Experiments in Why3

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SAVE **workshop**
Shanghai, 2013-12-14

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Plan

- Why3
- demos
- conclusions

Goal

Write elegant programs

with elegant correctness proofs

\+ training in program proofs

Why3

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Why3 (1/8)

A programming language tells you **what** a program does,
Why3 tells you **why** it works.

- 3rd release of system Why
- developed at LRI (orsay) + Inria
- `http://why3.lri.fr`

[Jean-Christophe Filliâtre,
Claude Marché,
Andrei Paskevich,
Guillaume Melquiond,
Vincent Bolot,
et al]

Why3 (2/8)

- small Pascal-like imperative programming language

  [with ML syntax  !!]

- invariants + assertions in Hoare logic

  [+ recursive functions, inductive datatypes, inductive predicates]

- interfaces with modern SMT's

  [**alt-ergo**, cvc3, cvc4, eprover, gappa, simplify, spass, yices, **z3**]

- interfaces with interactive proof assistants

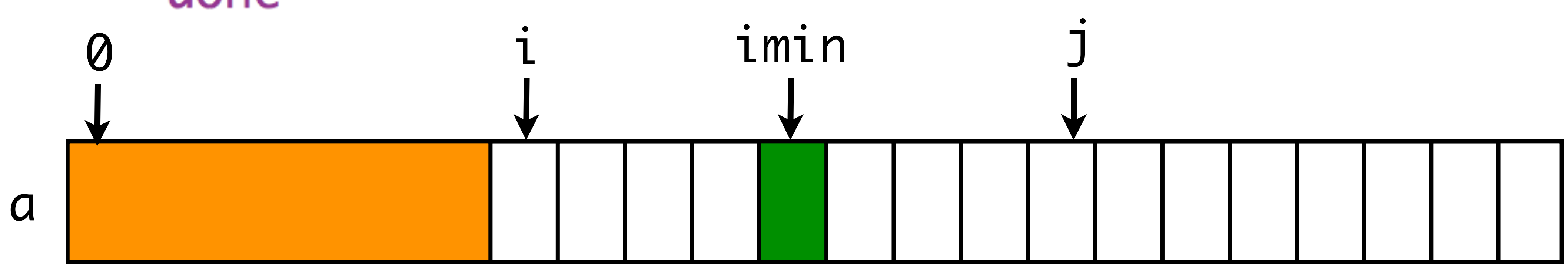
  [**coq**, pvs, isabelle-hol?]

Why3 (3/8)

- programming language MLW

```
let swap (a: array int) (i: int) (j: int) =
 let v = a[i] in
  a[i] <- a[j];
  a[j] <- v

let selection_sort (a: array int) =
  for i = 0 to length a - 1 do
    let imin = ref i in
    for j = i + 1 to length a - 1 do
      if a[j] < a[!imin] then imin := j
    done;
    swap a !imin i
  done
```

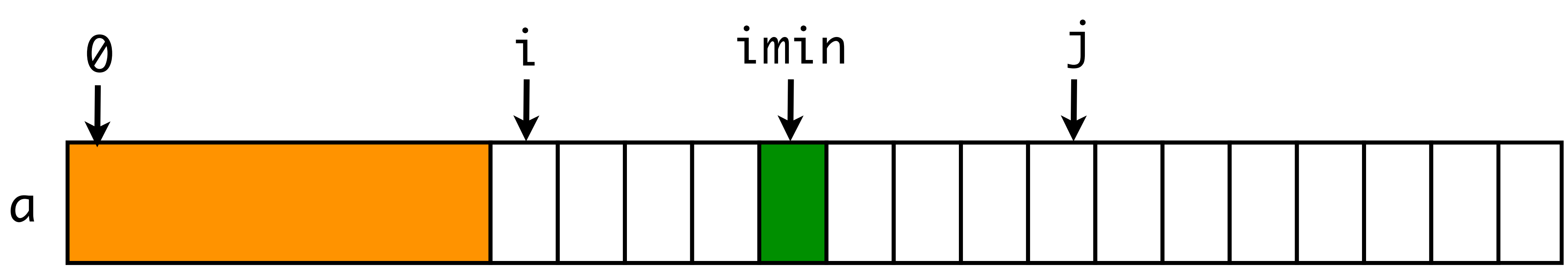


Why3 (4/8)

