Skink Refinement Loop with Predicate Abstraction

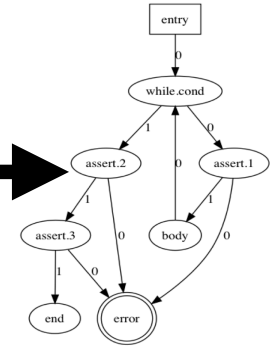
Pongsak Suvanpong, Anthony Sloane and Franck Cassez

Department of Computing
Macquarie University

Skink refinement loop

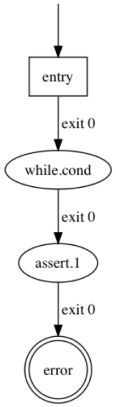
```
define i32 @main()
{
  entry:
    br label %do.body

  do.body:
    %0 = phi i32 [ %add, %do.body ], [ 0, %entry ]
    %add = add nsw i32 %0, 1
    %cmp = icmp slt i32 %add, 100
    br i1 %cmp, label %do.body, label %do.end

  do.end:
    %cmp1 = icmp eq i32 %add, 100
    br i1 %cmp1, label %ok, label %err

  ok:
    ret i32 0

  err:
    call void (...) @__VERIFIER_error()
    unreachable
}
```

Program (e.g. LLVM IR)



CFG

No more error trace



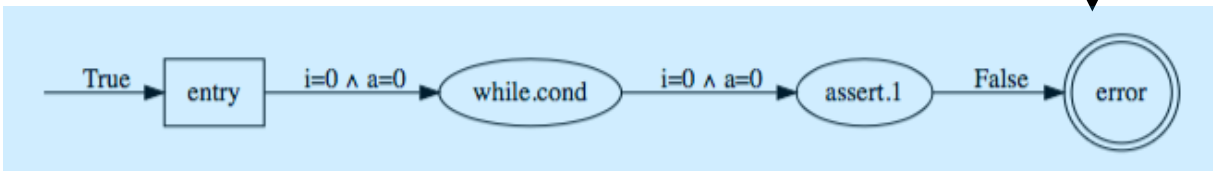
An error trace

the error trace infeasible?

NO

Yes

Refine CFG



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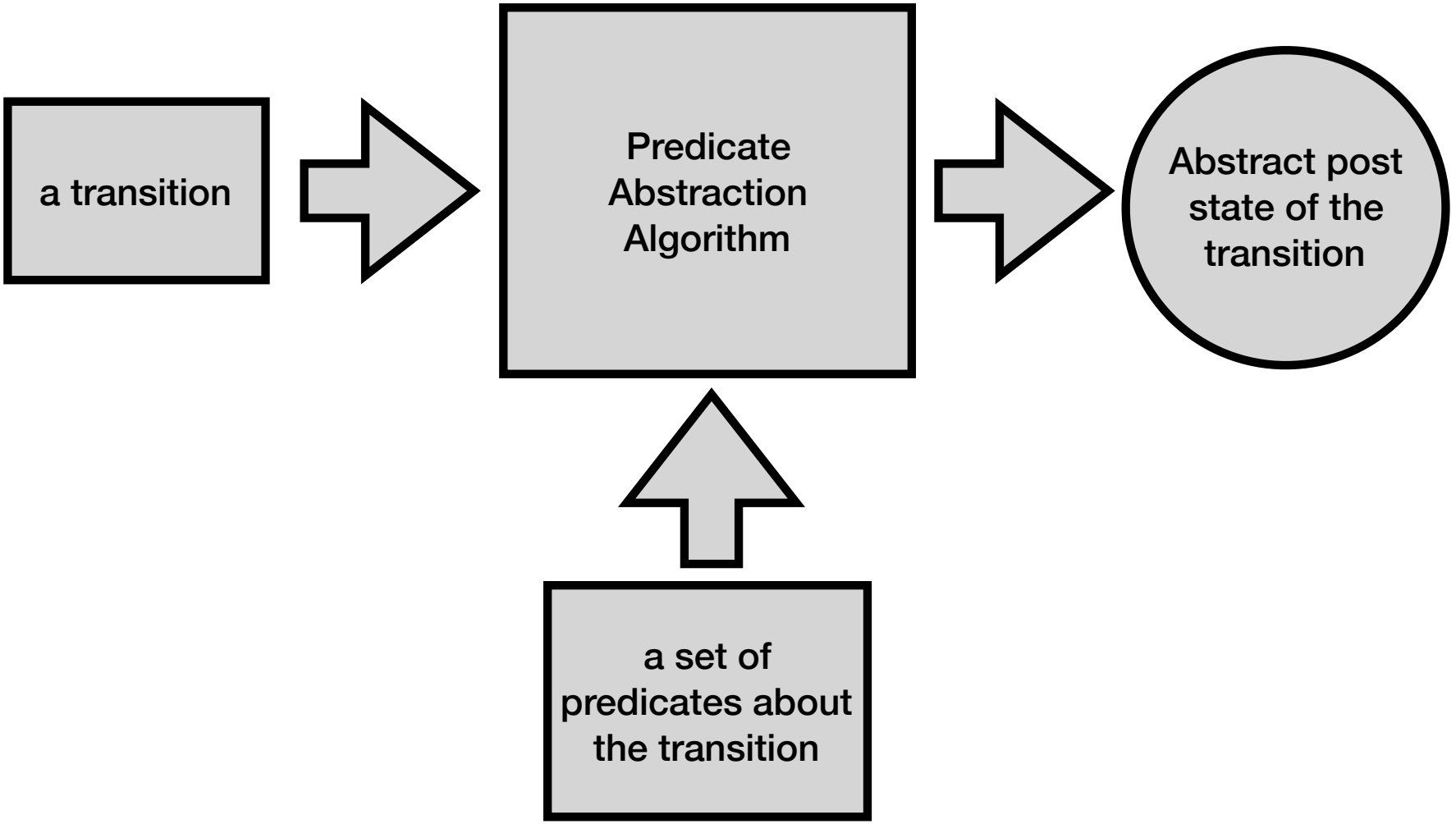
Predicate Abstraction



