A Counterexample-Based Incremental and Modular Verification Approach

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Motivation

Aims

Verification of LTL properties φ

Usual approach

- Convert the negation of φ into a Büchi automaton
- Synchronise the Büchi automaton and the system model
- Check that the composed system language is empty

Drawback

State space explosion problem

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Incremental Model-Checking [Klai Petrucci Reniers FORTE07]

- Decomposition of a Petri net according to the formula to check
- Abstraction of the environment
- Construction of local counterexamples
- Incremental processing until the property is proven true or false

Motivation

Symbolic Observation Graph [Haddad Ilié Klai ATVA04]

- Reduced graph
- Dedicated to the verification of LTL\X properties

Modular approach [Klai Petrucci ACSD08]

- Smaller structures
- Efficient especially with loosely coupled modules
- Allows for reuse
- Modular construction of the Symbolic Observation Graph for the verification of LTL\X properties

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Motivation

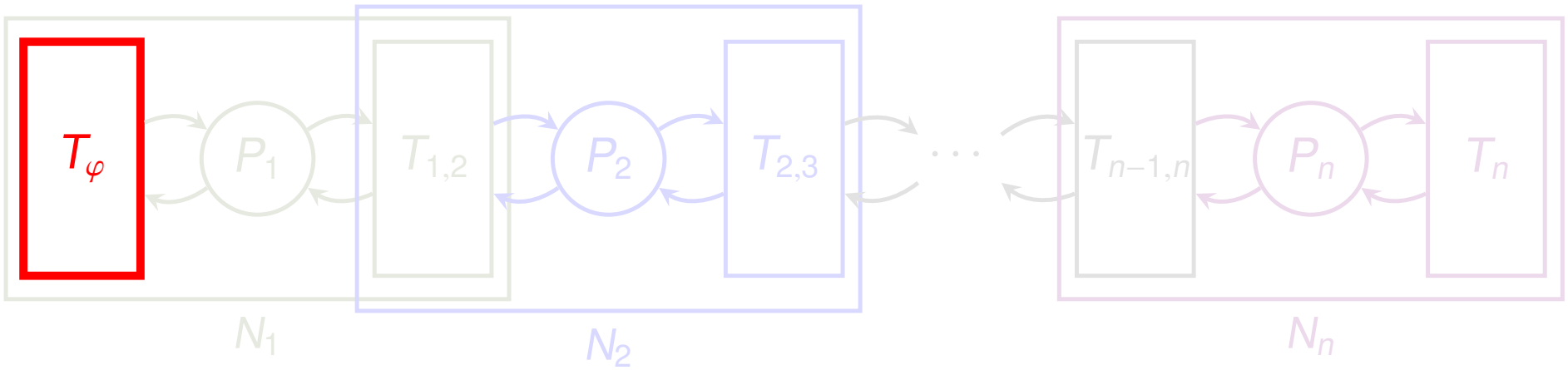
$\Rightarrow$ Combination of both approaches

Outline

1. Incremental Model-Checking [Klai Petrucci Reniers FORTE07]
   - Model decomposition
   - Abstraction of the environment
   - Incremental verification
2. Modular SOG construction [Klai Petrucci ACSD08]
   - Symbolic Observation Graph
   - Modular construction
3. Incremental and modular counterexample search
   - Drawbacks of previous approaches
   - Optimisation of the SOG Construction
   - Incremental verification revisited
4. Conclusion & Perspectives
   - Summary
   - Perspectives for future work

Model decomposition

Petri net models with fused transitions



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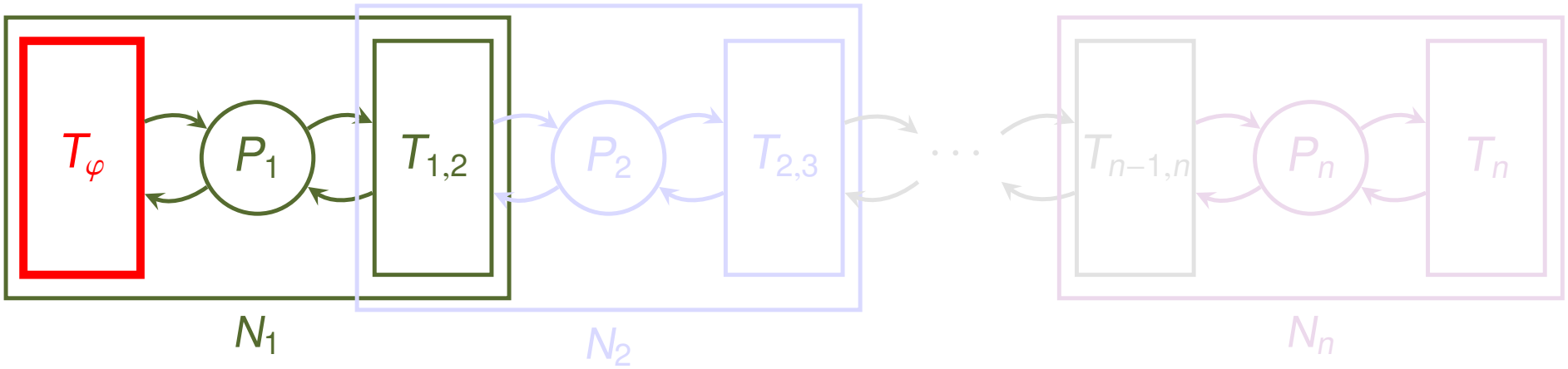

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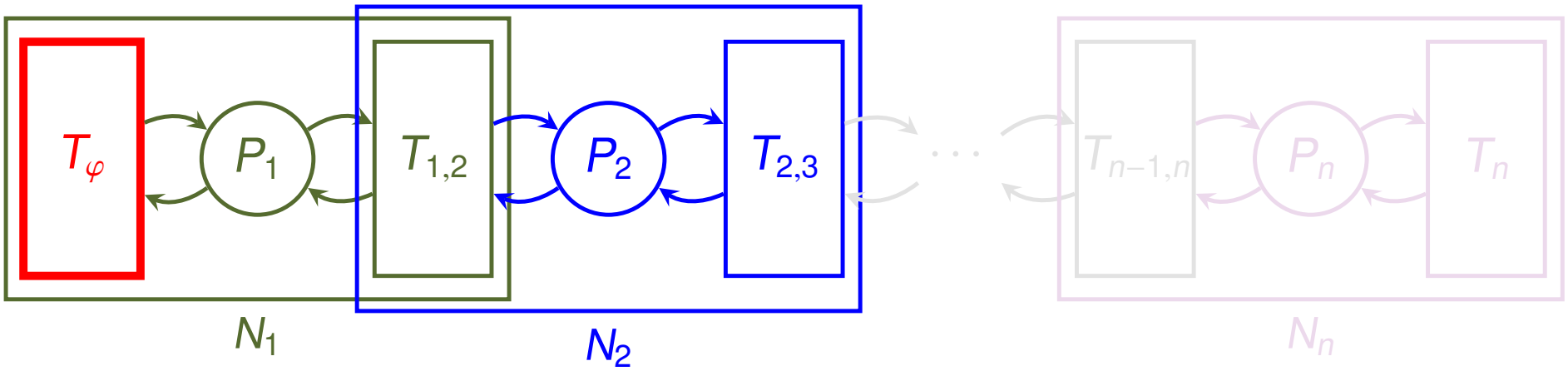

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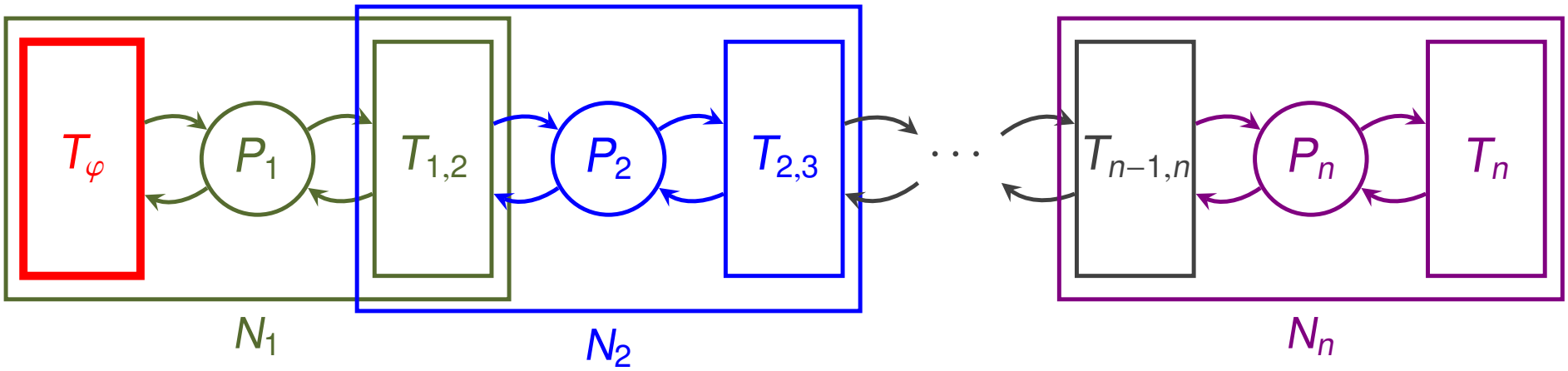
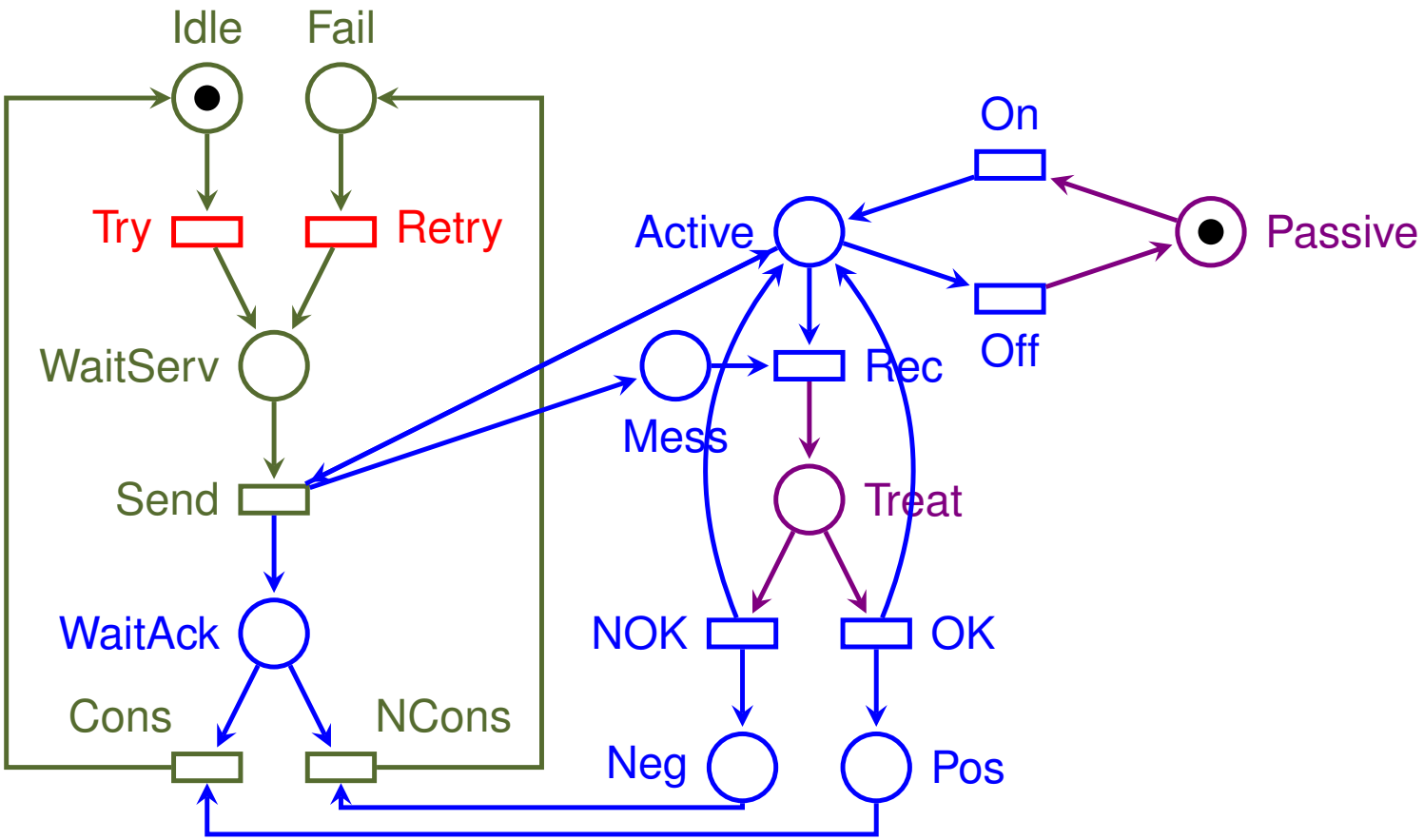


