



Starts in Why3

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Plan

- Why3
- demos
- conclusions

Goal

*Write elegant programs
with elegant correctness proofs*

+ training in program proofs

An abstract graphic featuring several overlapping circles in various colors: yellow, orange, green, red, and blue. The circles are outlined with a thick dark blue border. The text 'Why3' is centered in the white space between the red and blue circles.

Why3

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

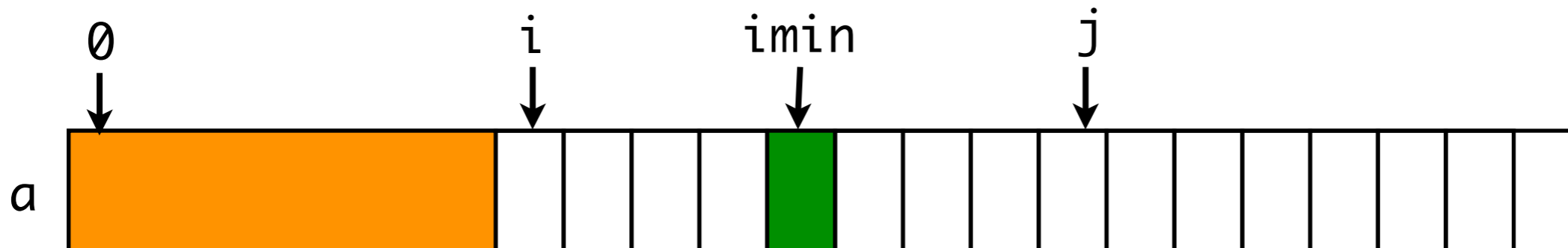
[**coq**, pvs, isabelle-hol]

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
```

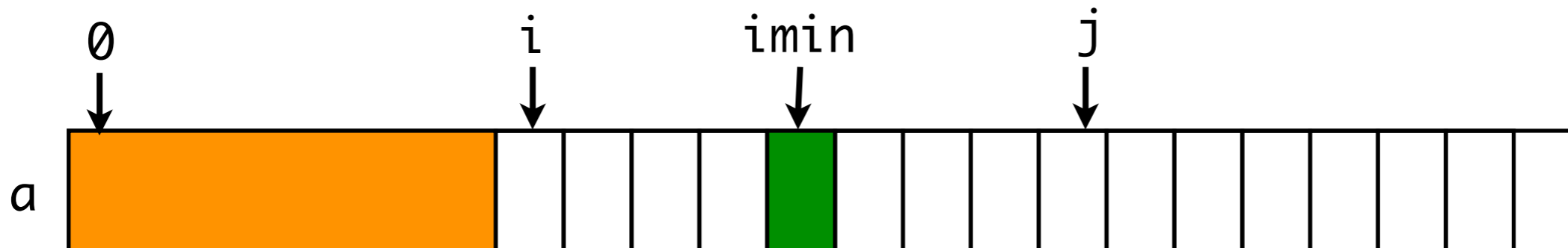


Why3 (4/8)

- 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>

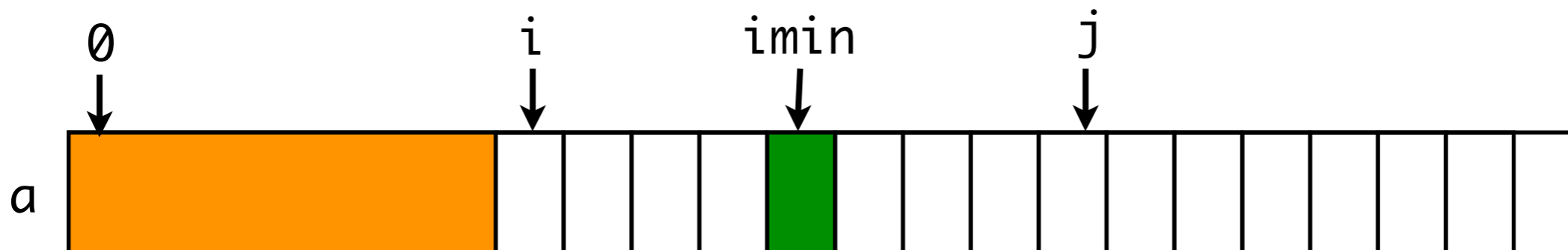
Why3 (6/8)

- theories on arrays

