

# Zoo : Un cadriciel pour la vérification de programmes OCaml 5 concurrents en logique de séparation

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Vérification de programmes OCaml 5 *concurrents*.



Saturn  
Kcas



V

## Logique de séparation Iris

- ▶ État logique personnalisable
  - ▶ Protocoles concurrents
  - ▶ Atomicité logique
  - ▶ Points de linéarisation externes
  - ▶ Points de linéarisation dépendants du futur
- ▶ Mécanisation en Rocq
- ▶ Modèle mémoire faible

Vérification de programmes OCaml 5 *concurrents*.



Saturn  
Kcas



## À la recherche d'un langage de vérification

langage	concurrency	Iris	$\simeq$ OCaml	traduction	automatisation
Cameleer	☹️	☹️	😊	😊	😊
coq_of_ocaml	☹️	☹️	😊	😊	☹️
CFML	☹️	☹️	😊	😊	☹️
Osiris	☹️	😊	😊	😊	☹️
HeapLang	😊	😊	☹️	☹️	😐
Zoo	😊	😊	😊	😊	😊

## Zoo, un langage pragmatique

- ▶ Fragment formalisé d'OCaml 5 suffisamment expressif pour Saturn et Kcas.
- ▶ Sémantique formelle correcte vis-à-vis d'OCaml.
- ▶ Instance Iris.
- ▶ Commodités :
  - ▶ outil de traduction d'OCaml vers Zoo
  - ▶ code reconnaissable
  - ▶ automatisation minimale (Diaframe)

## Zoo en pratique



**OCaml**



**DUNE**

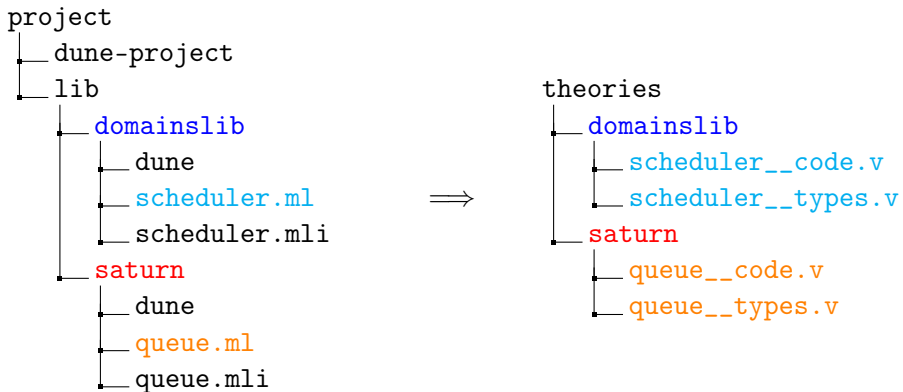
ocaml2zoo  
→



Zoo



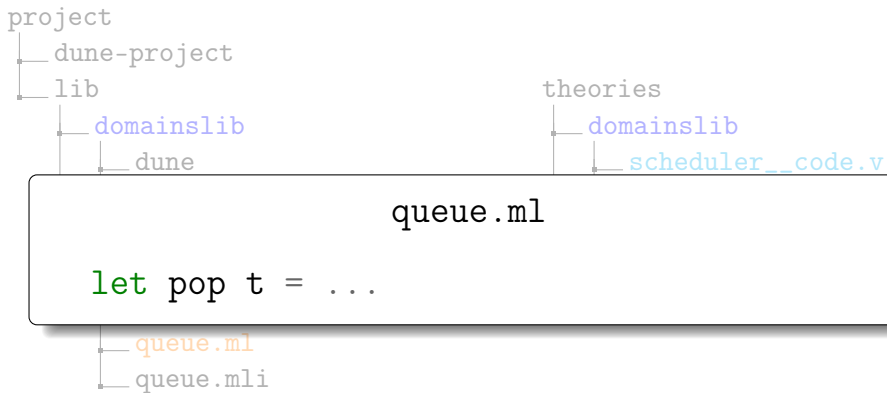
## Zoo en pratique



```
$ ocaml2zoo project theories
```