Abstracting the environment

- Control the interface using additional places
- Abstract the interface with one place per global invariant



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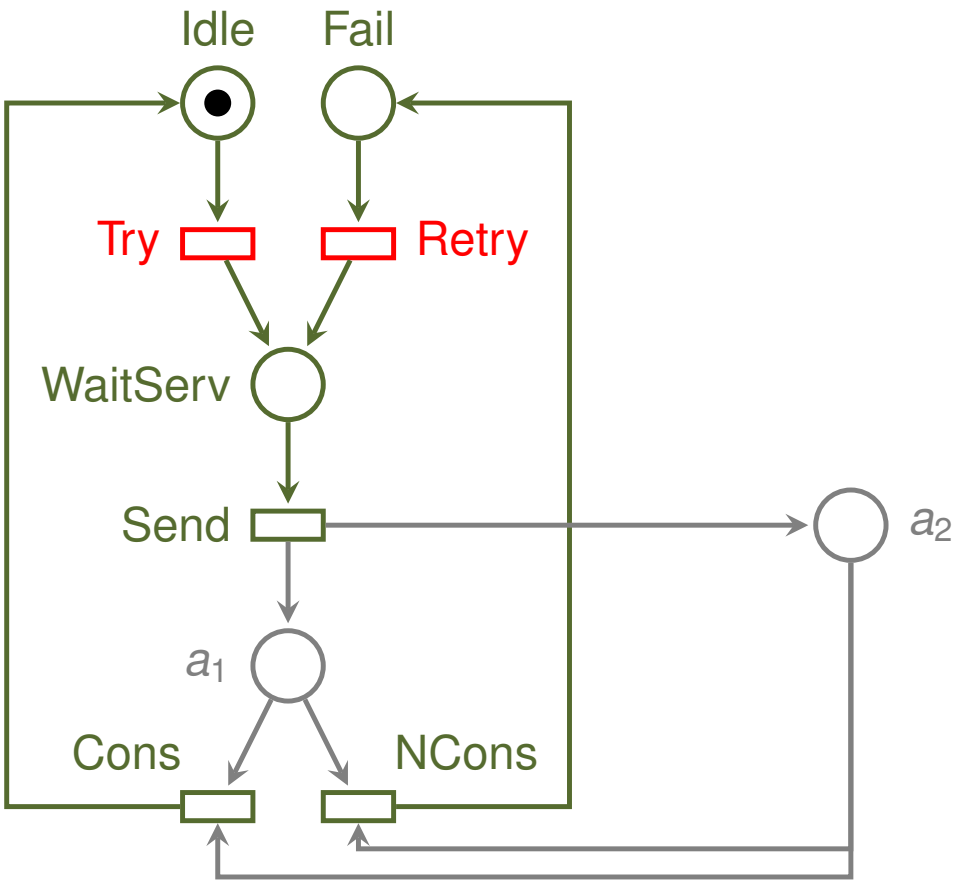
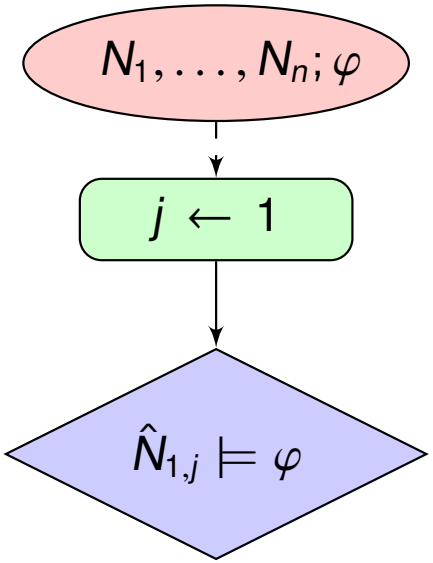


Incremental verification



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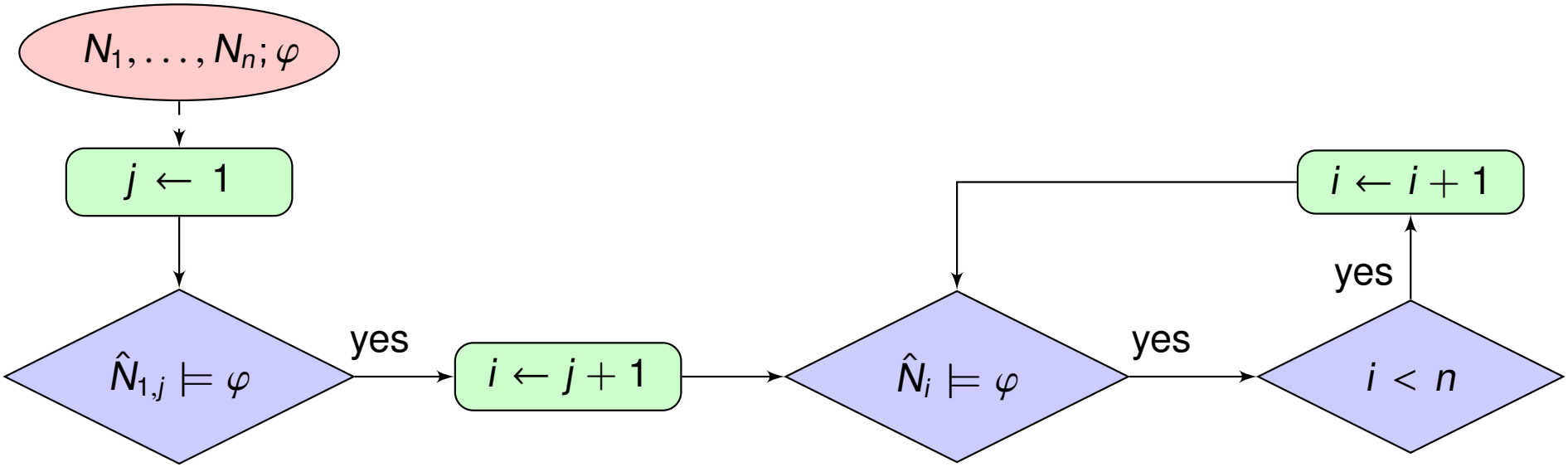

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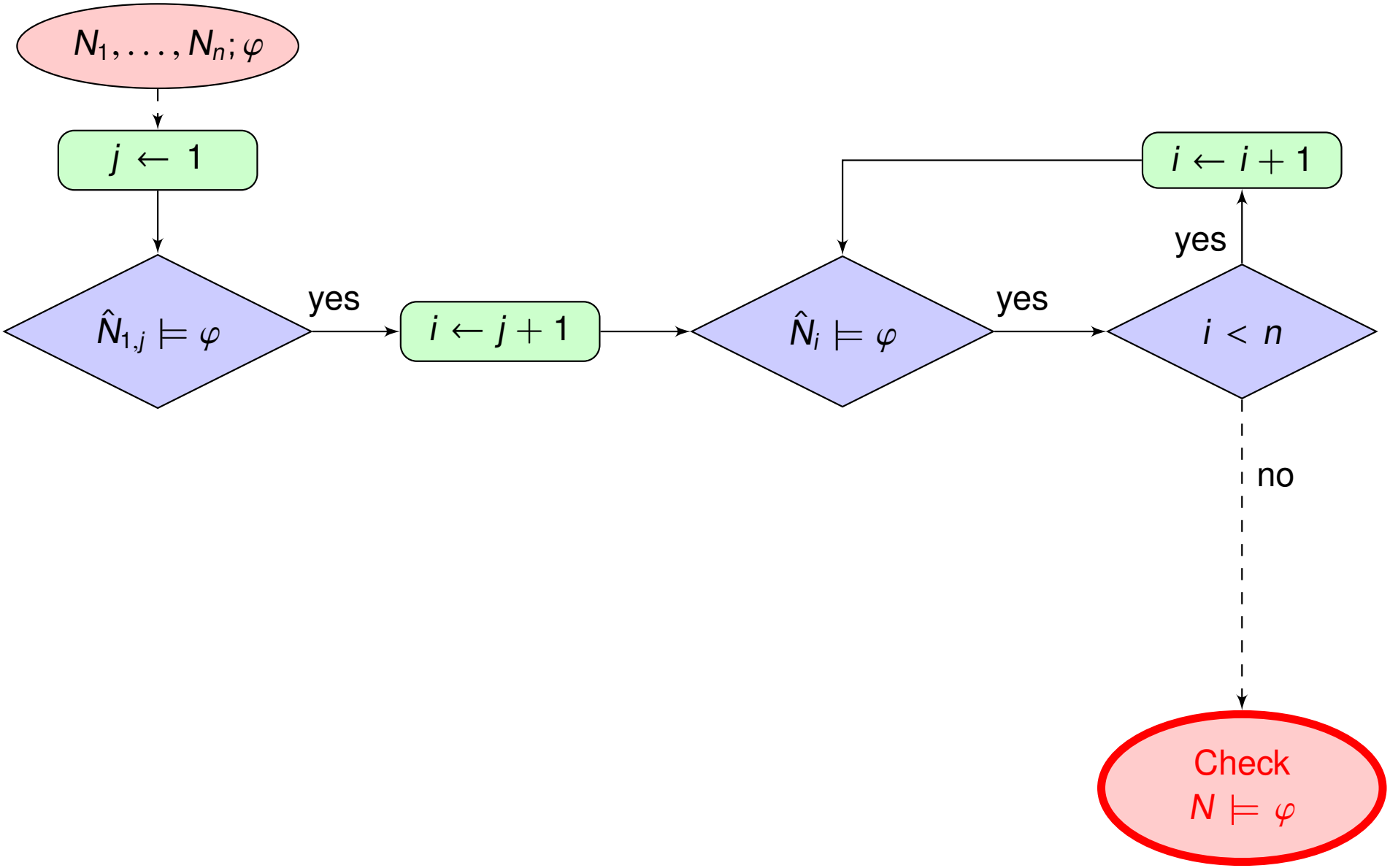