```
let selection_sort (a: array int) =  
  ensures { sorted a  $\wedge$  permut (old a) a }
```

'L:

```
for i = 0 to length a - 1 do  
  invariant { sorted_sub a 0 i  $\wedge$  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 for Why3 [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)

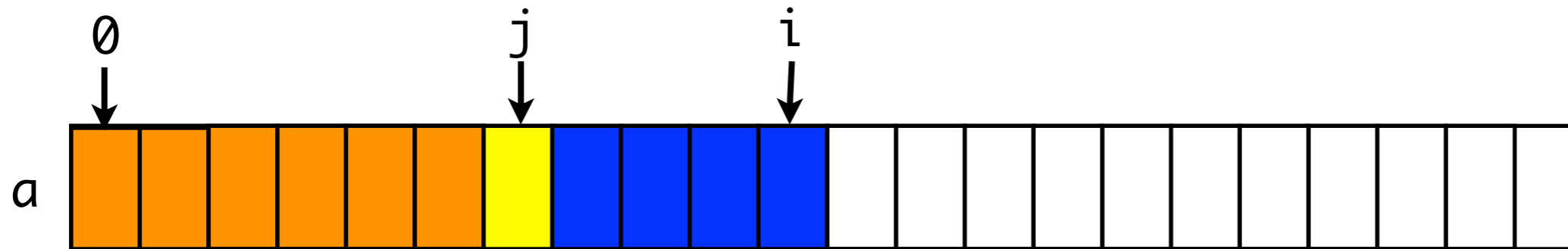
- interfaces with interactive proof assistants
- PVS [SRI, Shankar], Isabelle [Paulson, Nipkow]
- Coq [Inria, Herbelin et al]
 - Why3 theories are translated to Coq
 - lengthy proofs are feasible
 - use Ssreflect commands to shorten proofs [MSR-Inria, Gonthier et al]
 - unfortunately Why3 is not fully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

An abstract graphic design featuring four overlapping circles. The top-left circle is yellow, the top-right is blue, the bottom-left is green, and the bottom-right is red. The circles are outlined with a thick, dark blue border. The word "Demos" is written in a white, sans-serif font across the center of the composition, overlapping the green and red circles.

Demos

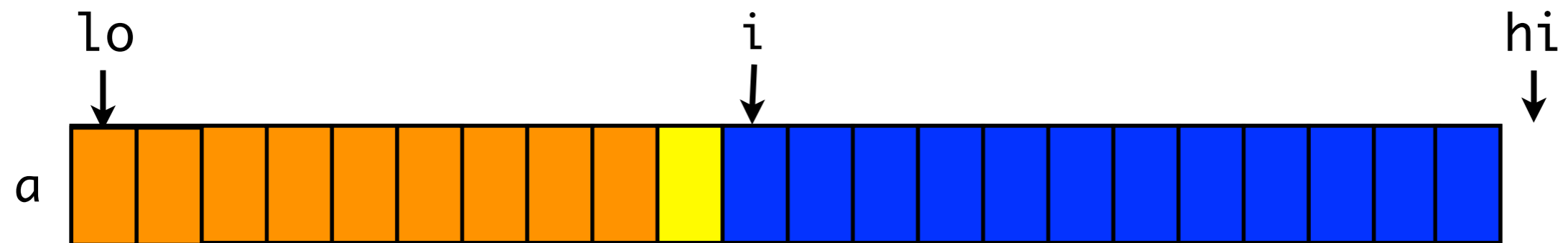
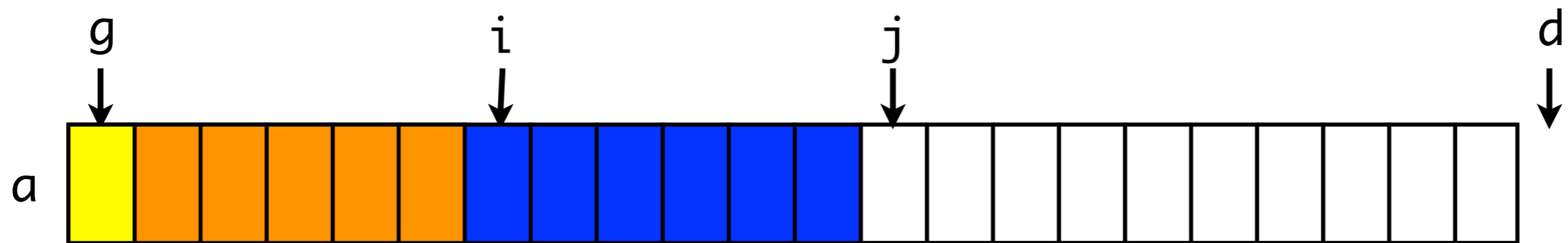
A few sorting algorithms

