Automatic State Reaching for Debugging Reactive Programs

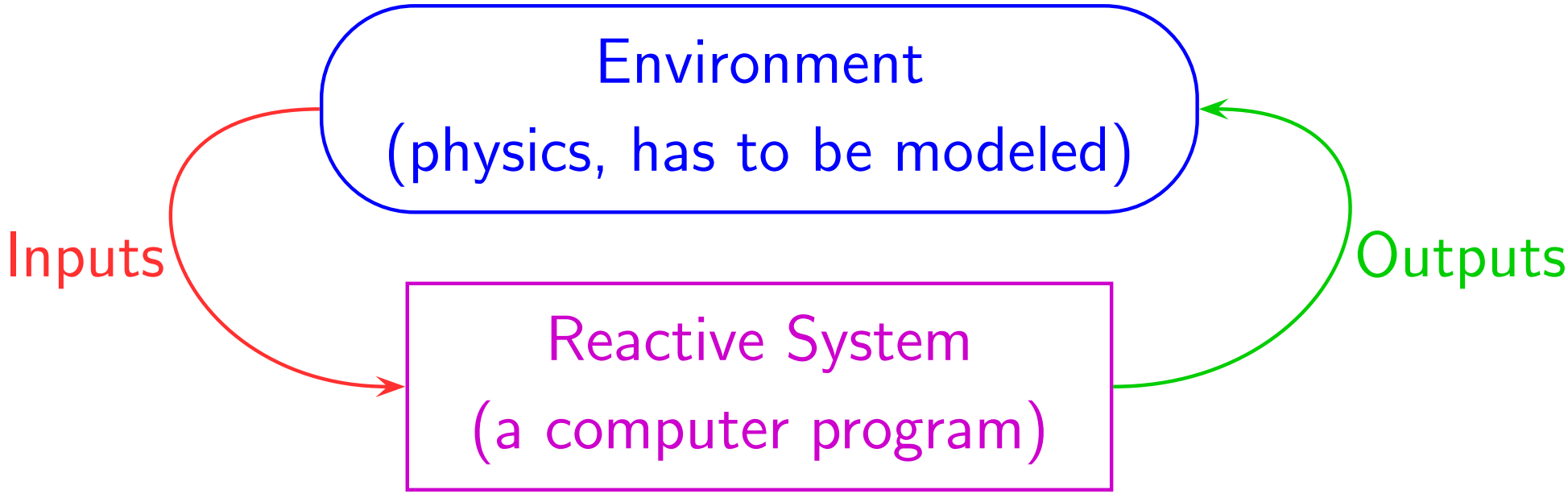
Fabien Gaucher, Erwan Jahier, Bertrand Jeannet &
Florence Maraninchi

Reactive Systems in the Synchronous Approach

Environment
(physics, has to be modeled)

Reactive System
(a computer program)

Reactive Systems in the Synchronous Approach



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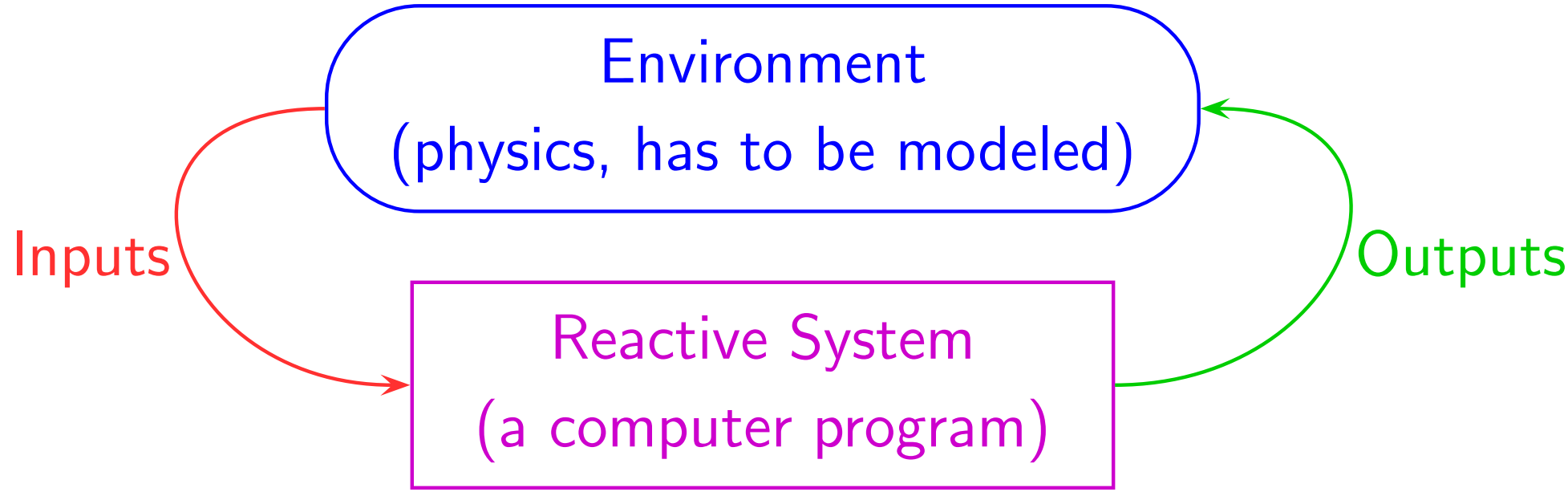

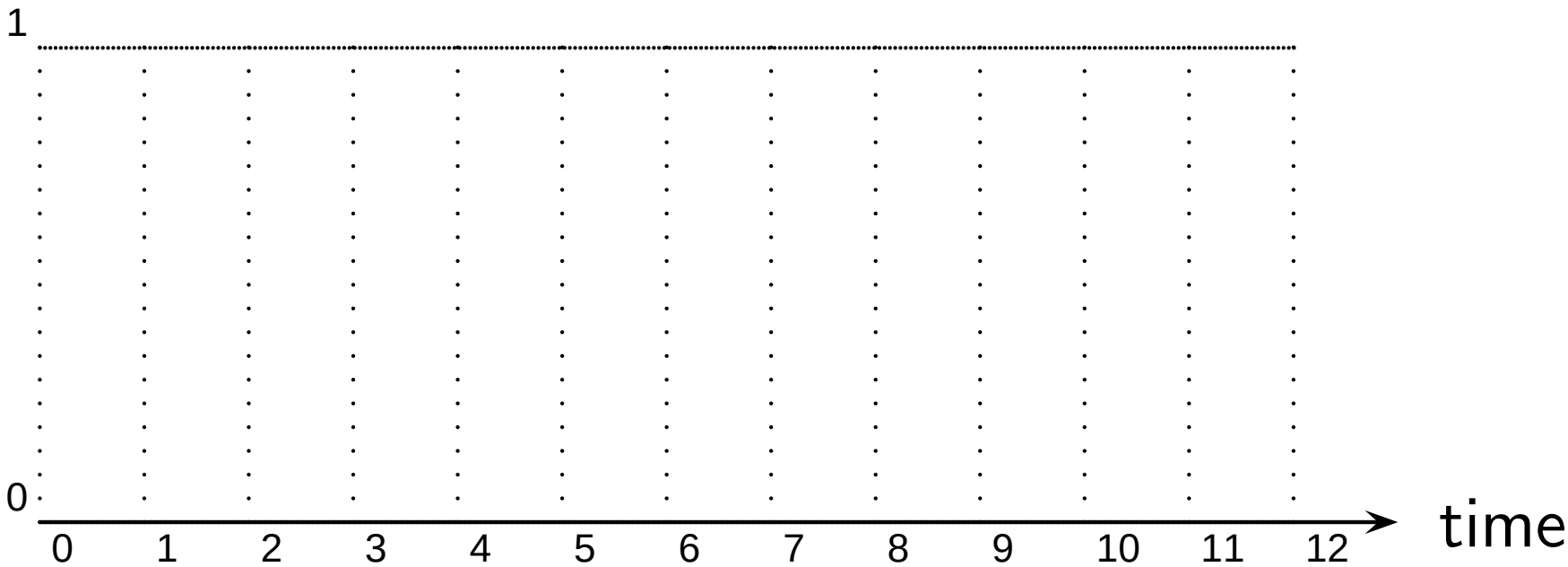

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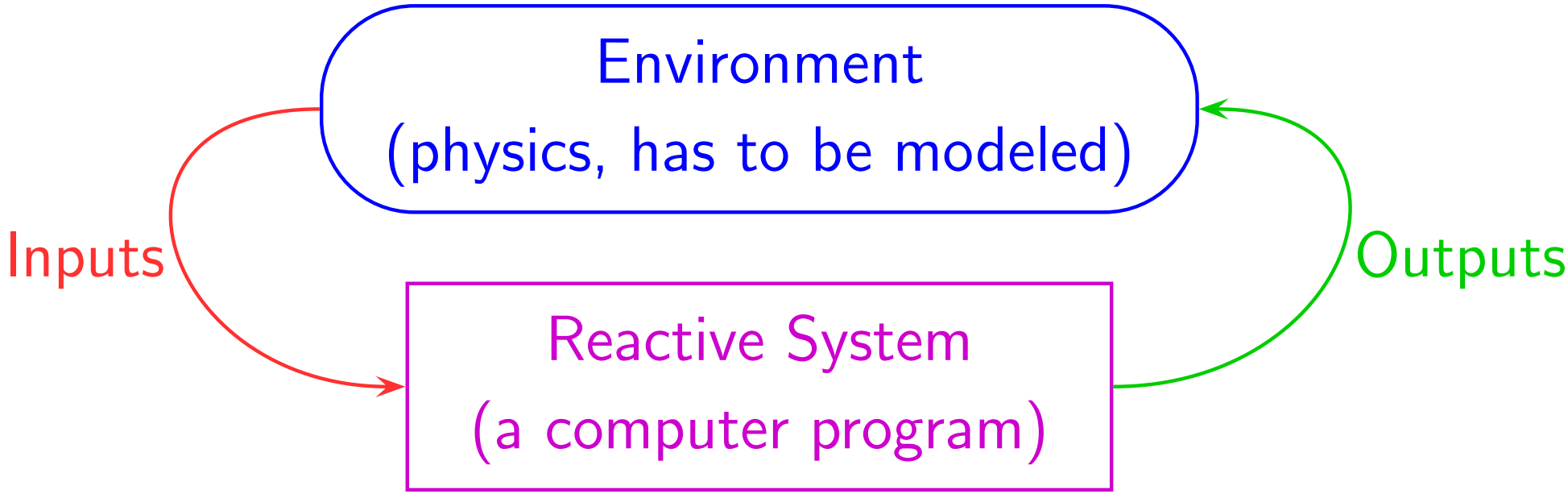