- Hoare logic

```
let swap (a: array int) (i: int) (j: int) =
 let v = a[i] in
  a[i] <- a[j];
  a[j] <- v

let selection_sort (a: array int) =
   for i = 0 to length a - 1 do
    let imin = ref i in
    for j = i + 1 to length a - 1 do
      invariant { i <= !imin < j }
      invariant { forall k: int. i <= k < j -> a[!imin] <= a[k] }
      if a[j] < a[!imin] then imin := j
    done;
    swap a !min i
  done
```



Why3 (5/8)

- theories on arrays

```
let swap (a: array int) (i: int) (j: int) =
  requires { 0 <= i < length a /\ 0 <= j < length a }
  ensures { exchange (old a) a i j }
 let v = a[i] in
  a[i] <- a[j];
  a[j] <- v
```

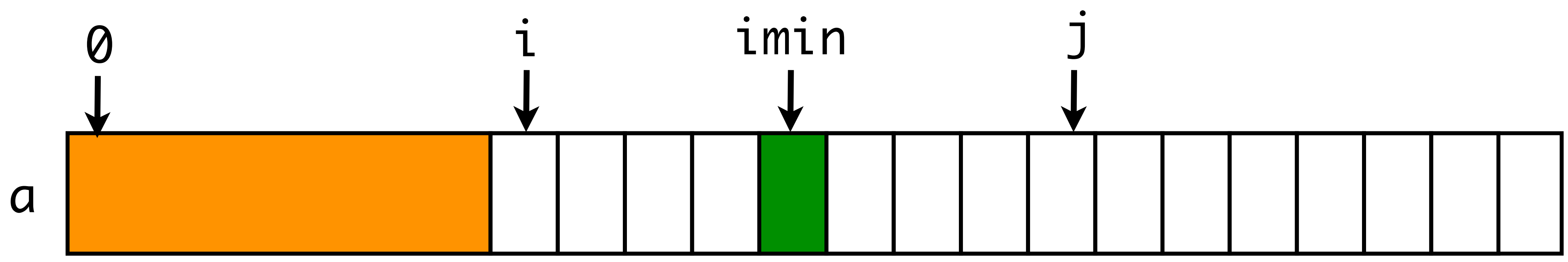
(see the why3 libraries)

http://why3.lri.fr

Why3 (6/8)

- theories on arrays

```
  let selection_sort (a: array int) =
    ensures { sorted a /\ permut (old a) a }
'L:
    for i = 0 to length a - 1 do
      invariant { sorted_sub a 0 i /\ permut (at a 'L) a}
      invariant { forall k1 k2: int. 0 <= k1 < i <= k2 < length a -> a[k1] <= a[k2] }
      let imin = ref i in
      for j = i + 1 to length a - 1 do
        invariant { i <= !imin < j }
        invariant { forall k: int. i <= k < j -> a[!imin] <= a[k] }
        if a[j] < a[!imin] then imin := j
      done;
      swap a !imin i ;
    done
```



Why3 (7/8)

- interfaces with automatic provers (SMT's)

- SMT tool successful if «good assertion»
  - impact on writings of Hoare logic formulae
  - impact on program text

- Alt-Ergo among best `[LRI, Conchon, et al]`
- Z3 is excellent `[MSRR, Bjorner/de Moura]`
- CVC3 top on recursive datatypes
- Gappa for real numbers `[Inria, Melquiond]`

Why3 (8/8)

- interfaces with interactive proof assistants
- PVS `[SRI, Shankar]`
- Coq `[Inria, Herbelin et al]`
  - Why3 theories are translated to Coq
  - lengthy proofs are feasible
  - use SSreflect commands to shorten proofs `[MSR-Inria, Gonthier et al]`
  - unfortunately Why3 is not fully compatible with SSreflect

Demos

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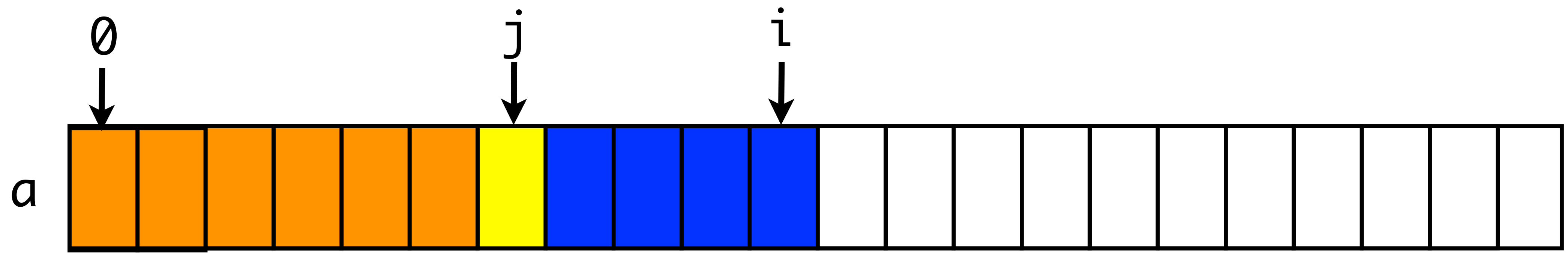
A few sorting algorithms

