# Saturn: a library of verified concurrent data structures for OCaml 5

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# Plan

- ❒ Why Saturn?
- ❒ What is in Saturn?
- ❒ Optimizations and benchmarks
- ❒ Testing
- ❒ Verification

# Why Saturn?

Github: ocaml-multicore/saturn

- A collection of concurrent-safe data structures for OCaml 5:
  - ◇ well-tested
  - ◇ benchmarked
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- Writting concurrent code is hard

# Buggy queue with size

```
module Queue = Saturn.Queue
type 'a t = {size : int Atomic.t; queue : 'a Queue.t}

let create () =
    {size = Atomic.make 0; queue = Queue.create ()}

let push t msg =
  Atomic.incr t.size;
  Queue.push t.queue msg

let pop_opt t =
  match Queue.pop_opt t.queue with
  | Some elt ->  Atomic.decr t.size; Some elt
  | None -> Atomic.set t.size 0; None

let size t = Atomic.get t.size
```

# Buggy queue with size

```
let test () =
 let queue = create () in
 let d1 = Domain.spawn (fun () -> push queue 1) in
 let d2 = Domain.spawn (fun () -> pop_opt queue |>
     ignore) in
 Domain.join d1;
 Domain.join d2;
 pop_opt queue |> ignore;
 size queue
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In 10 to 20% of the tries, the test returns a size of $-1$.

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# Concurrent stack: Treiber stack

```
type 'a t = 'a list Atomic.t

let create () = Atomic.make []

let rec push q a =
  let old = Atomic.get q in
  if Atomic.compare_and_set q old (a :: old) then ()
  else push q a

let rec pop_opt q =
  let old = Atomic.get q in
  match old with
  | [] -> None
  | x :: xs ->
    if Atomic.compare_and_set q old xs then Some x
    else pop_opt q
```

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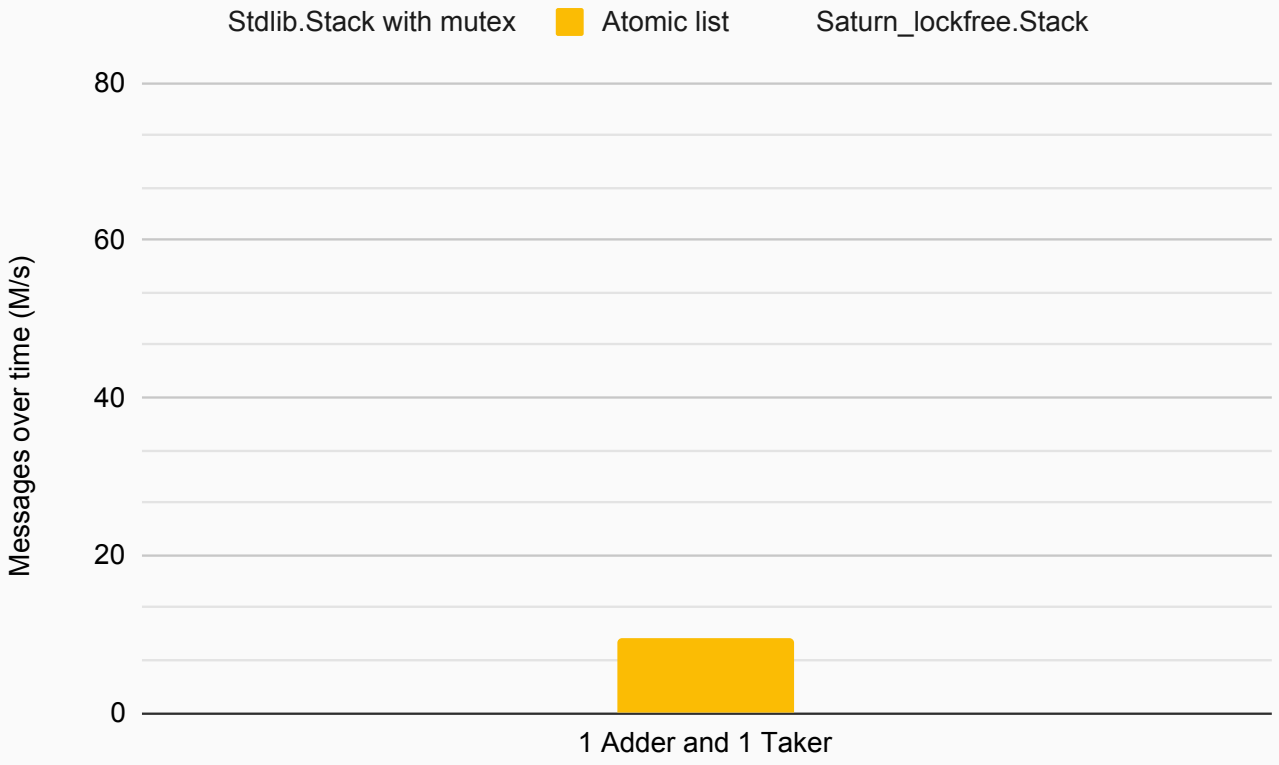
```
type 'a t = 'a list Atomic.t

