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Reconstruction of Function Block Controllers Based on Test Scenarios and Verification

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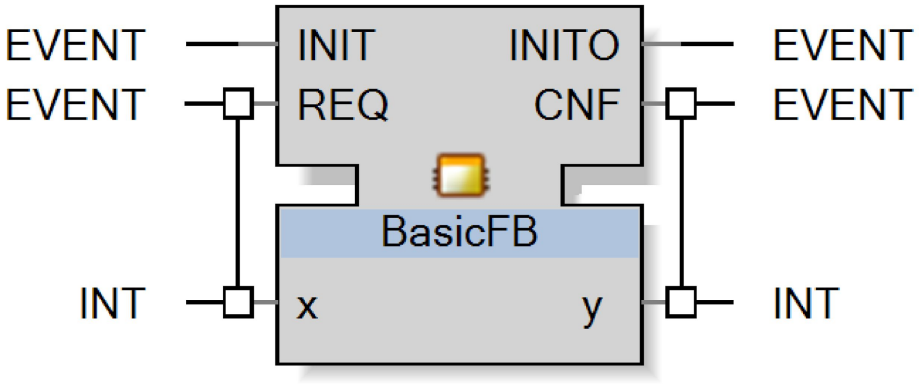
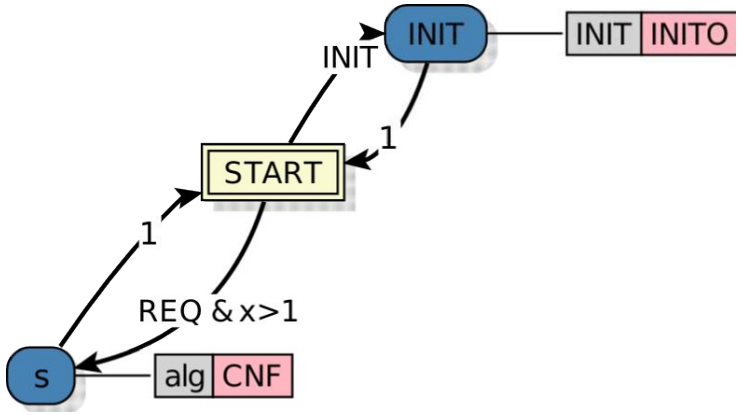
IEC 61499 function blocks

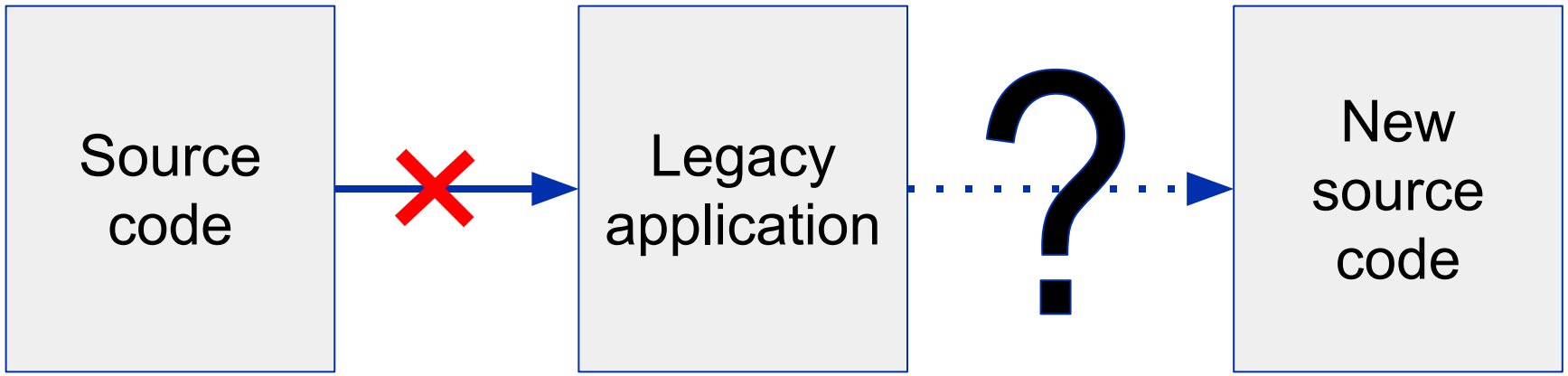


Function block interface

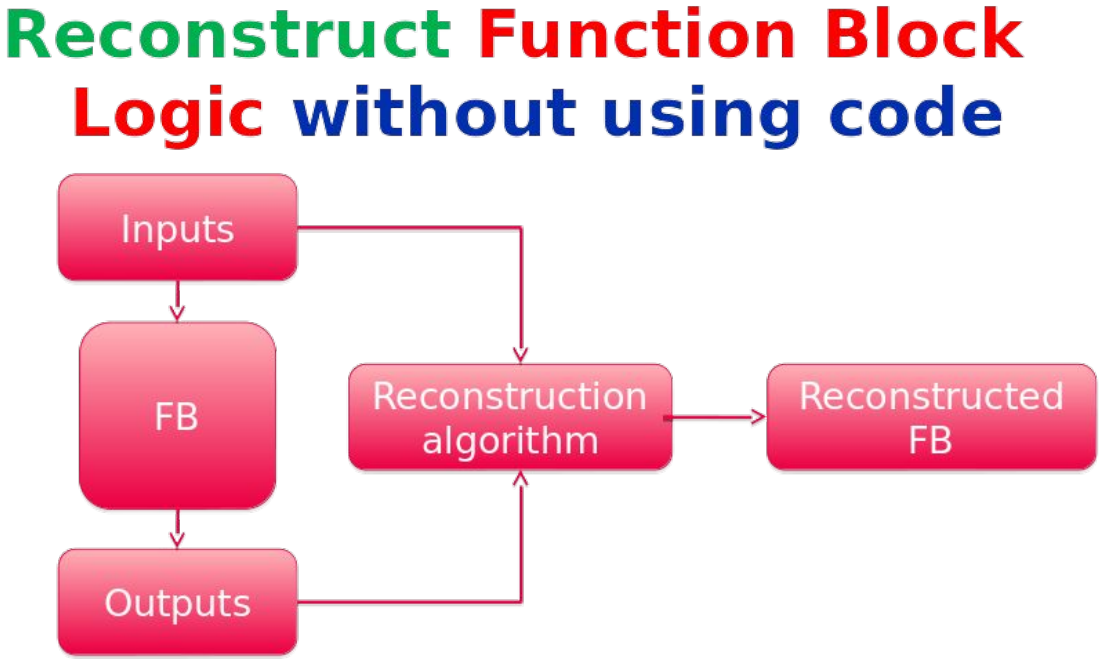


Execution Control Chart (ECC)

