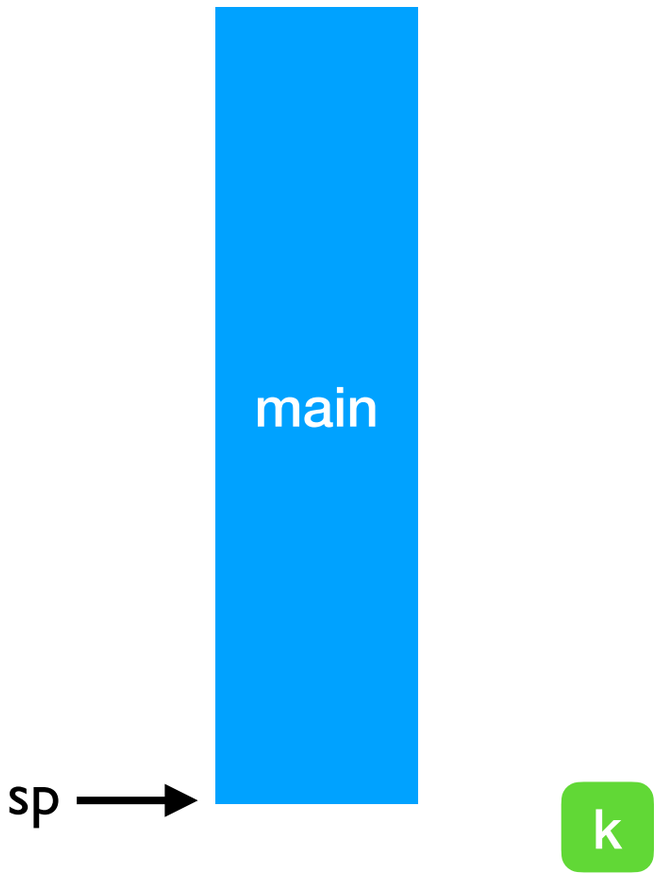

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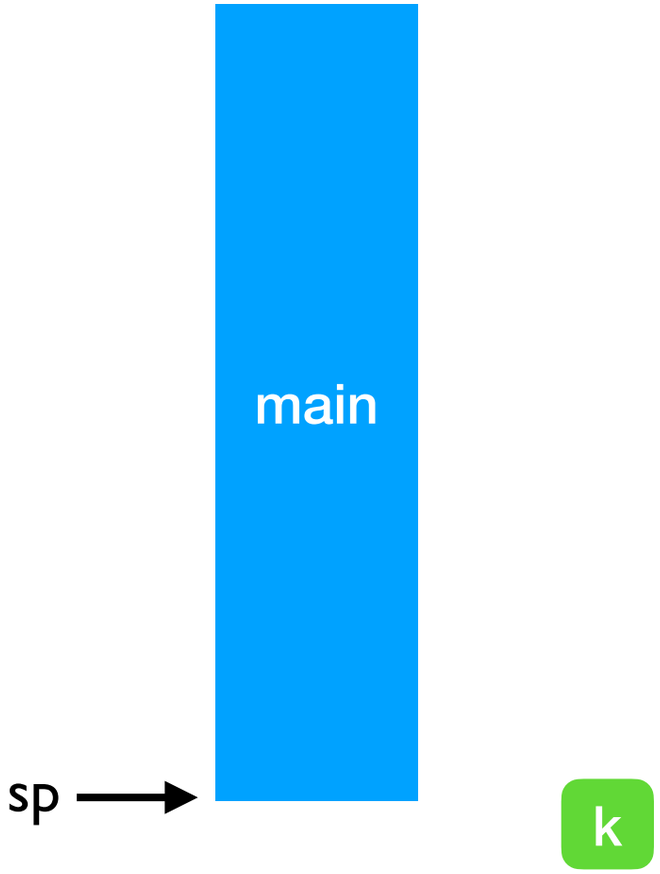

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Lightweight Threading

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effect Fork  : (unit -> unit) -> unit
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let run main =
  ... (* assume queue of continuations *)
  let run_next () =
    match dequeue () with
    | Some k -> continue k ()
    | None -> ()
in
let rec spawn f =
  match f () with
    | () -> run_next ()
    | effect Yield k -> enqueue k; run_next ()
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let fork f = perform (Fork f)
let yield () = perform Yield
```

Lightweight threading