let cr

let re
  let
  if A
  else

let re
  let
  matc
  | []
  | x
    if Atomic.compare_and_set q old xs then Some x
    else pop_opt q
```



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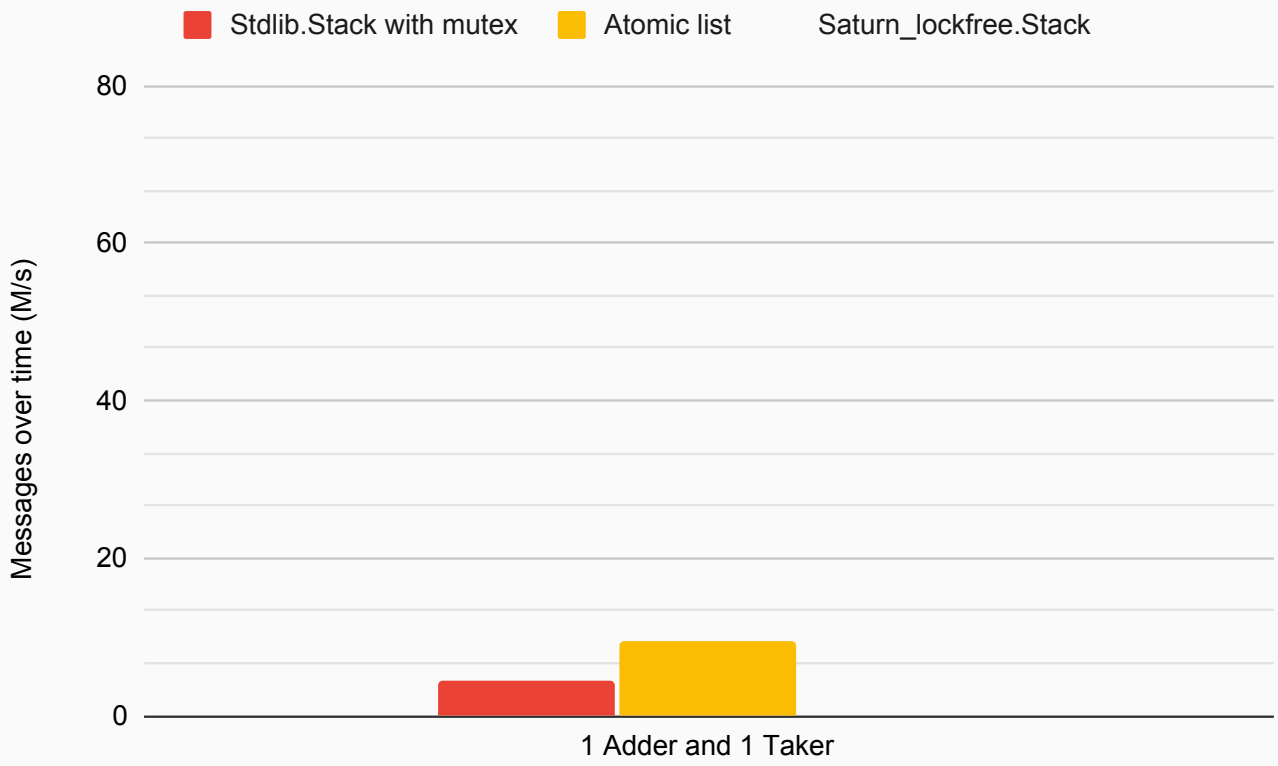

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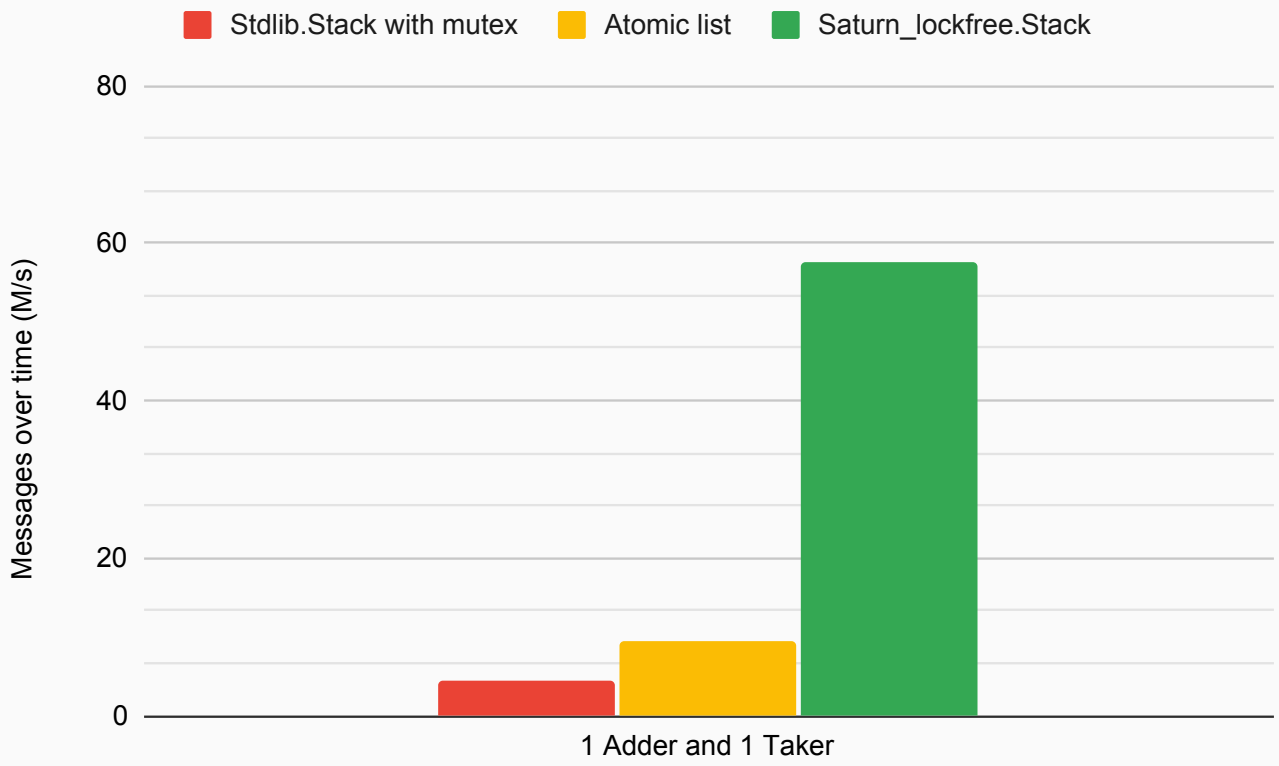

# Why Saturn?

- OCaml 5 : multicore programming
- Writting concurrent code is hard
  - ◇ bugs that can be hard to reproduce and understand