Graf, S. and Saïdi, H. 1997. Construction of abstract state graphs with PVS. *International Conference on Computer Aided Verification* (1997), 72–83.

Flanagan, C. and Qadeer, S. 2002. Predicate abstraction for software verification. *ACM SIGPLAN Notices* (2002), 191–202.

Predicate Abstraction

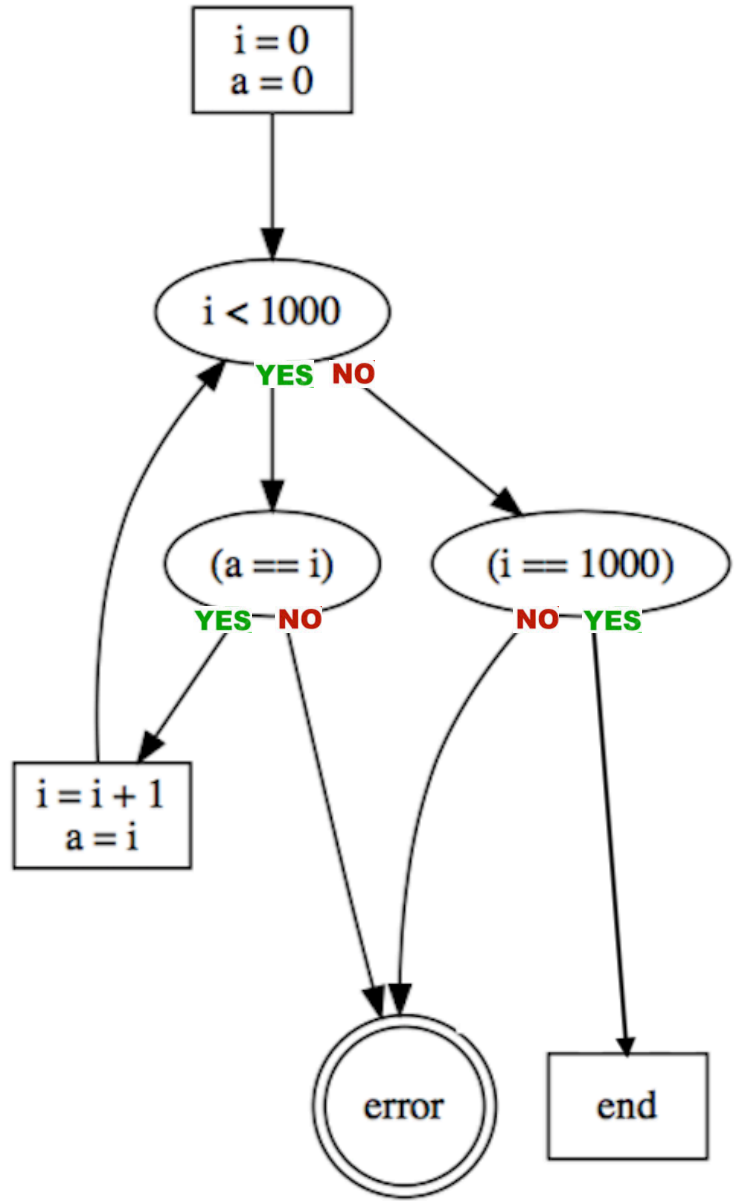
- SLAM (Static Driver Verifier: Technology Transfer of Formal Methods inside Microsoft)
- BLAST is a software model checker for C programs. (http://cseweb.ucsd.edu/~rjhala/blast.html)
- MAGIC: Modular Analysis of proGrams In C (http://www.cs.cmu.edu/~chaki/magic/)