Motivation

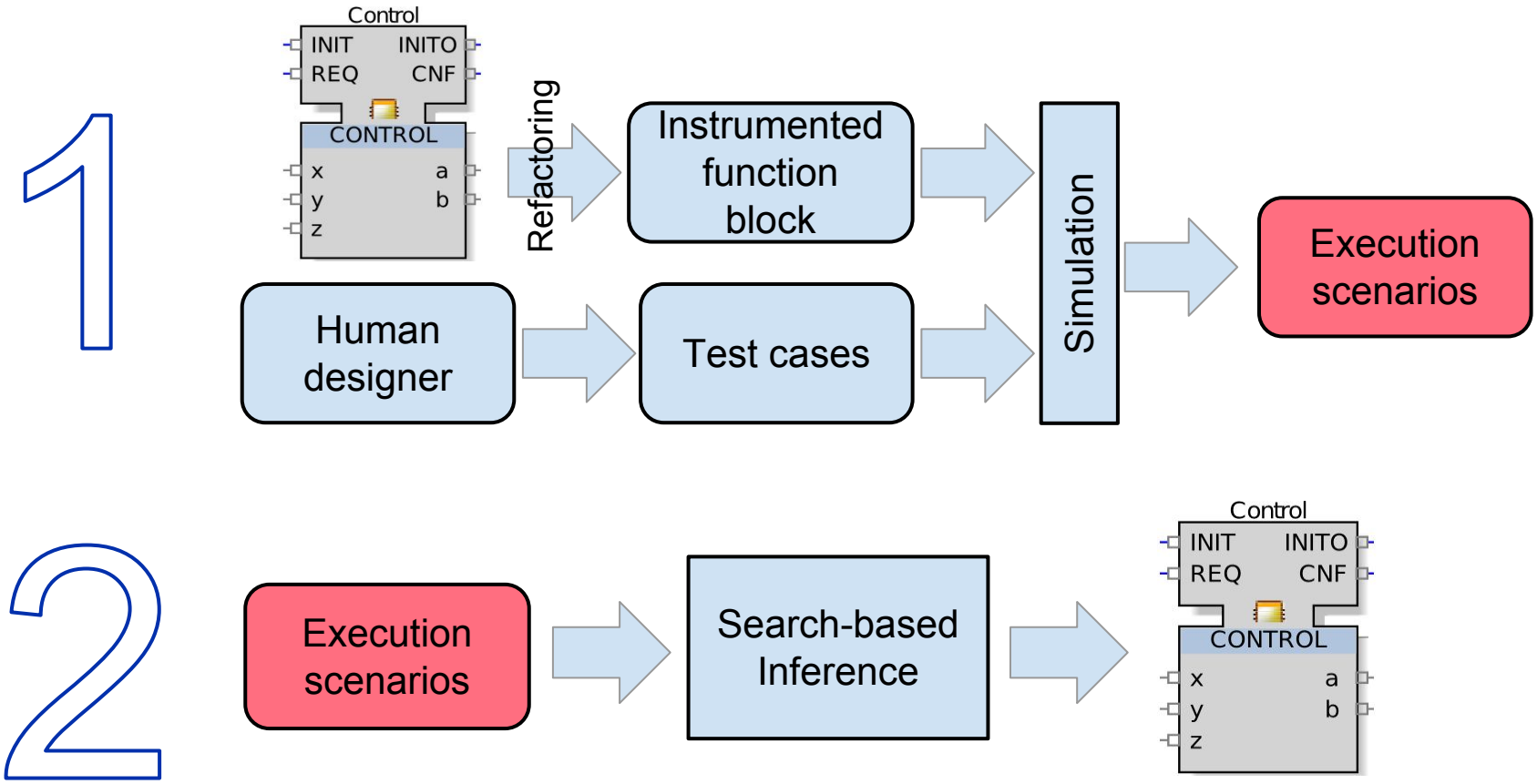


Previous work: Test-based FB reconstruction

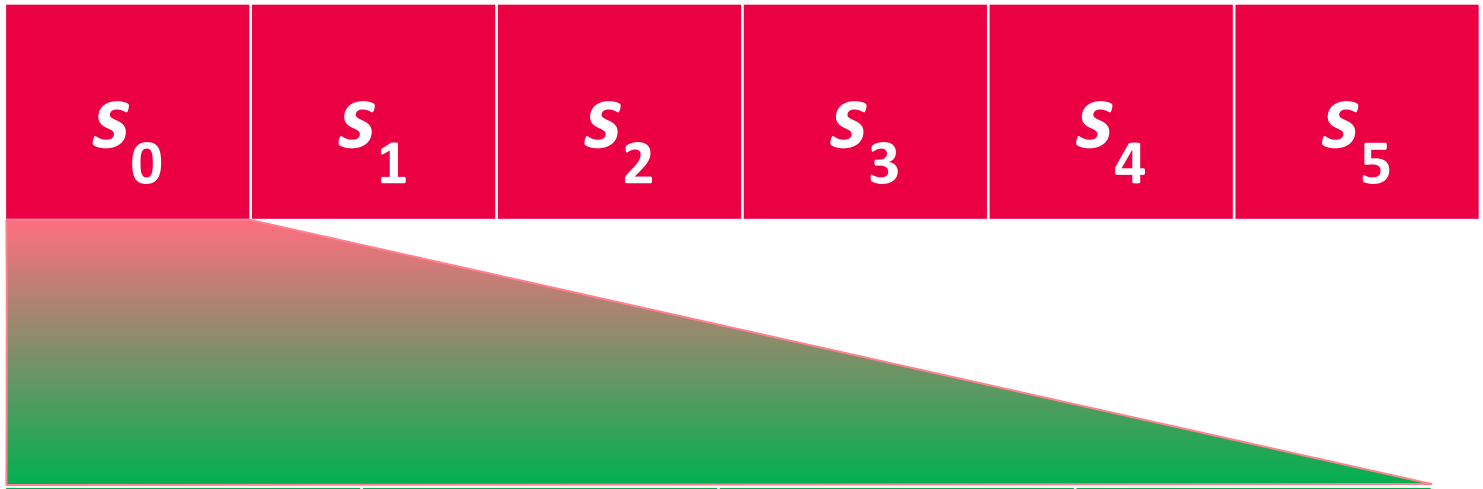


Chivilikhin D. et al. Reconstruction of Function Block Logic using Metaheuristic Algorithm: Initial Explorations / In Proceedings of INDIN'15