  - ◇ progress properties: deadlock, starvation etc..
- Writting efficient concurrent code is even harder
  - ◇ different behaviors on different CPU architectures
  - ◇ space to benchmarks is way larger
  - ◇ ...

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  - ◇ Stacks
  - ◇ Hashtable (opened PR)
  - ◇ Skiplist: a sorted linked list with $o(\log(n))$ operations
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- Most available data structures are lock-free
  - → Two libraries: Saturn and Saturn_lockfree

# Testing in Saturn

What should (and can) be tested ?

- Correctness
- Linearizability
- Progress (i.e. lock freedom)

How ?

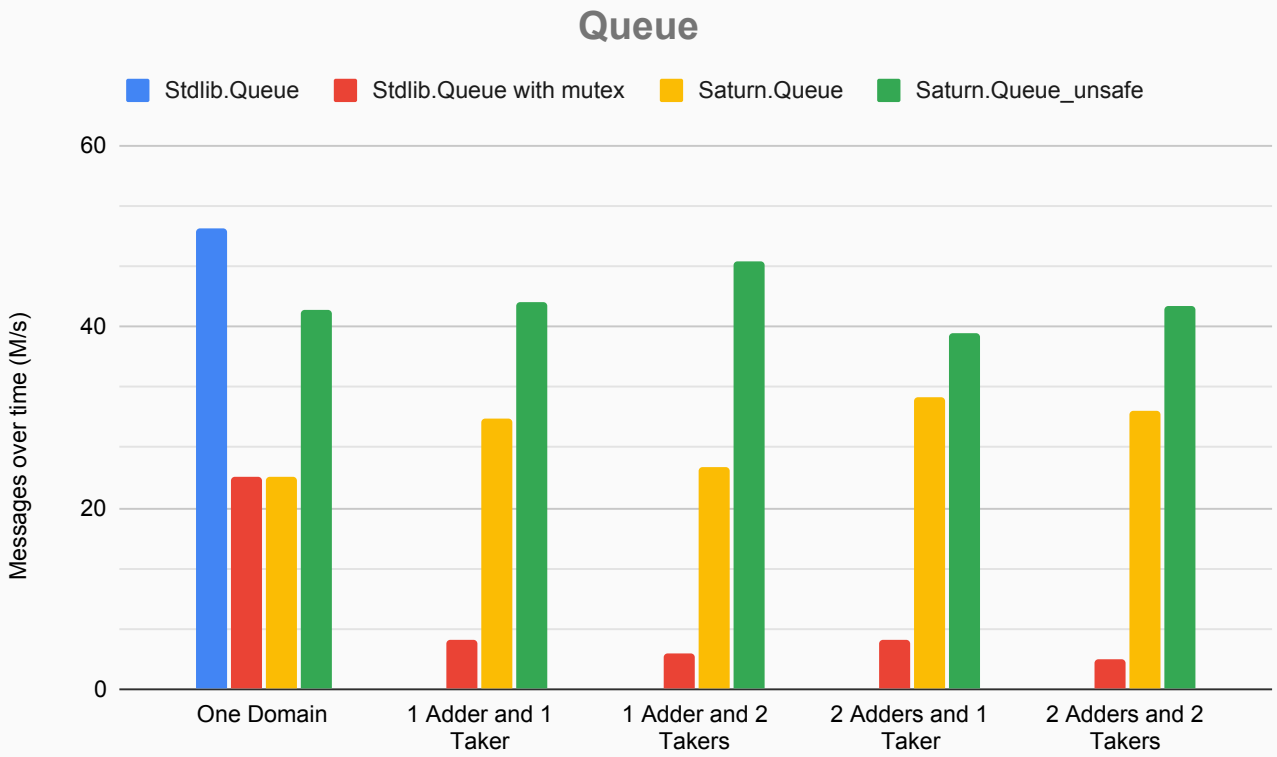
- Lin / STM (ocaml-multicore/multicoretest):
  - ◇ Correctness
  - ◇ Linearizability
- Dscheck (ocaml-multicore/dscheck):
  - ◇ Correctness
  - ◇ Lock-freedom

# Optimizations

Micro-optimizations

- On algorithms, to prevent false sharing, indirections etc..