Example

YES indicates an exit point where the condition in the block is **true**

NO indicates an exit point where the condition in the block is **false**

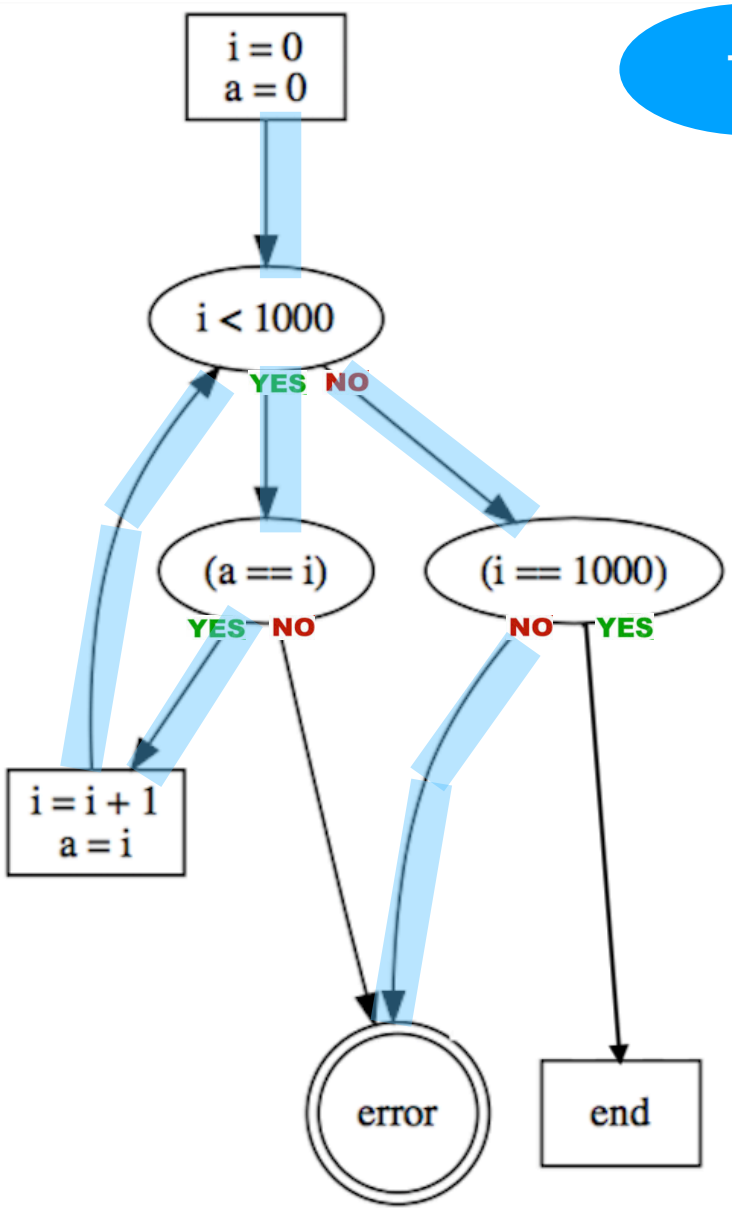
CFG



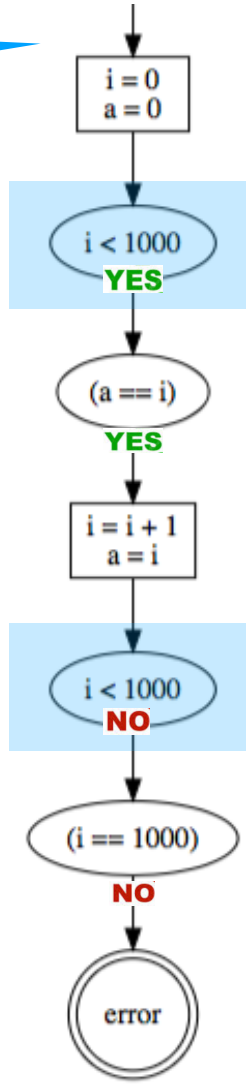
pseudo code

```
var i:Int, a:Int
i = 0, a = 0
while(i < 1000) do
    assert(a == i)
    i = i + i, a = i
assert(i == 1000)
```