Test-based FB reconstruction

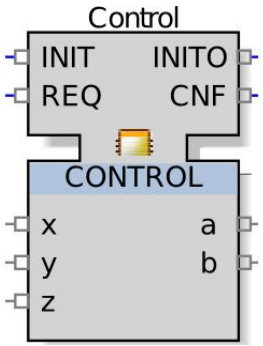


Execution scenario



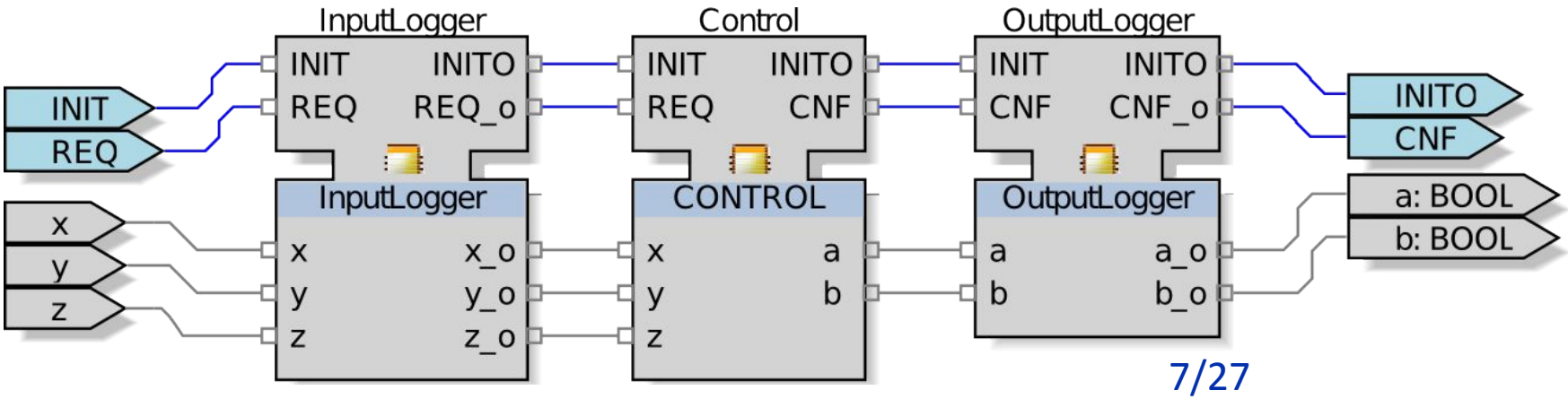
Input event	Input variables	Output variables	Output event
REQ	01011010	101010	CNF