- Experimental: some use **Obj.magic** (e.g. Saturn.Queue_unsafe)

# Is it any good ?



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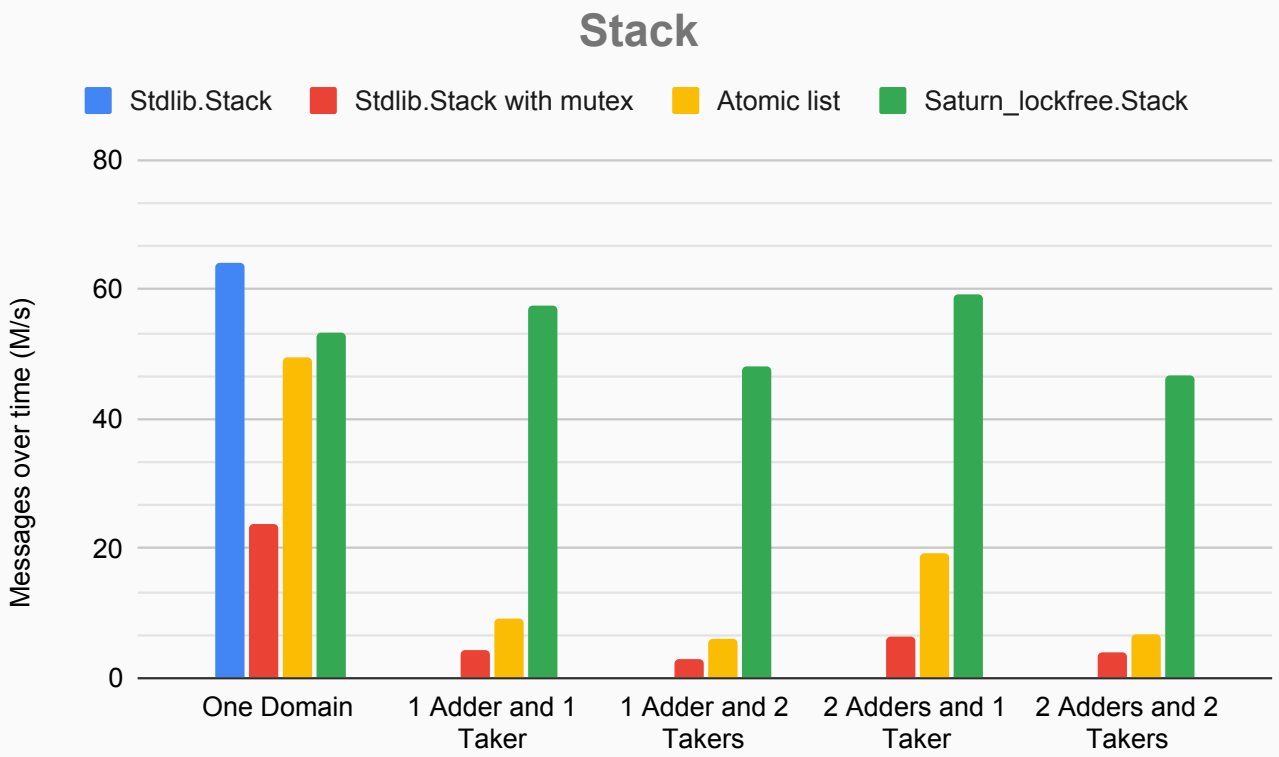

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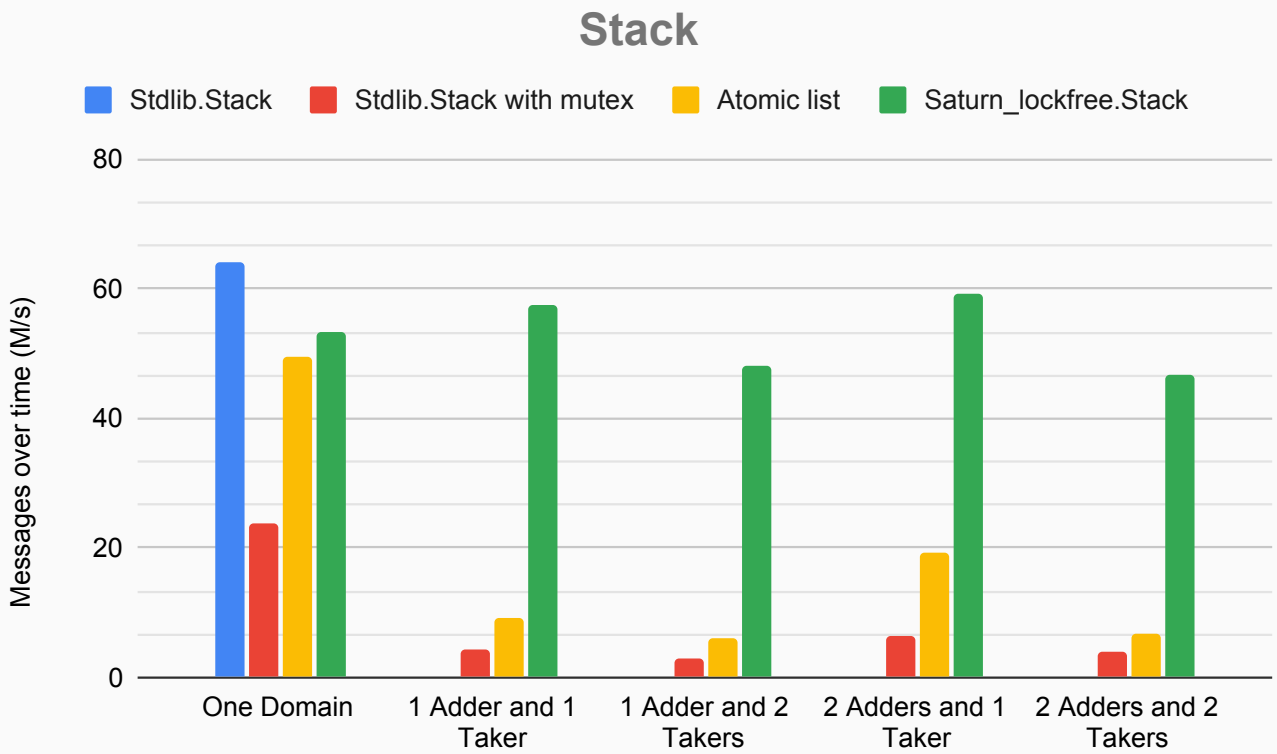


https://github.com/lyrm/saturn-benchmarks/

# Formal verification

*Testing* a concurrent algorithm is hard due to the number of potential interleavings.

*Formal verification* is here to help us!


# From OCaml to Coq