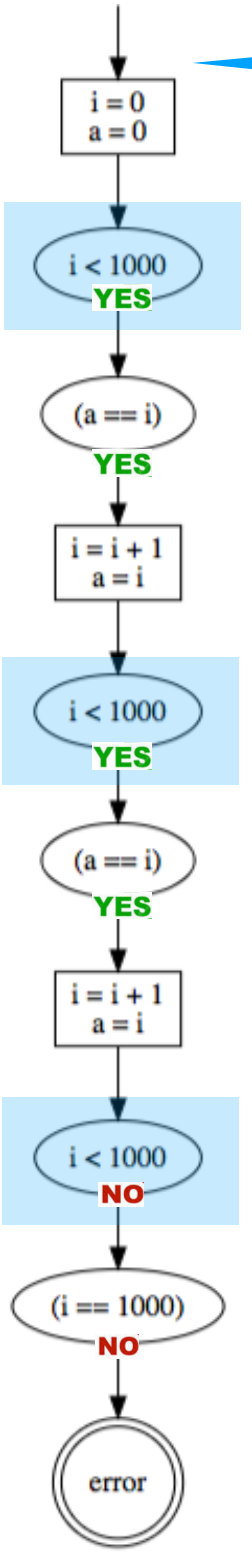
Example



T1

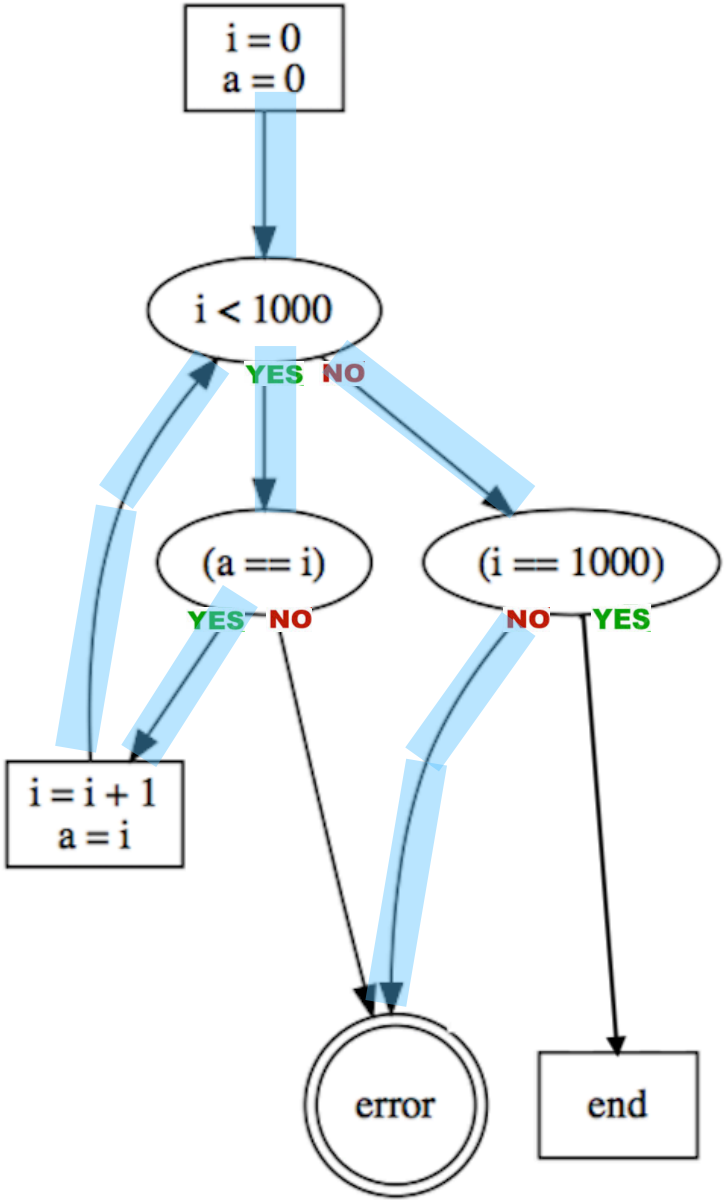


T2

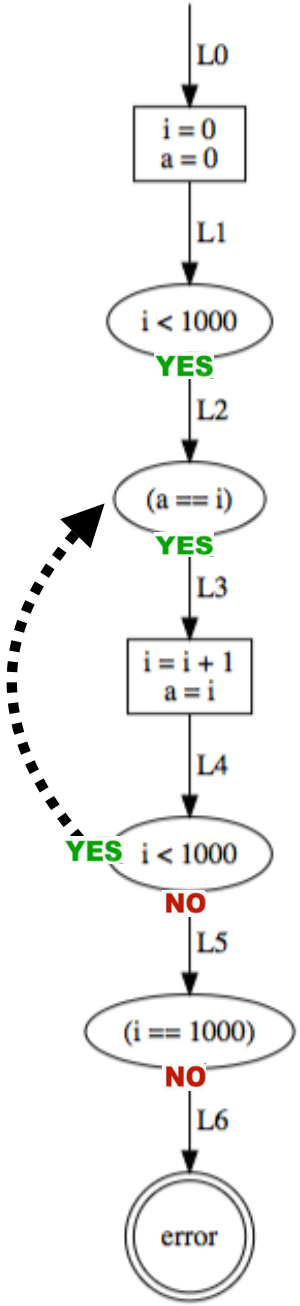


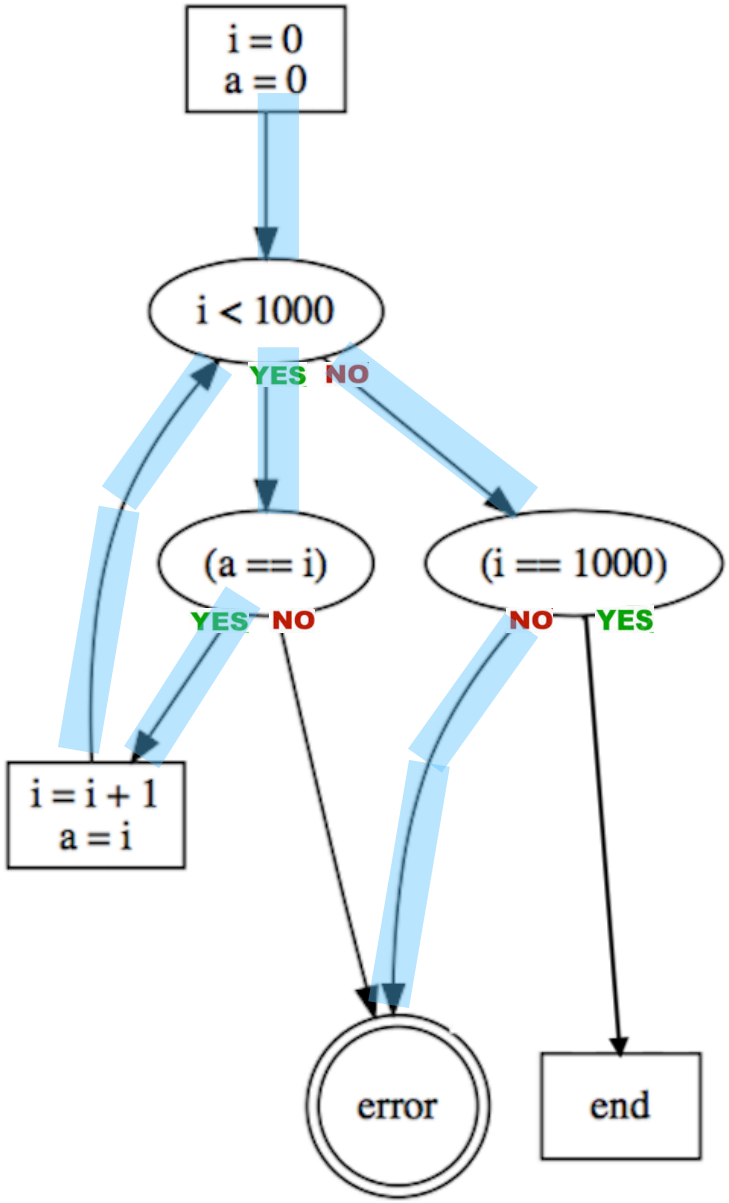
.....