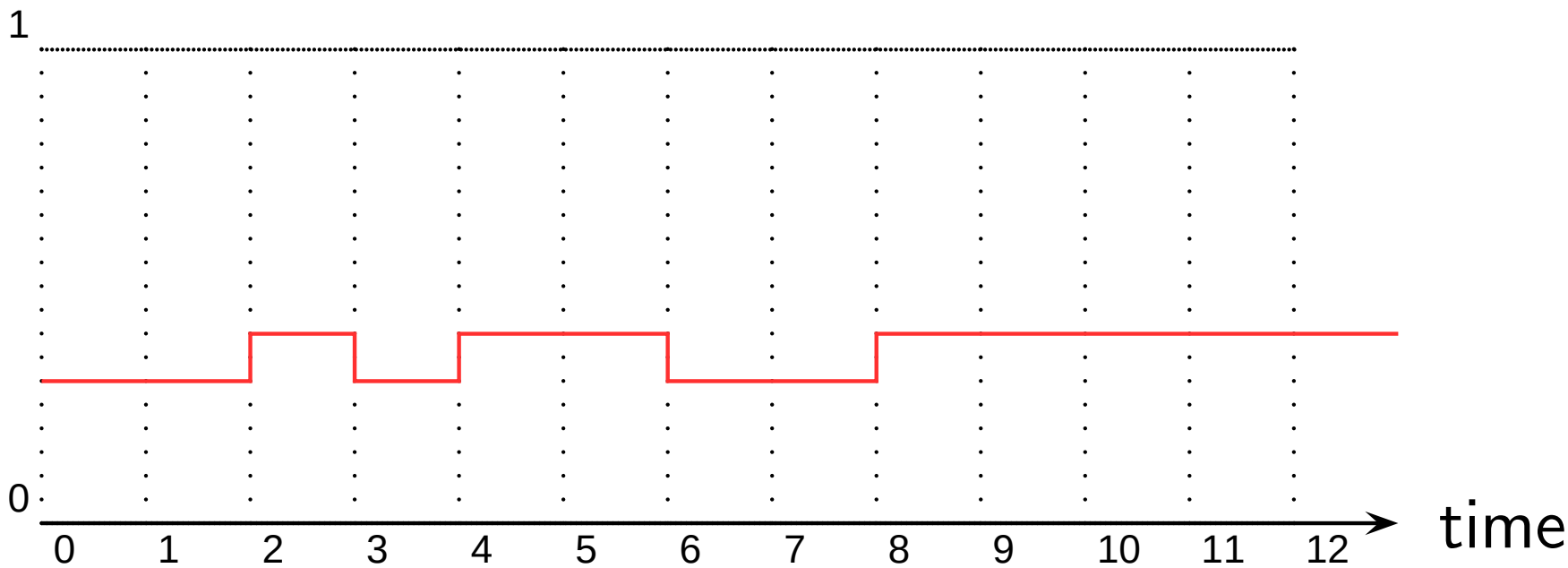

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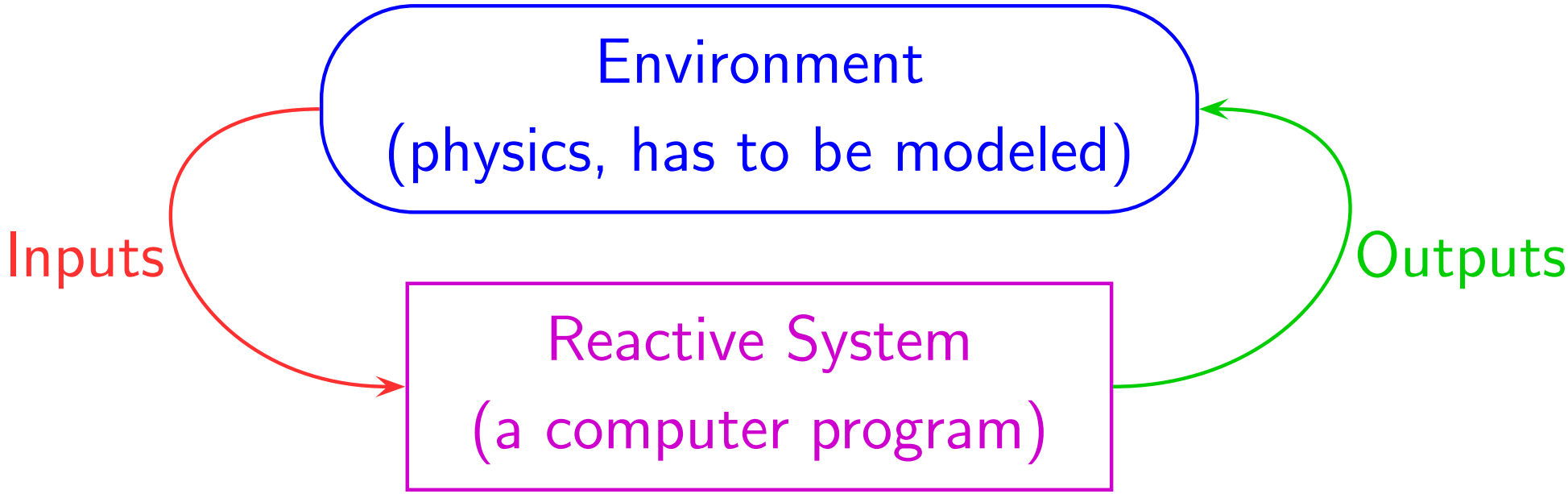

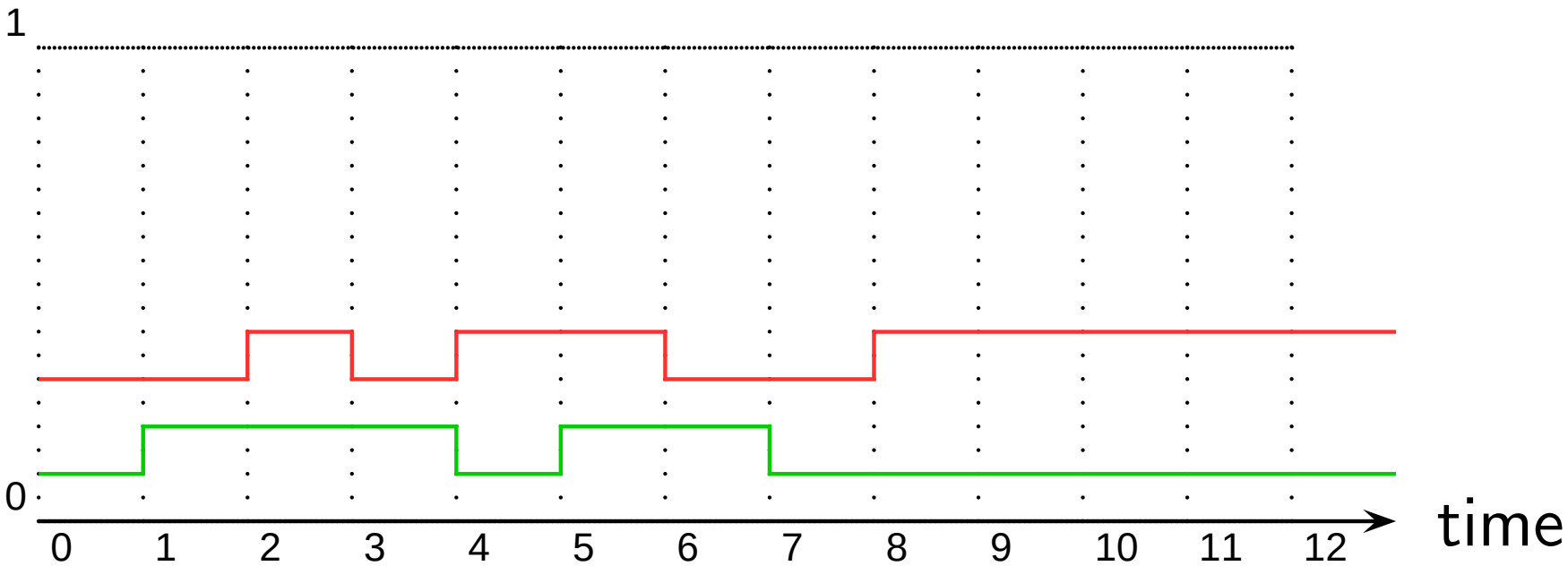

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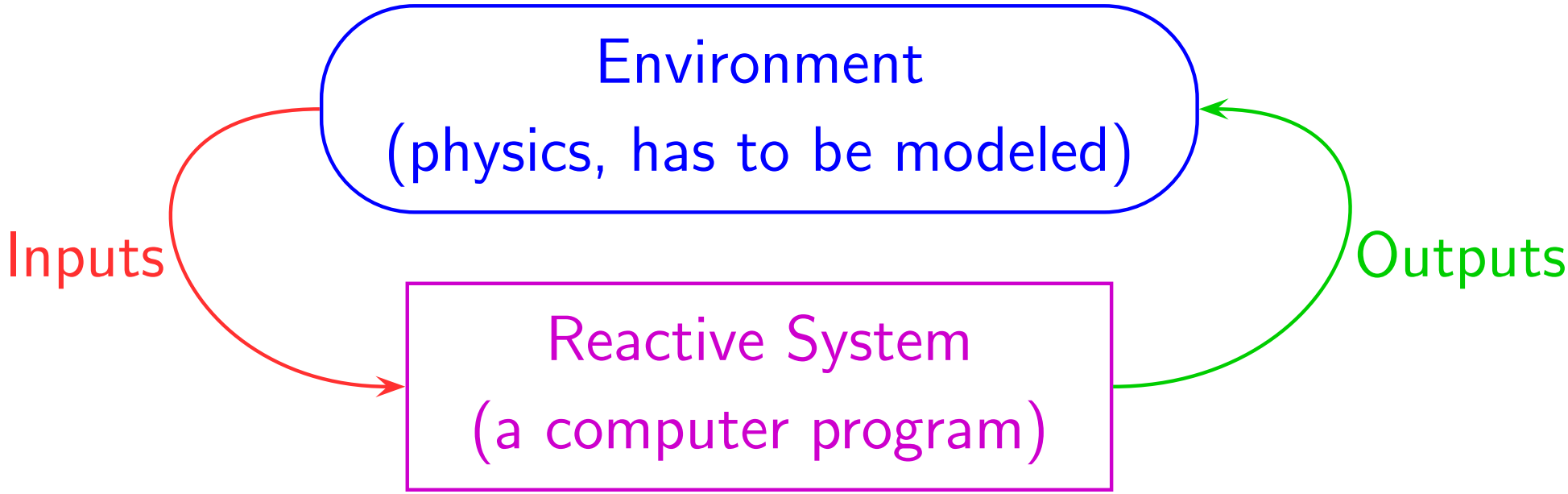

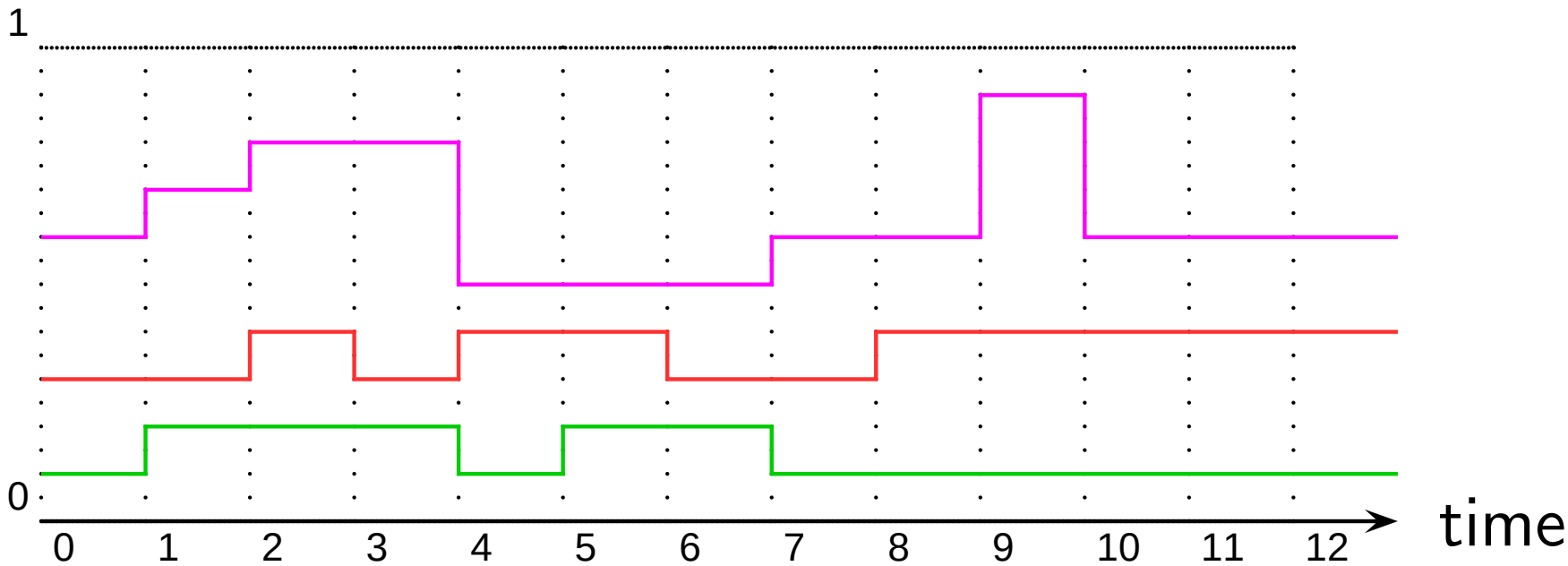

Our running example

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node maintain(n:int; val:bool) returns (m:bool);
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let cpt = if val then (0 -> pre(cpt)) + 1 else 0;
    m = cpt >= n;
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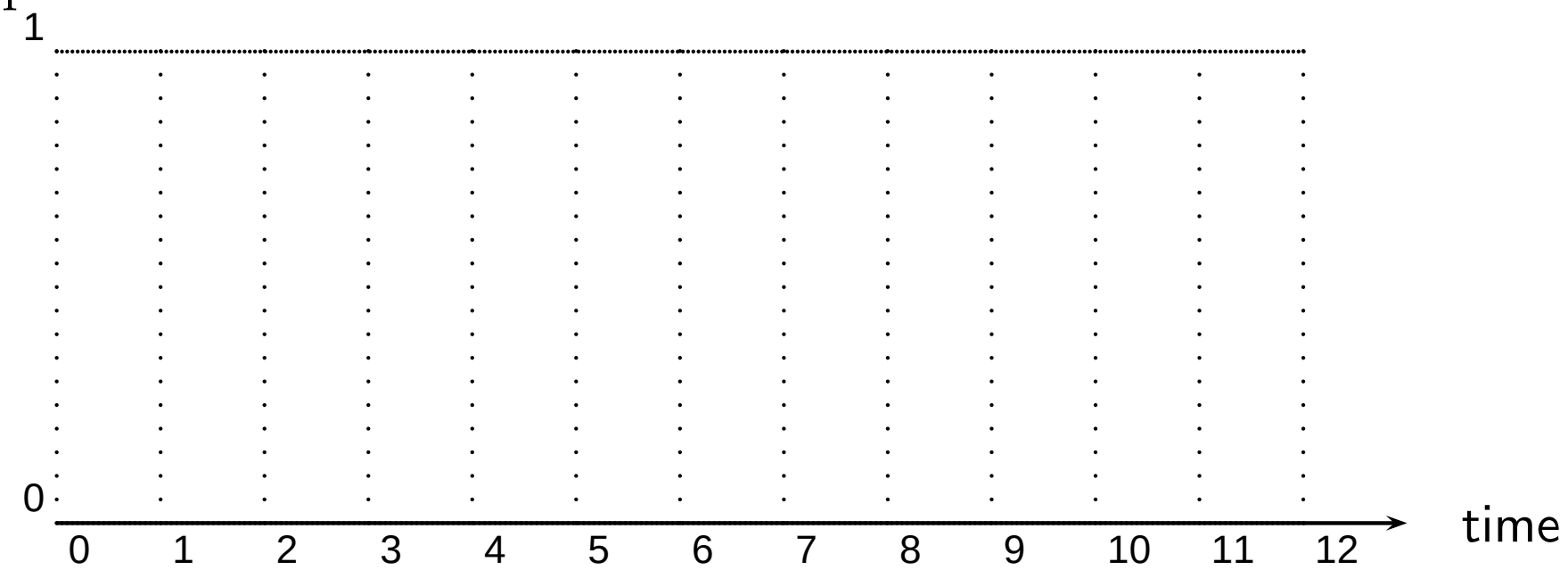