```
let rec push t v =
  let old = Atomic.get t in
  let new_ = v :: old in
  if not (Atomic.compare_and_set t old new_) then (
    Domain.cpu_relax () ;
    push t v
  )
```

OCaml

---

Coq

```
Definition stack_push : val :=
  rec: "stack_push" "t" "v" =>
    let: "old" := !"t" in
    let: "new" := `Cons( "v", "old" ) in
    ifnot: CAS "t" "old" "new" then (
      Yield ;;
      "stack_push" "t" "v"
    ).
```

# Proving linearizability

$$\text{linearizability} \quad \underset{\text{in SC}}{\simeq} \quad \frac{\frac{\frac{\frac{\{\,\text{stack-inv}\ t\,\}}{\langle\, vs.\,\text{stack-model}\ t\ vs\,\rangle}}{\texttt{stack\_push}\ t\ v}}{\langle\,\text{stack-model}\ t\ (v :: vs)\,\rangle}}{\{\ ()\,.\,\text{True}\,\}}$$

*Theorems for free from separation logic specifications*

Birkedal, Dinsdale-Young, Guéneau, Jaber, Svendsen & Tzevelekos

# Relaxed memory model (future work)

$$\frac{\{\,\text{stack-inv } t\,\}}{\langle\, v_0, \ldots, v_n, \mathcal{V}_0, \ldots, \mathcal{V}_n.\, \text{stack-model } t\ ((v_0, \mathcal{V}_0), \ldots (v_n, \mathcal{V}_n))\,\rangle}$$
$$\frac{}{\texttt{stack\_push}\ t\ v, \mathcal{V}}$$
$$\frac{\langle\, \text{stack-model } t\ ((v, \mathcal{V}), (v_0, \mathcal{V}_0), \ldots (v_n, \mathcal{V}_n))\,\rangle}{\{\ ()\ .\ \text{True}\,\}}$$

*Cosmo: a concurrent separation logic for multicore* OCaml, Mével, Jourdan & Pottier

*Formal verification of a concurrent bounded queue in a weak memory model*, Mével & Jourdan

# Writing concurrent protocols in Iris

```
Definition stack_inv t ι : iProp Σ :=
  ∃ l γ,
  ⌜t = #l⌝ ∗ meta l nroot γ ∗
  inv ι (
    ∃ vs, l ↦ lst_to_val vs ∗ stack_model₂ γ vs
  ).

Lemma stack_push_spec t ι v :
  <<< stack_inv t ι
  |   ∀∀ vs, stack_model t vs >>>
        stack_push t v @ ↑ι
  <<< stack_model t (v :: vs)
  |   RET (); True             >>>.
Proof.
  ...
Qed.
```

Thank you for your attention!