```
let main () =
  fork (fun _ -> print_endline "1.a"; yield (); print_endline "1.b");
  fork (fun _ -> print_endline "2.a"; yield (); print_endline “2.b")
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run main
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2.a
1.b
2.b
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```

- Direct-style (no monads)
- User-code need not be aware of effects

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- *Iterator* — idiomatic recursive traversal
- Generator
  - ✦ Hand-written generator (*hw-generator*)
    - ✤ CPS translation + defunctionalization to remove intermediate closure allocation
  - ✦ Generator using effect handlers (*eh-generator*)

Performance: Generators

Multicore OCaml

Variant	Time (milliseconds)
Iterator (baseline)	202
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nodejs 14.07

Variant	Time (milliseconds)
Iterator (baseline)	492
generator	43842 (**89.1x**)

Performance: WebServer

- Effect handlers for asynchronous I/O in direct-style
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- Variants
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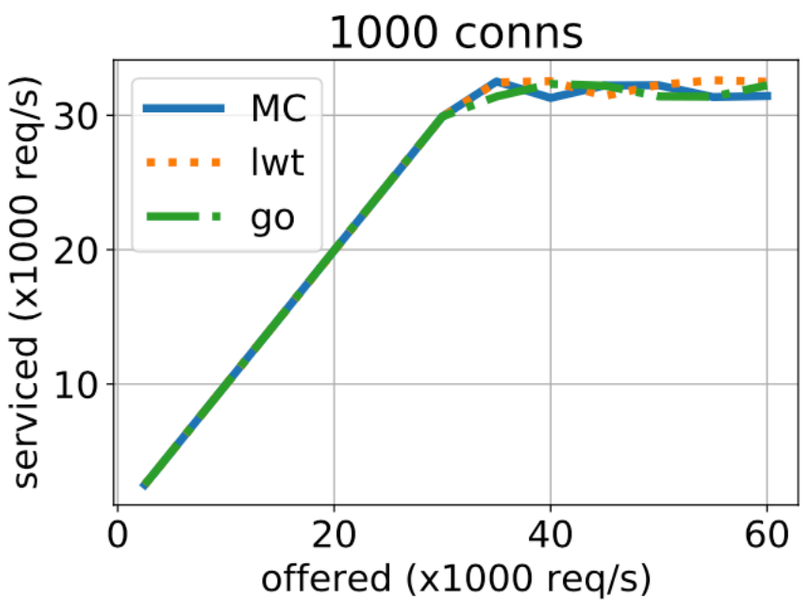
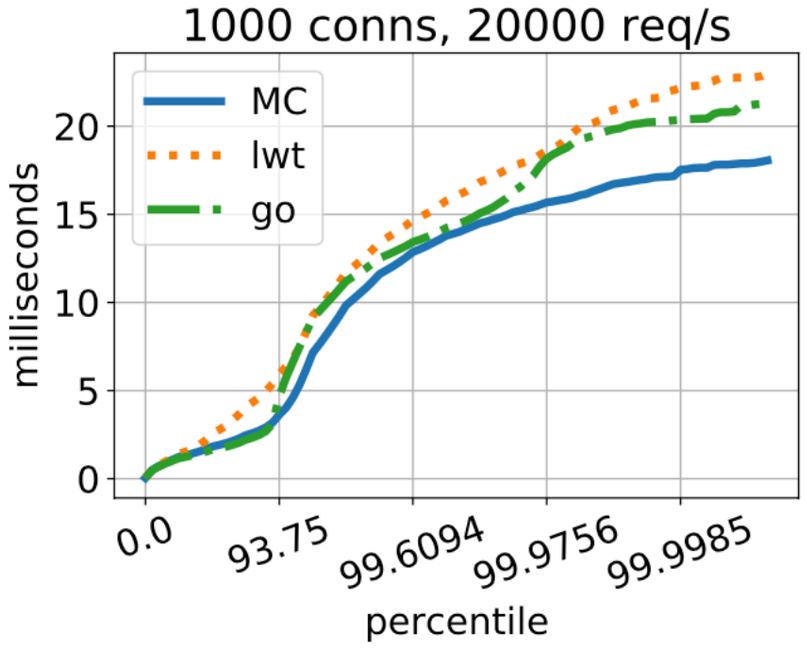