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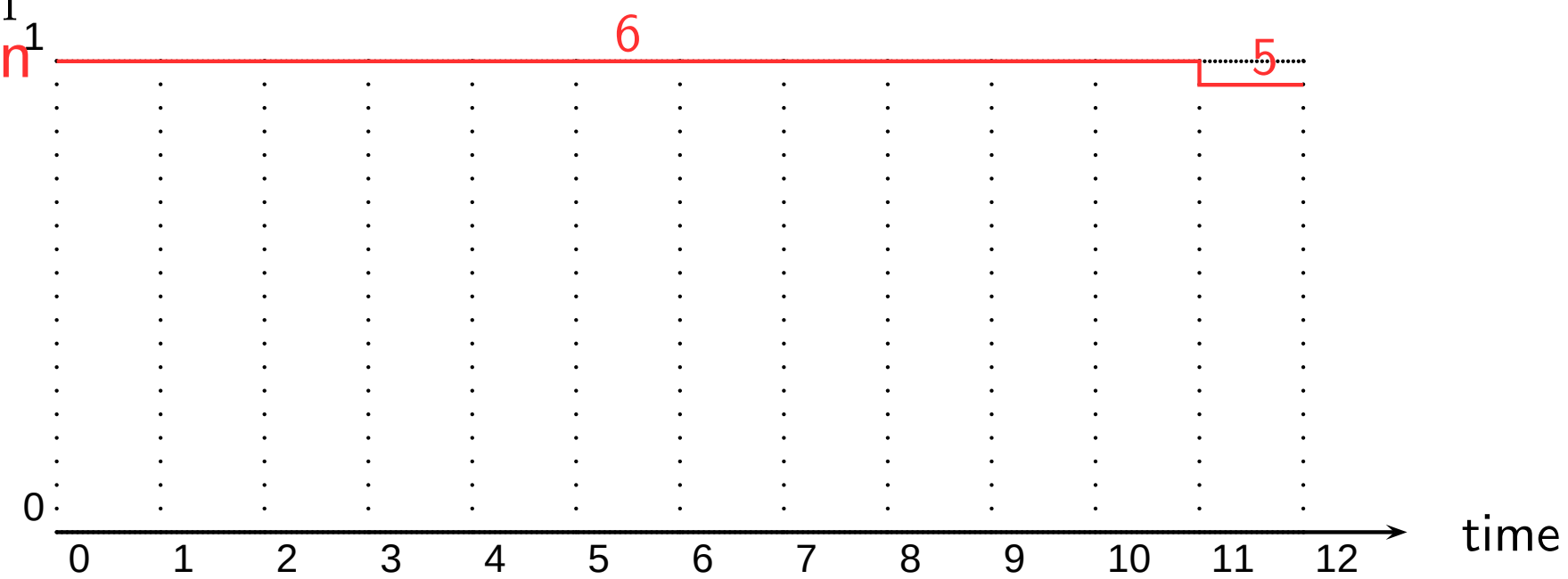

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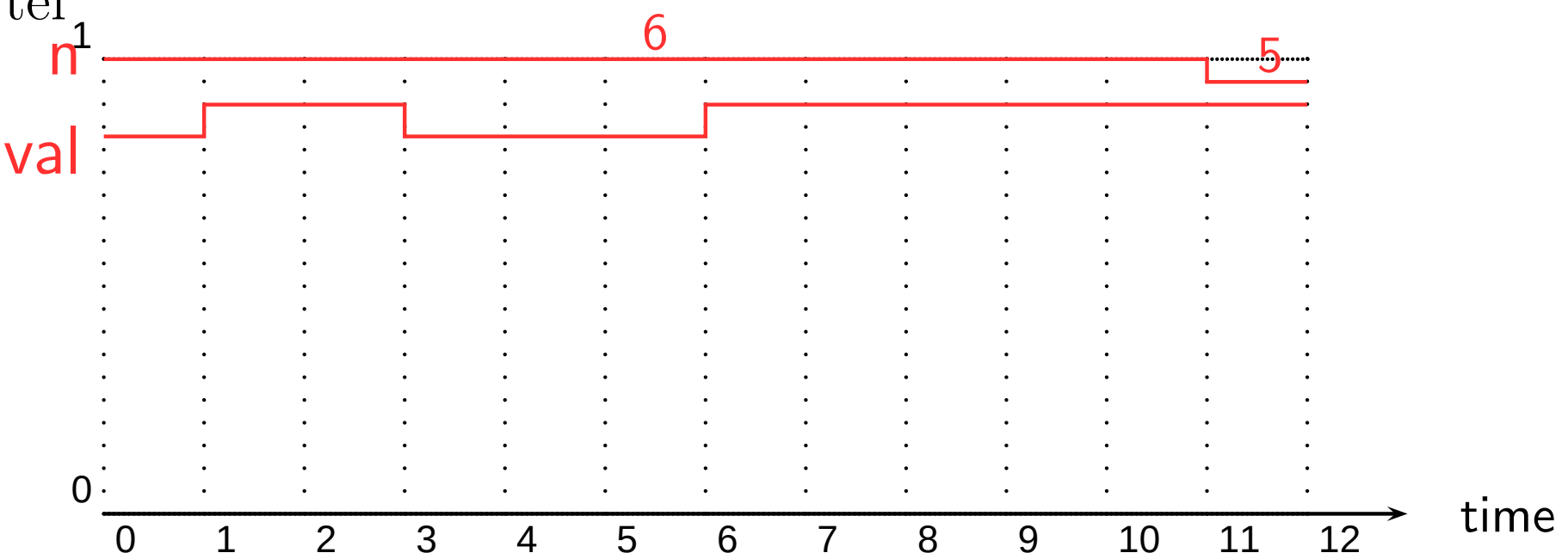

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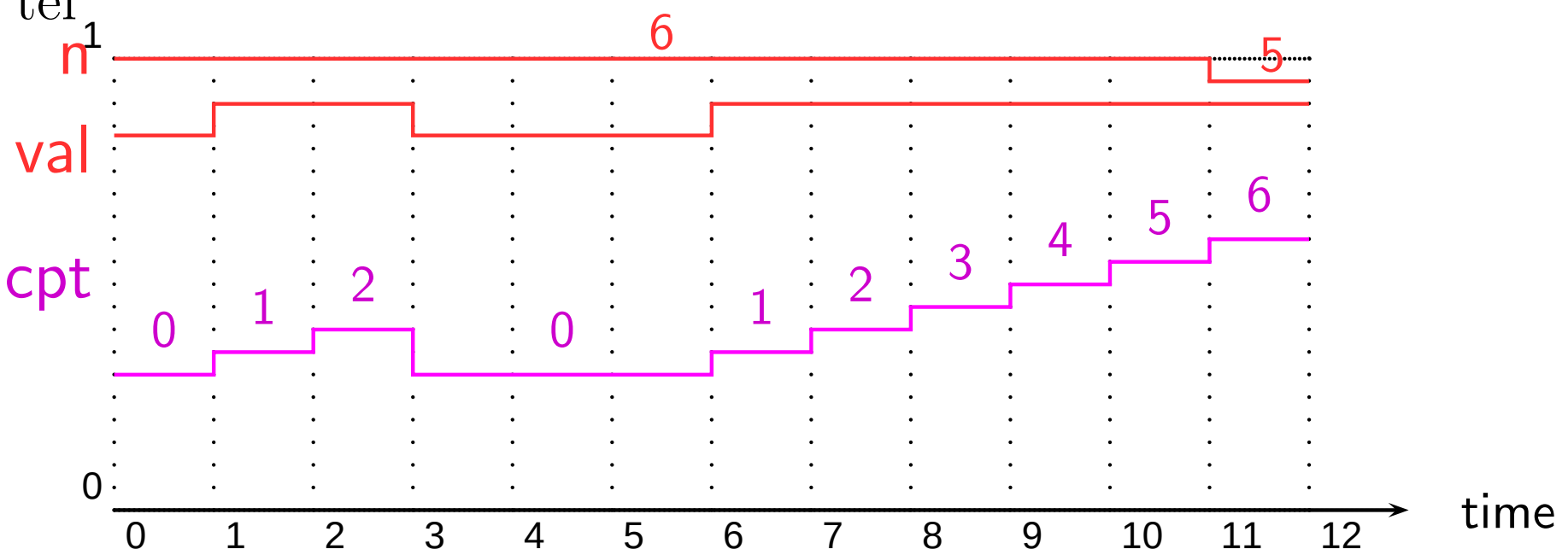

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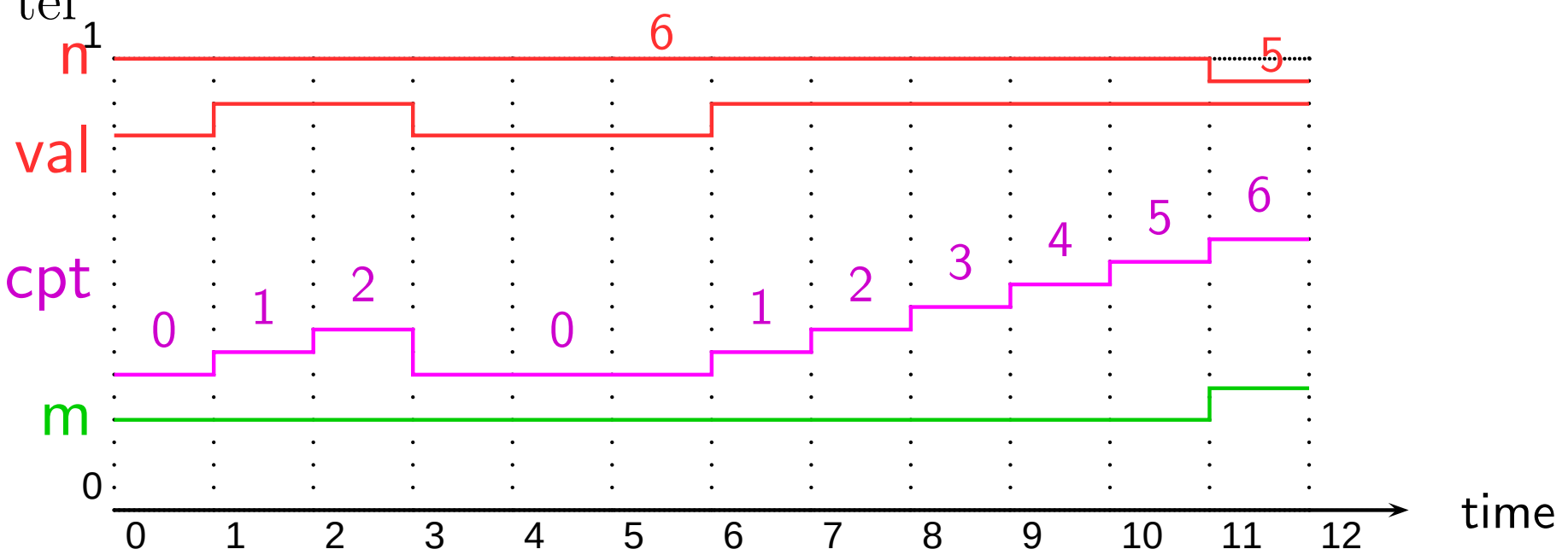

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Useful features in a debugger

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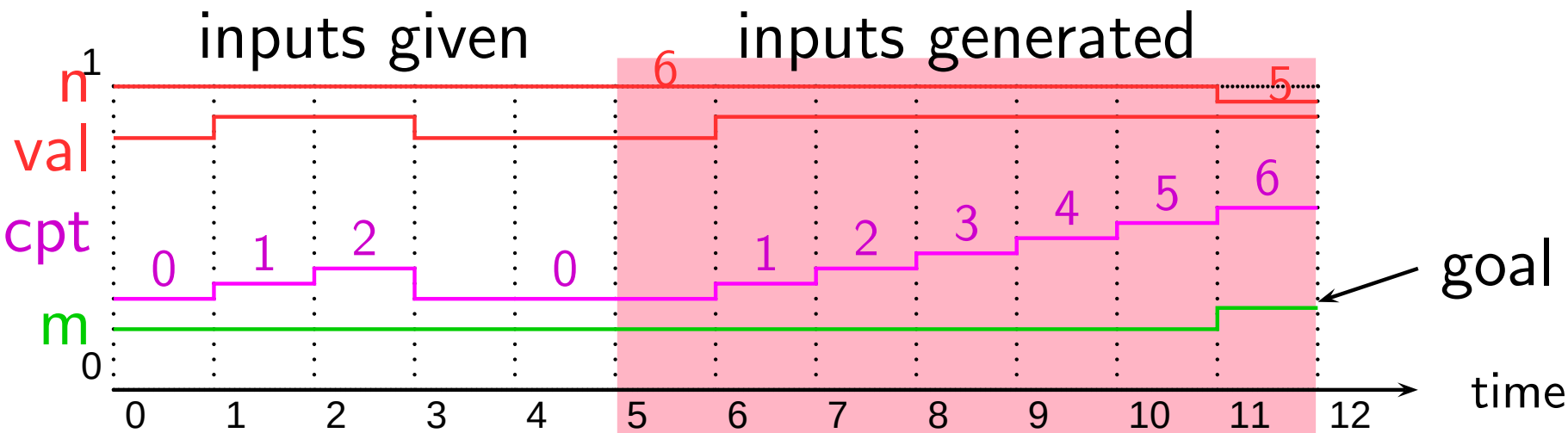
- Simulation: choose inputs and play the program until some instant n. Can be very tedious !
- But also "goalpoint": is it possible to reach some interesting state (here, satisfying m true) ? If it is, give me a sequence of inputs (here, n,val) that, from the current state, leads to such a goal state.