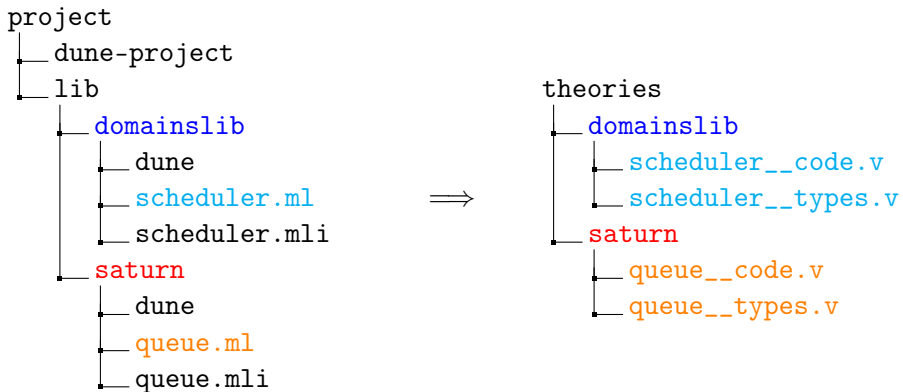


## Zoo en pratique



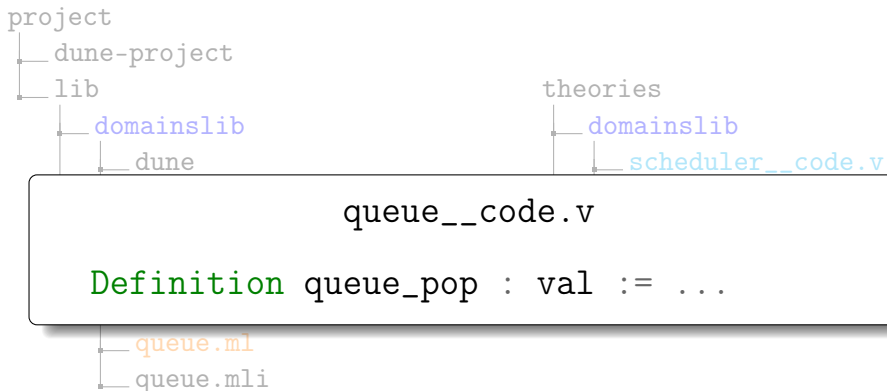
```
$ ocaml2zoo project theories
```

## Zoo en pratique



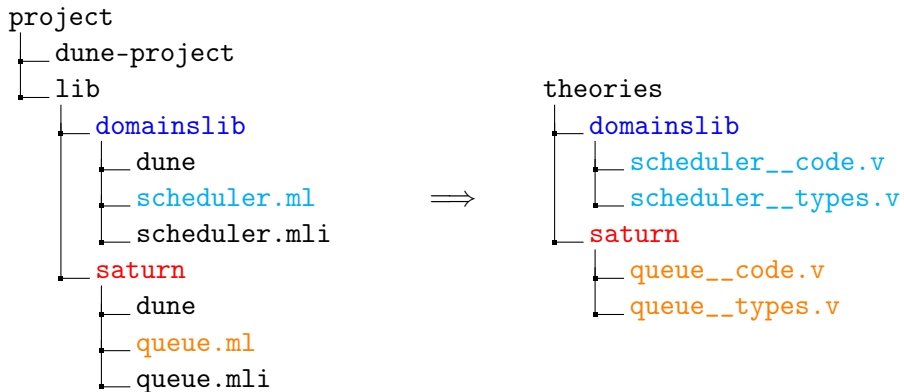
\$ ocaml2zoo project theories

## Zoo en pratique



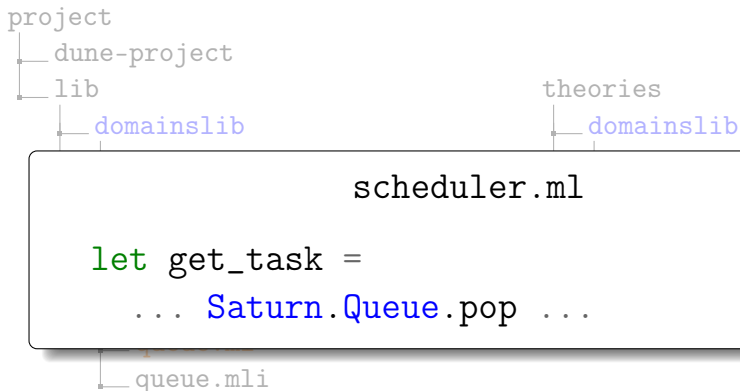
```
$ ocaml2zoo project theories
```

## Zoo en pratique



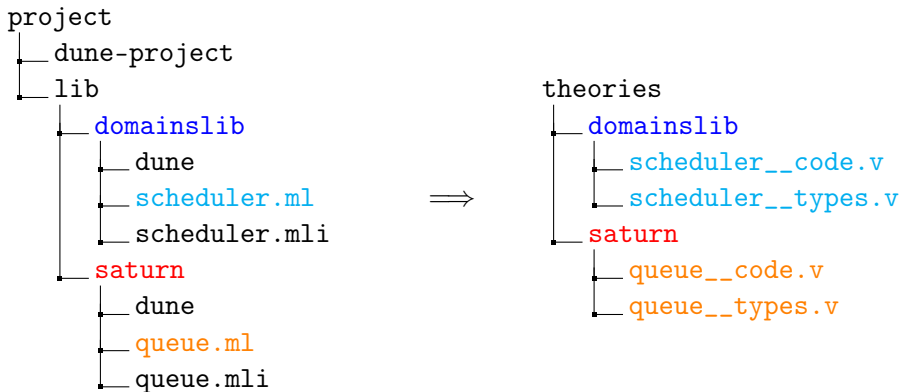
```
$ ocaml2zoo project theories
```