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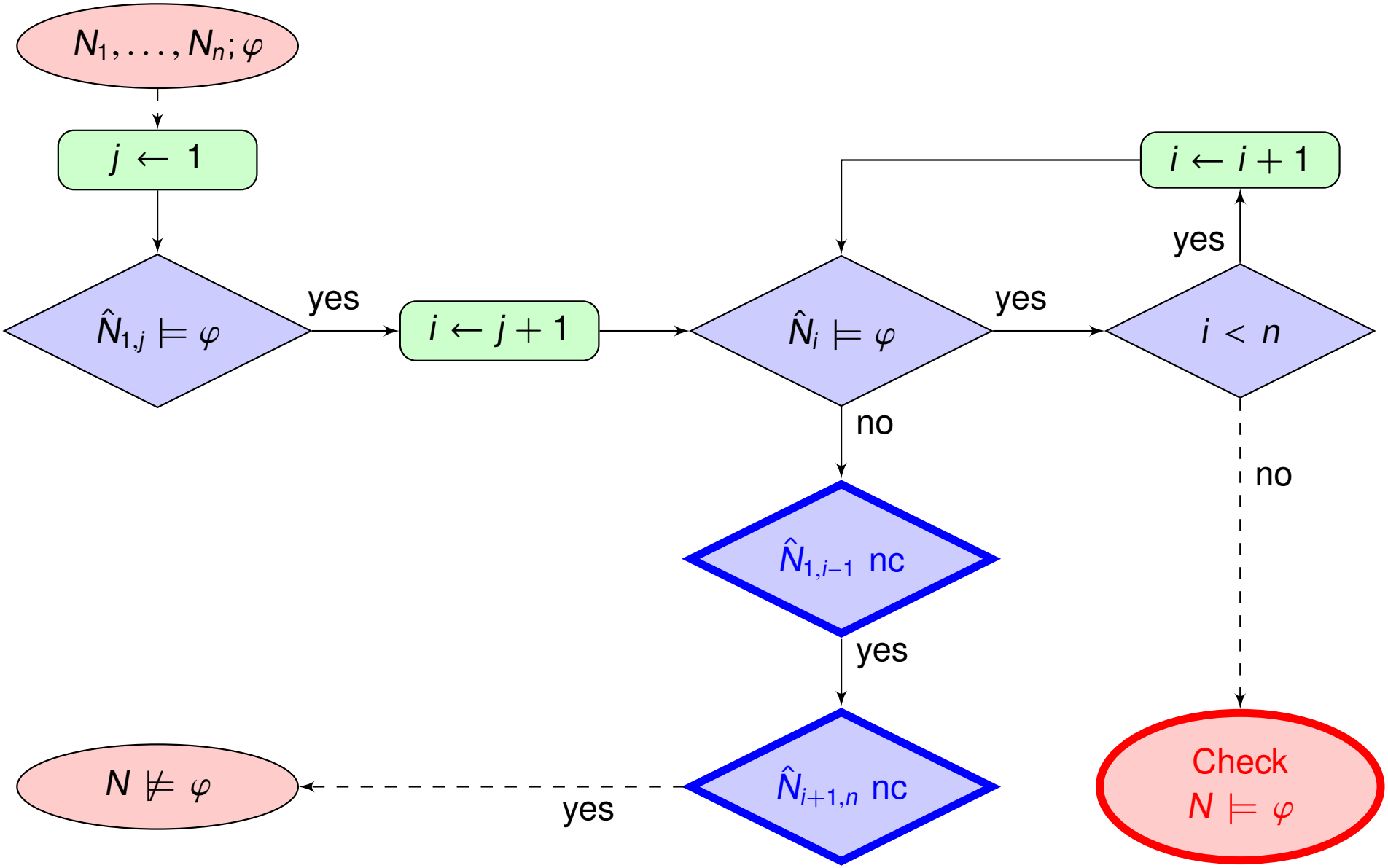

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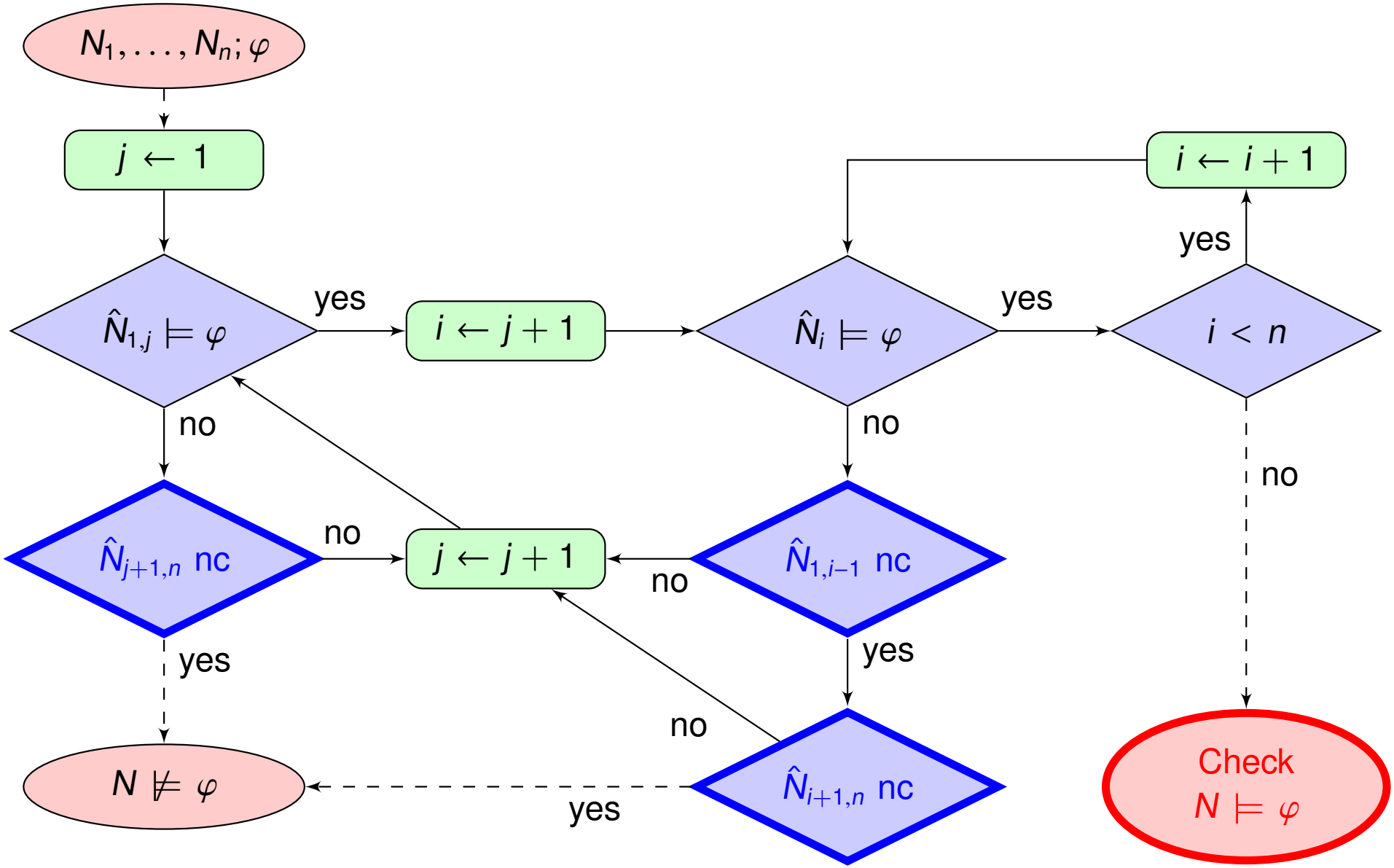

Symbolic Observation Graph

Observable/Unobservable actions

Partition the set of actions: $Act = UnObs \cup Obs$ where:

- *Obs* contains the observable actions, occurring in the formula φ
- *UnObs* contains the unobservable actions, i.e. all the other ones

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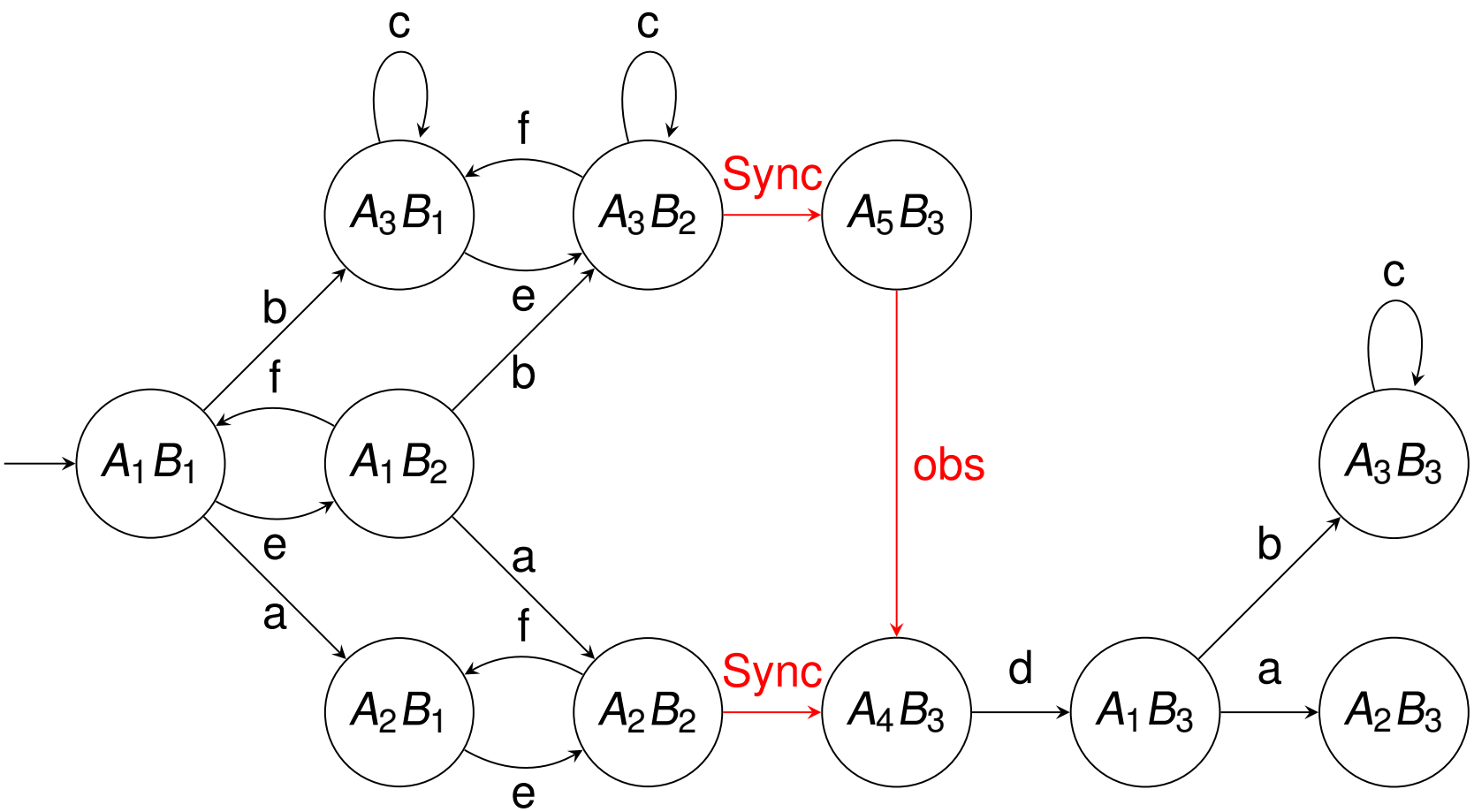
Symbolic Observation Graph

- Nodes are meta-states:
  - set of states, possibly reachable from one another using unobservable transitions
  - $loop \in \mathbb{B}$ indicating whether the meta-state contains a cycle
  - $deadlock \in \mathbb{B}$ indicating whether the meta-state contains a deadlock
- Arcs are labelled by actions in *Obs*