Formalization

- We have a program, whose semantics can be described by $(s', o) = f(s, i)$
  s, s' are states, i the input, o the output
  An execution is: $s_0 \overset{i_0/o_0}{\longrightarrow} s_1 \overset{i_1/o_1}{\longrightarrow} s_2 \ldots$
  with $(s_{k+1}, o_k) = f(s_k, i_k)$
- We are in some state $\mathbf{Init} = \{s\}$
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Remark 1: if an observer depends on inputs and/or outputs, we can transform it into a state observer

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Remark 2: equivalent view of the problem: search for a counter-example to the invariance property $\mathbf{not\ Final}$

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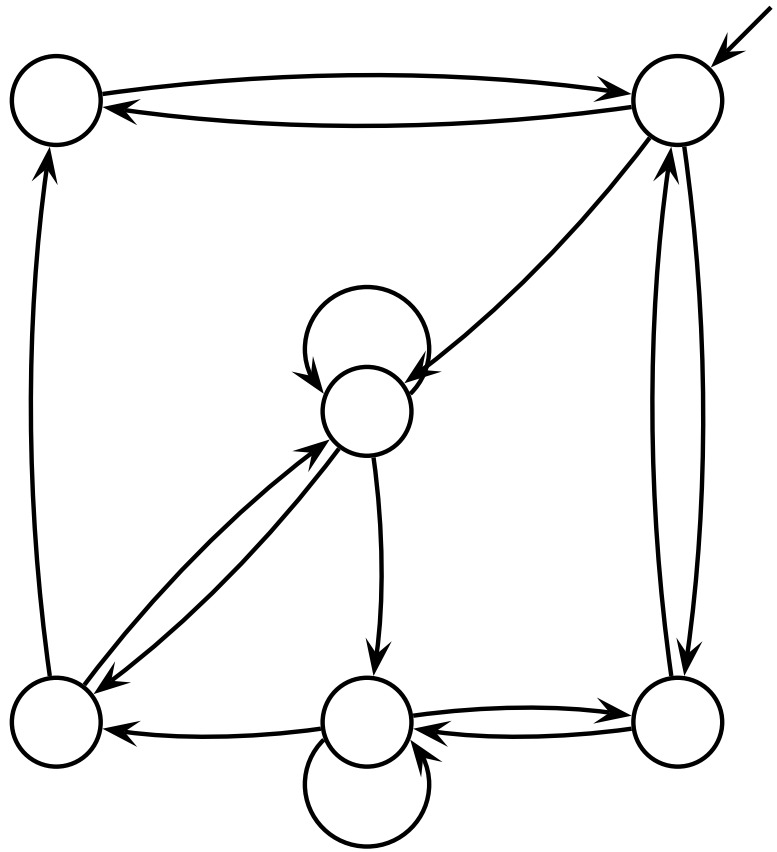

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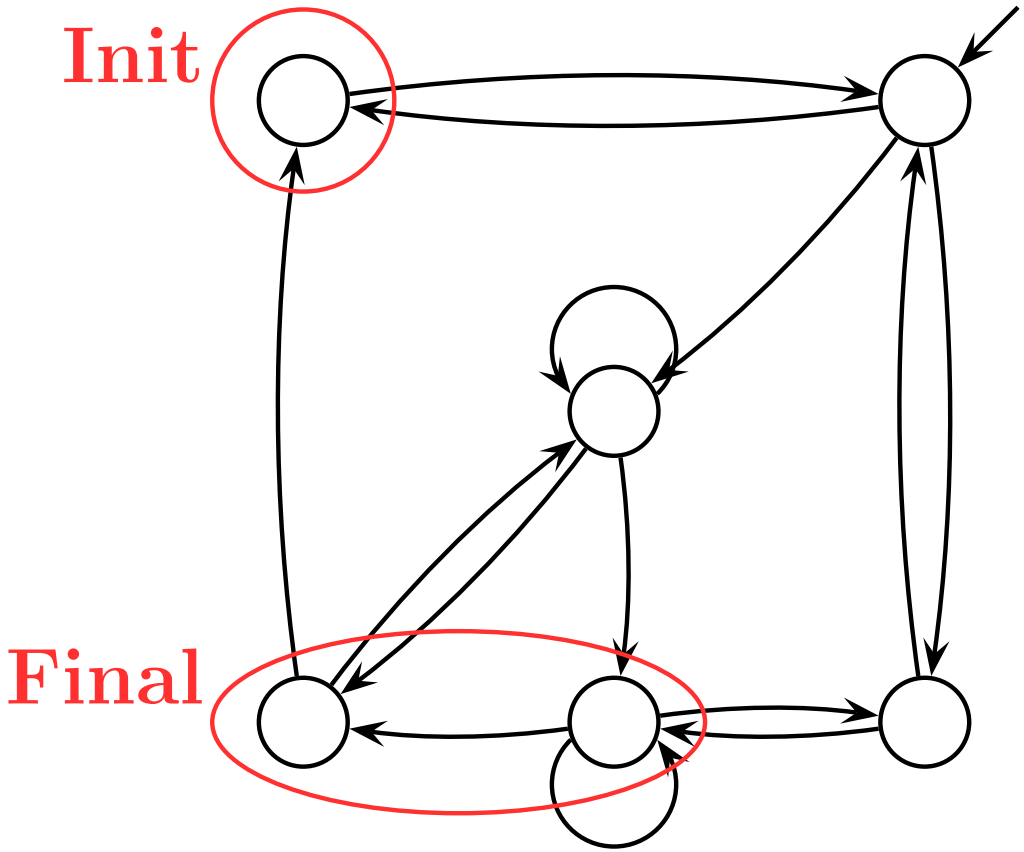

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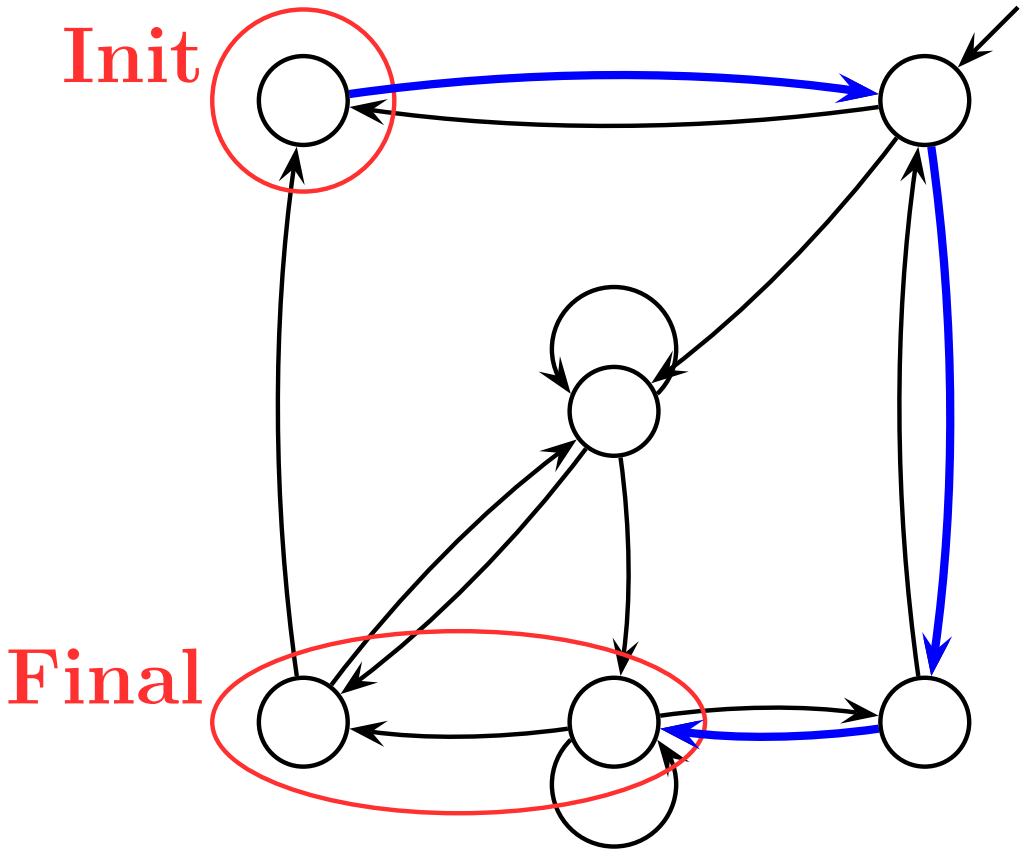

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Otherwise, one takes $s_n \in X_n \cap \mathbf{Final}$,

$s_{n-1} \in pre(\{s_n\}) \cap X_{n-1}$ and $i_{n-1} \mid s_{n-1} \stackrel{i_{n-1}/?}{\longrightarrow} s_n$,
and so on until $s_O \in \mathbf{Init}$, $\Rightarrow$ shortest execution

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Method already experimented by Halbwachs, Pace & Raymond 01, here refinement of it

Connecting tools

Debugger (Ludic)

$\boldsymbol{X} \longrightarrow \boldsymbol{Y}$?

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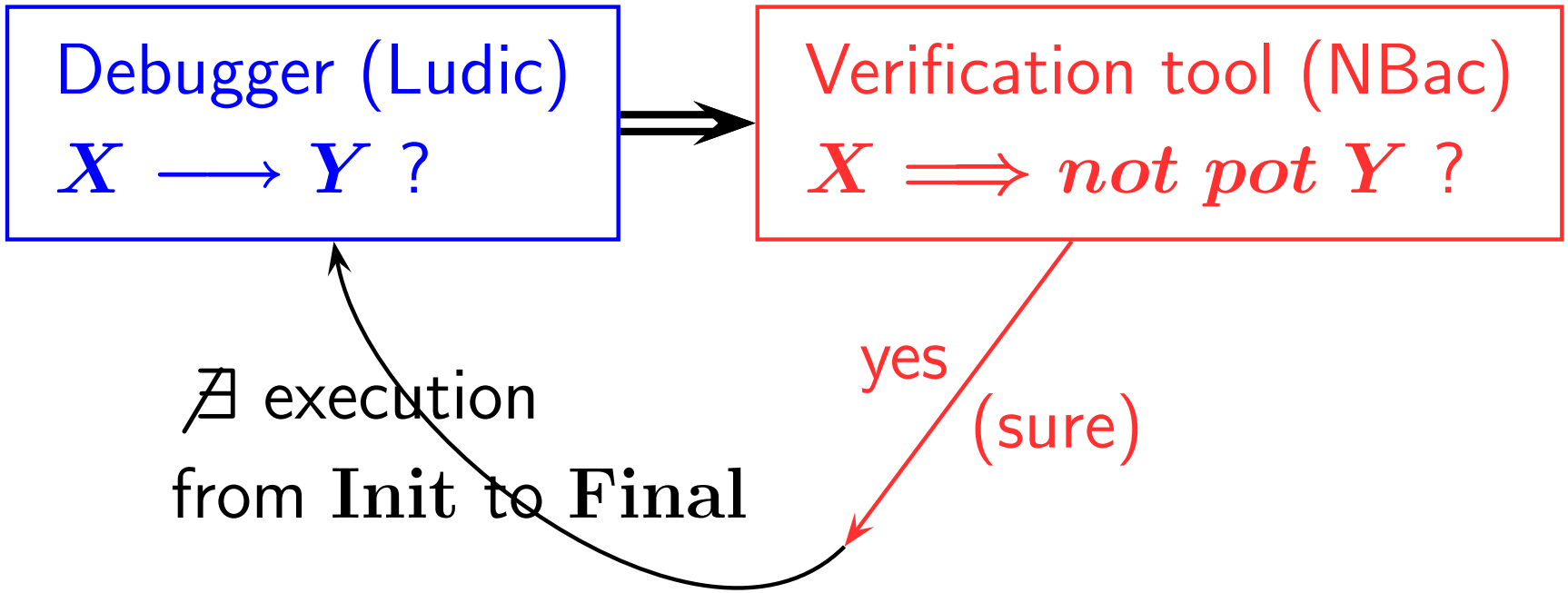
$X \longrightarrow Y$?