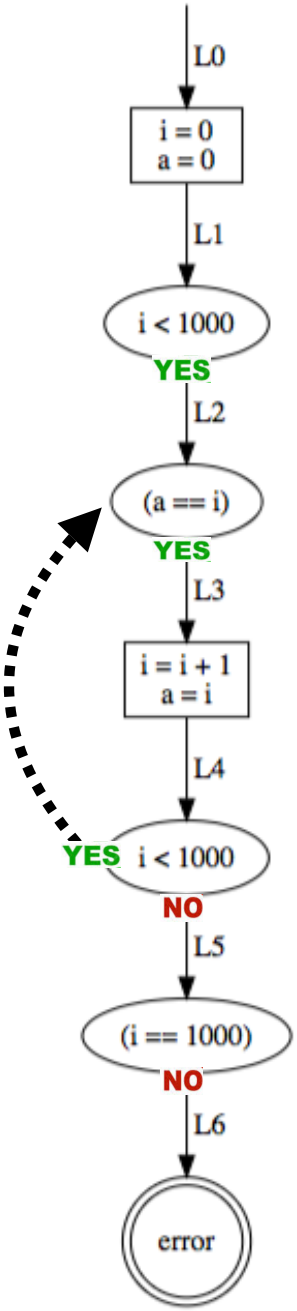
Example: back edge



add new edge to the linear trace




i = 0
a = 0
i < 1000
YES
NO
(a == i)
YES
NO
(i == 1000)
NO
YES
i = i + 1
a = i
error
end