SOG Construction



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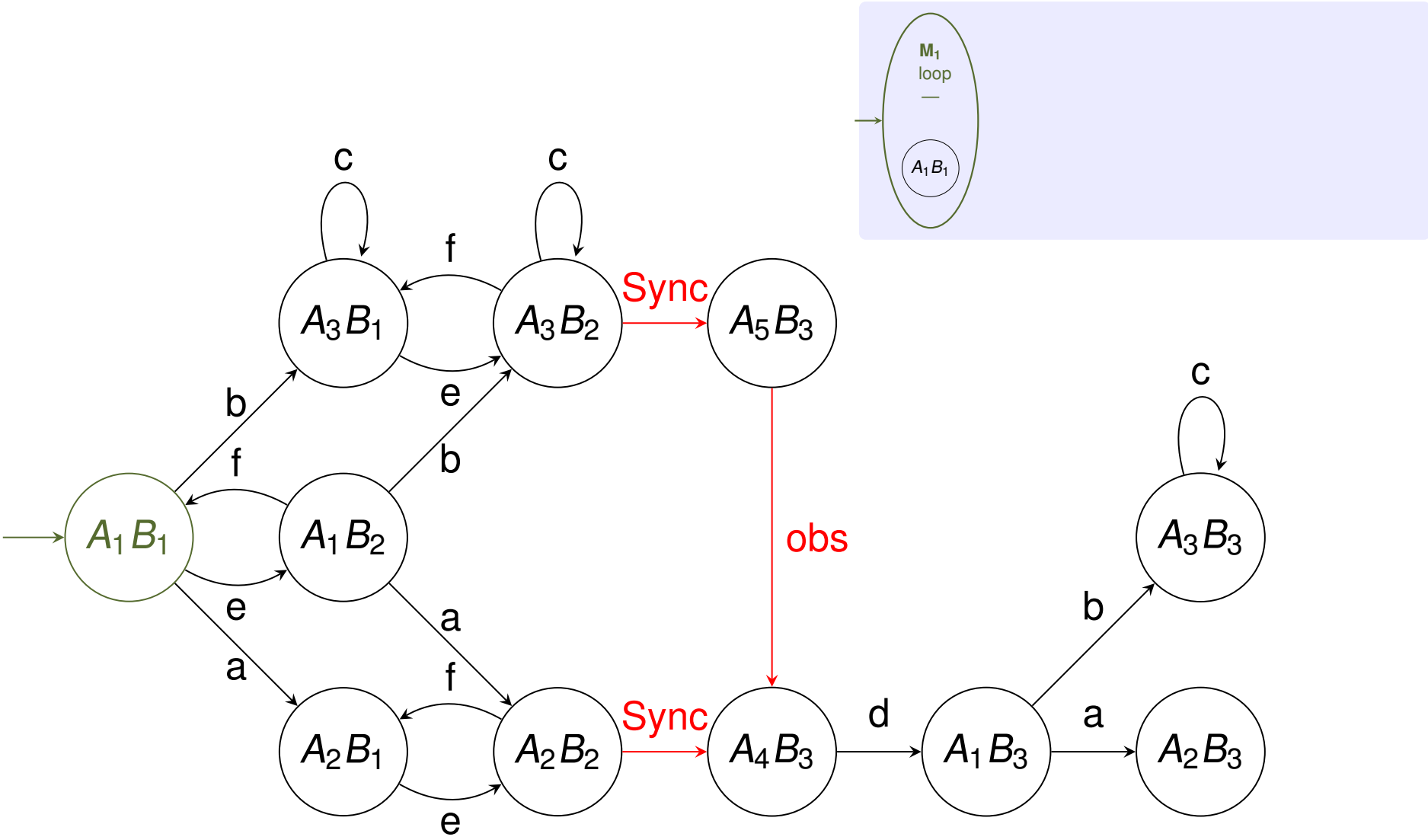

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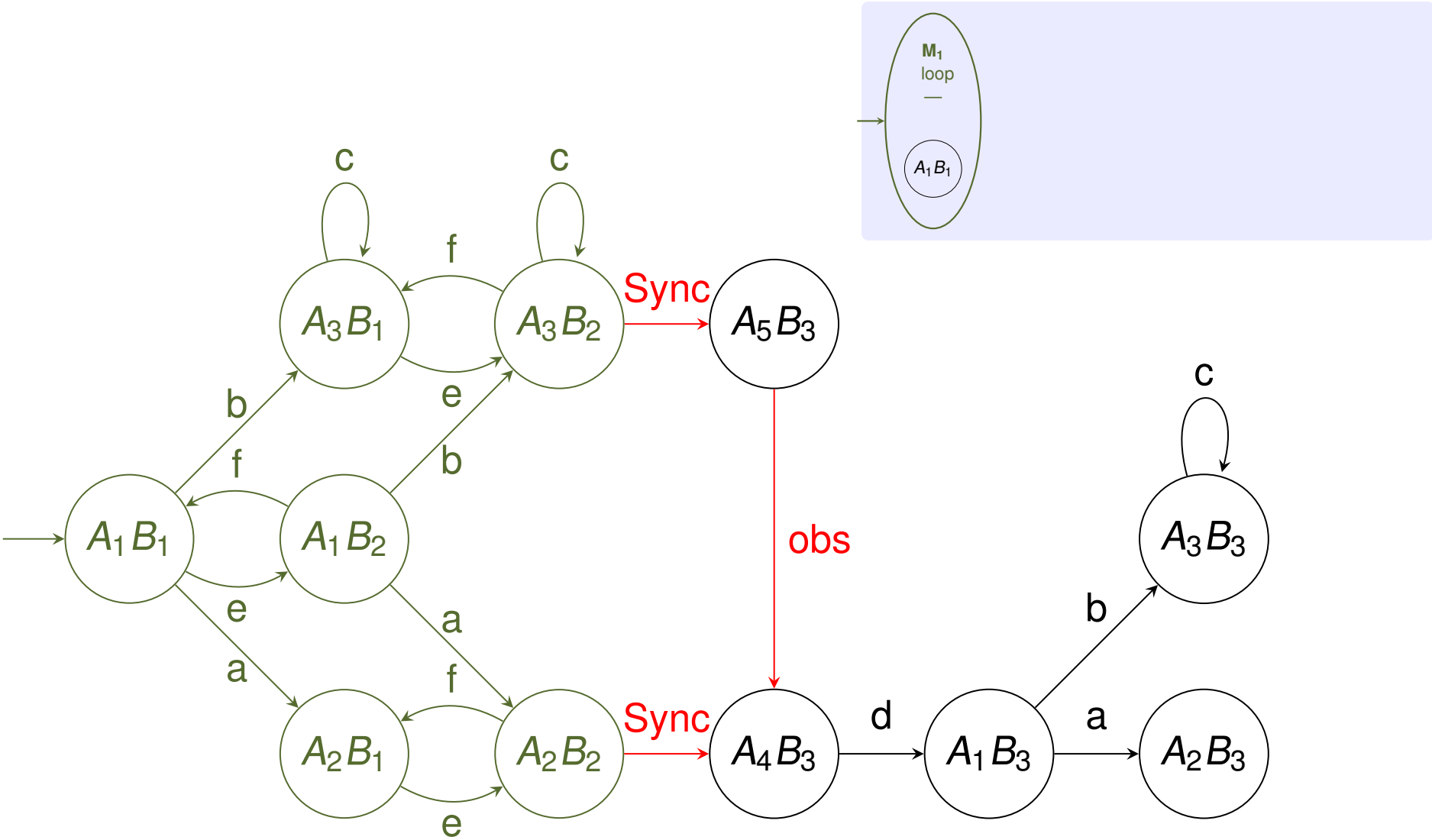

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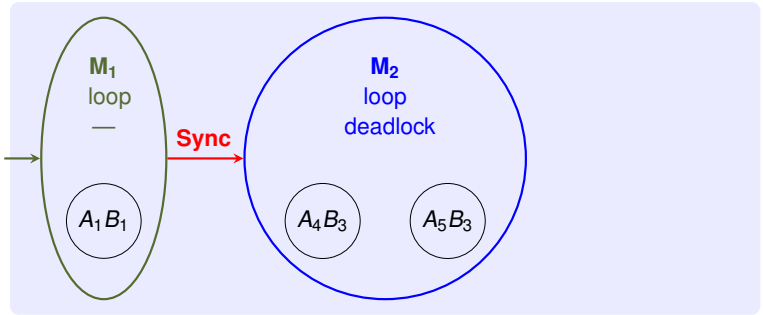

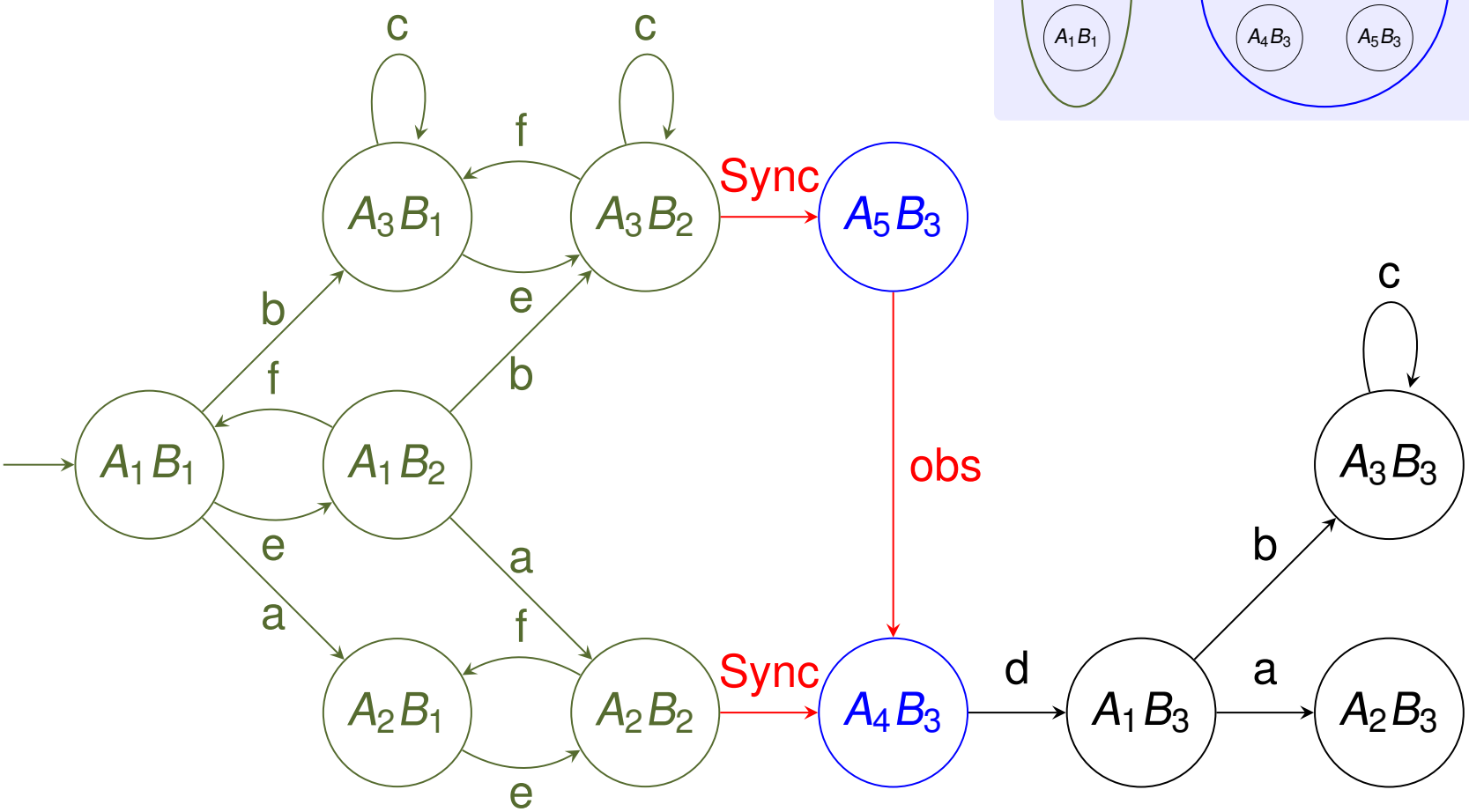

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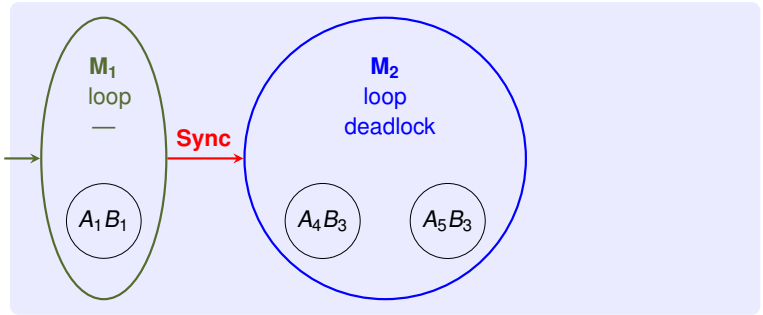