Verification tool (NBac)

$X \Longrightarrow not\ pot\ Y$?

Connecting tools



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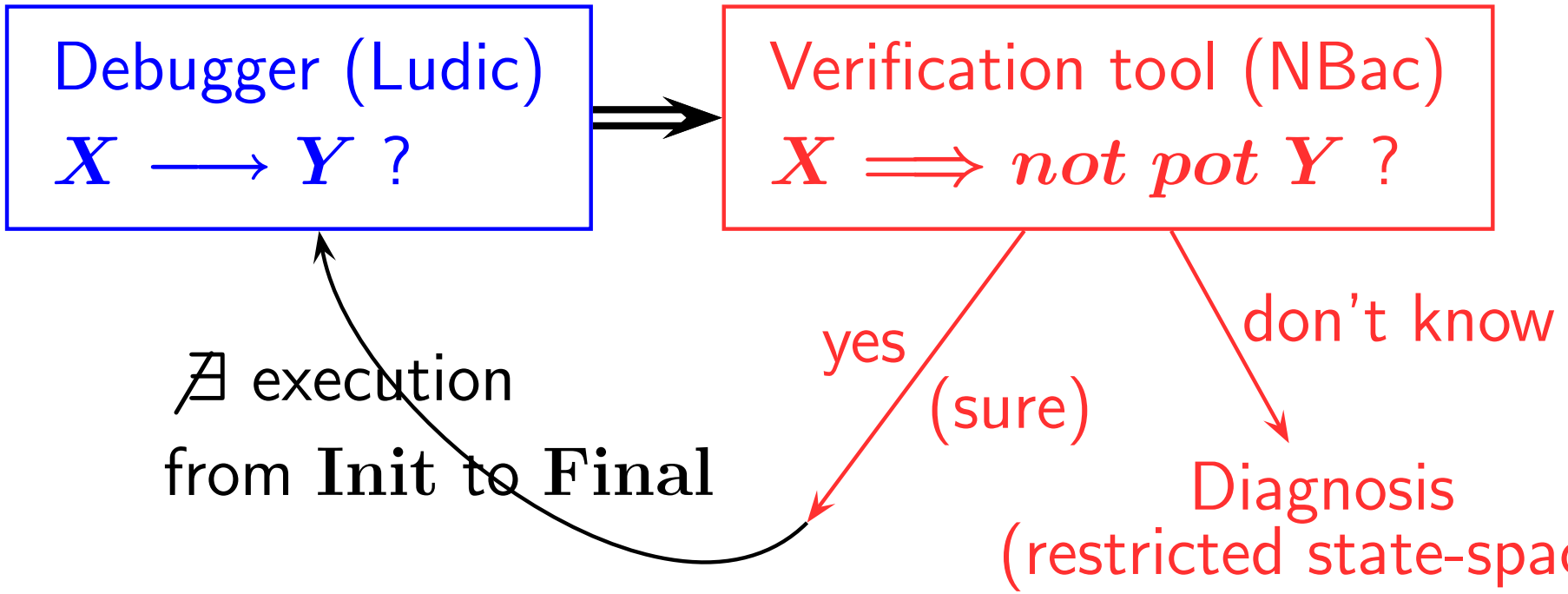

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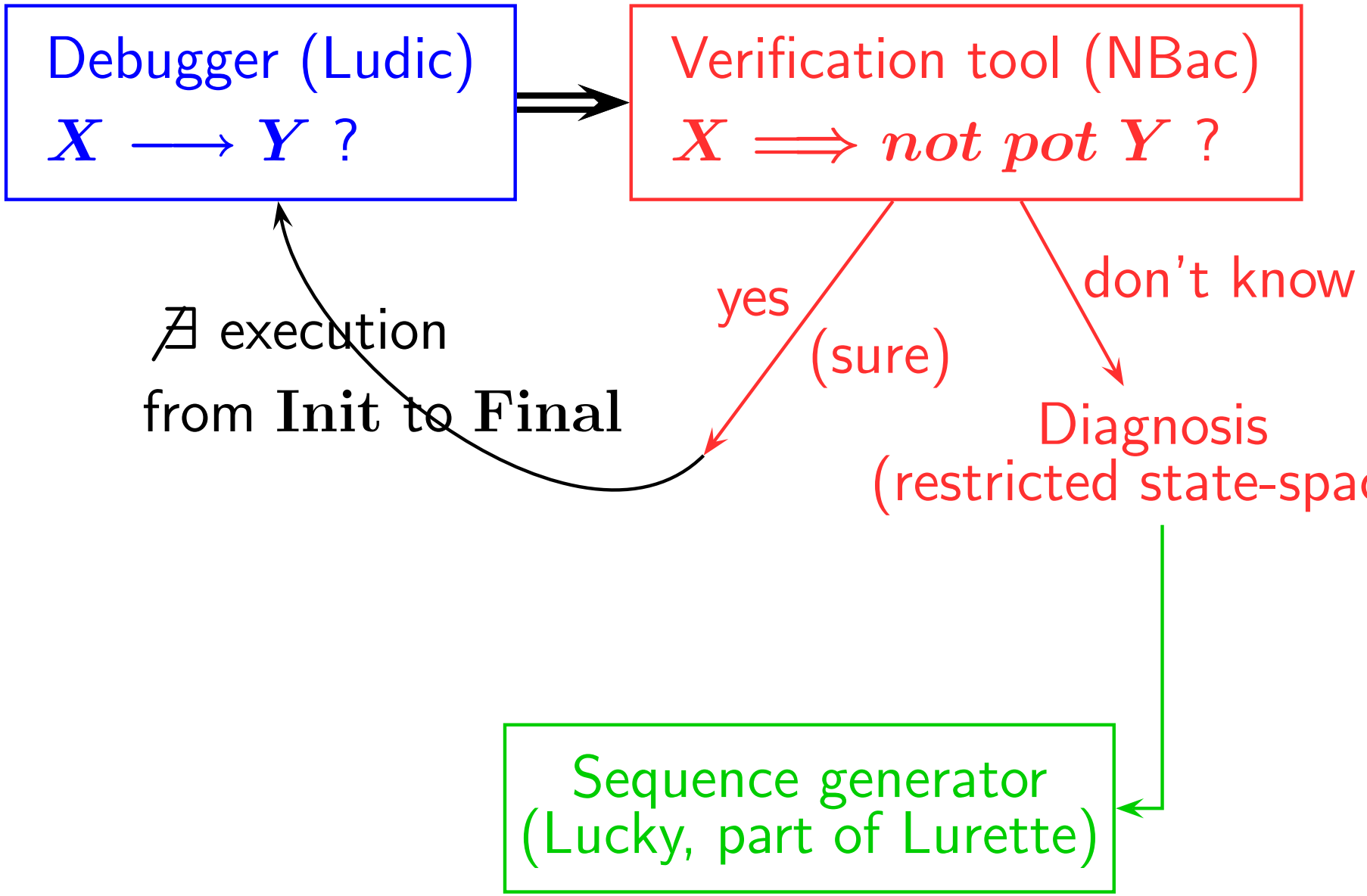

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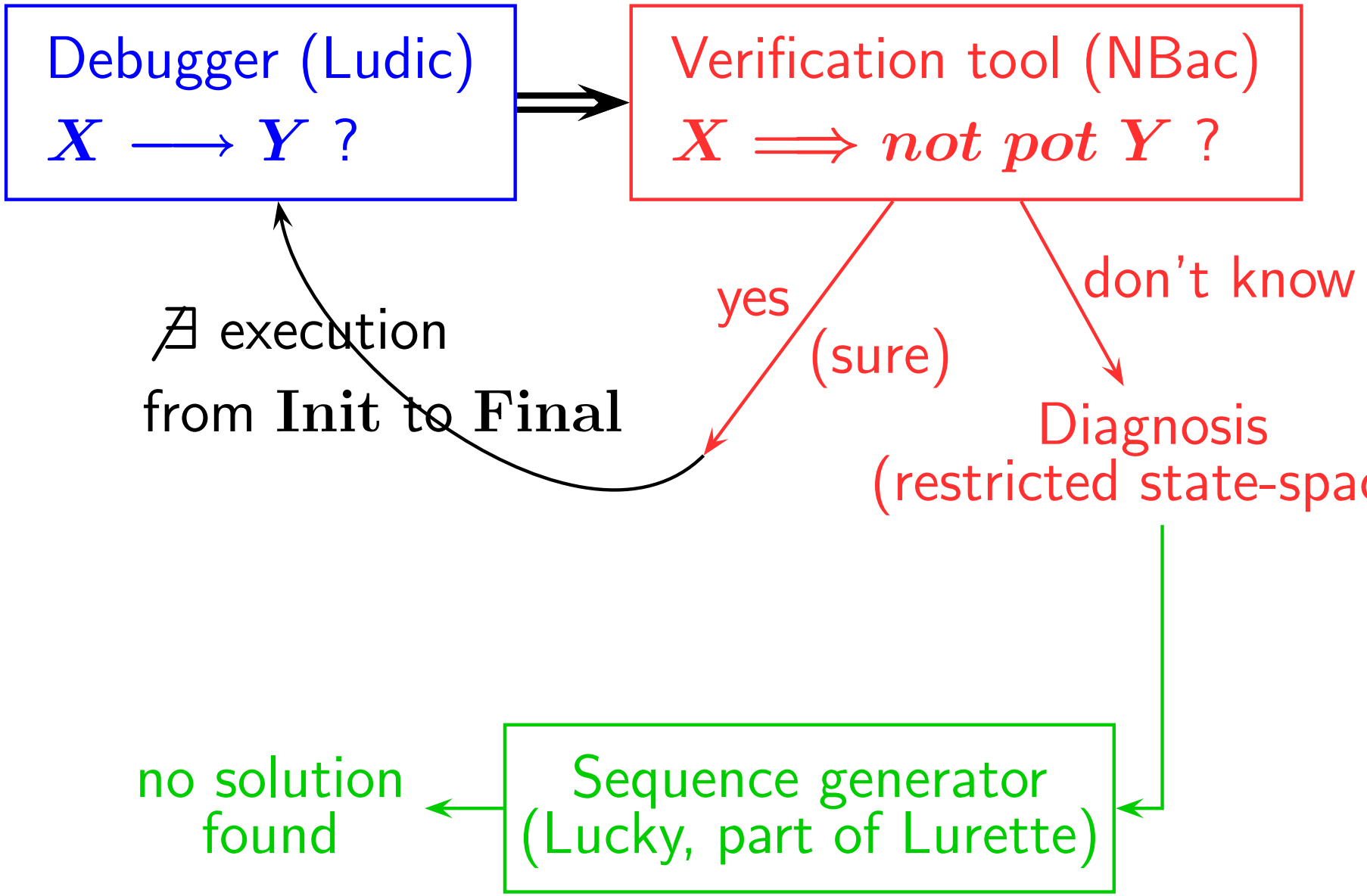