L0
i = 0
a = 0
L1
i < 1000
YES
L2
(a == i)
YES
L3
i = i + 1
a = i
L4
YES
i < 1000
NO
L5
(i == 1000)
NO
L6
error

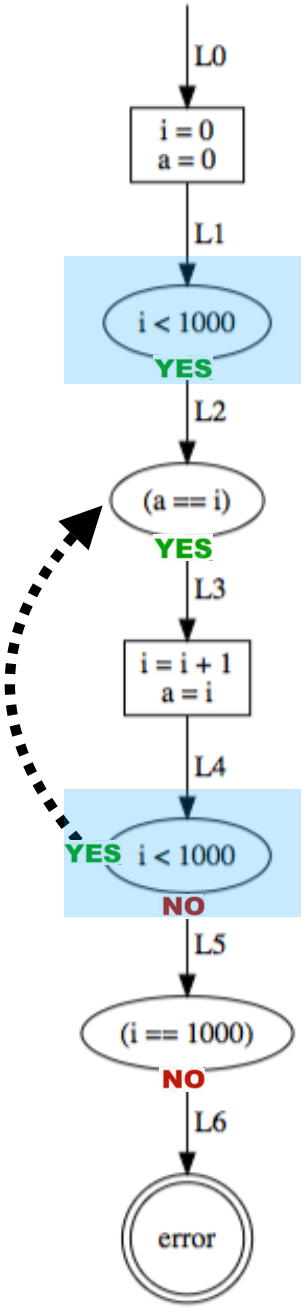
Example: Safe to add?

Triples for this error trace

{L0 (True)} *i = 0; a = 0* {L1}
{L1} *i < 1000* {L2}
{L2} *a == i* {L3}
{L3} *i = i + 1; a = i* {L4}
{L4} *!(i < 1000)* {L5}
{L5} *!(a == 1000)* {L6 (False)}

Triple for the new edge

{L4} i < 1000 {L2}



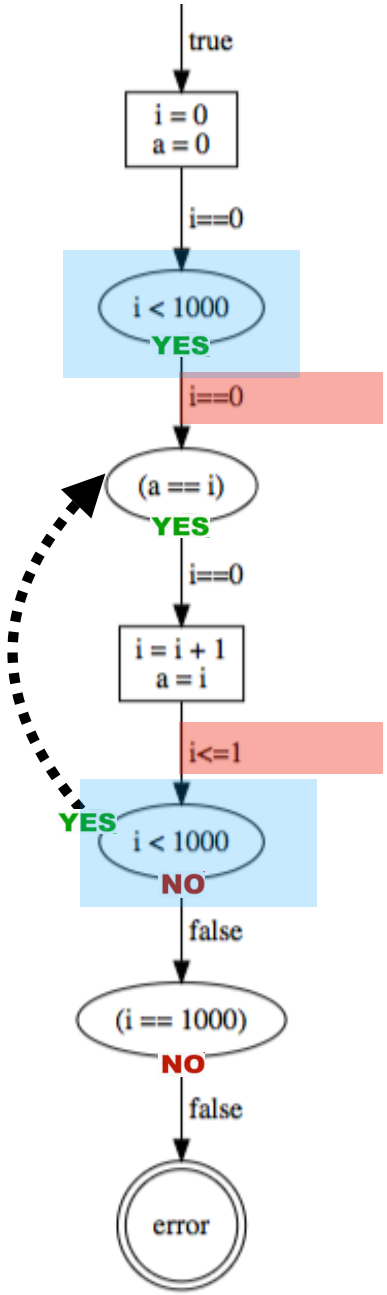
Compute predicates at L1 to L6 such that all the triples hold.

