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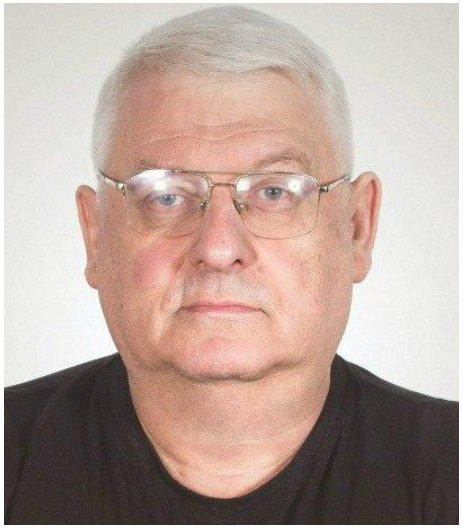
# CSP-based inference of function block finite-state models from execution traces



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INDIN 2017, Emden, Germany

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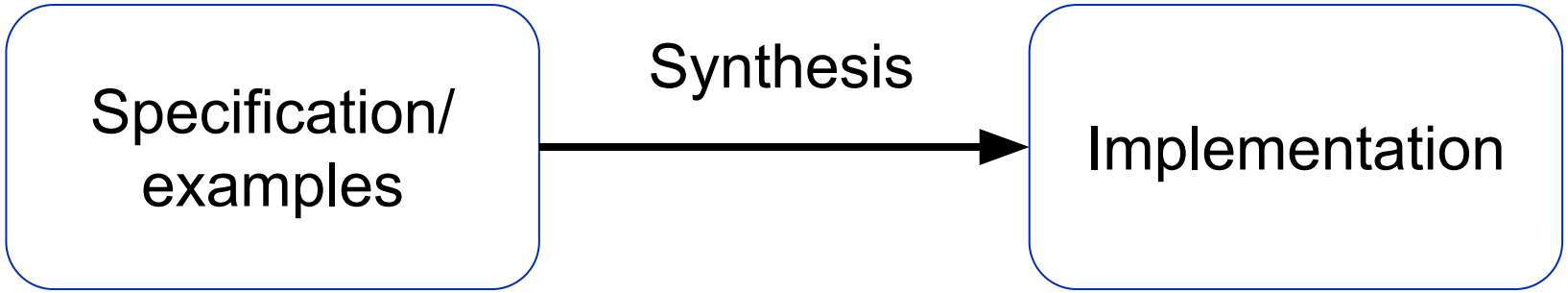
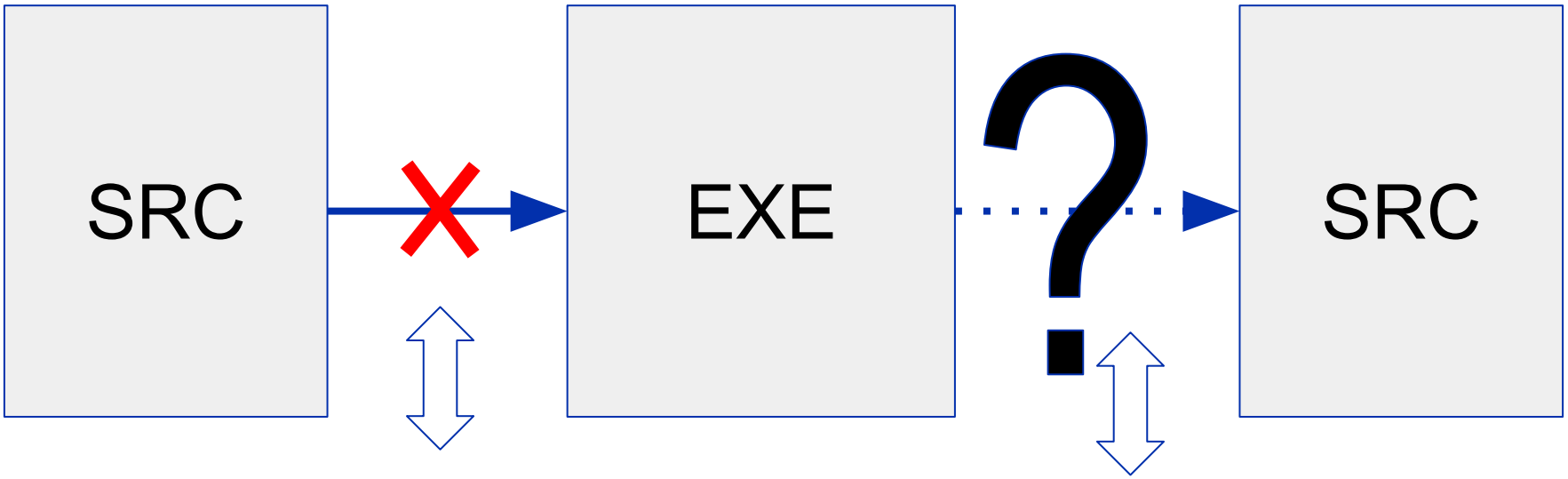
# Program synthesis

- Derive implementation from examples/specification
  - From seminal work [A. Church, 1963]




- Motivation
  - Fundamental in computer science
  - Automation of software engineering
    - Reverse engineering

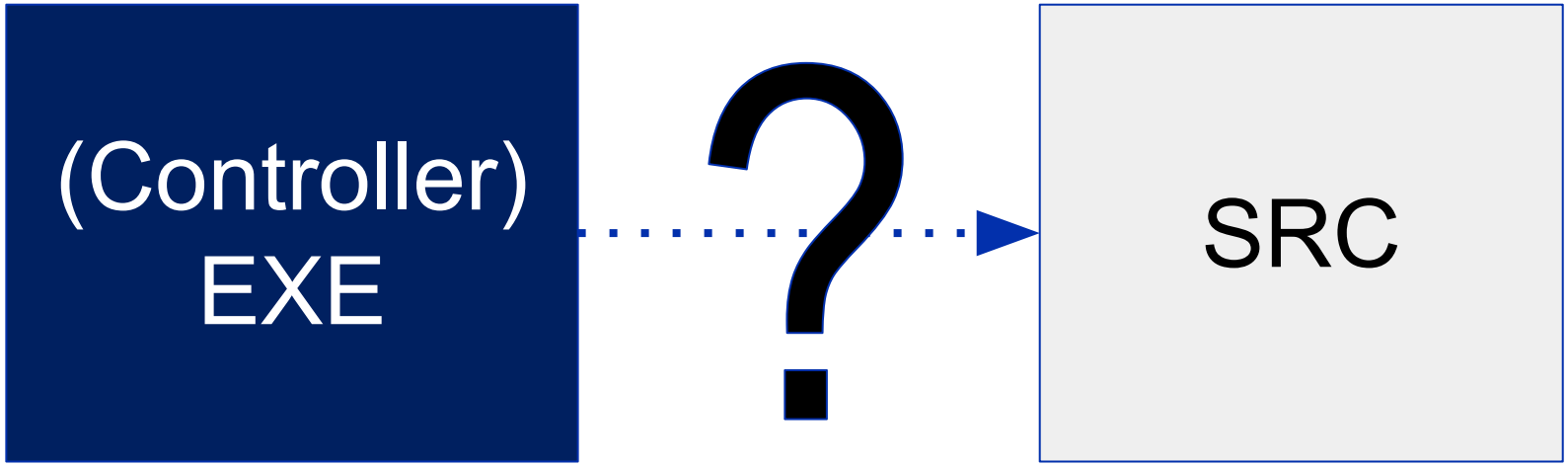
# Reverse engineering of software




- Rights limitations
- Changing standards
- ….