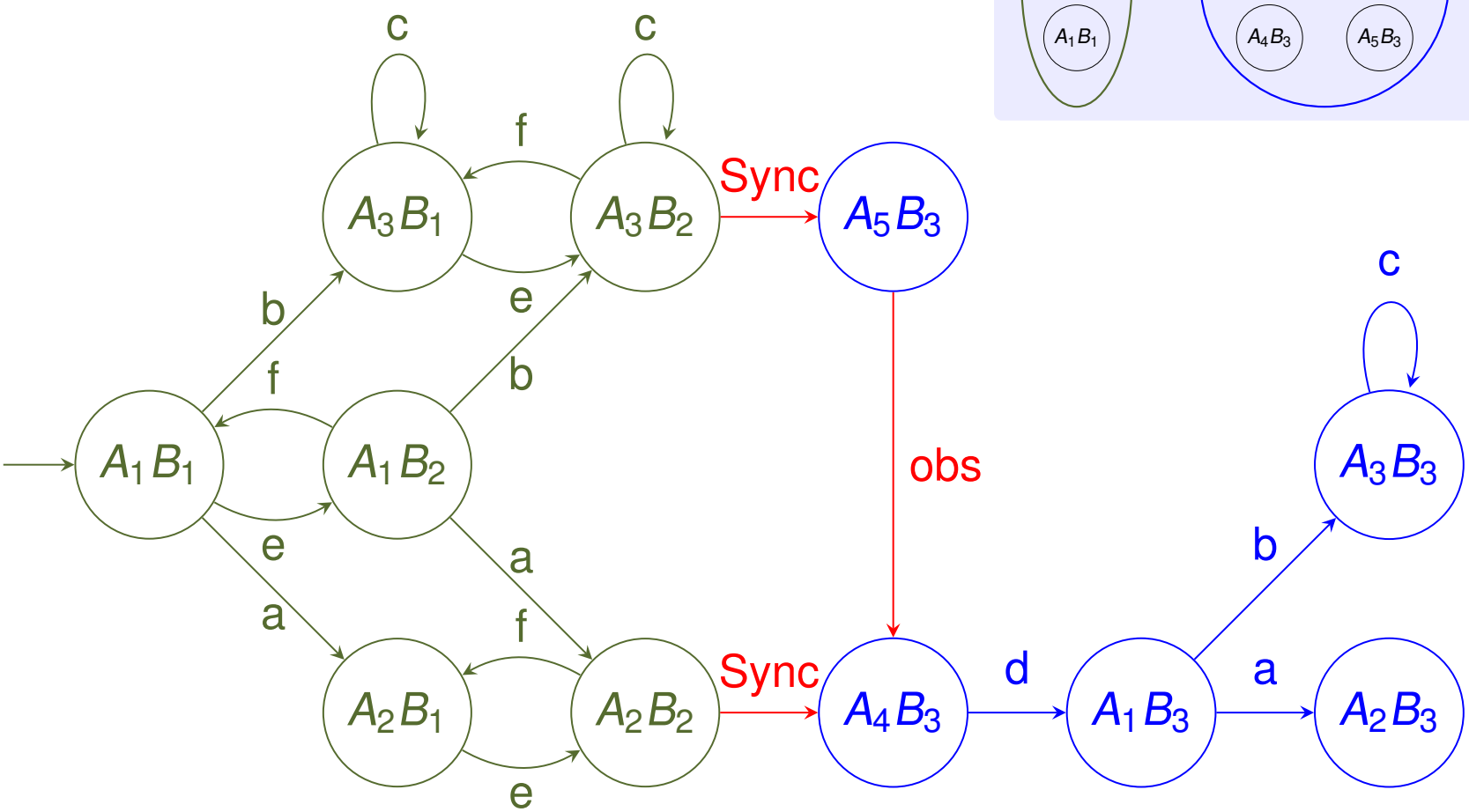

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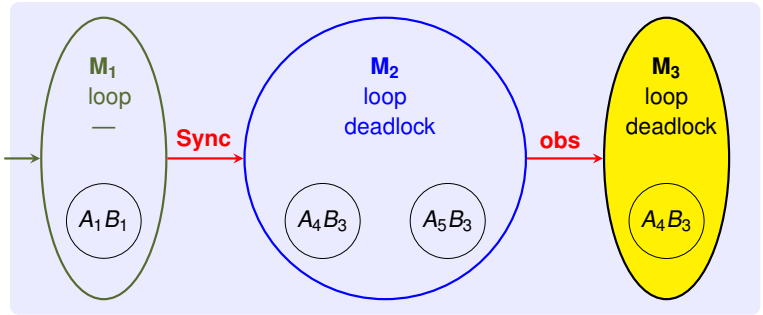