- demos
- insertion sort



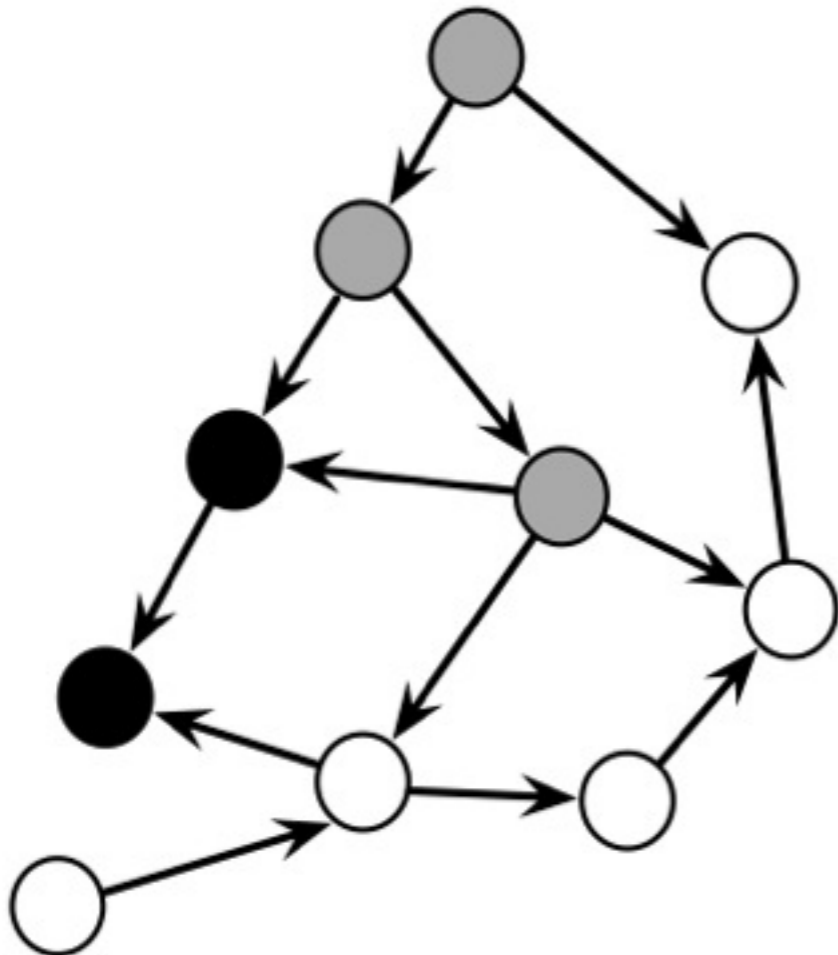
A few sorting algorithms

- quicksort



Depth-first search in graphs

- reachability [the ‘white path theorem’]
- non white-to-black edges in undirected graphs
- acyclicity test
- articulation point
- strongly connected components



The background features four large, overlapping circles in vibrant colors: yellow, green, blue, and red. Each circle is outlined with a thick, dark blue border. The circles overlap in the center, creating a complex geometric pattern. The word "Conclusions" is centered over this pattern in a white, sans-serif font.

Conclusions


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.