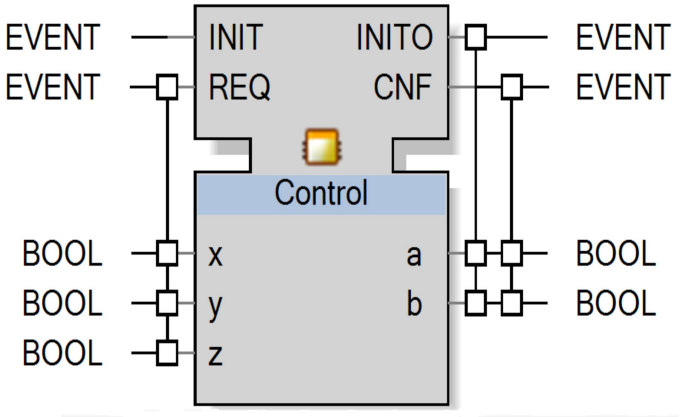
- Understanding
- Optimization
- Verification
- ….

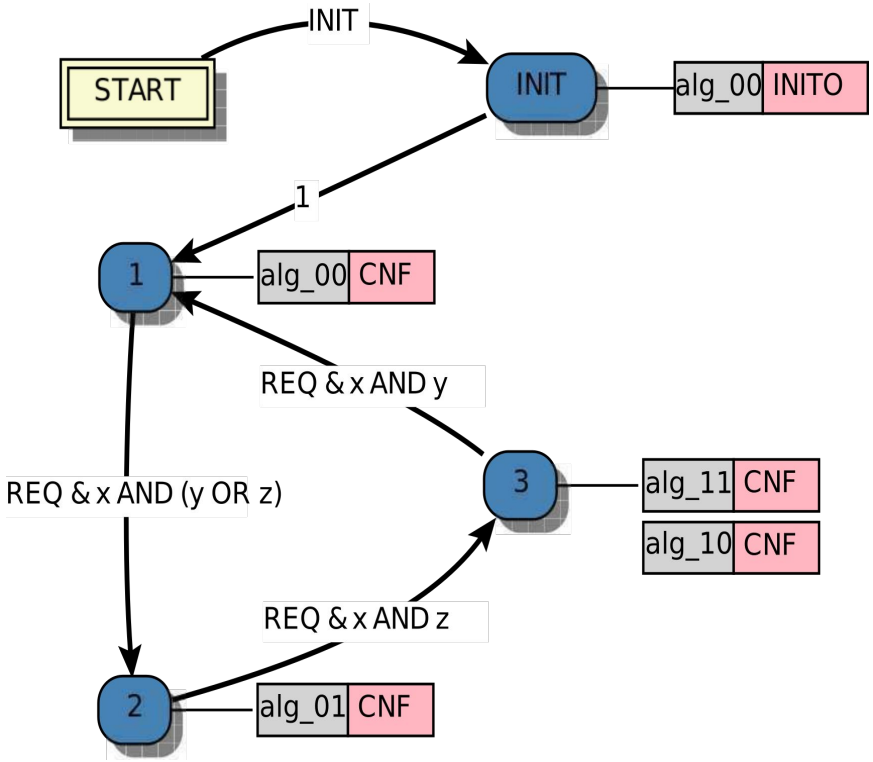
# Black-box approach



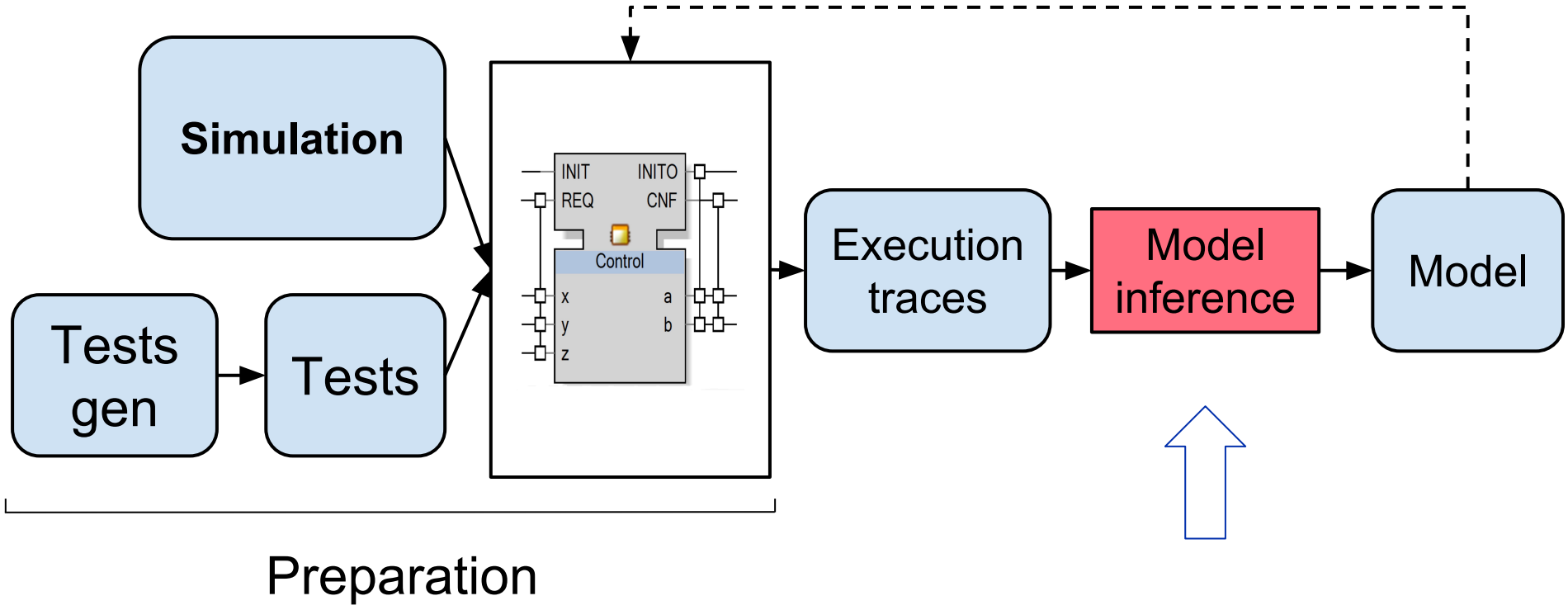

What’s in the box?