Recording execution scenarios

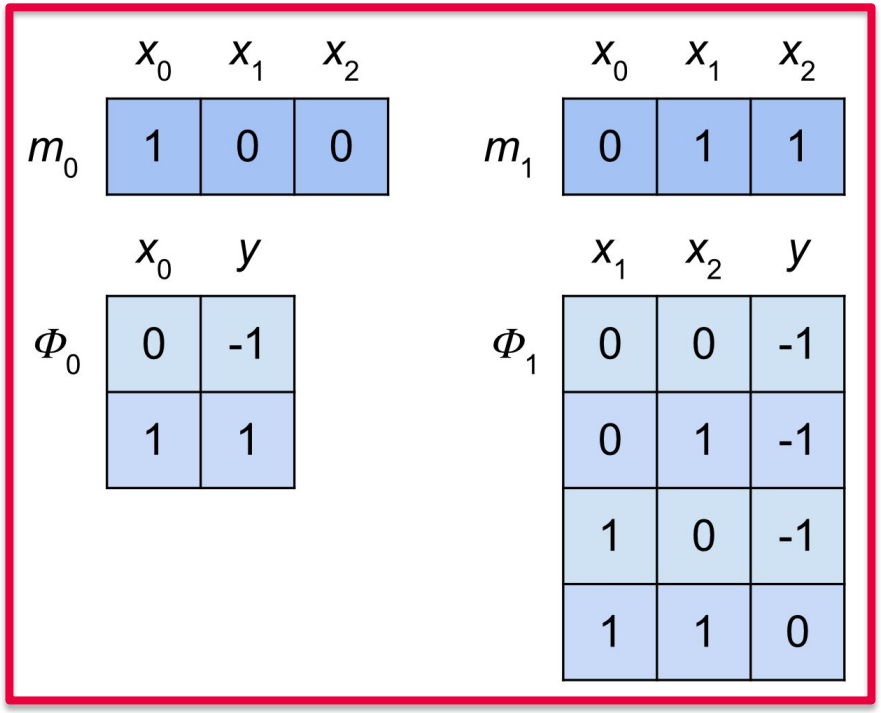


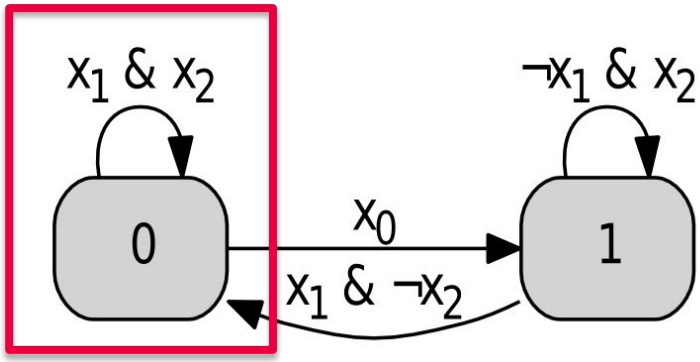
Original function block

Automated refactoring



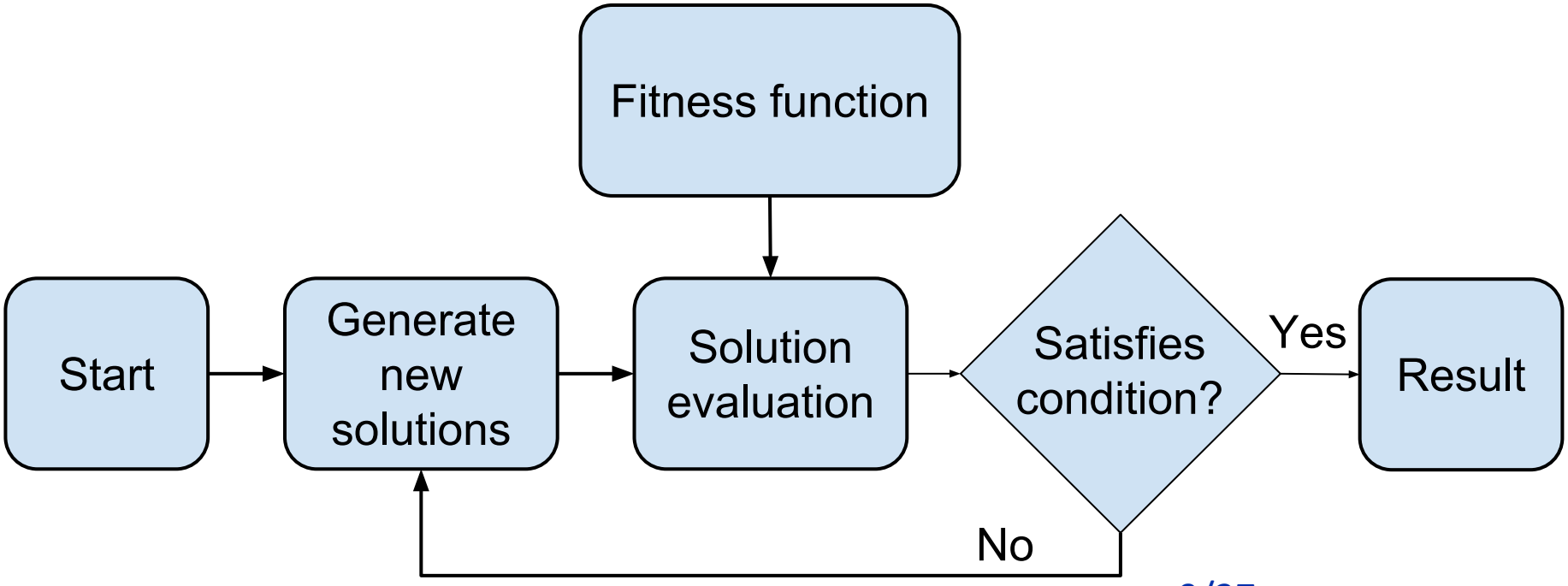
Solution representation





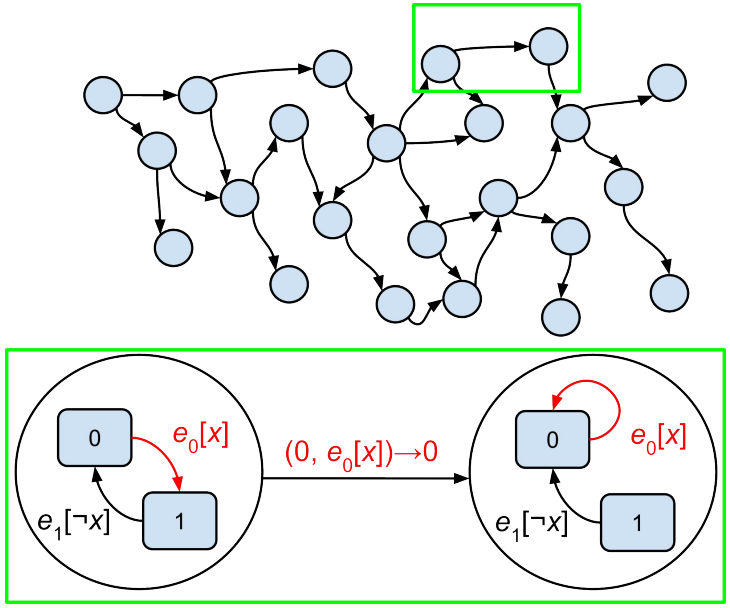
Inference algorithm (1)

- Parallel MuACO algorithm [Chivilikhin et al, 2014]