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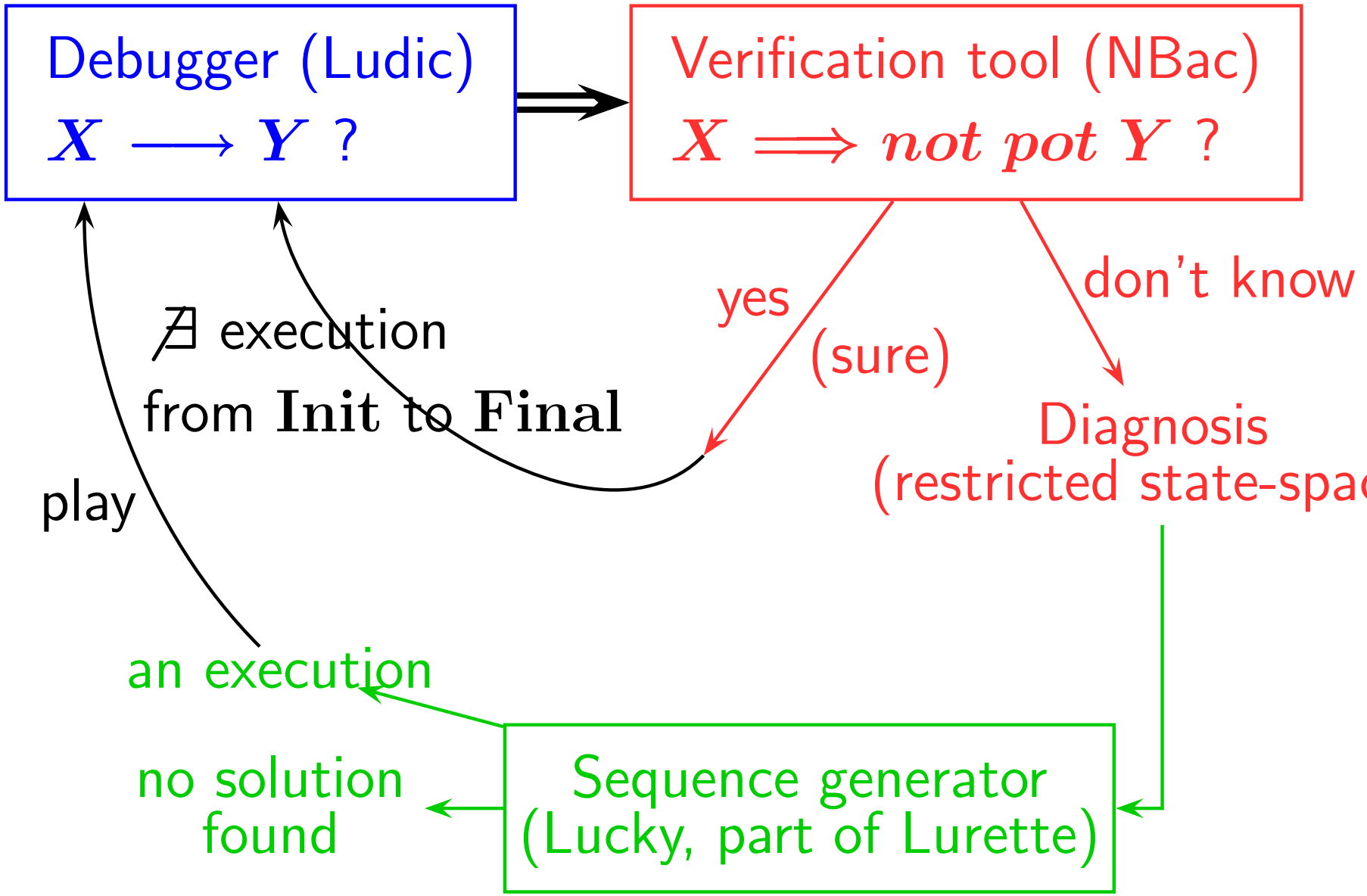
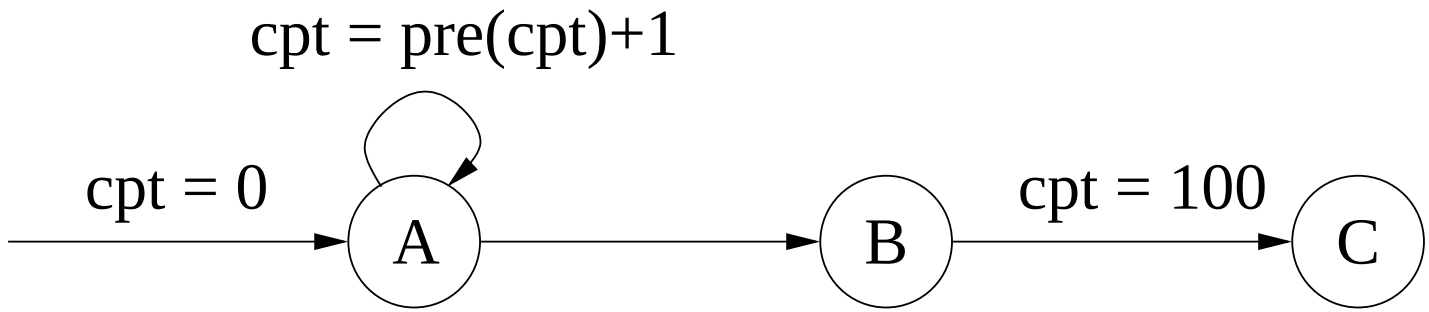


Why restricting the search space is important

A problematic case:



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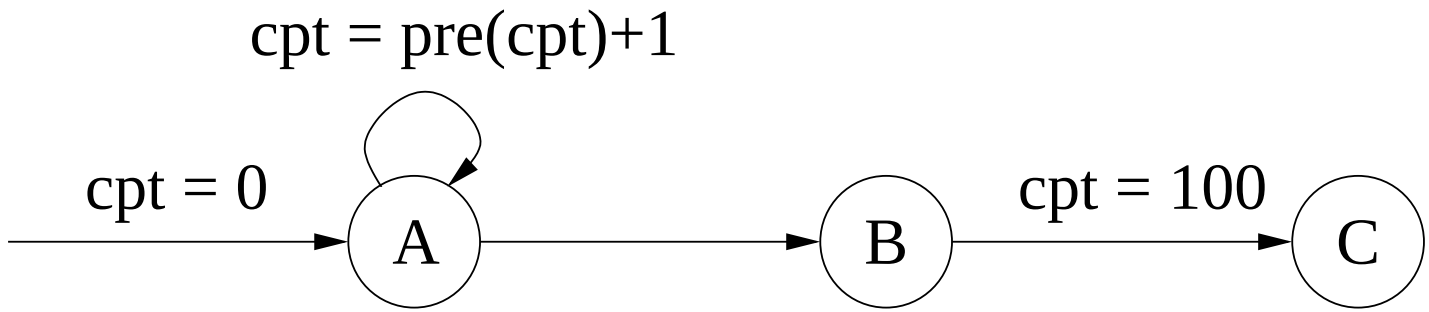

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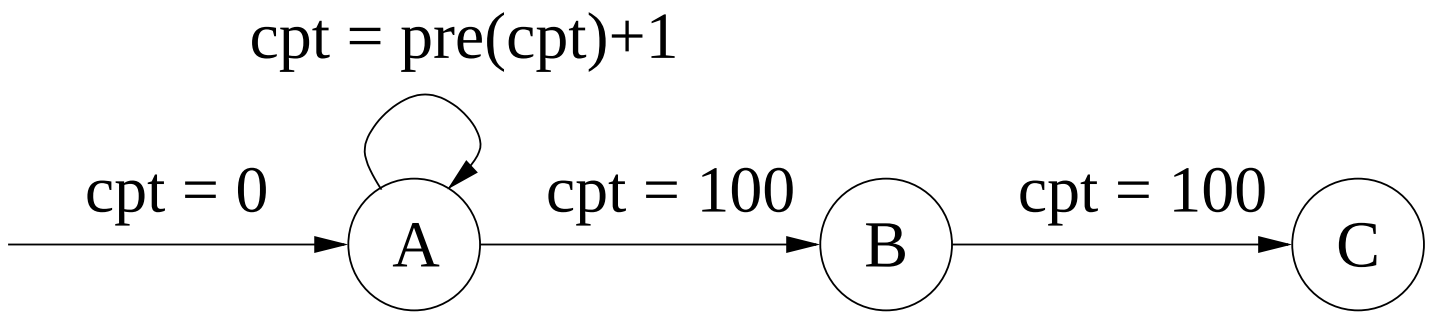
However, a backward analysis on numerical variables gives:



The debugger Ludic

Debugger for Lustre programs

Offer among other features:

- step-by-step execution, both forward and backward
- inspection of program's state
- slicing algorithms to analyse computations within a step

Role of Ludic in the present context: given a program, a current execution state and a goal property observer,

- performs slicing of the program to select its relevant part of w.r.t. the goal property
- generates the verification problem for NBac
- at the end, in case of success, plays the computed execution

From Ludic to NBac

Given the program

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let cpt = if val then (0 -> pre(cpt)) + 1 else 0;
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tel
```

and the observer

```
node goal(m:bool) returns (ok:bool);
let ok = false -> pre(m); tel
```

From Ludic to NBac