# Target language: IEC 61499 function blocks

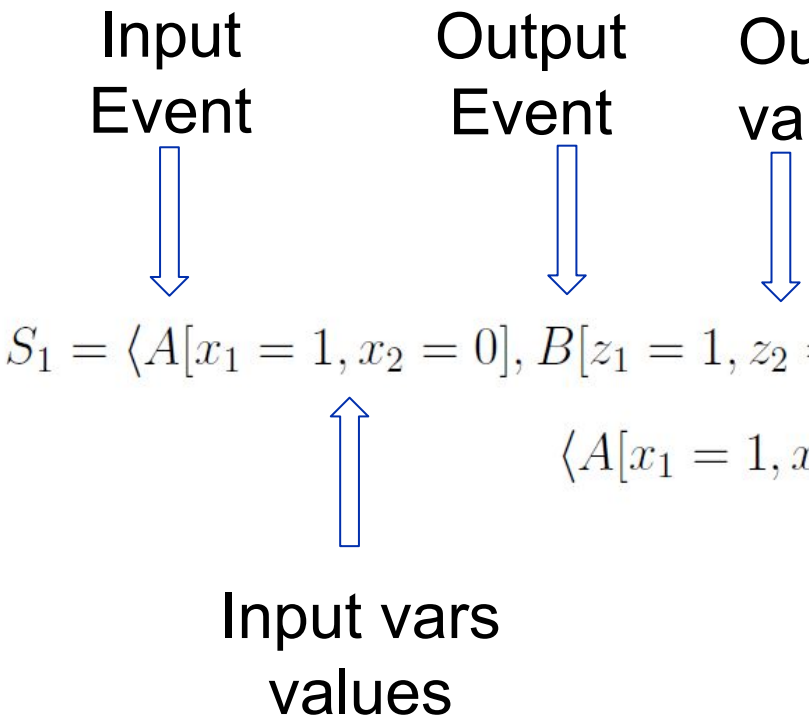


# Test-based reverse engineering

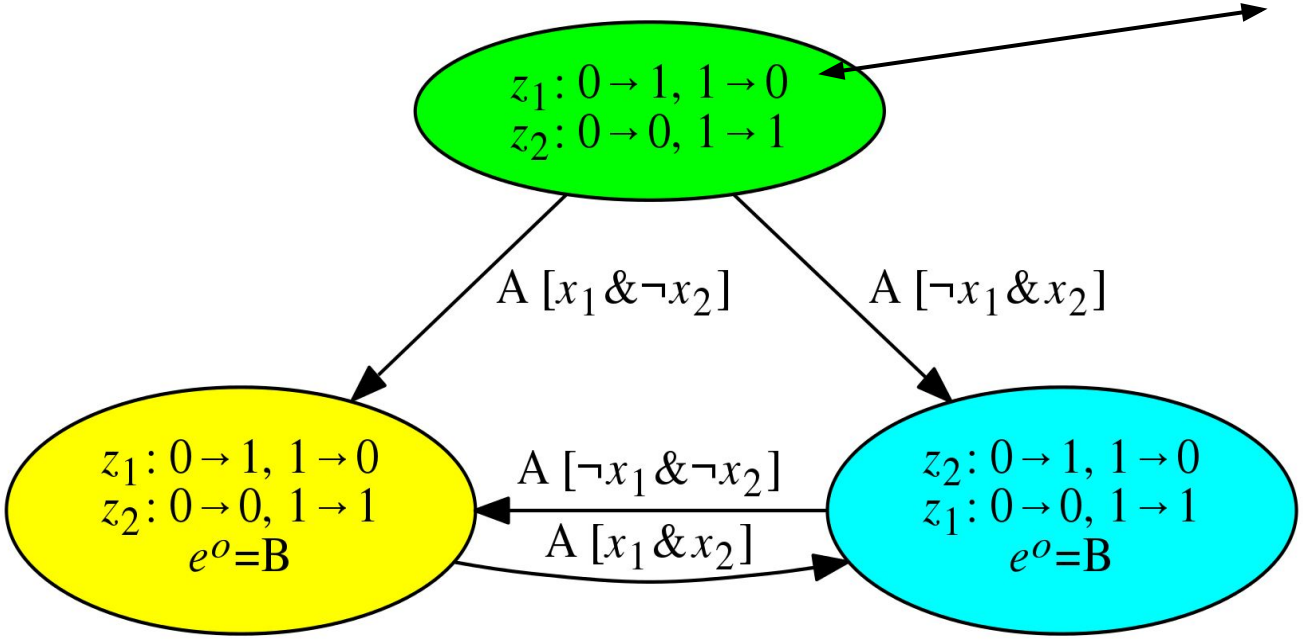


# Scenarios


Input Event
Output Event
Output vars values
$S_1 = \langle A[x_1 = 1, x_2 = 0], B[z_1 = 1, z_2 = 0]\rangle;$
$\langle A[x_1 = 1, x_2 = 1], B[z_1 = 1, z_2 = 1]\rangle;$
$\langle A[x_1 = 0, x_2 = 0], B[z_1 = 0, z_2 = 1]\rangle.$
Input vars values

# Basic function block model

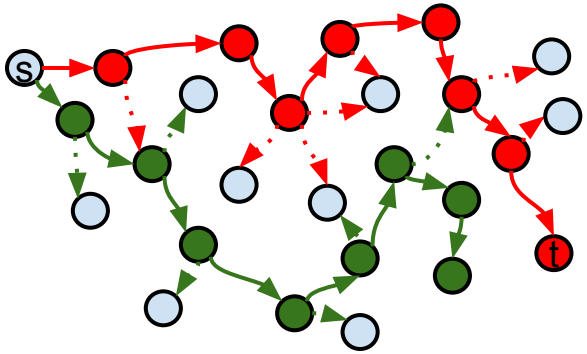
Boolean input/output vars




```
IF NOT z1 THEN
    z1 := TRUE
ELSE
    z1 := FALSE
END_IF;
```