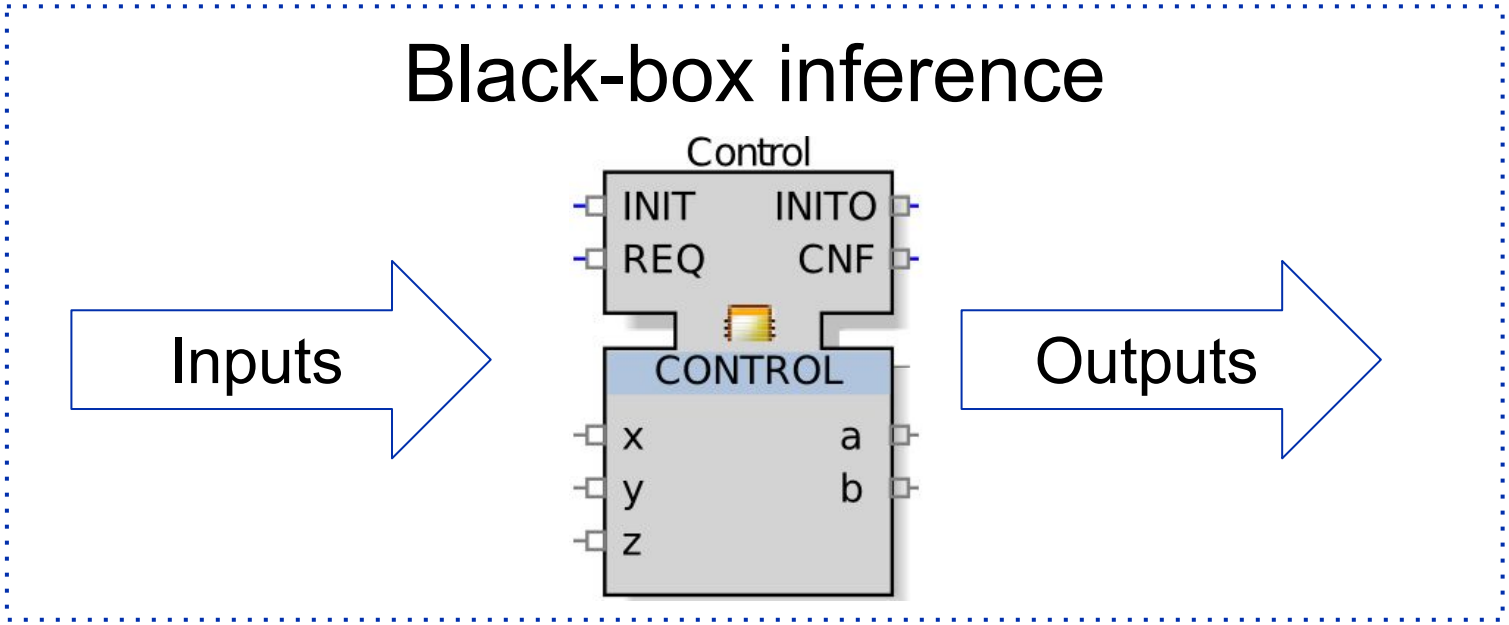


Inference algorithm (2)

1. Start with **random** solution
2. **Build** new solutions with **mutation operators**
3. **Evaluate** new solutions with **fitness function**