## Zoo en pratique



```
$ ocaml2zoo project theories
```

## Zoo en pratique



```
$ ocaml2zoo project theories
```

## Zoo en pratique

```
project
```

```
  dune-project
```

```
  scheduler__code.v
```

```
  From saturn Require Import
```

```
    queue__code
```

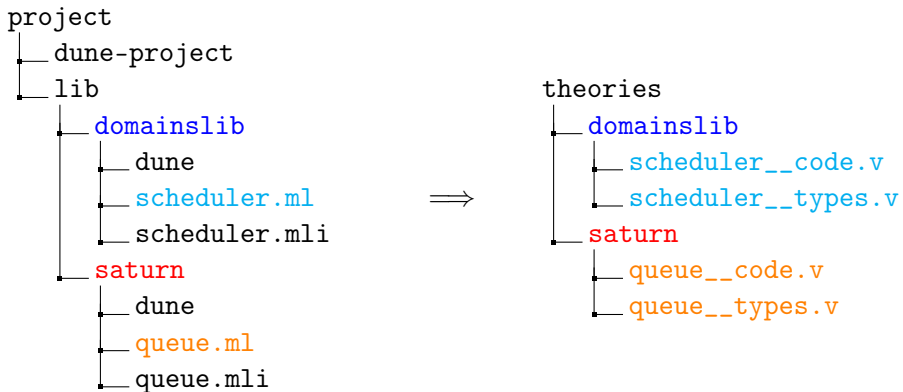
```
    queue__types.
```

```
  Definition scheduler_get_task : val :=
```

```
    ... queue_pop ...
```

```
$ ocaml2zoo project theories
```