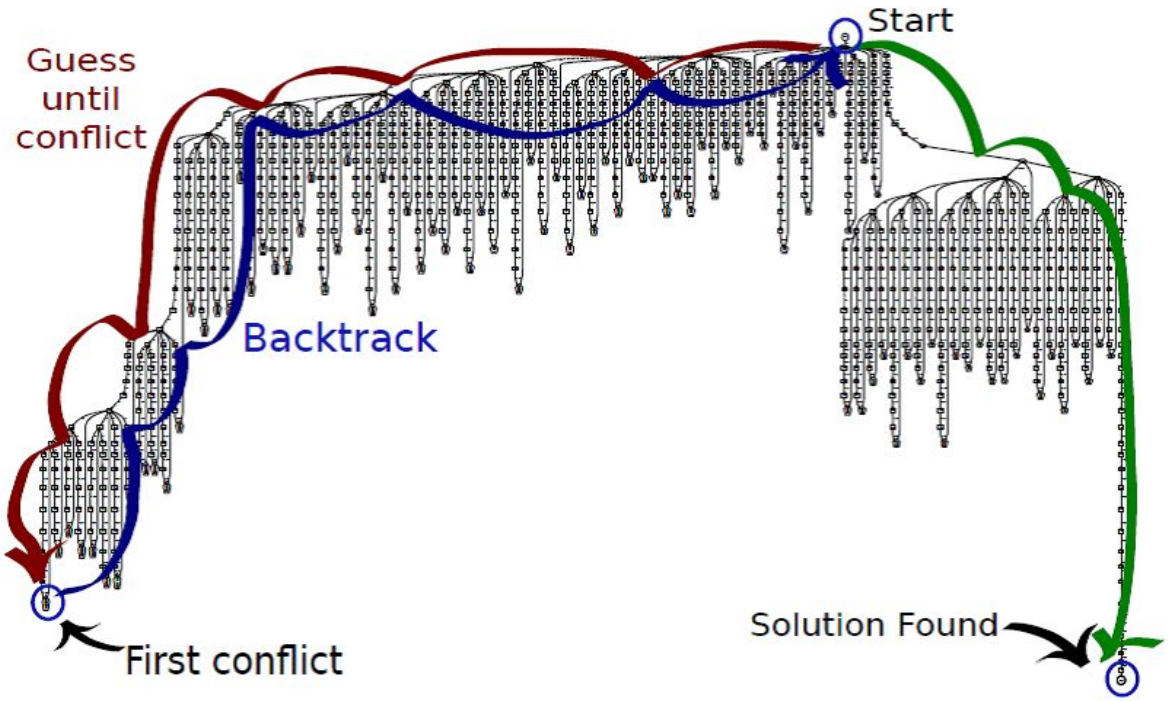
# Previous/proposed approaches

1. Metaheuristic: [Chivilikhin et al / INDIN'15]
   - Slow
   - Approximate




2. We propose **CSP-translation** approach
   - Could be faster in practice
   - Exact

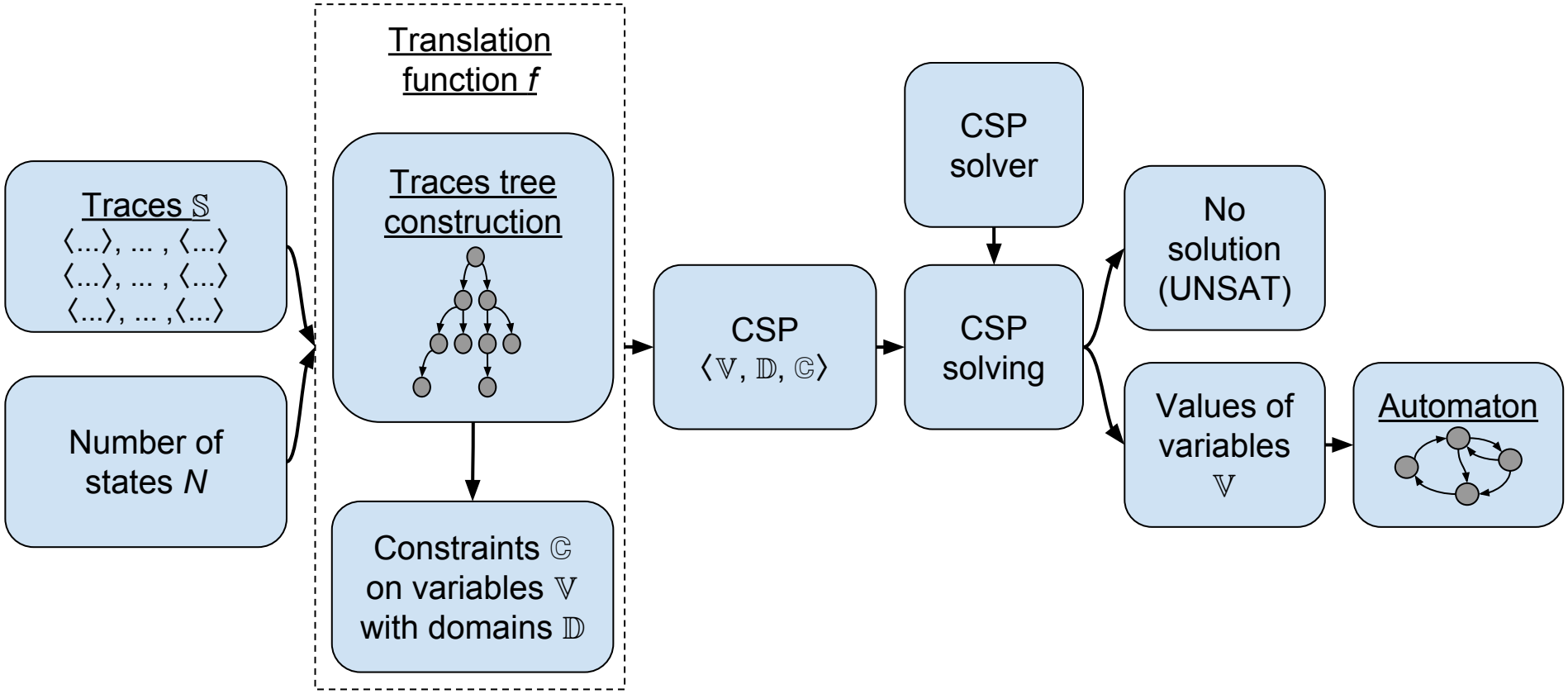
# Proposed approach: translation to Constraint Satisfaction Problem



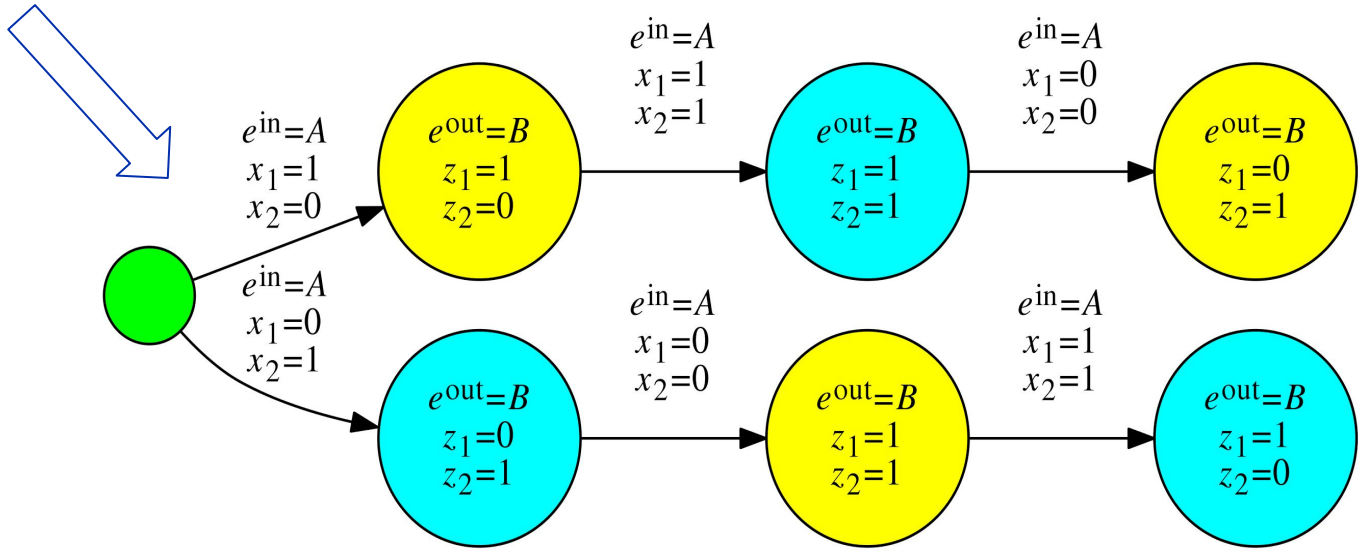

https://srlabs.de/bites/minisat-intro/

# Proposed approach scheme



# Traces tree

$$S_1 = \langle A[x_1 = 1, x_2 = 0], B[z_1 = 1, z_2 = 0]\rangle;$$
$$\langle A[x_1 = 1, x_2 = 1], B[z_1 = 1, z_2 = 1]\rangle;$$
$$\langle A[x_1 = 0, x_2 = 0], B[z_1 = 0, z_2 = 1]\rangle.$$
$$S_2 = \langle A[x_1 = 0, x_2 = 1], B[z_1 = 0, z_2 = 1]\rangle;$$
$$\langle A[x_1 = 0, x_2 = 0], B[z_1 = 1, z_2 = 1]\rangle;$$
$$\langle A[x_1 = 1, x_2 = 1], B[z_1 = 1, z_2 = 0]\rangle.$$