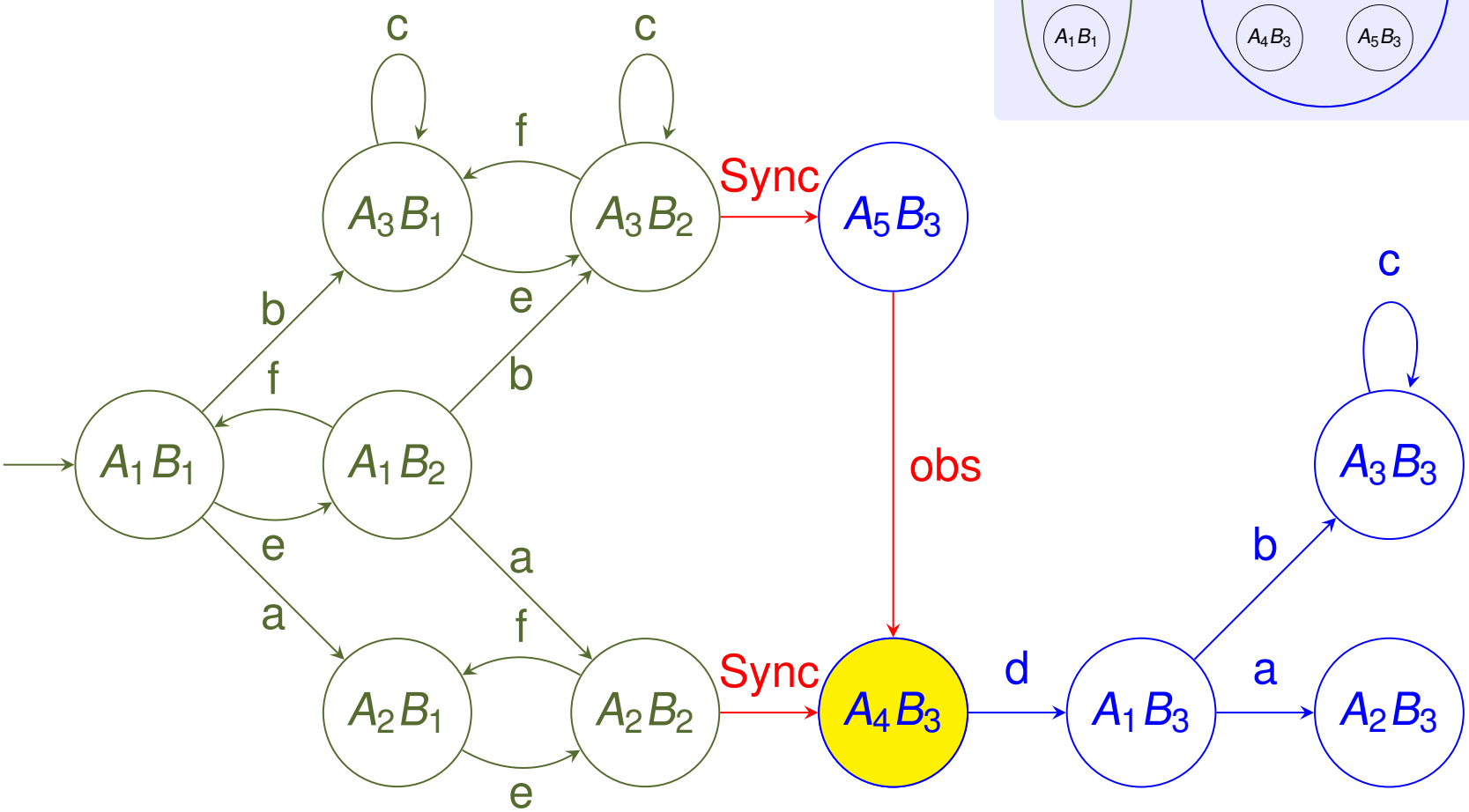

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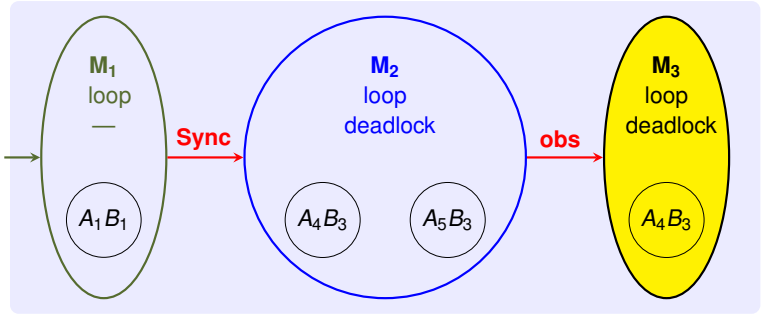
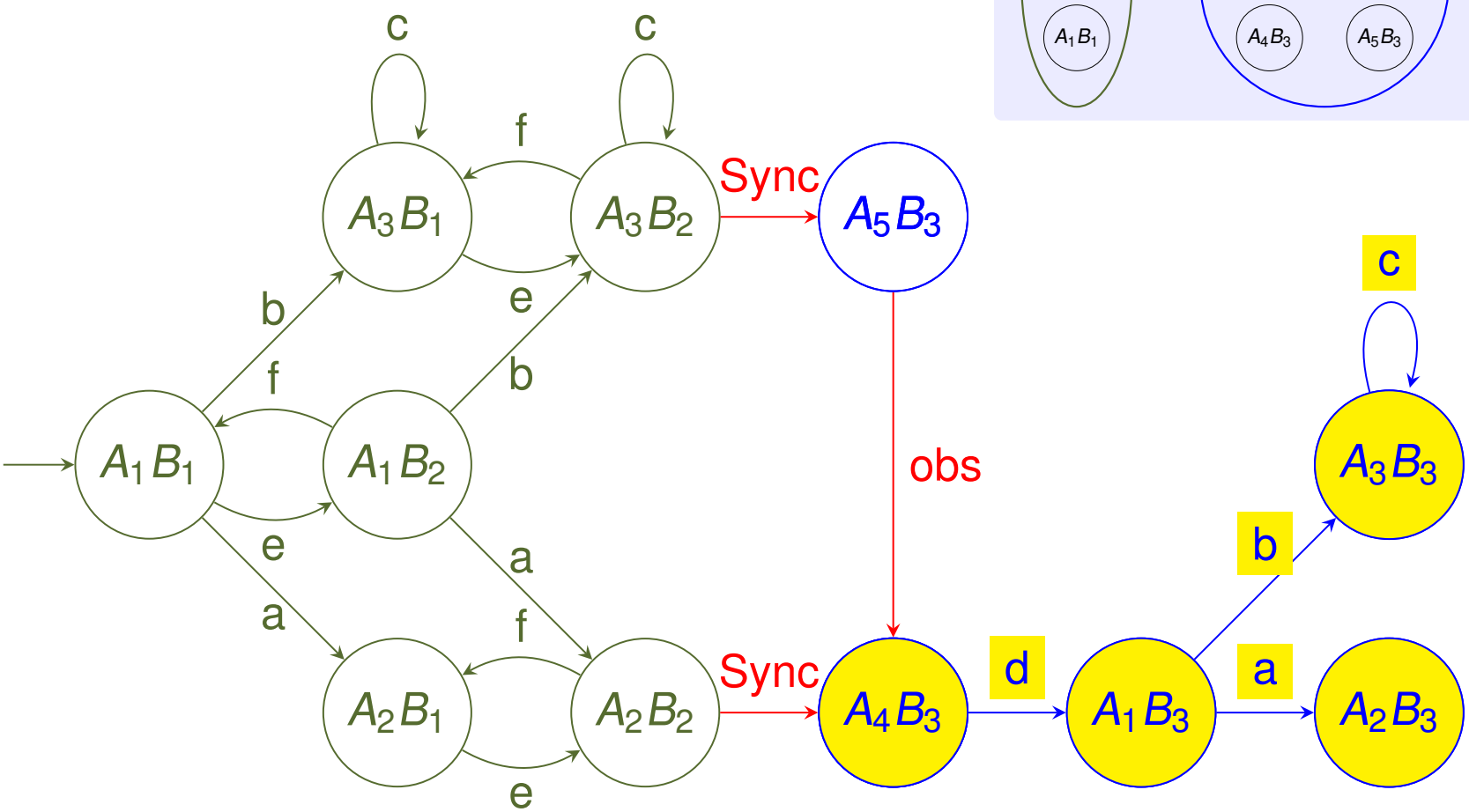
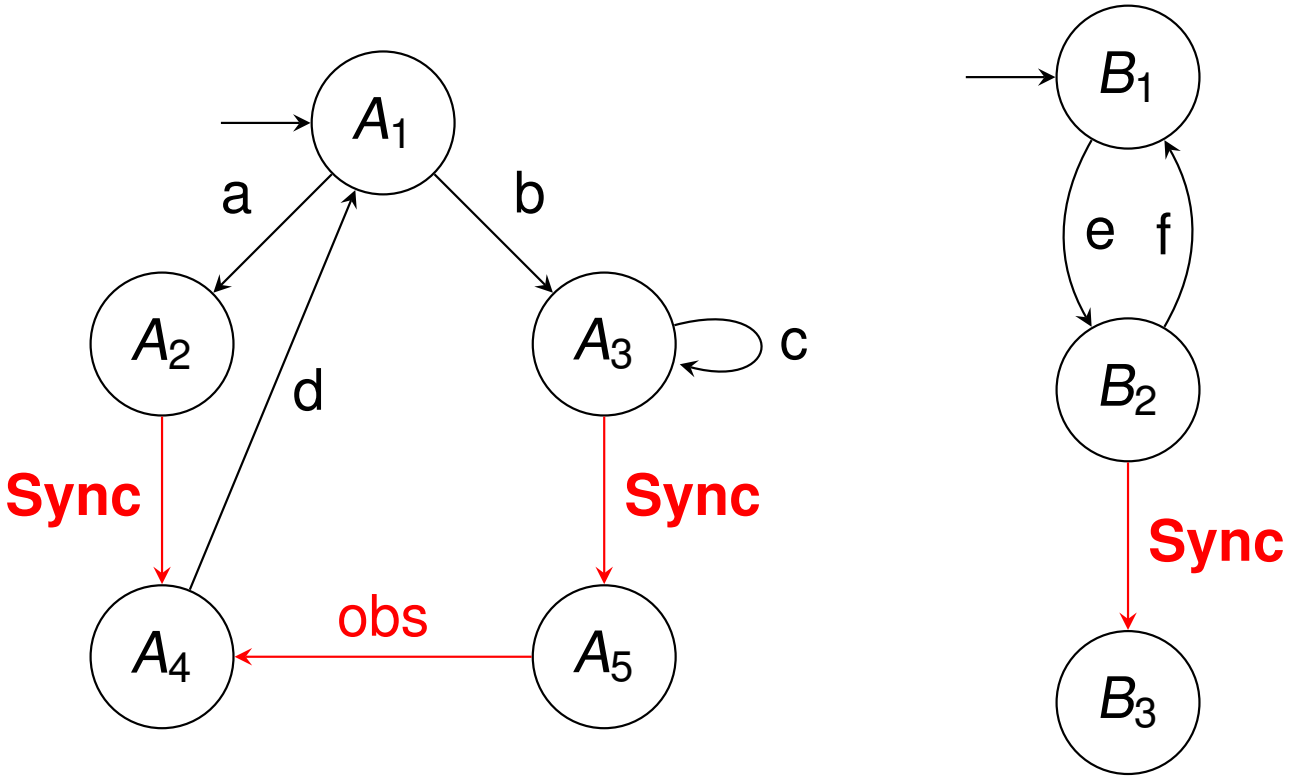
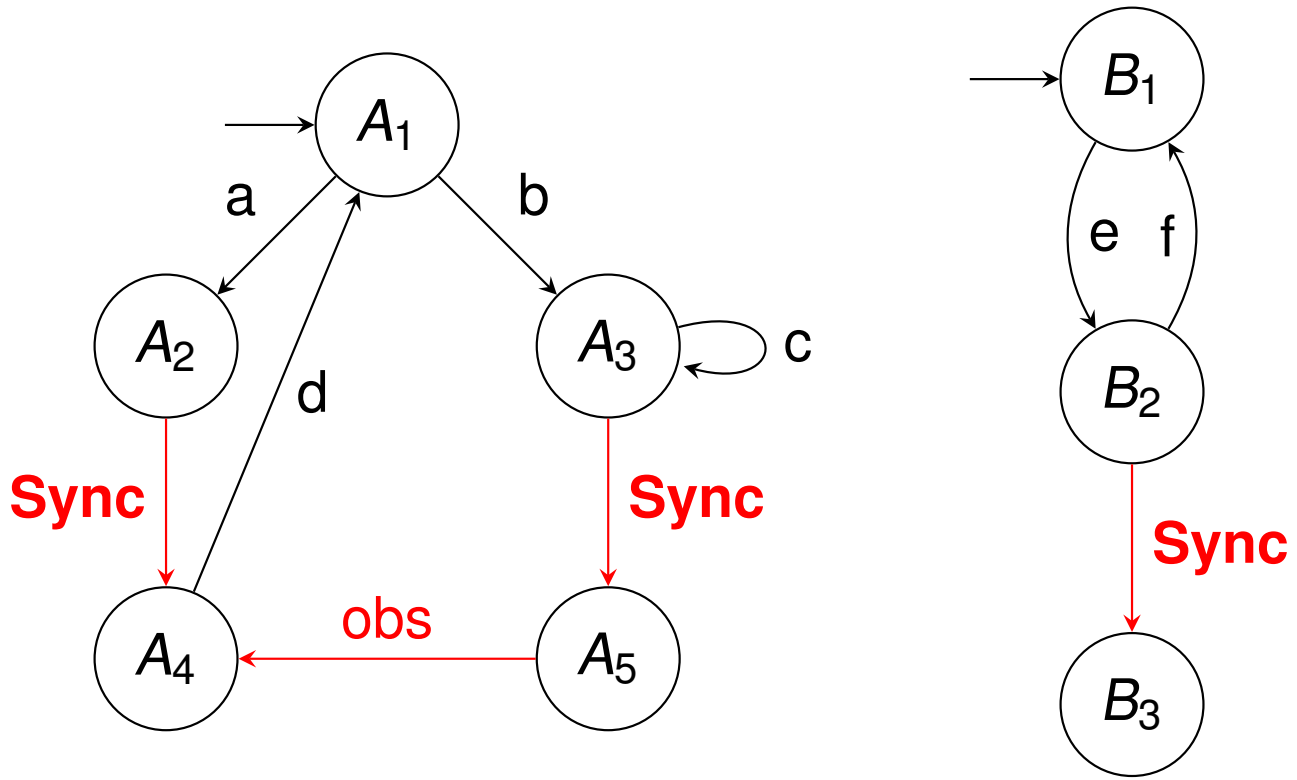




Modular Construction

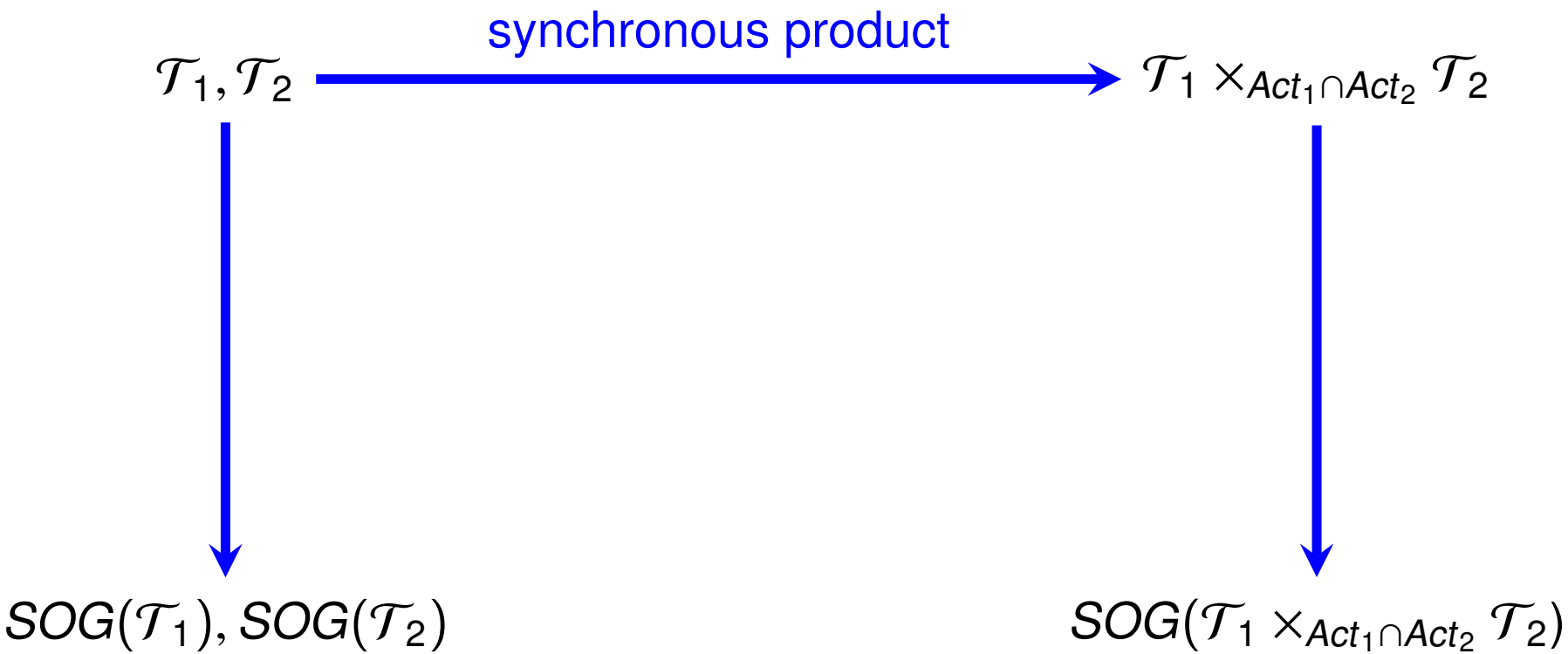


Modular Construction



Observe both synchronised actions and those of the formula.

Symbolic Observation Graphs Product



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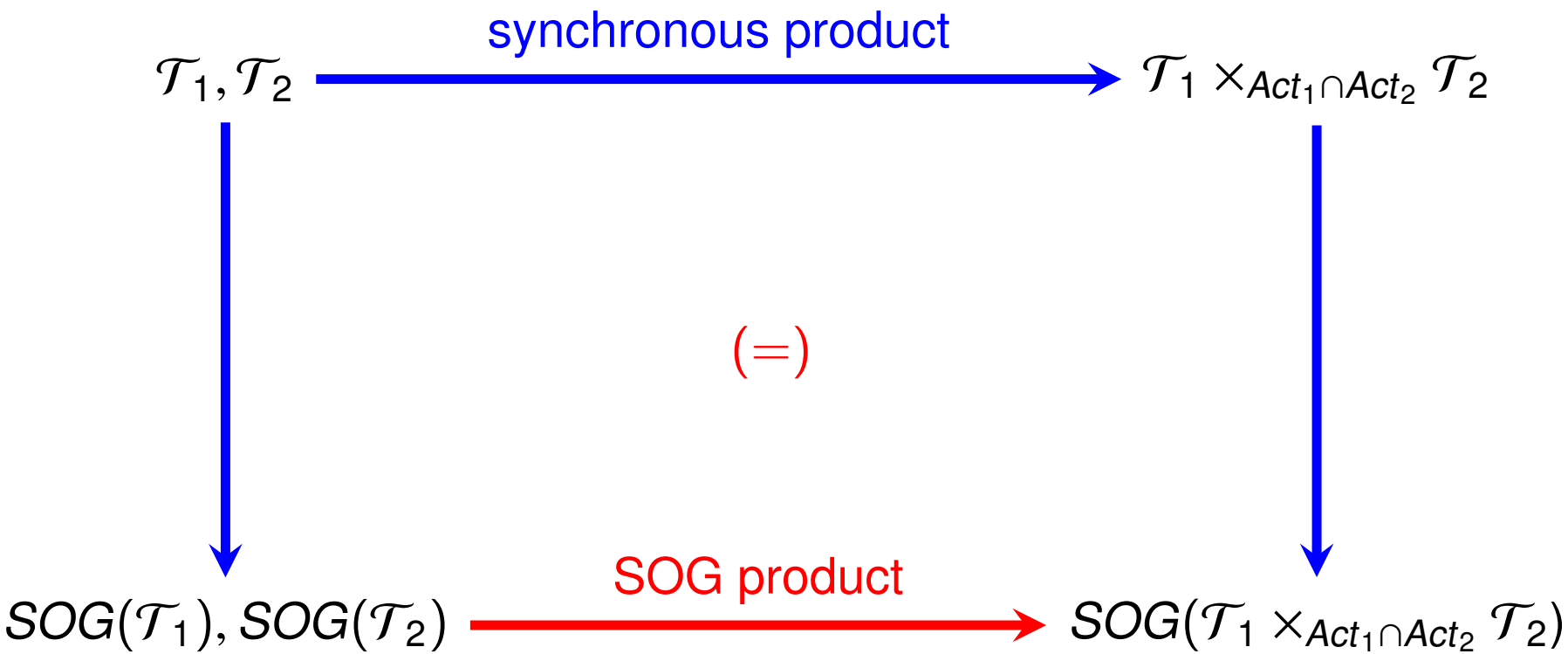