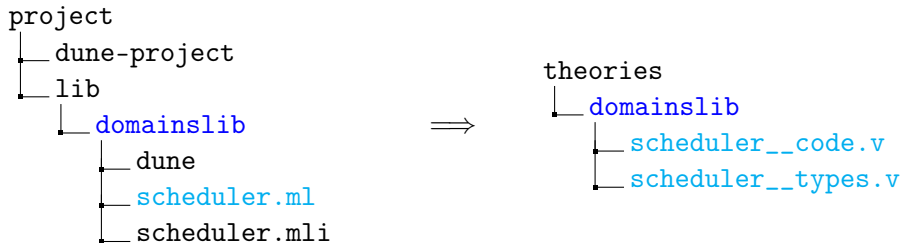
## Zoo en pratique



\$ ocaml2zoo project theories



## Zoo en pratique



```
$ ocaml2zoo project theories
```

préfixe

scheduler\_\_code.v

From saturn Require Import

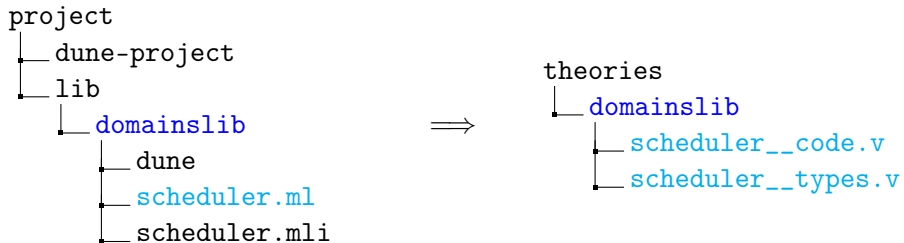
queue\_\_code

queue\_\_types.

Definition scheduler\_get\_task : val :=

... queue\_pop ...

## Zoo en pratique



```
$ ocaml2zoo project theories
```

## Zoo en pratique

**Lemma** `stack_push_spec_seq t  $\iota$  v :`

```
{{{  
  stack_model t vs  
}}}  
  stack_push t v  
{{{  
  RET ();  
  stack_model t (v :: vs)  
}}}.  
}}}
```

**Proof.**

...

**Qed.**

**Lemma** `stack_push_spec_atomic t  $\iota$  v :`

```
<<<  
  stack_inv t  $\iota$   
|  $\forall$  vs,  
  stack_model t vs  
>>>  
  stack_push t v @  $\uparrow\iota$   
<<<  
  stack_model t (v :: vs)  
| RET (); True  
>>>.
```

**Proof.**

...

**Qed.**

# Types algébriques de données

```
type 'a t =  
  | Nil  
  | Cons of 'a * 'a t
```

```
let rec map fn t =  
  match t with  
  | Nil -> Nil  
  | Cons (x, t) ->  
    let y = fn x in  
    Cons (y, map fn t)
```

```
Notation "'Nil'" := (  
  in_type "t" 0  
) (in custom zoo_tag).  
Notation "'Cons'" := (  
  in_type "t" 1  
) (in custom zoo_tag).
```

```
Definition map : val :=  
  rec: "map" "fn" "t" =>  
    match: "t" with  
    | Nil => §Nil  
    | Cons "x" "t" =>  
      let: "y" := "fn" "x" in  
      'Cons( "y", "map" "fn" "t" )  
  end.
```

# Enregistrements

```
type 'a t =  
  { mutable f1: 'a;  
    mutable f2: 'a;  
  }
```

```
let swap t =  
  let f1 = t.f1 in  
  t.f1 <- t.f2 ;  
  t.f2 <- f1
```

```
Notation "'f1'" := (  
  in_type "t" 0  
) (in custom zoo_field).  
Notation "'f2'" := (  
  in_type "t" 1  
) (in custom zoo_field).
```

```
Definition swap : val :=  
  fun: "t" =>  
    let: "f1" := "t".{f1} in  
    "t" <- {f1} "t".{f2} ;;  
    "t" <- {f2} "f1".
```

## Enregistrements en place

```
type 'a node =  
  | Null  
  | Node of  
    { mutable next: 'a node;  
      mutable data: 'a;  
    }
```

```
Notation "'Null'" := (  
  in_type "node" 0  
) (in custom zoo_tag).
```

```
Notation "'Node'" := (  
  in_type "node" 1  
) (in custom zoo_tag).
```

```
Notation "'next'" := (  
  in_type "node__Node" 0  
) (in custom zoo_field).
```

```
Notation "'data'" := (  
  in_type "node__Node" 1  
) (in custom zoo_field).
```

## Fonctions mutuellement récursives

```
let f x = g x
and g x = f x
```

```
Definition f_g := (
  recs: "f" "x" => "g" "x"
  and:  "g" "x" => "f" "x"
)%zoo_recs.
```

```
(* boilerplate *)
```

```
Definition f := ValRecs 0 f_g.
```

```
Definition g := ValRecs 1 f_g.
```

```
Instance : AsValRecs' f 0 f_g [f;g].
```

```
Proof. done. Qed.
```

```
Instance : AsValRecs' g 1 f_g [f;g].
```

```
Proof. done. Qed.
```