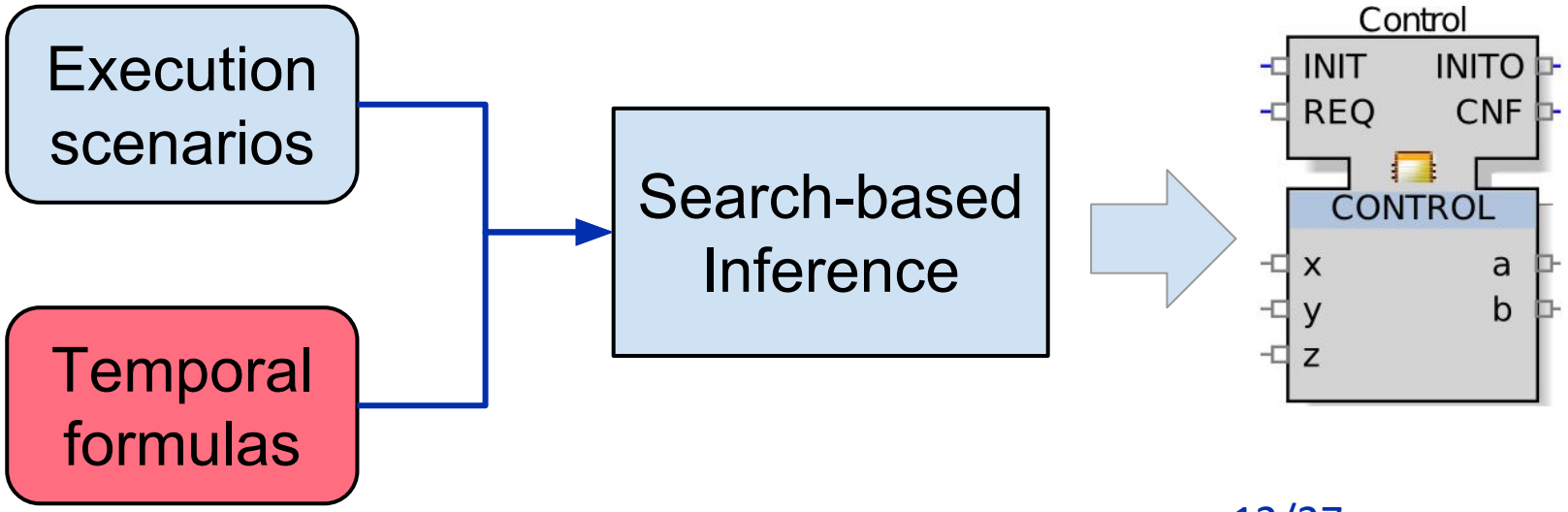
Issue with previous approach



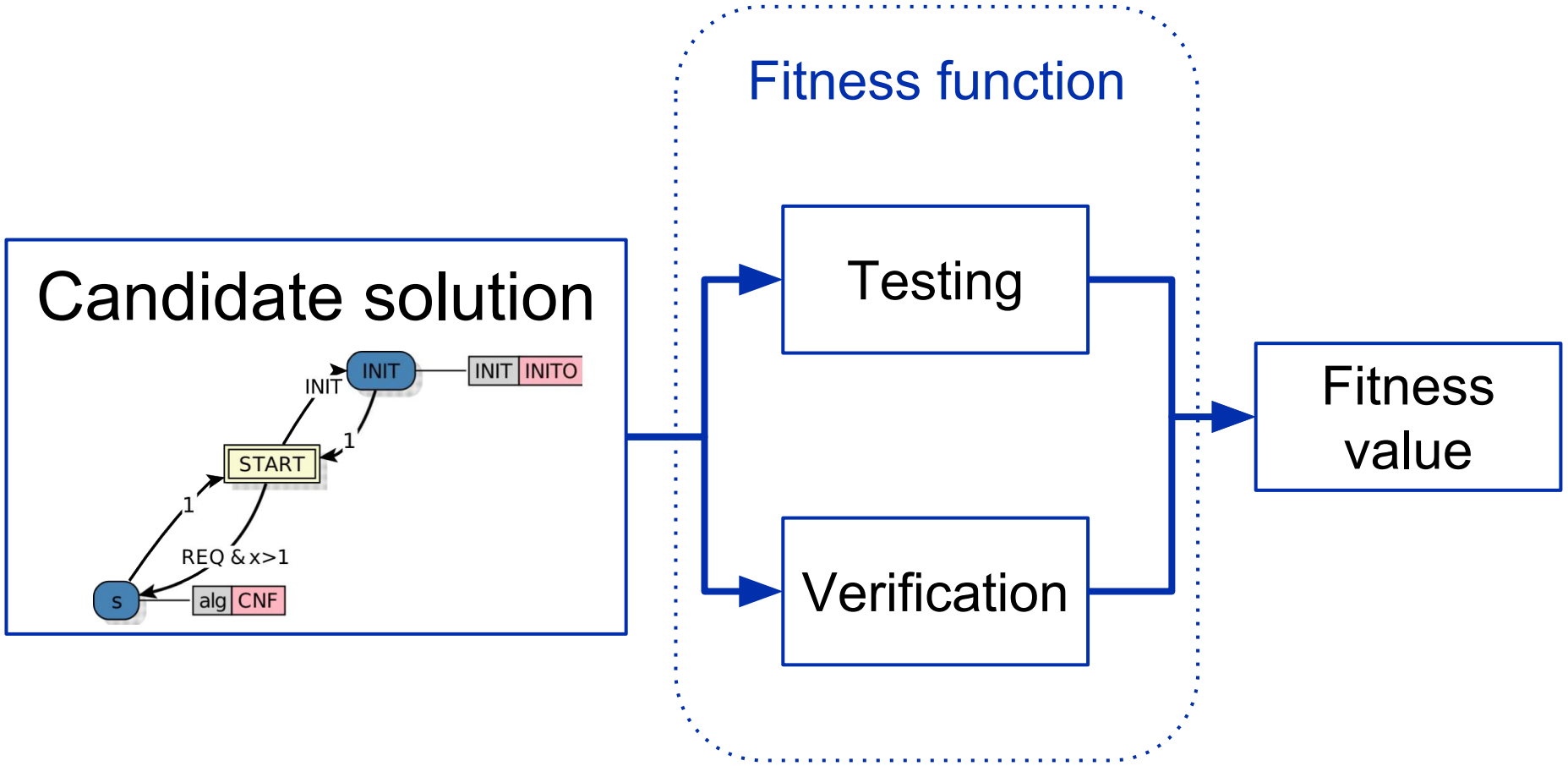
How do we ensure sufficient coverage?

Proposal

- Use **Temporal Logic formulas** as input
- We assume that these temporal properties cover the **most important** functionality of the FB



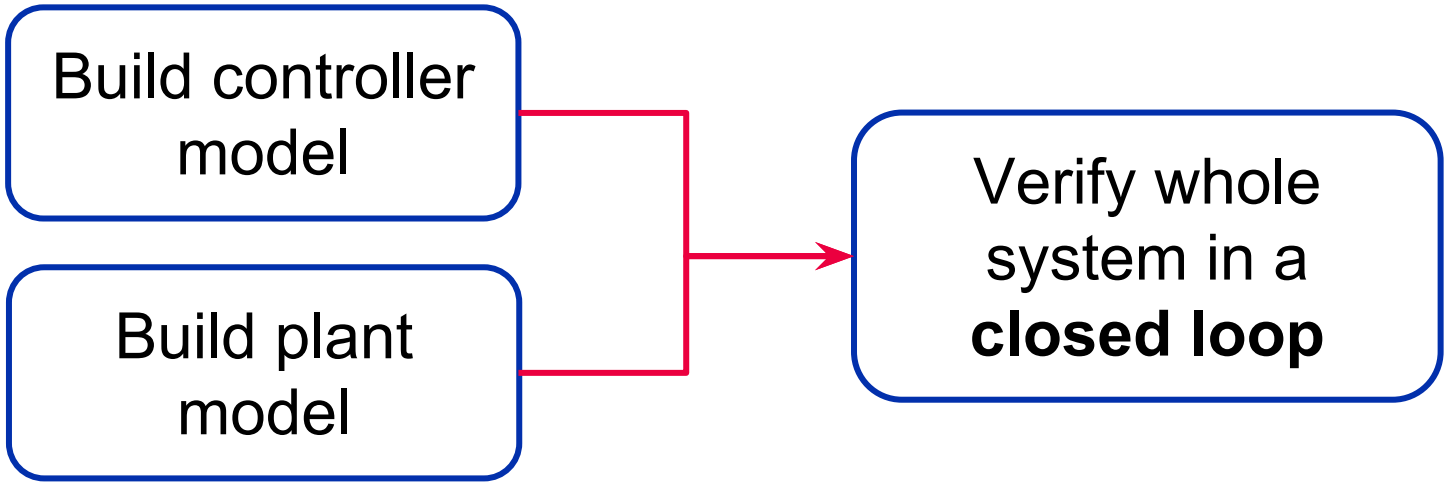
Essence of the approach



Which temporal logic to use?

- Linear temporal logic
- NuSMV is used for formula verification

Closed-loop verification



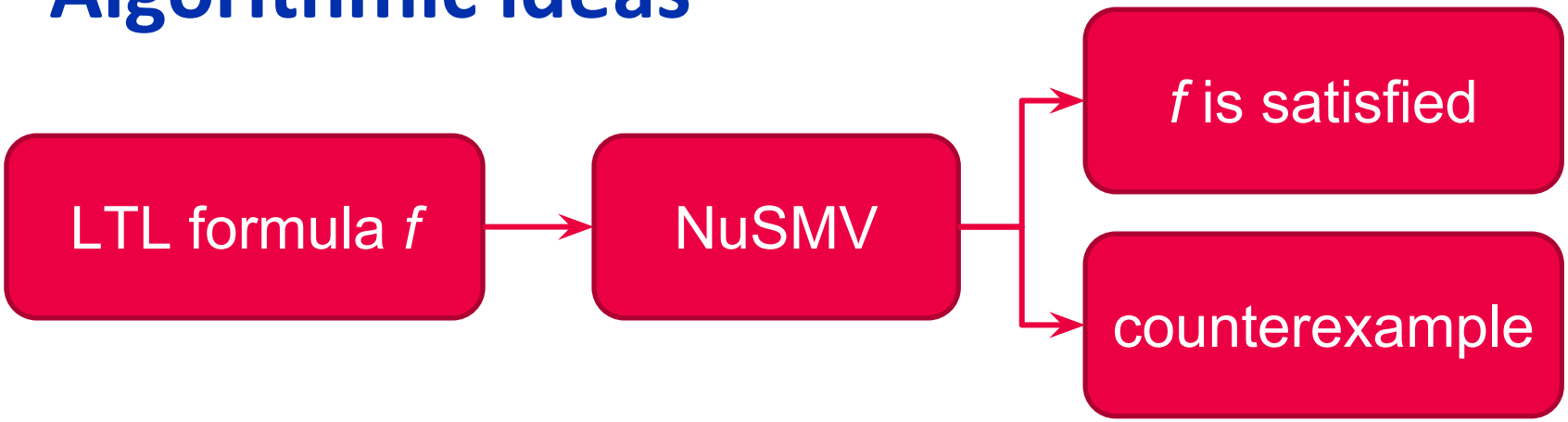
Issues

- We need the model of the plant
- Verification will take a lot of time
  - e.g., verification of PnP properties takes several hundred seconds