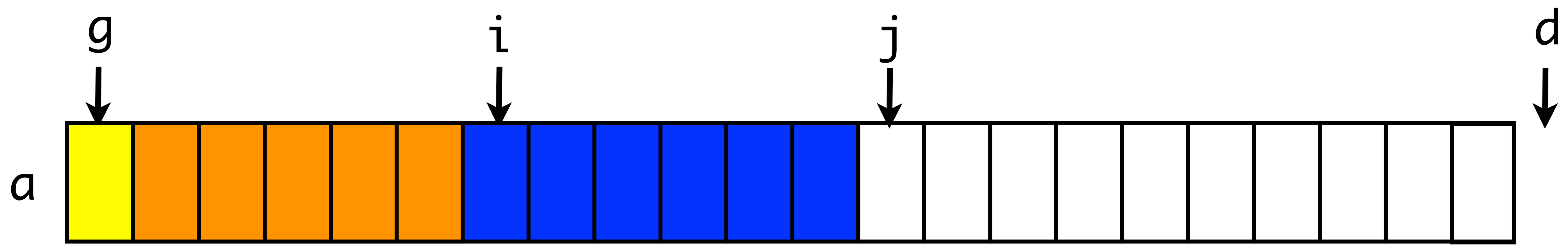
- demos

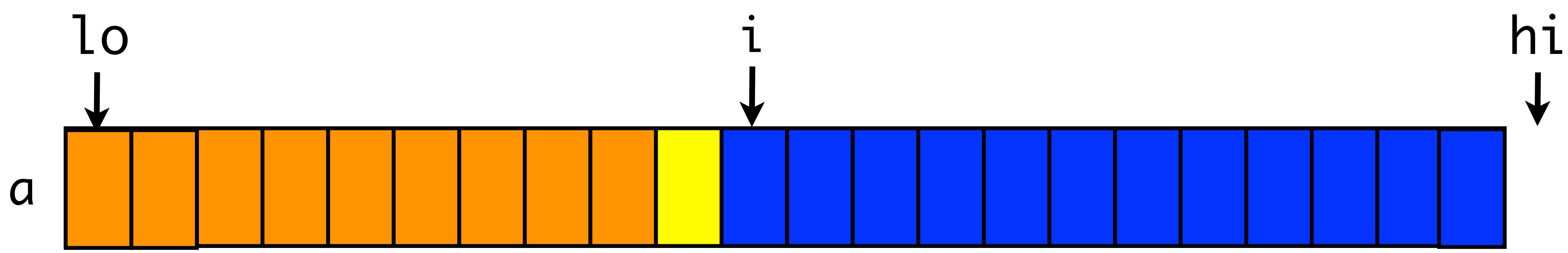
- insertion sort



A few sorting algorithms

- quicksort





Conclusions

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Conclusion (1/3)

- **Automatic** part of proof for **tedious** case analyzes
- **Interactive** proofs for the **conceptual** part of the algorithm

→ the ideal world

- From interactive part, one must call the automatic part
  - possible extensions of Why3 theories
  - but typing problems (inside Coq)

Conclusion (2/3)

- Hoare logic prevents to write awkward denotational semantics

- Nobody cares about termination ! 

- Explore **simple** programs about algorithms before jumping to **large** programs.

- Why3 **memory model** is naive. It is a «back-end for other systems».

- Plan to experiment on **graph** algorithms and prove all `Sedgewick`'s book on algorithms.

Conclusion (3/3)

- Why3 is **excellent** for mixing formal proofs and SMT's calls
- Interface **still rough** for beginners
- Concurrency ?
- Functional programs ?
- Hoare logic vs Type refinements (F* `[MSR]`)
- **Frama-C** project at french CEA extends Why3 to C programs.