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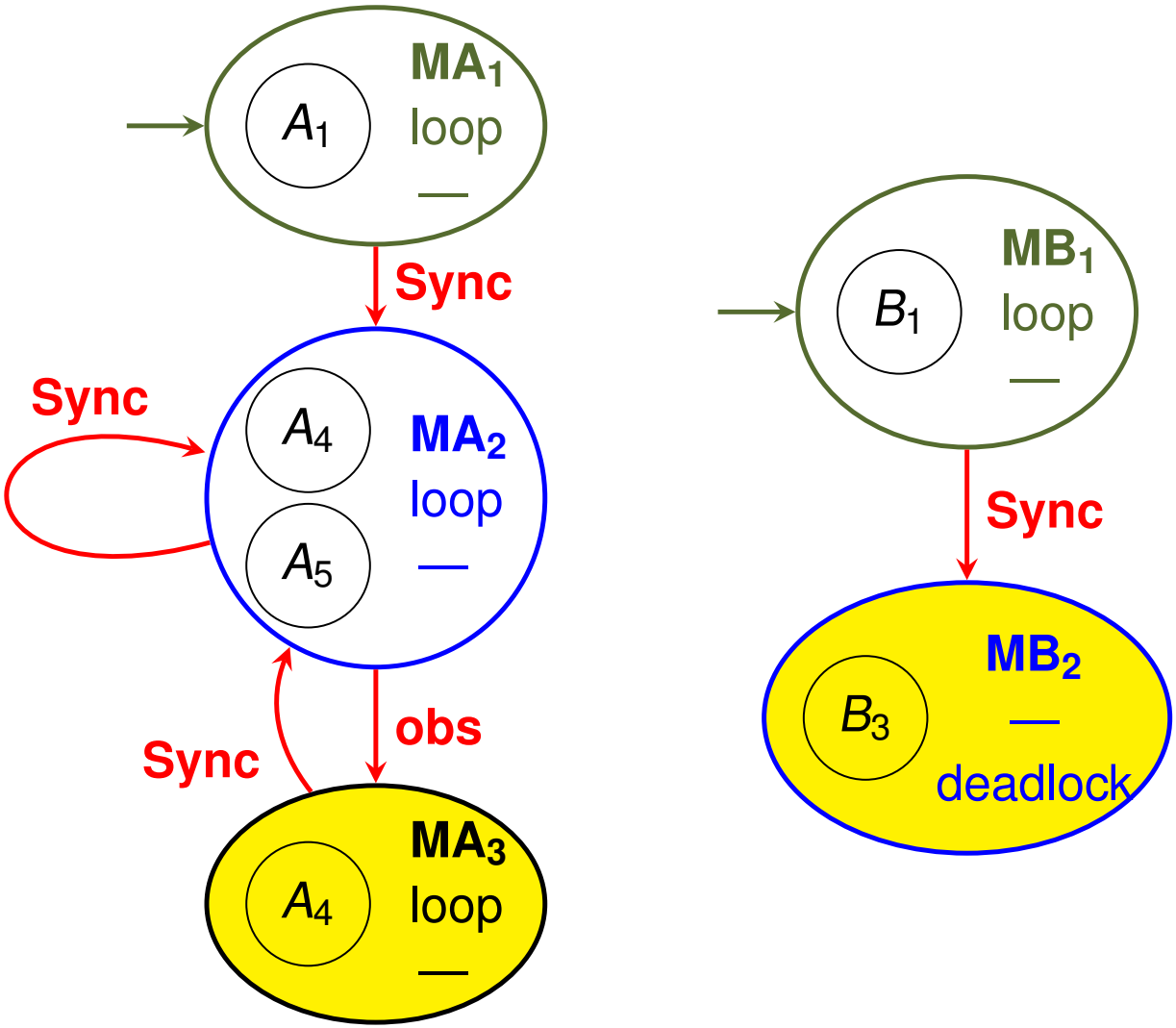

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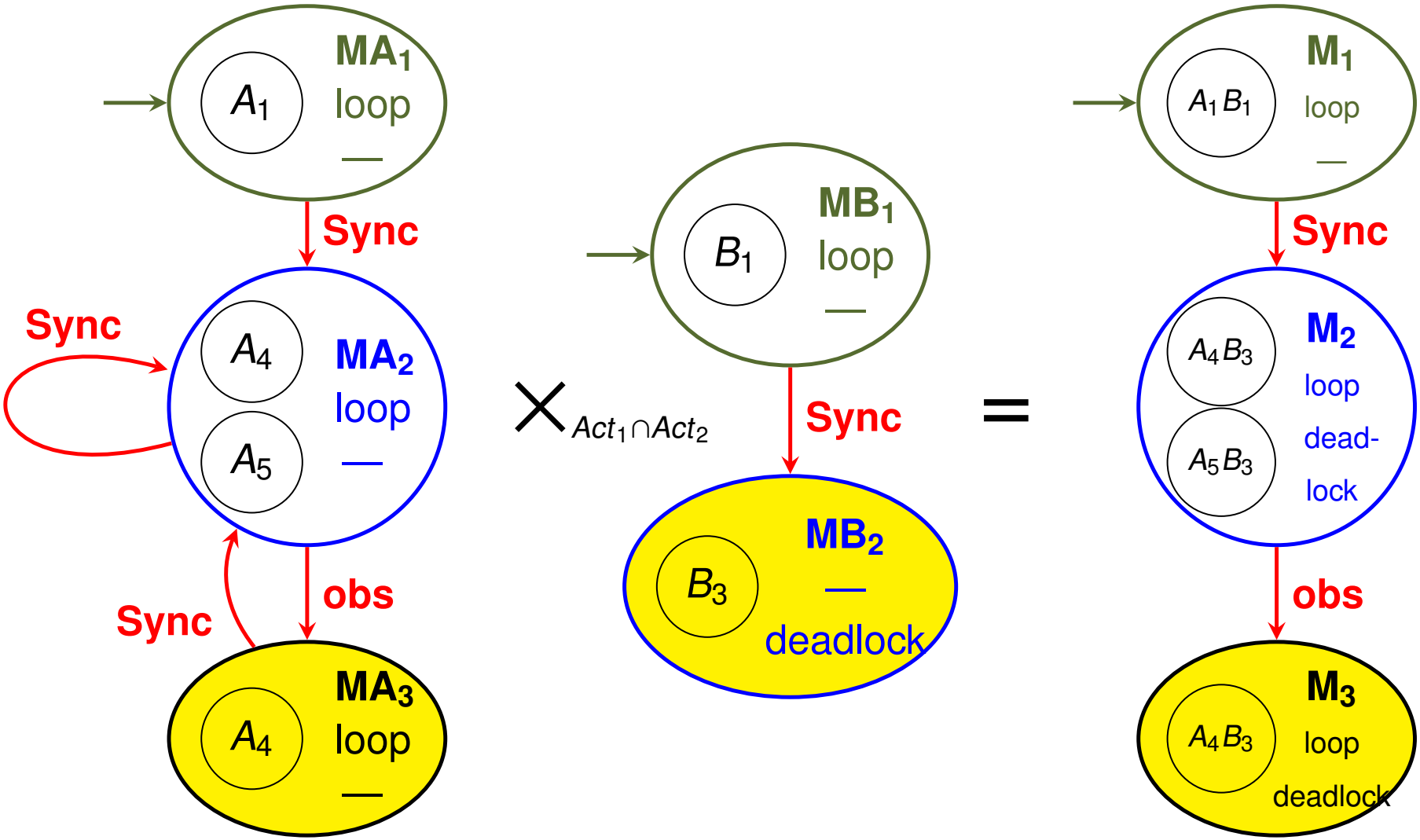


Experimental Results

Model	**param**	N_{OG}	N_{MSS}	N_{MSOG}
5 AGVs		$30,965,760$	900	12
Database	n	$n \times 3^{n-1} + 1$	$6n + 3$	$n + 1$
Philosophers	2	3	11	3
	3	4	16	4
	n	$N_{OG}(n-1)$ $+N_{OG}(n-2)$	$N_{OG}(n) + 4n$	$N_{OG}(n)$
Poisoned philosophers	2	21	33	17
	3	99	99	75
	n	$4N_{OG}(n-1)$ $+3N_{OG}(n-2)$ $+6$	$4N_{MSS}(n-1)$ $+N_{MSS}(n-2)$ $+8n+4$	$4N_{MSOG}(n-1)$ $+N_{MSOG}(n-2)$ $+4$
Railway	n	$4(n^2+n+1)$	$\frac{n(n+1)}{2} + 5n + 10$	$\frac{n(n+1)}{2} + 2n + 3$