Closed-loop verification with surrogate plant model

- Solution – create small **surrogate** model
- Use the model for FB synthesis
  - “+”: fast verification
  - “-”: it may be nontrivial to create the model

Algorithmic ideas



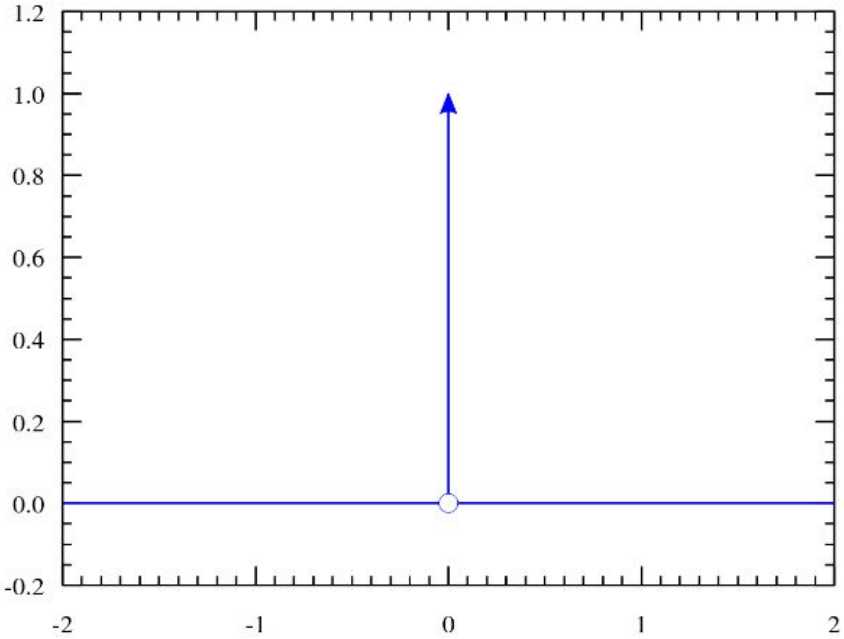
How can we use this information for FB synthesis?

1. Ratio of satisfied formulas
2. Longest counterexample length
3. Verification-aware mutation operator

1. Ratio of satisfied formulas

$$\frac{\#\text{ of satisfied formulas}}{\#\text{ of formulas}}$$

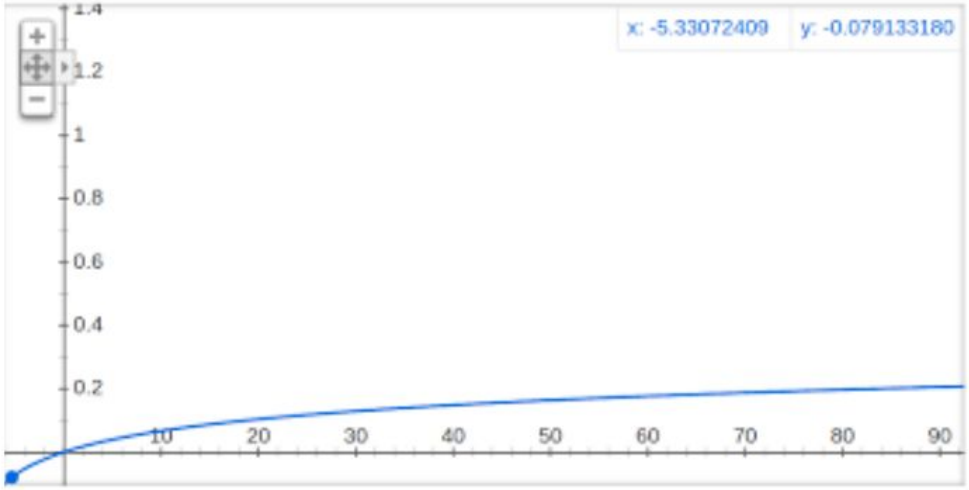
Issue – this variable has too few possible values!



2. Length of the longest counterexample

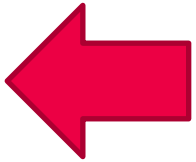
- Solutions with long counterexamples are probably better than solutions with short ones

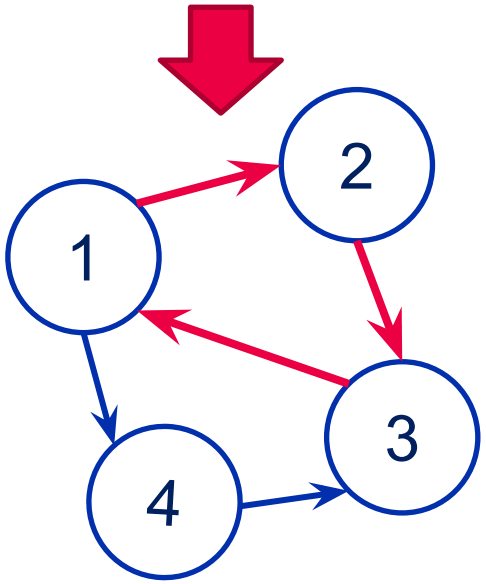
$$F^{\text{ce}}_{\text{smv}} = \begin{cases} 1, & \text{if } l_{\max} = 0; \\ 1 - \dfrac{1}{(1+\frac{1}{10} l_{\max})^{\frac{1}{10}}}, & \text{otherwise.} \end{cases}$$