Example

Interpolating SMT Solver

{i <= 1} i < 1000 {i == 0}

✗



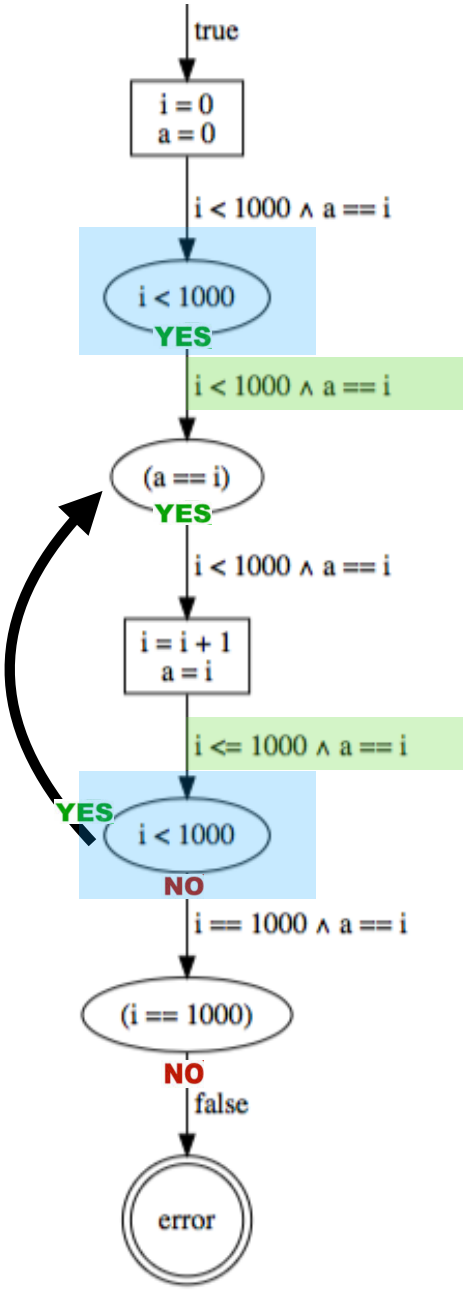
McMillan, K. 2005. Applications of Craig interpolation to model checking. *International Conference on Application and Theory of Petri Nets* (2005), 15–16.