(a) Throughput



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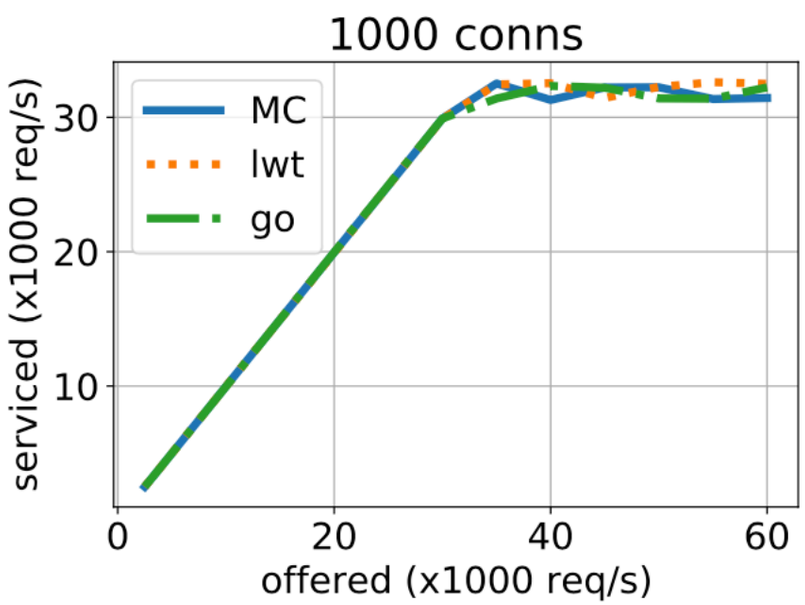
- Direct style (no monadic syntax)
- Can use OCaml exceptions!
- Backtrace per thread (request)
- gdb & perf work!

- Performance measured using wrk2



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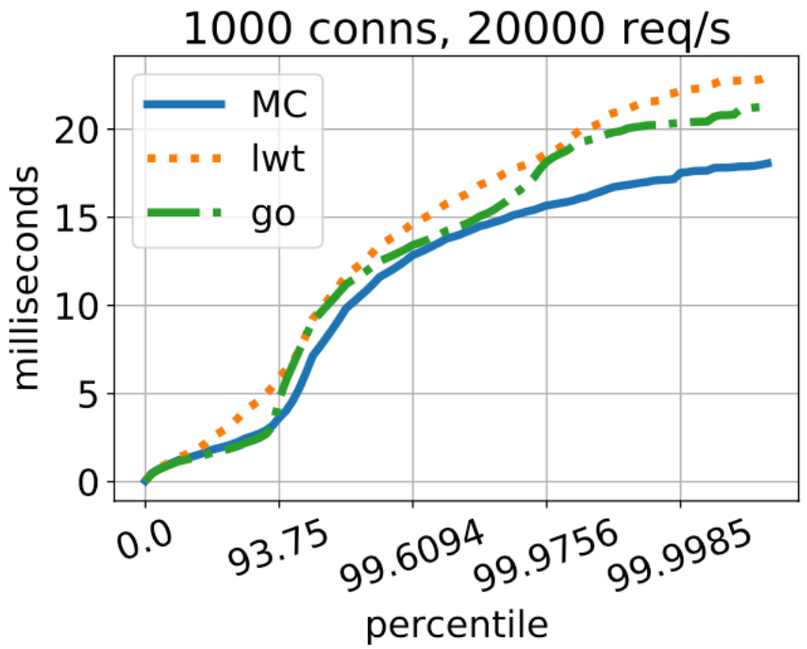

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```
let foo () = print_string "hello, world"

val foo : unit -[ io ]-> unit
```

Syntax is still in the works

Multicore OCaml + Tezos

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- An end-to-end Multicore Tezos demonstrator (mid-2021)

Thanks!

Install Multicore OCaml

```
$ opam switch create 4.10.0+multicore \
    --packages=ocaml-variants.4.10.0+multicore \
    --repositories=multicore=git+https://github.com/ocaml-multicore/multicore-opam.git,default
```

- Multicore OCaml — https://github.com/ocaml-multicore/ocaml-multicore
- Effects Examples — https://github.com/ocaml-multicore/effects-examples
- Sivaramakrishnan et al, "*Retrofitting Parallelism onto OCaml*", ICFP 2020
- Dolan et al, "*Concurrent System Programming with Effect Handlers*", TFP 2017