```
state
   init, pre_m : bool;
   pre_cpt : int;
input
   val : bool;
   n : int;
local
   goal, start : bool;
   m : bool;
   cpt : int;
definition
   start = (not init) and (pre_cpt = 0);
   goal = if start then false else pre_m;
   cpt = if val then pre_cpt + 1 else 0;
   m = cpt >= n;
transition
   pre_cpt' = cpt;
   pre_m' = m;
   init' = false;
assertion
   n>=5;
initial start;
final goal;
```

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Actually, partition $\Leftrightarrow$ explicit control structure

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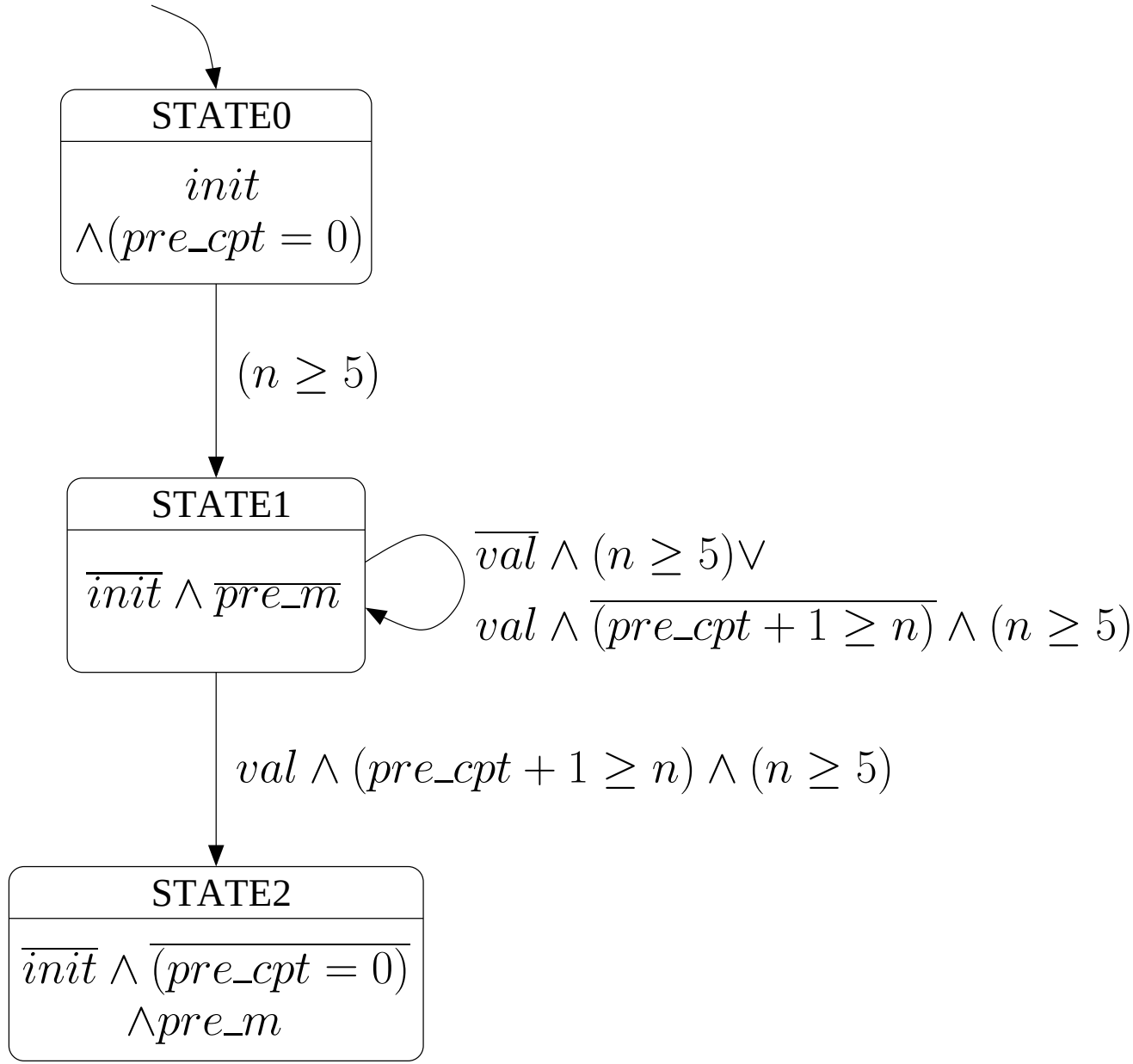
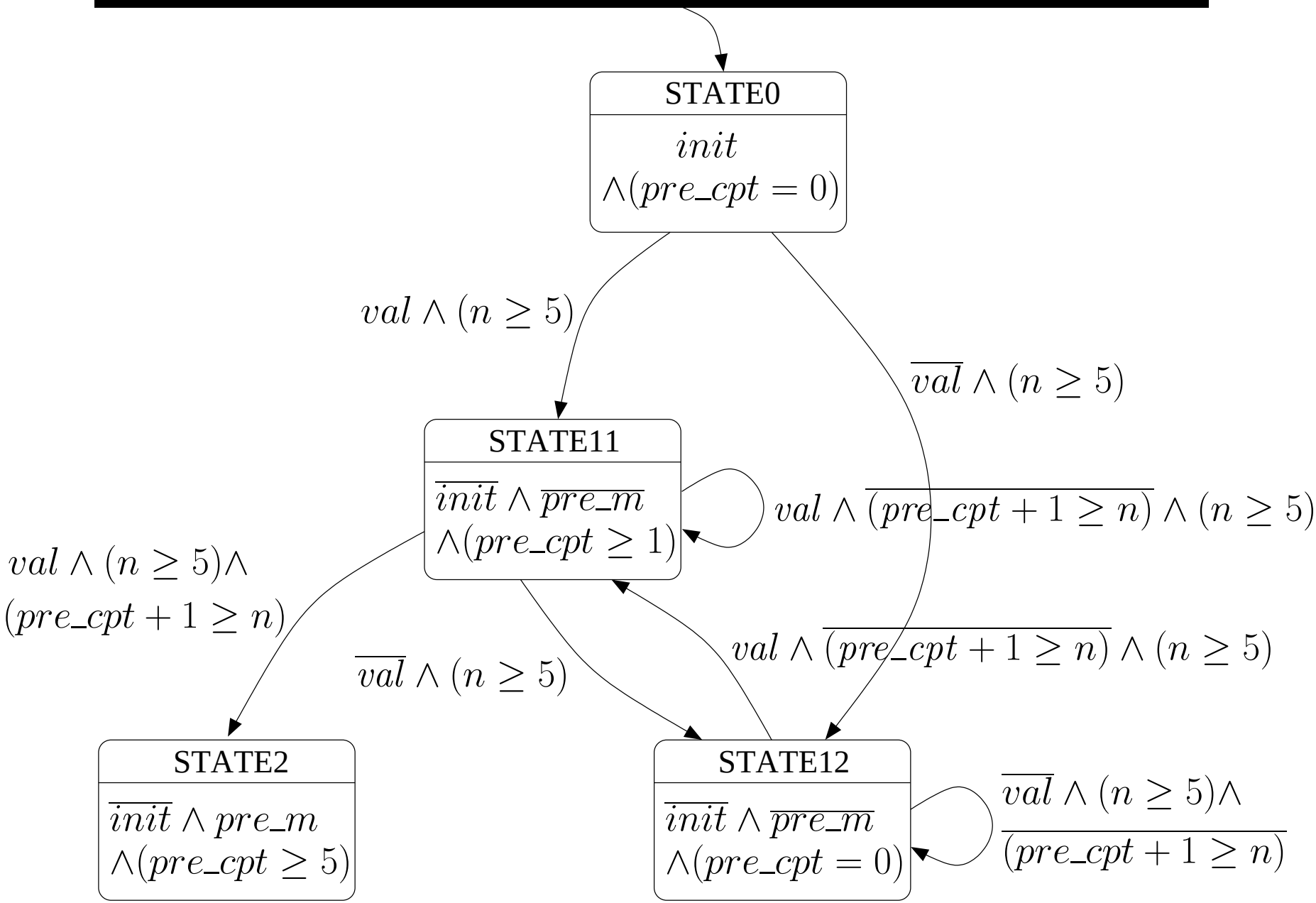
NBac on the example: initial control structure



NBac on the example: output control structure

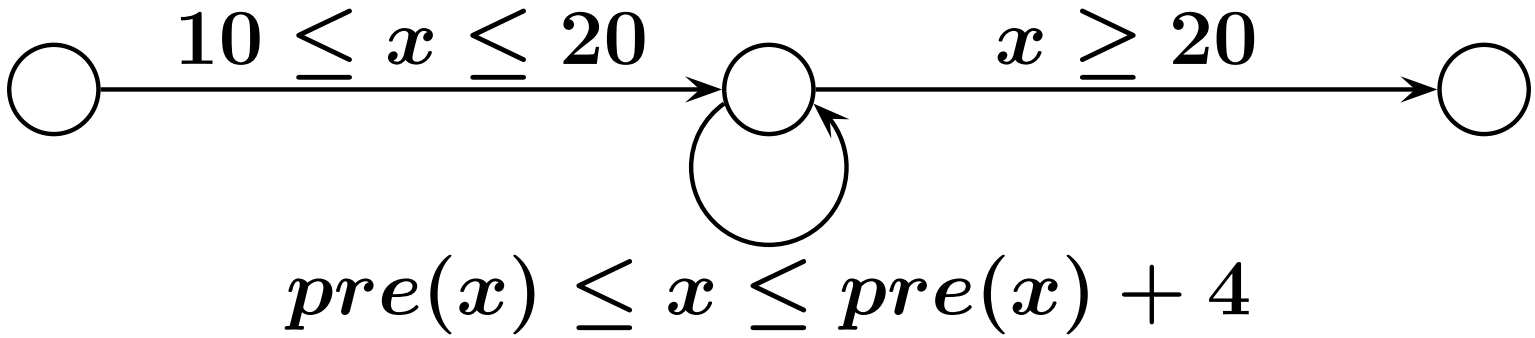


The sequence generator Lucky

Generates sequences from a non-deterministic automaton

Main use: modeling realistic environments

Example of a Lucky automaton:



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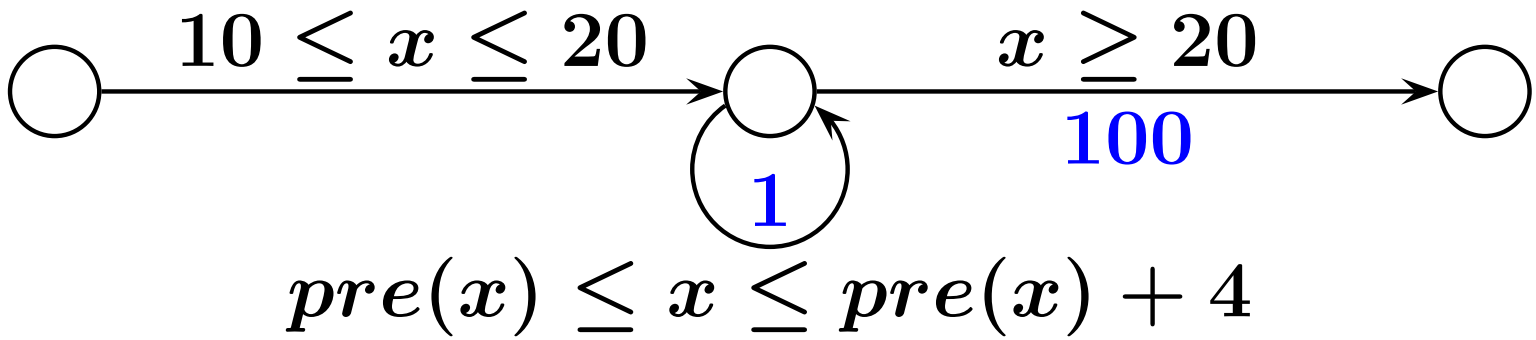

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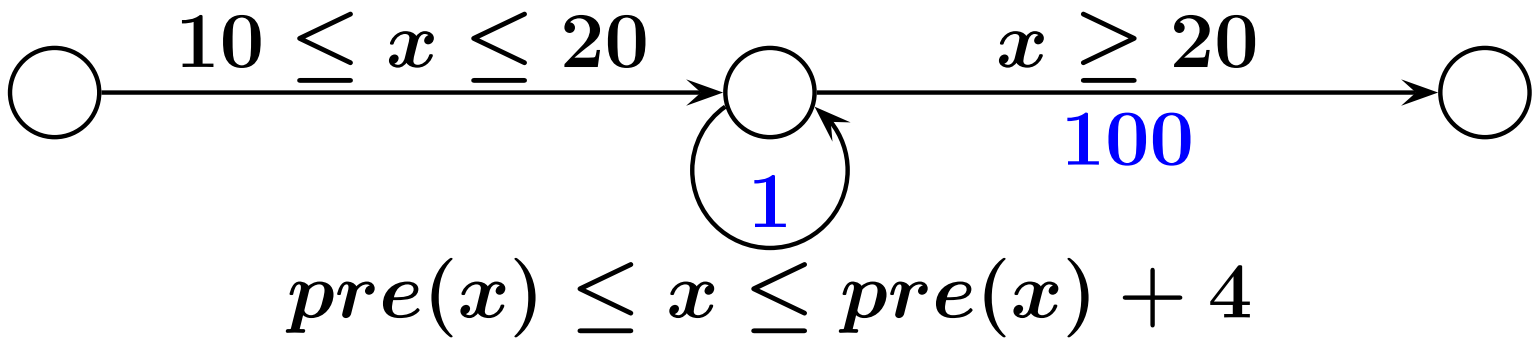
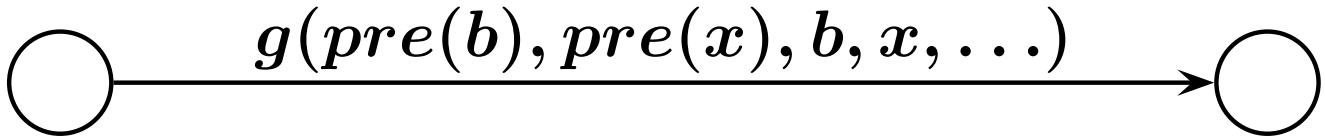


Use in our context:

- automaton generating all the sequences (states & inputs) staying in the restricted state space
- guiding the exploration of the Lucky tool, so as to obtain a (short) sequence leading to a $\mathbf{Final}$ state

The sequence generator Lucky

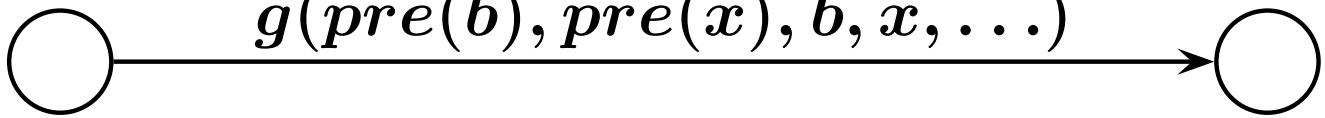
How it works ?



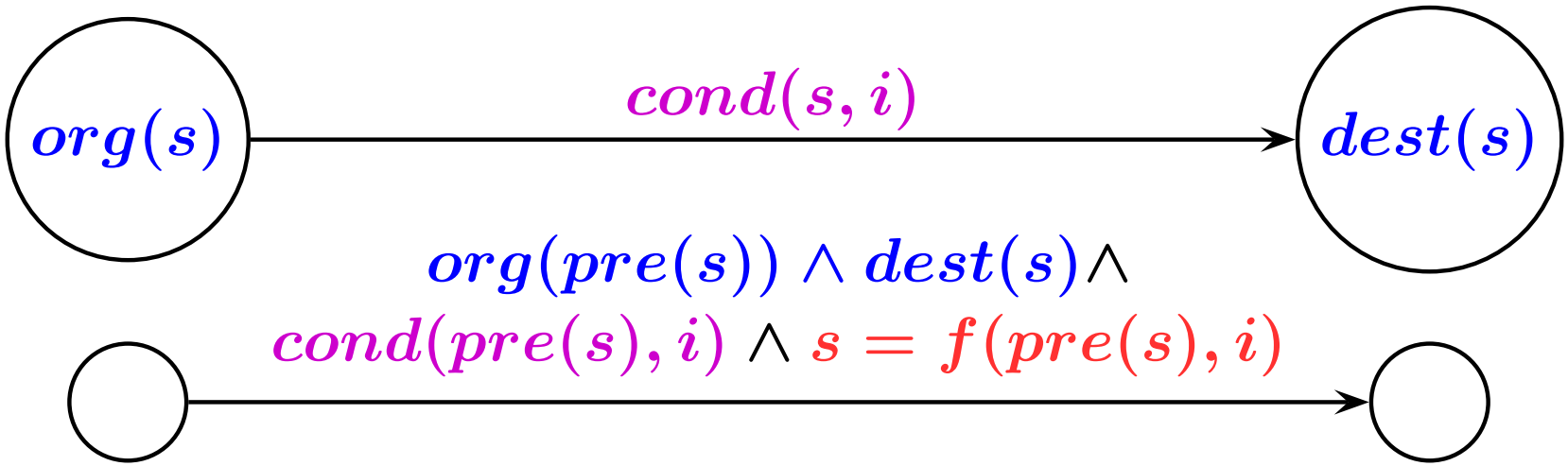
Given a memory state (value of $pre(\cdot)$), builds the set of solutions for $b, x, \ldots$ such that $g = true$
(Using BDDs and convex polyhedra)
Performs uniform random choice to extract one solution

The sequence generator Lucky

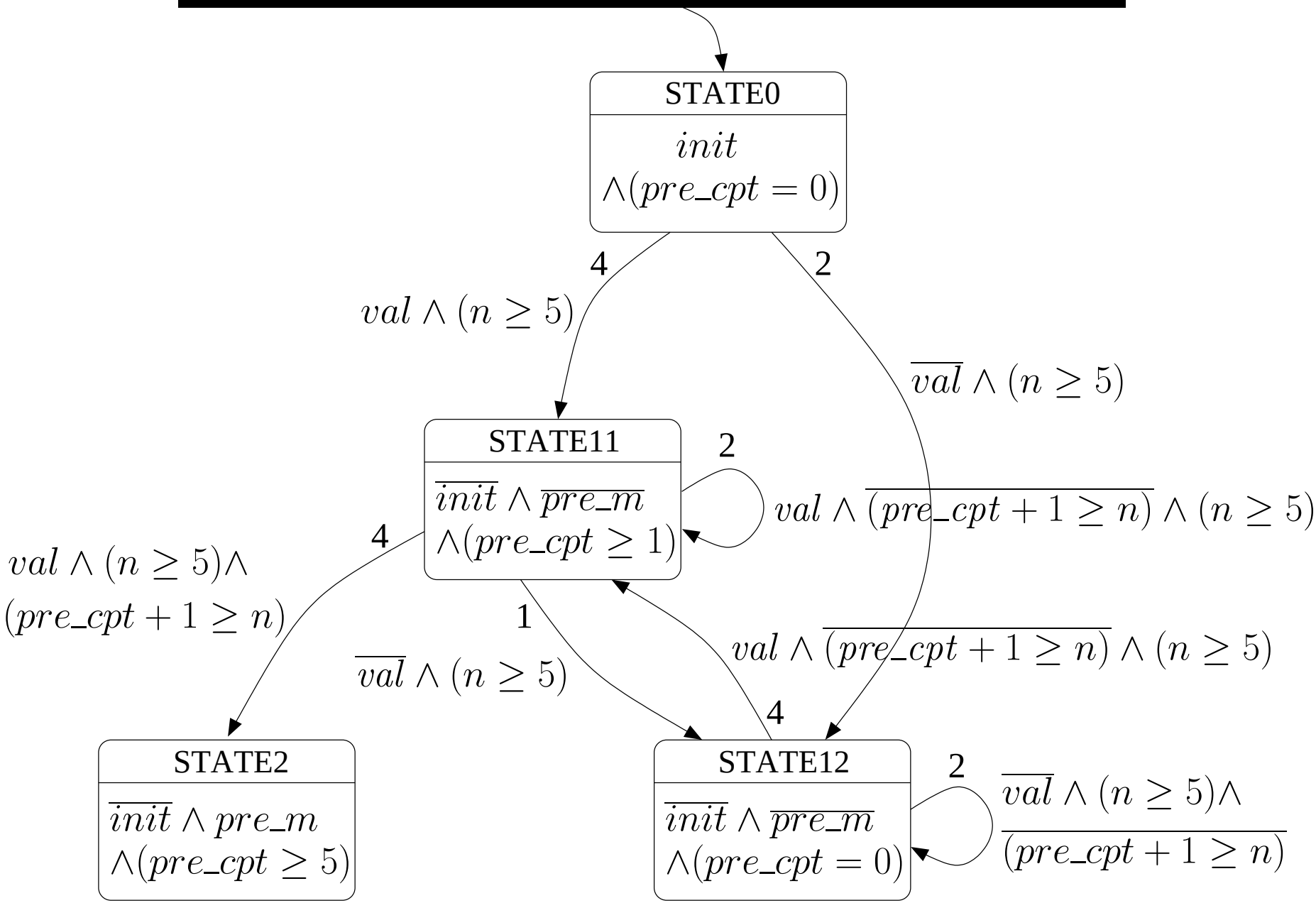