Example

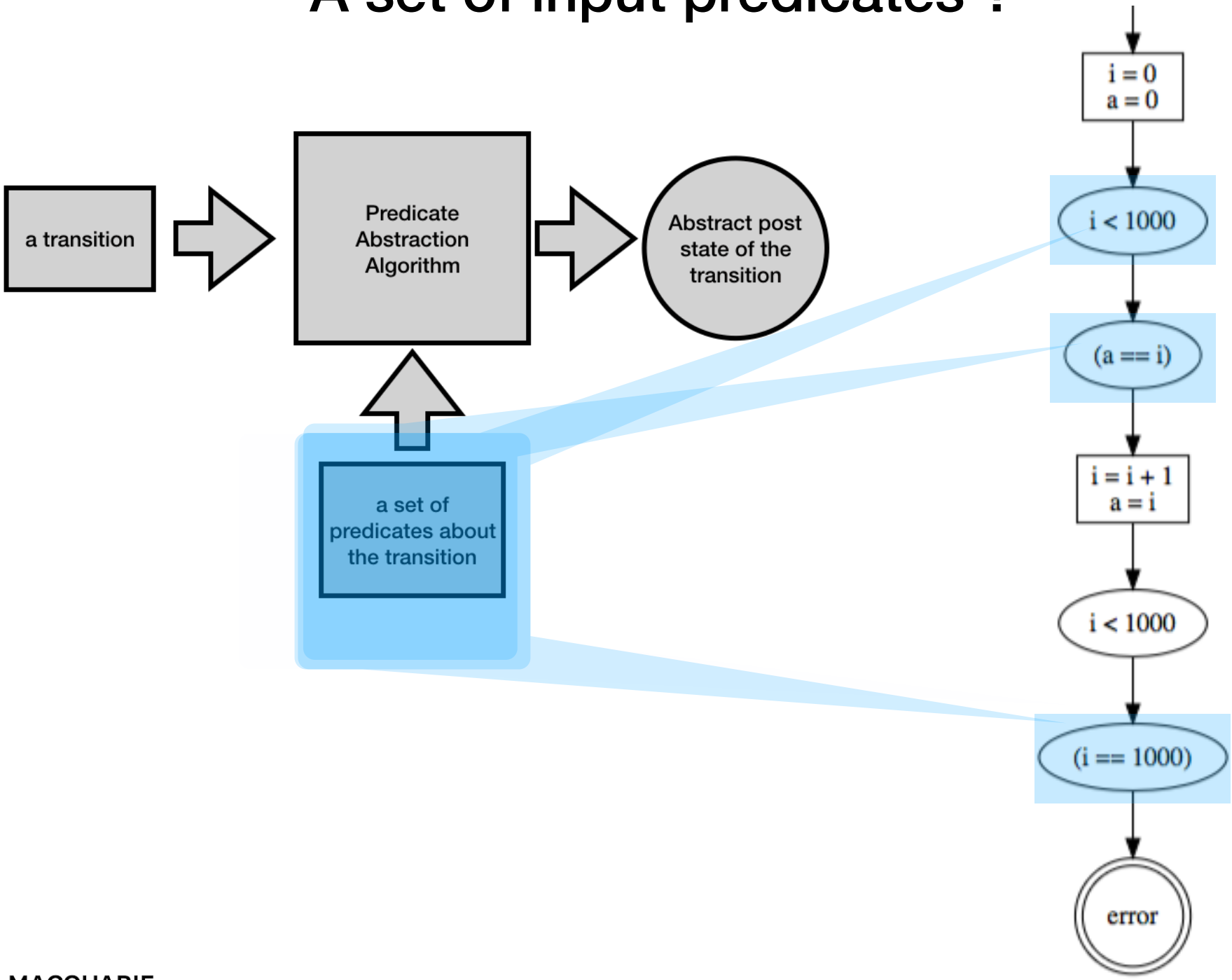
Using predicate abstraction

{i ≤ 1000 ∧ a == i} i < 1000 {i < 1000 ∧ a == i}

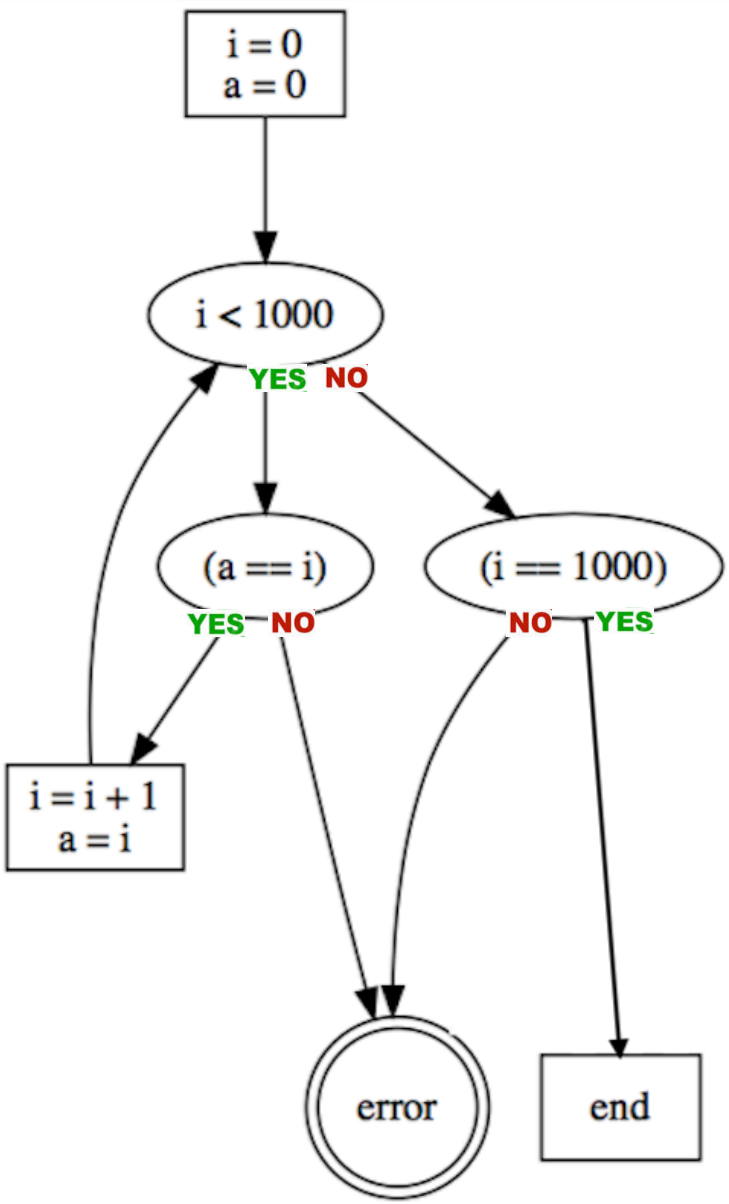
✔



A set of input predicates ?



Result (from the example)



	Number of refinement Iteration
Predicate Abstraction	4
Interpolating SMT Solver (z3)	> 20

Result (preliminary)

Loop Acceleration	Predicate Abstraction	Interpolating SMT Solver
const_true-unreach-call1.c	2	2
diamond_true-unreach-call1.c	7	> 20
nested_true-unreach-call1.c	7	> 20
overflow_true-unreach-call1.c	2	3
multivar_true-unreach-call1.c	2	2
phases_true-unreach-call1.c	> 20	> 20
simple_true-unreach-call1.c	2	> 20
simple_true-unreach-call2.c	2	2
simple_true-unreach-call3.c	2	> 20
simple_true-unreach-call4.c	2	> 20
underapprox_true-unreach-call1.c	2	8
underapprox_true-unreach-call2.c	2	7
phases_true-unreach-call2.c	unknown	unknown

ETAPS
EUROPEAN JOINT CONFERENCES ON THEORY & PRACTICE OF SOFTWARE
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Competition on Software Verification (SV-COMP)

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Next Step

- Program with Array (require quantified invariants)
- Better heuristic to automatically generate input predicates for Predicate Abstraction.

????

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