3. Verification-aware mutation operator

Increase probability of changing visited transitions





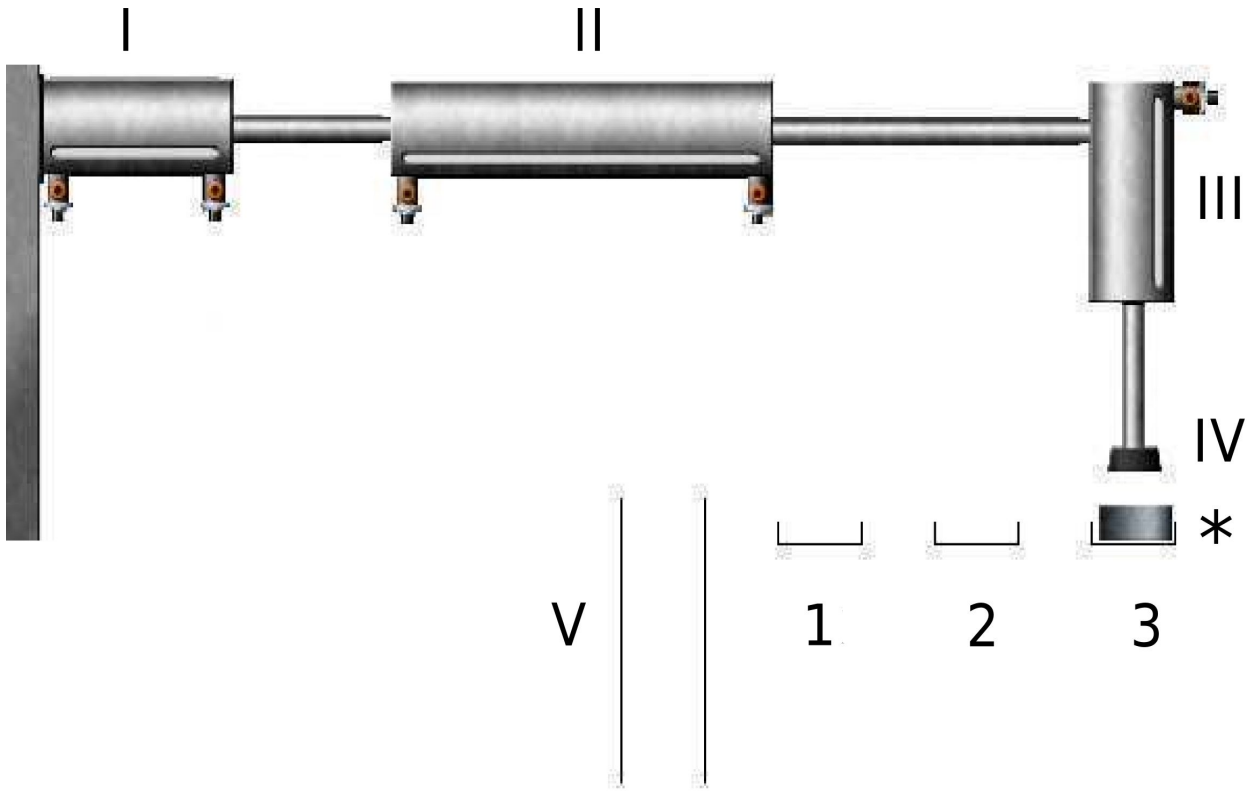
Efficiency issues

- Closed-loop with surrogate model is fast, but not fast enough
  - Verification takes ~ 0.5-1 seconds

Solution

- Calculate verification-based fitness only for *p* % of solutions
- Definitely calculate for good solutions

Example: Pick-and-Place manipulator



Considered LTL properties

Property	Description
G(not (c_1Extend & c_1Retract))	Cylinder I must never be given commands to extend and retract simultaneously
G(not (c_2Extend & c_2Retract))	Analogous safety property about cylinder II
G($pp_1 \rightarrow$ not F(vp_1))	If a work piece appears on the first input track, it will eventually be picked up by the manipulator

Experiments

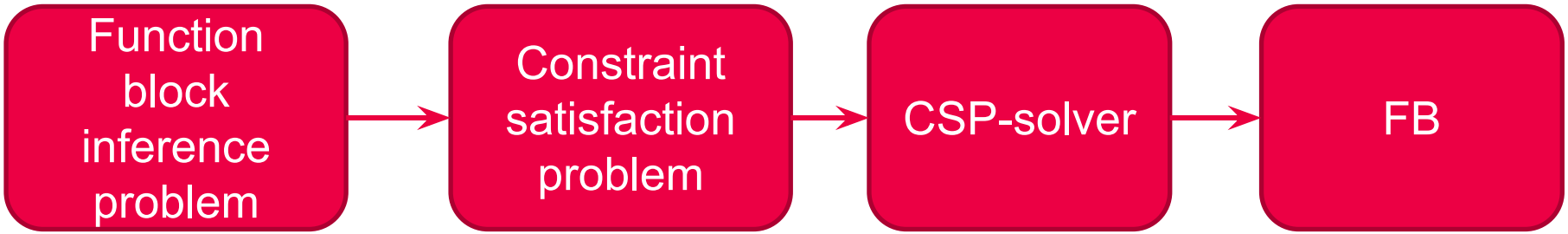
- Machine with 64-core AMD OpteronTM6378 @ 2.4 GHz processor, 32 Gb of RAM
- Used 16 cores

#	Configuration	Time, s				Satisfied all LTL
		min	mean	median	max	
1	Scenario	32	85	81	280	0%
2	Scenario + LTL (no F^{ce}_{smv})	222	752	656	1689	100%
3	Scenario + LTL	164	563	561	1575	100%

Conclusion

- Developed method of FB inference from tests and LTL properties
- Demonstrated viability on the PnP example
- Still a long way to go…

Ongoing work: CSP-based inference

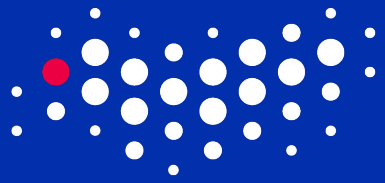


Advantages

- Typically – very fast
- Possibility to find all solutions
- Symmetry breaking
- Indirect solution of “tests + LTL” synthesis problem

Acknowledgements

- Financially supported by Government of Russian Federation, Grant 074-U01.
- Partially funded by RFBR according to the research project No. 16-37-00205 mol_a.



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Thank you for your attention!

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