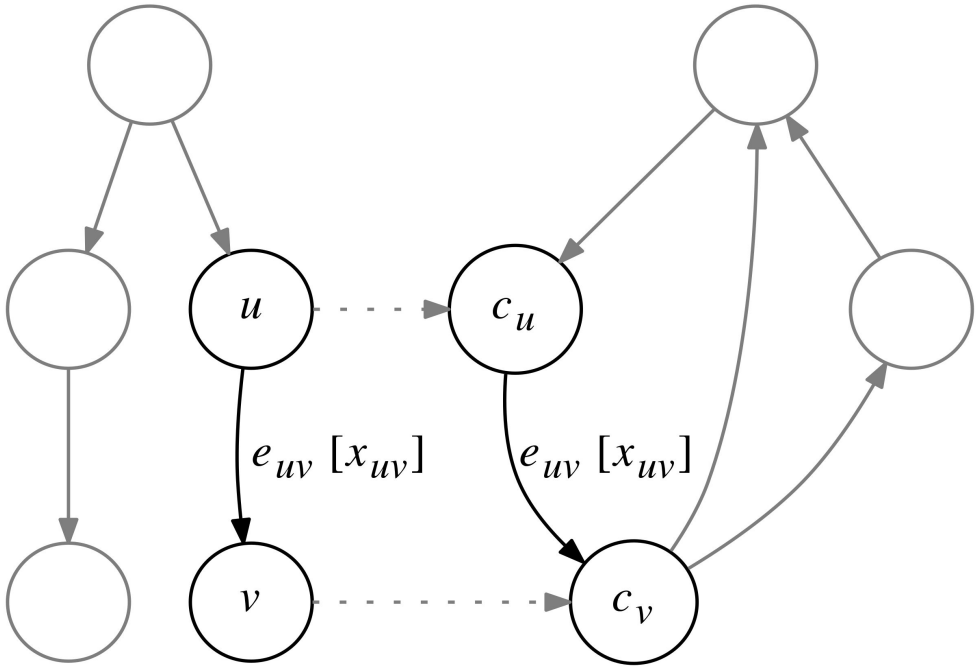


# Variables

- $c_v \in [1..N]$ for $v \in V$ – color of traces tree vertex $v$;
- $t_{n,e,x} \in [1..N]$ for $n \in [1..N]$, $e \in [1..|E^{\mathrm{I}}|]$, $x \in [1..|\hat{X}|]$ – target state of the transition from state $n$ labeled with input event $e$ and guard condition $x$;
- $o_n \in [1..|E^{\mathrm{O}}| + 1]$ for $n \in [1..N]$ – index of the output event in state $n$ ($|E^{\mathrm{O}}| + 1$ corresponds to $\varepsilon$);
- $d^0_{n,i} \in \{0, 1\}$ for $n \in [1..N]$, $i \in [1..|Z|]$ – value of the $i$-th output variable in state $n$ if its previous value equals zero;
- $d^1_{n,i} \in \{0, 1\}$ $n \in [1..N]$, $i \in [1..|Z|]$ – value of the $i$-th output variable in state $n$ if its previous value equals one.

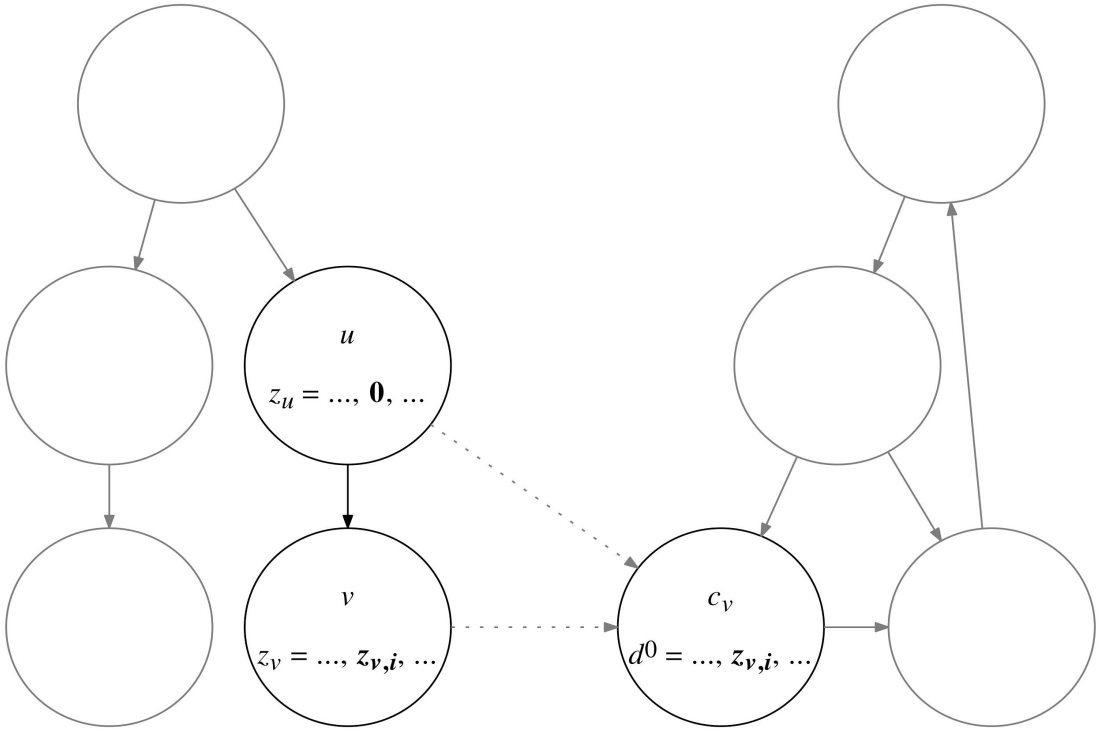
# Main constraints (1)

$$\bigwedge_{u,v \in V} \bigwedge_{uv \in E} \left( t_{c_u, e^{\text{in}}_{uv}, x_{uv}} = c_v \right)$$