How it works ?



Given a memory state (value of $pre(\cdot)$), builds the set of solutions for $b, x, \ldots$ such that $g = true$
(Using BDDs and convex polyhedra)
Performs uniform random choice to extract one solution
Translation of NBac to Lucky



Decorate NBac automaton with weights



Putting weight in NBac automaton

Main heuristics:

We compute for each location l the minimal distance $\delta(l)$ (in number of edges) leading to a $\mathbf{Final}$ location

Weight of an edge $l \longrightarrow l'$: $p^{\delta(l)-\delta(l')}$

$p > 0$: parameter of the heuristics

Intuition: favorizing edges getting closer to the goal location, and inversally for edges getting more far of it

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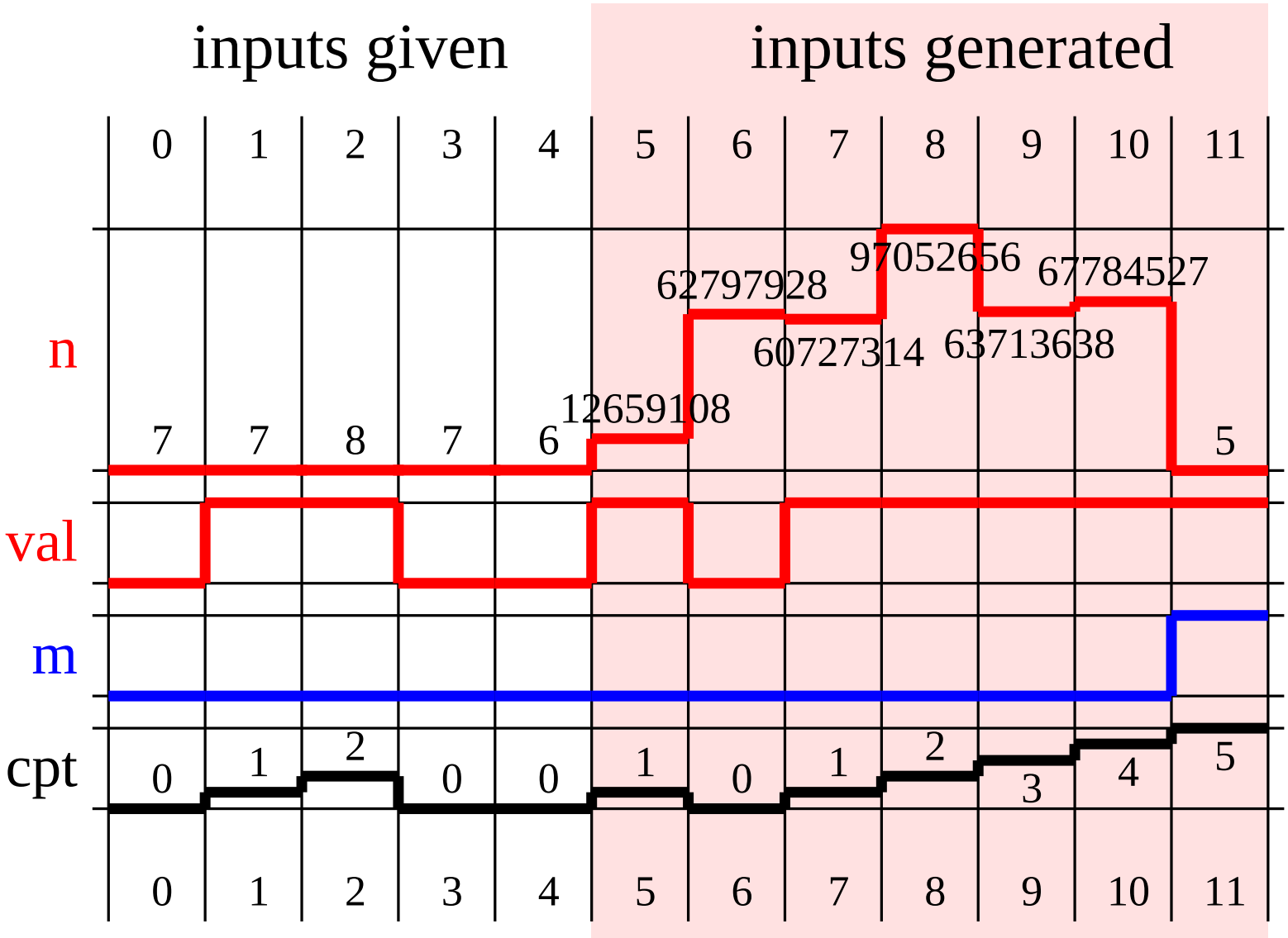
Other possible heuristics: Using Strongly Connected (Sub-)Components decomposition, and favorizing edges exiting components

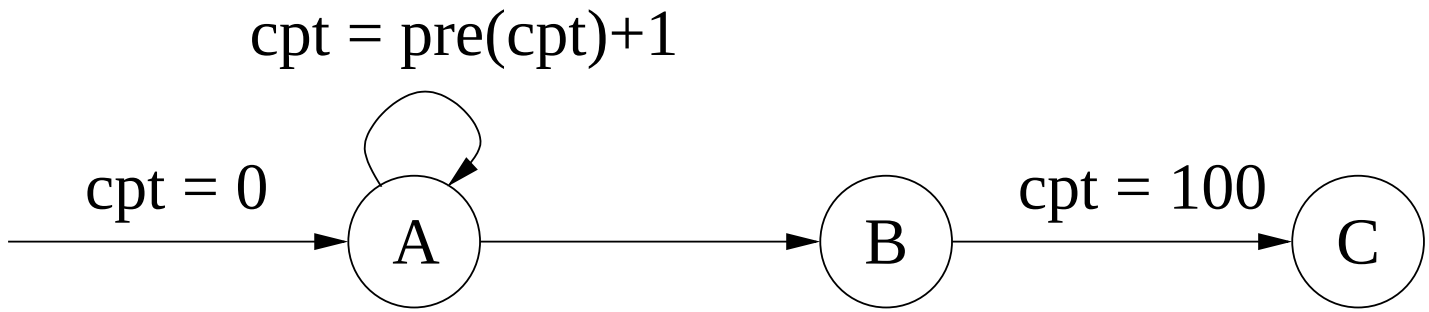
(Could be combined with the previous heuristics)

A sequence generated by Lucky



Why restricting the search space is important

A problematic case:



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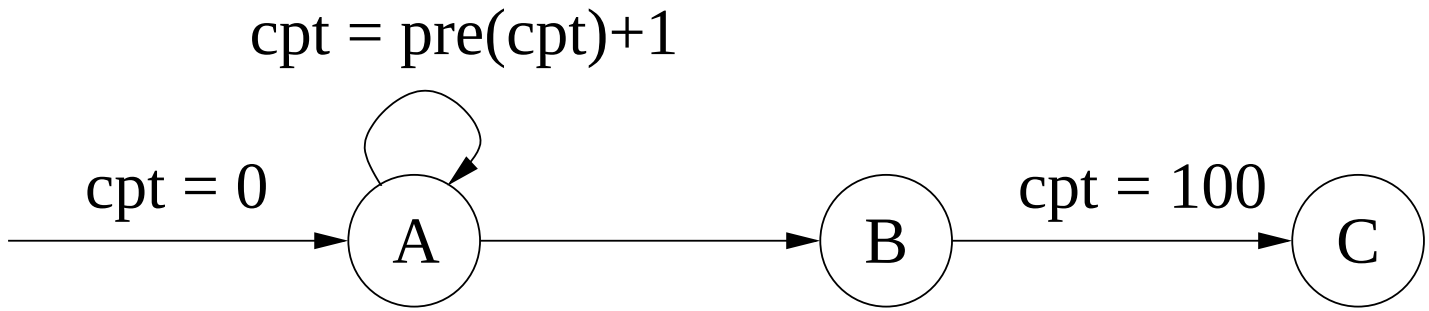

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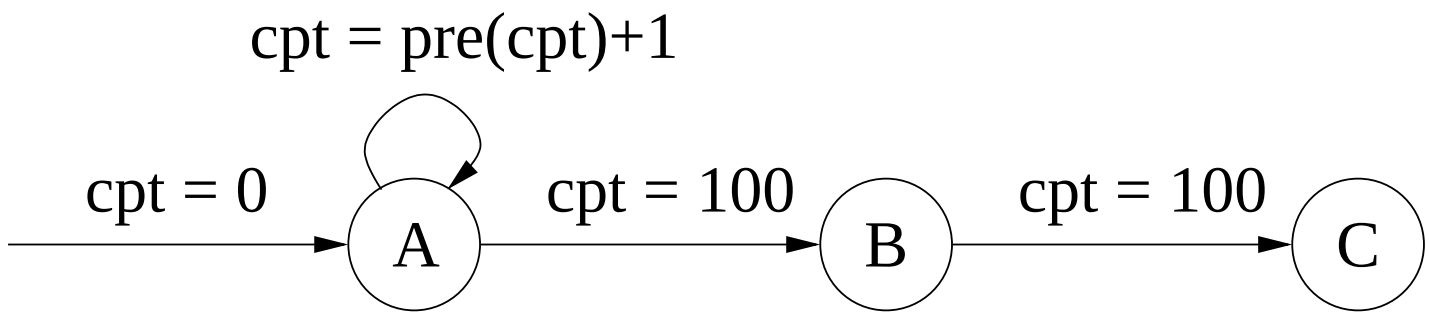
Hopefully, NBac cannot produce such an automaton: the backward analysis gives:



Conclusion

- Lightweight implementation work (connecting tools)
- We have used it for debugging, but application to counter-example generation is straightforward
- More experiments should be conducted
  First experiments are encouraging: slicing is efficient and NBac can often handle the verification problem
- Here, we looked for short sequences
  Other criteria might be interesting (sequences with few input changes between two steps)