# Concurrency

<code>Atomic.set e<sub>1</sub> e<sub>2</sub></code>	<code>e<sub>1</sub> &lt;- e<sub>2</sub></code>
<code>Atomic.exchange e<sub>1</sub> e<sub>2</sub></code>	<code>Xchg e<sub>1</sub>. [contents] e<sub>2</sub></code>
<code>Atomic.compare_and_set e<sub>1</sub> e<sub>2</sub> e<sub>3</sub></code>	<code>CAS e<sub>1</sub>. [contents] e<sub>2</sub> e<sub>3</sub></code>
<code>Atomic.fetch_and_add e<sub>1</sub> e<sub>2</sub></code>	<code>FAA e<sub>1</sub>. [contents] e<sub>2</sub></code>
<code>Atomic.Loc.exchange [%atomic.loc e<sub>1</sub>.f] e<sub>2</sub></code>	<code>Xchg e<sub>1</sub>. [f] e<sub>2</sub></code>
<code>Atomic.Loc.compare_and_set [%atomic.loc e<sub>1</sub>.f] e<sub>2</sub> e<sub>3</sub></code>	<code>CAS e<sub>1</sub>. [f] e<sub>2</sub> e<sub>3</sub></code>
<code>Atomic.Loc.fetch_and_add [%atomic.loc e<sub>1</sub>.f] e<sub>2</sub></code>	<code>FAA e<sub>1</sub>. [f] e<sub>2</sub></code>

<https://github.com/ocaml/ocaml/pull/13404>

<https://github.com/ocaml/ocaml/pull/13707>

## Bibliothèque standard

- ▶ Array
- ▶ Dynarray
- ▶ List
- ▶ Stack
- ▶ Queue
- ▶ Deque
- ▶ Domain
- ▶ Atomic\_array
- ▶ Mutex
- ▶ Condition

## Égalité physique : pile de Treiber

```
type 'a t =  
  'a list Atomic.t  
  
let create () =  
  Atomic.make []  
  
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  
  )
```

## Partage

```
let test1 = Some 0 == Some 0 (* true *)  
let test2 = [0;1] == [0;1]   (* true *)
```

## Conflits de représentation des valeurs

```
let test1 = Obj.repr false == Obj.repr 0 (* true *)  
let test2 = Obj.repr None == Obj.repr 0 (* true *)  
let test3 = Obj.repr [] == Obj.repr 0 (* true *)
```

## Partage + conflits

```
type any =  
  Any : 'a -> any
```

```
let test1 = Any false == Any 0 (* true *)
```

```
let test2 = Any None == Any 0 (* true *)
```

```
let test3 = Any [] == Any 0 (* true *)
```

## Pile de Treiber

```
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  
  )
```

## Égalité physique : Eio.Rcfd

```
type state = Open of Unix.file_descr | Closing of (unit -> unit)
type t = { mutable ops: int [@atomic]; mutable state: state [@atomic]; }

let make fd = { ops= 0; state= Open fd }

let closed = Closing (fun () -> ())
let close t =
  match t.state with
  | Closing _ -> false
  | Open fd as prev ->
    let close () = Unix.close fd in
    let next = Closing close in
    if Atomic.Loc.compare_and_set [%atomic.loc t.state] prev next then
      ...
    else
      false
```



# Départage

```
let x = Some 0  
let test = x == x (* false *)
```



**Clément Allain**  
Impossible ! Identité unique.



**Armaël Guéneau**  
Ce serait du départage.



**Vincent Laviro**  
C'est possible !

## Eio.Rcfd

```
let closed = Closing (fun () -> ())
let close t =
  match t.state with
  | Closing _ -> false
  | Open fd as prev ->
    let close () = Unix.close fd in
    let next = Closing close in
    if Atomic.Loc.compare_and_set [%atomic.loc t.state] prev next then
      ...
    else
      false
```

## Constructeurs génératifs

```
type 'a liste =  
  | Nil  
  | Cons of 'a * 'a liste [@generative]  
  
type state =  
  | Open of Unix.file_descr [@generative] [@zoo.reveal]  
  | Closing of (unit -> unit)
```

Merci de votre attention !