# Main constraints (2)

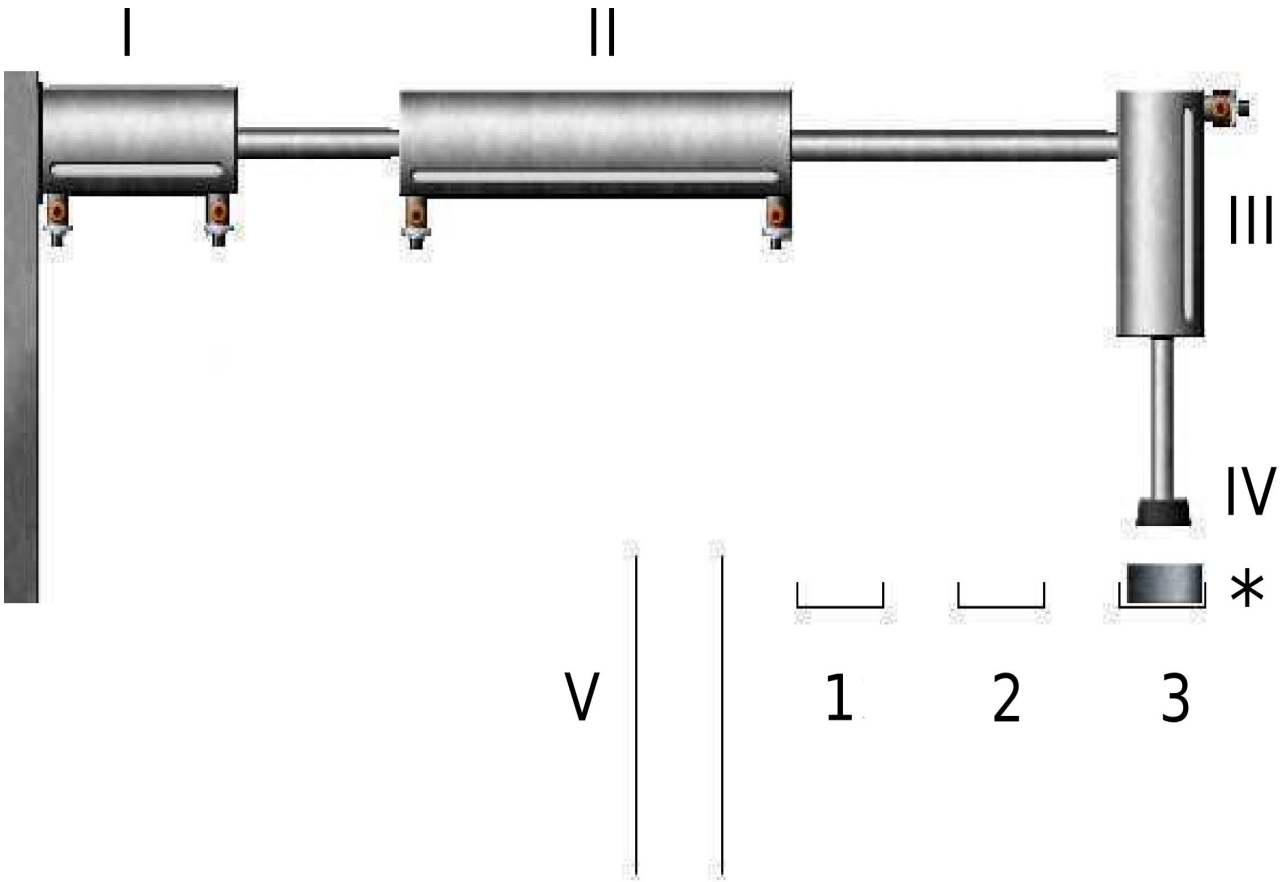
$$\bigwedge_{u,v \in V} \bigwedge_{1 \leqslant i \leqslant |Z|} \left( z_{u,i} = 0 \implies d^0_{c_v,i} = z_{v,i} \right)$$



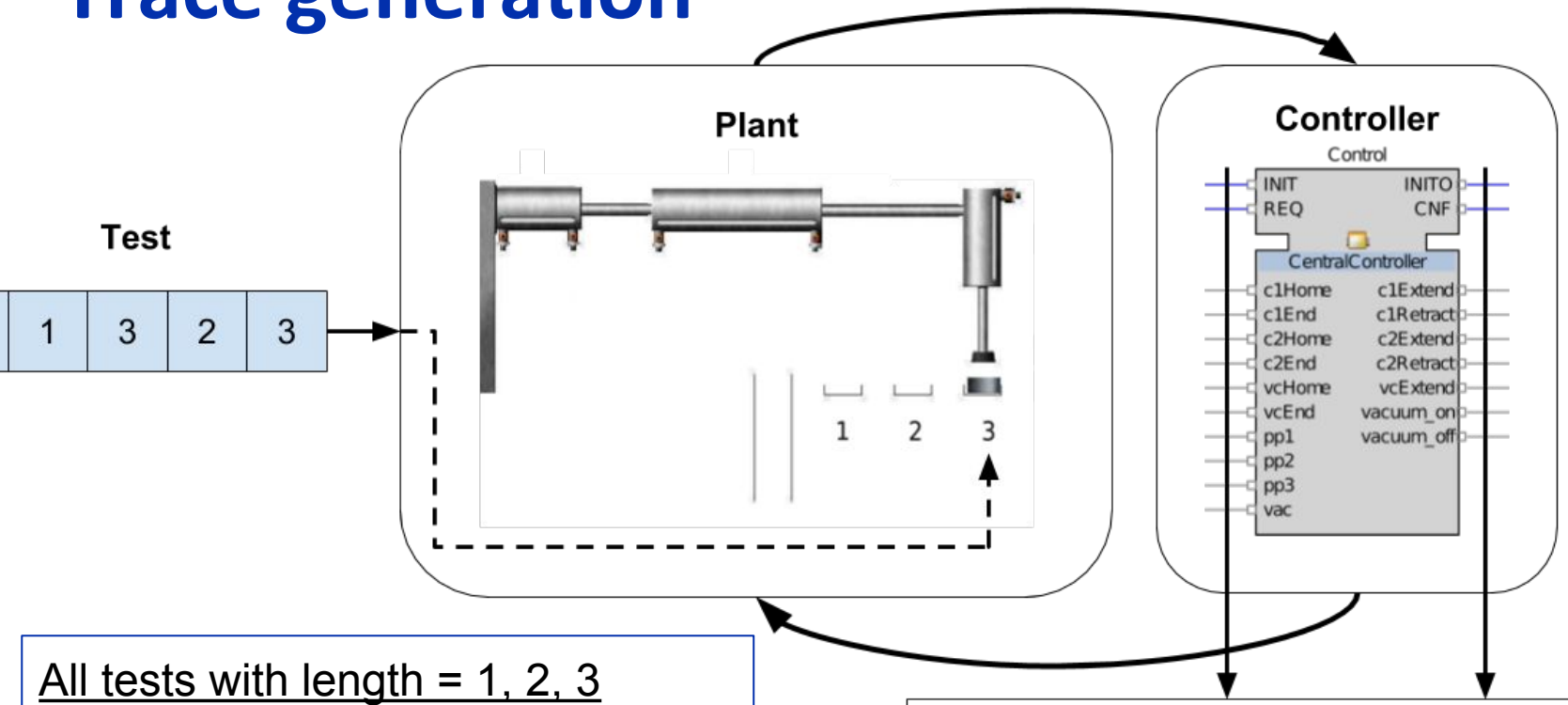

Tree

Automaton

# Case study: pick-and-place manipulator



# Trace generation




All tests with length = 1, 2, 3

#1: 1
#2: 2
…
#12: 1, 1, 1
…
#39: 3, 3, 3

**Execution trace**

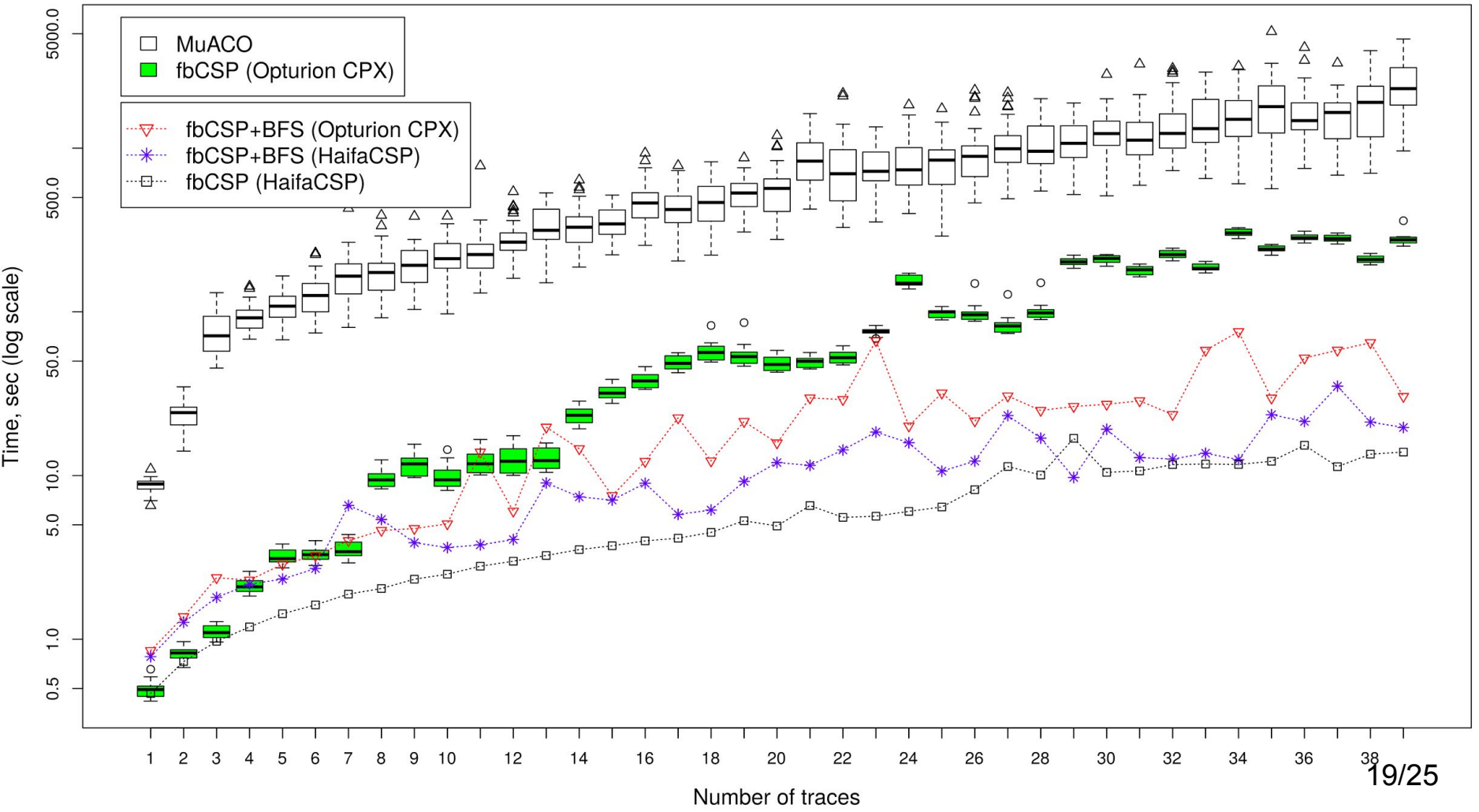
……
……
REQ [0, 1, 0, 1, 0, 0, 0, 0, 1, 0], CNF [1, 0, 1, 0, 1, 0, 0]
……
……

# Experimental setup

- Methods
  - ✓ MuACO
    - metaheuristic [Chivilikhin et al (2015)]
  - ✓ fbCSP
    - Proposed approach
  - ✓ fbCSP+BFS
    - fbCSP + BFS-based symm breaking

- State-of-the-art CSP-solvers
  - ✓ Opturion CPX (Minizinc Challenge 2015 winner)
  - ✓ HaifaCSP (Minizinc Challenge 2016 winner)

# Fixed number of states: N = 10

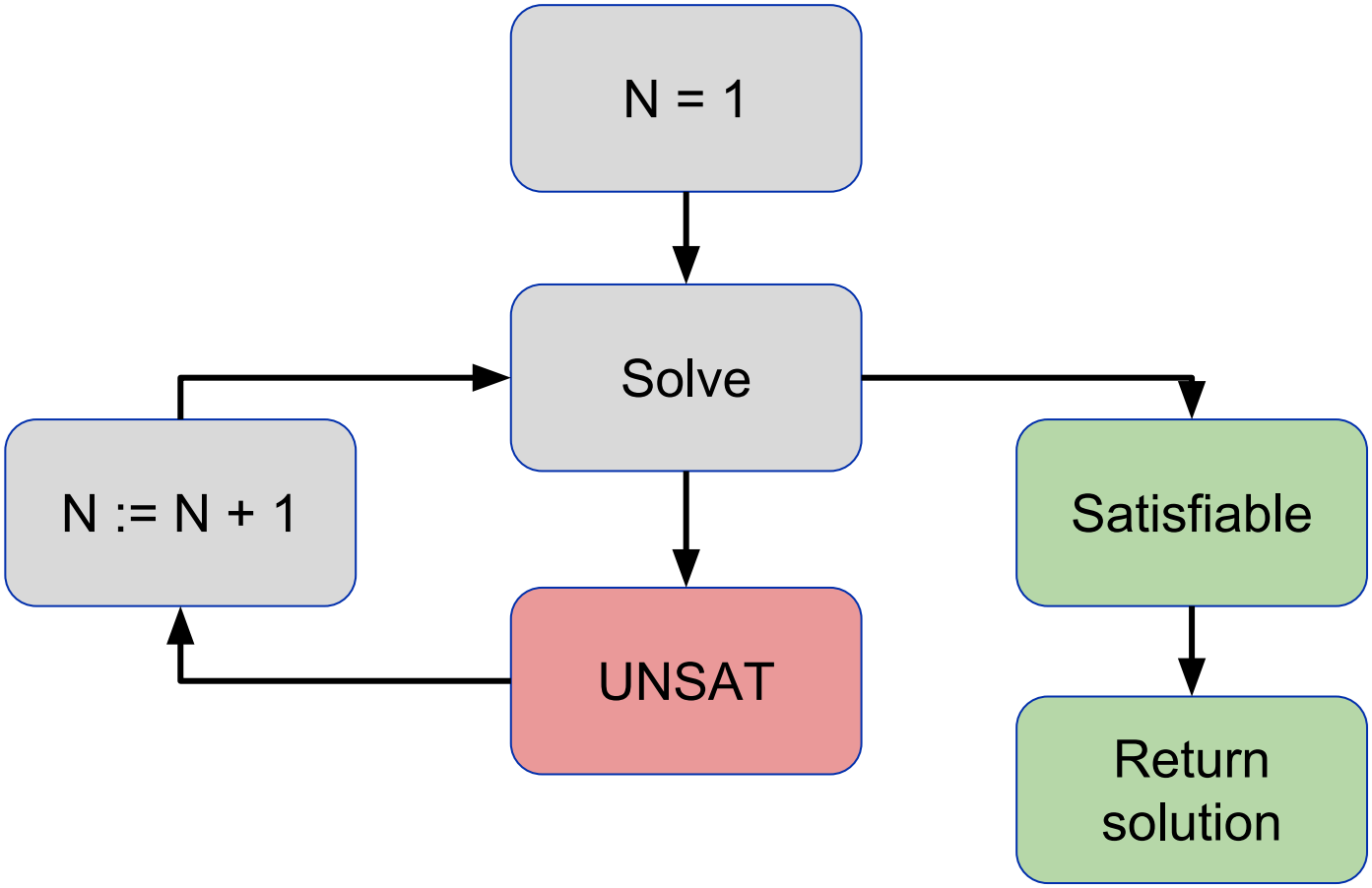


# Minimal model generation

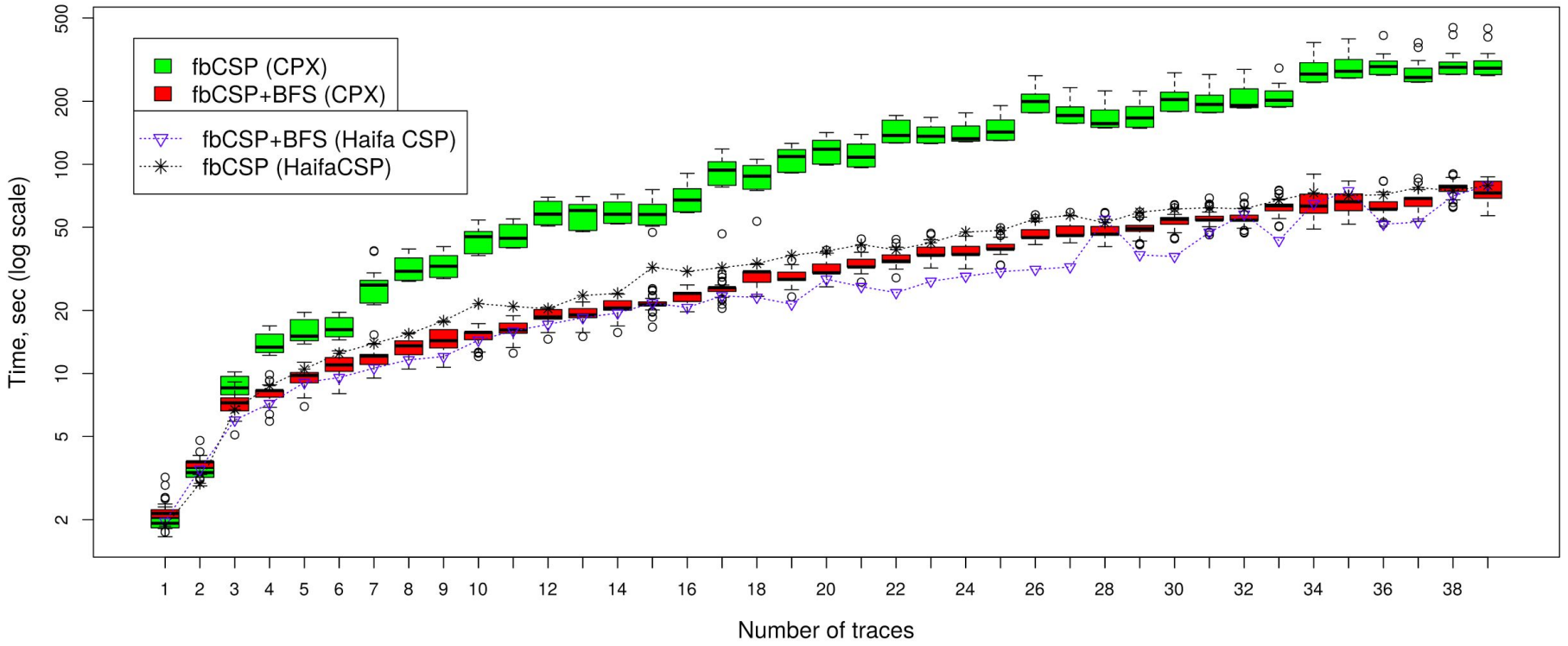
- Most general pattern in the given data
- Occam's razor (law of parsimony):

  *"Among competing hypotheses, the one with the fewest assumptions should be selected"*

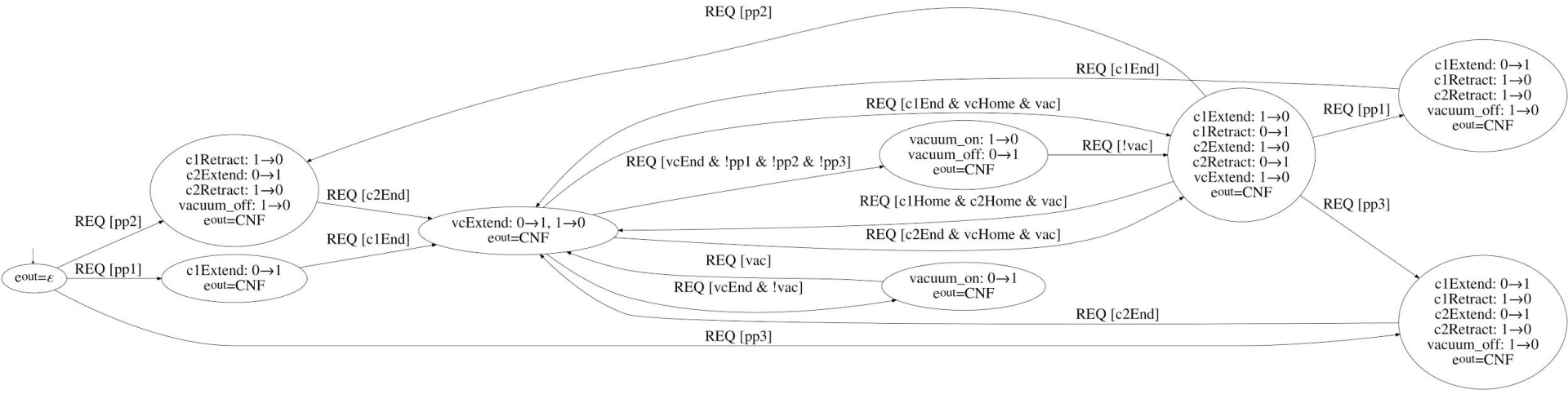
# Minimal model generation



# Minimal model generation: results

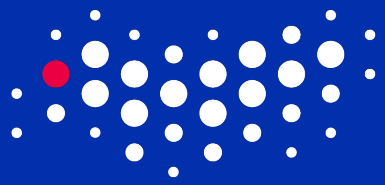


# Generated model example



# Conclusion and Future work

- Proposed fast **exact algorithm** for inferring **minimal-sized** models of basic FBs for logic control
- Available: https://github.com/chivdan/cspgen
- Future/ongoing work
  - Integer/real variables
  - Timers
  - Composite FBs
  - CEGAR for LTL/CTL based inference



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# Thank you for your attention!

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