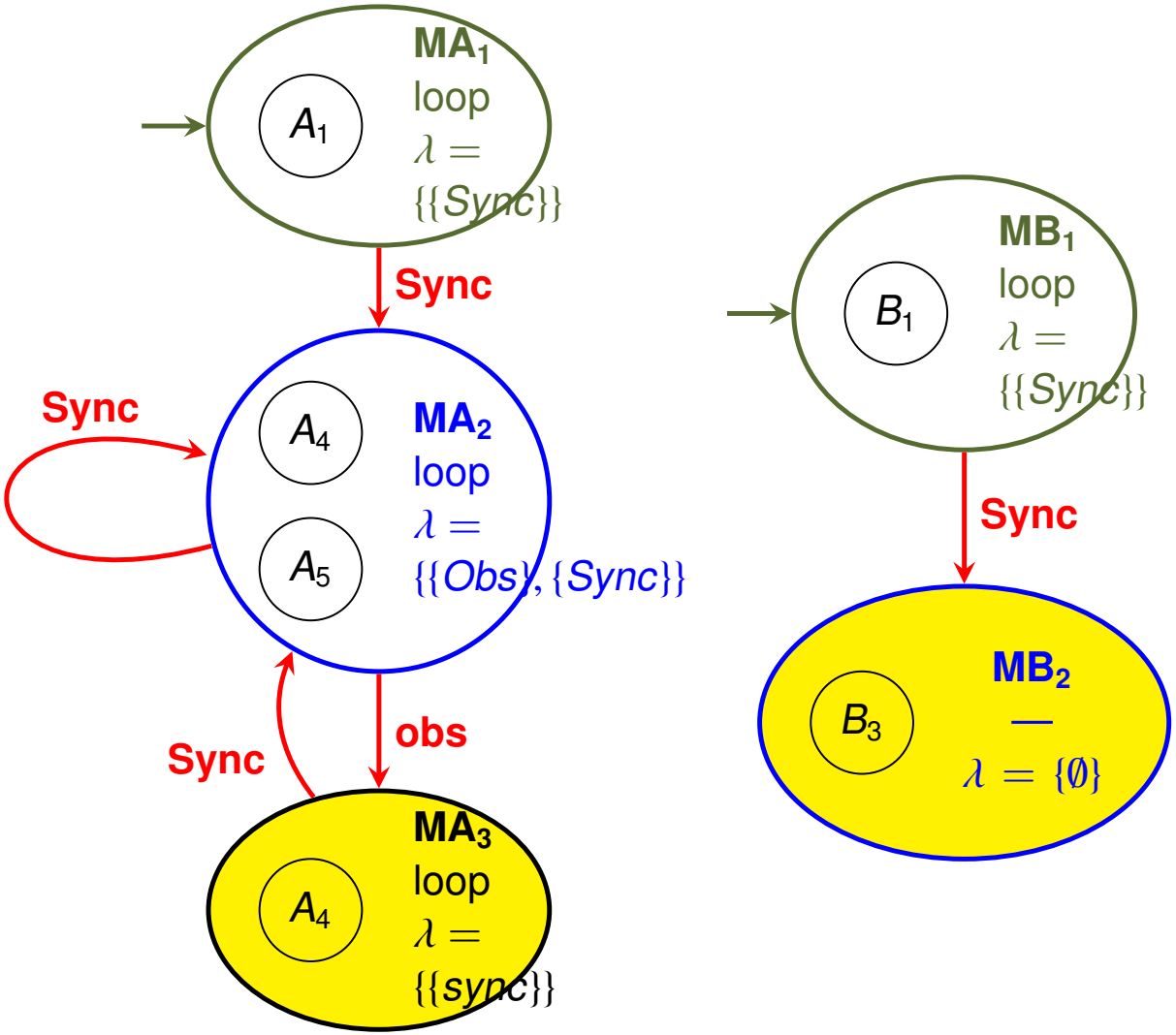
Drawbacks of Previous Approaches

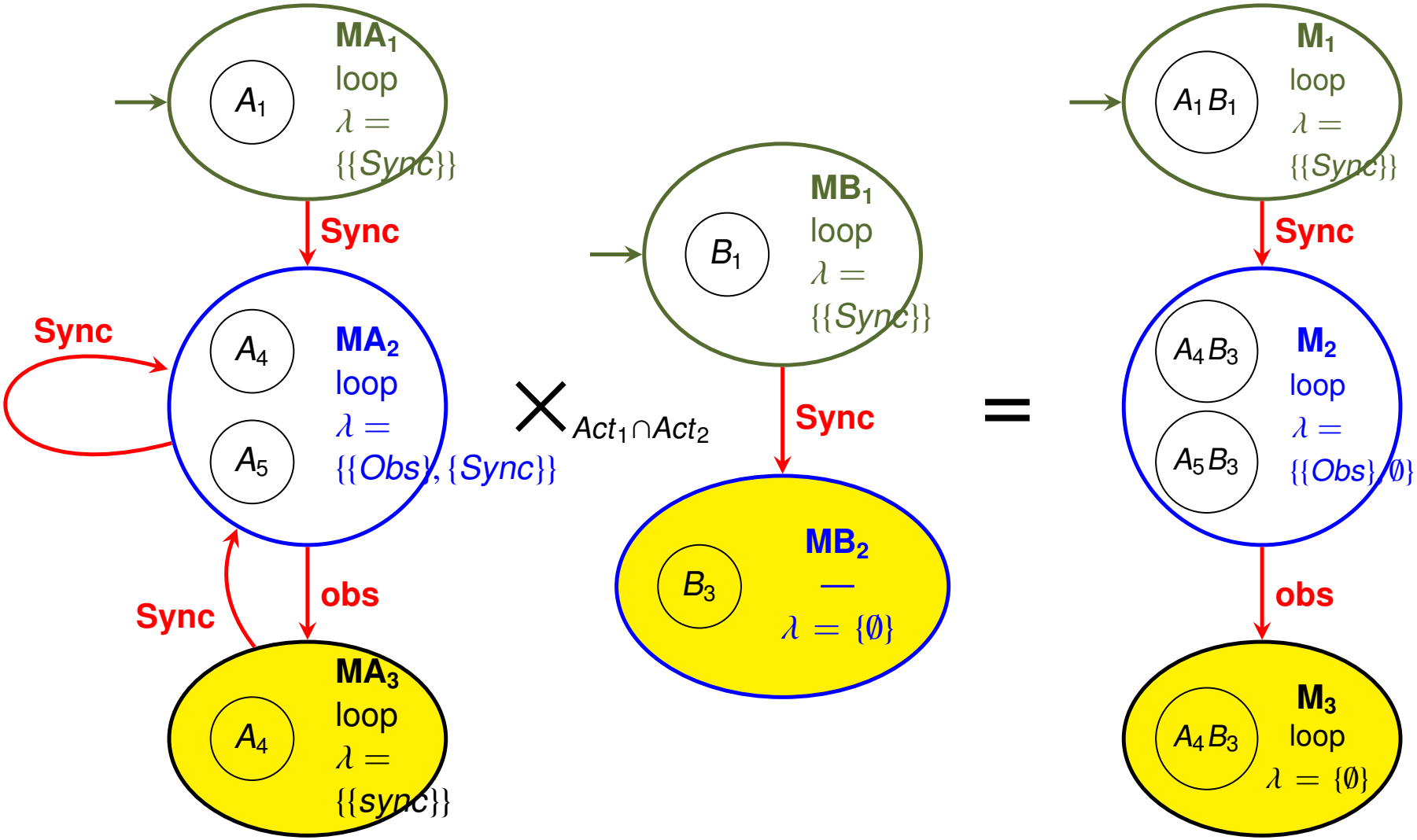
Drawbacks

1. Decomposition of the Petri net model according to the formula
2. Non-constraining relation checked using language inclusion
3. Model-checking the complete model in case the formula holds
4. Computing the synchronised meta-states deadlock attribute

Improvements

1. Synchronised LTSs
2. Checking validity of counterexamples
3. Use of the SOG as a reduced structure for model-checking
4. Introducing an observed behaviour mapping


MA1
loop
λ =
{{Sync}}
A1
Sync
Sync
A4
A5
MA2
loop
λ =
{{Obs}, {Sync}}
Sync
obs
MA3
loop
λ =
{{sync}}
A4
MB1
loop
λ =
{{Sync}}
B1
Sync
MB2
—
λ = {∅}
B3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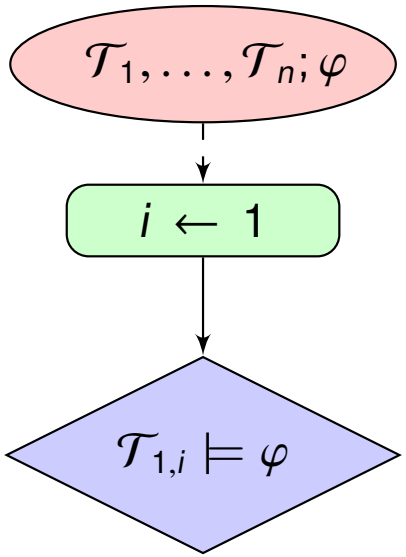
A4
A5
Sync
obs
MA3
loop
λ =
{{sync}}
A4
MB1
loop
λ =
{{Sync}}
B1
Sync
MB2
—
λ = {∅}
B3
Act1∩Act2
=
M1
loop
λ =
{{Sync}}
A1 B1
Sync
M2
loop
λ =
{{Obs}, ∅}
A4 B3
A5 B3
obs
M3
loop
λ = {∅}
A4 B3

Incremental Verification Revisited



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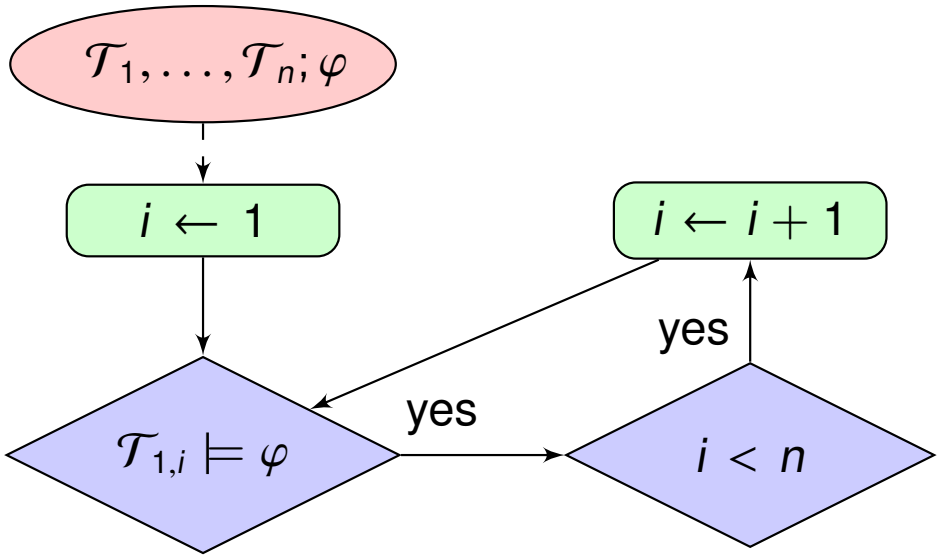

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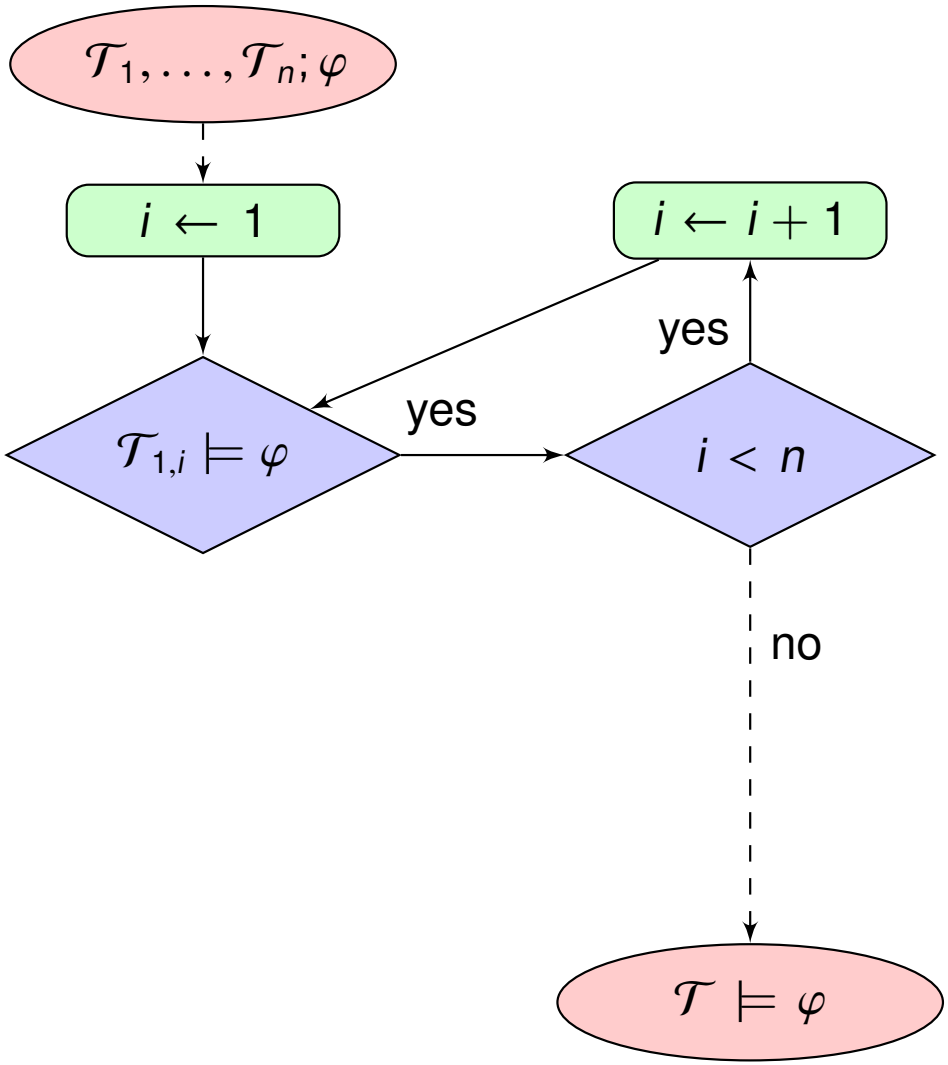

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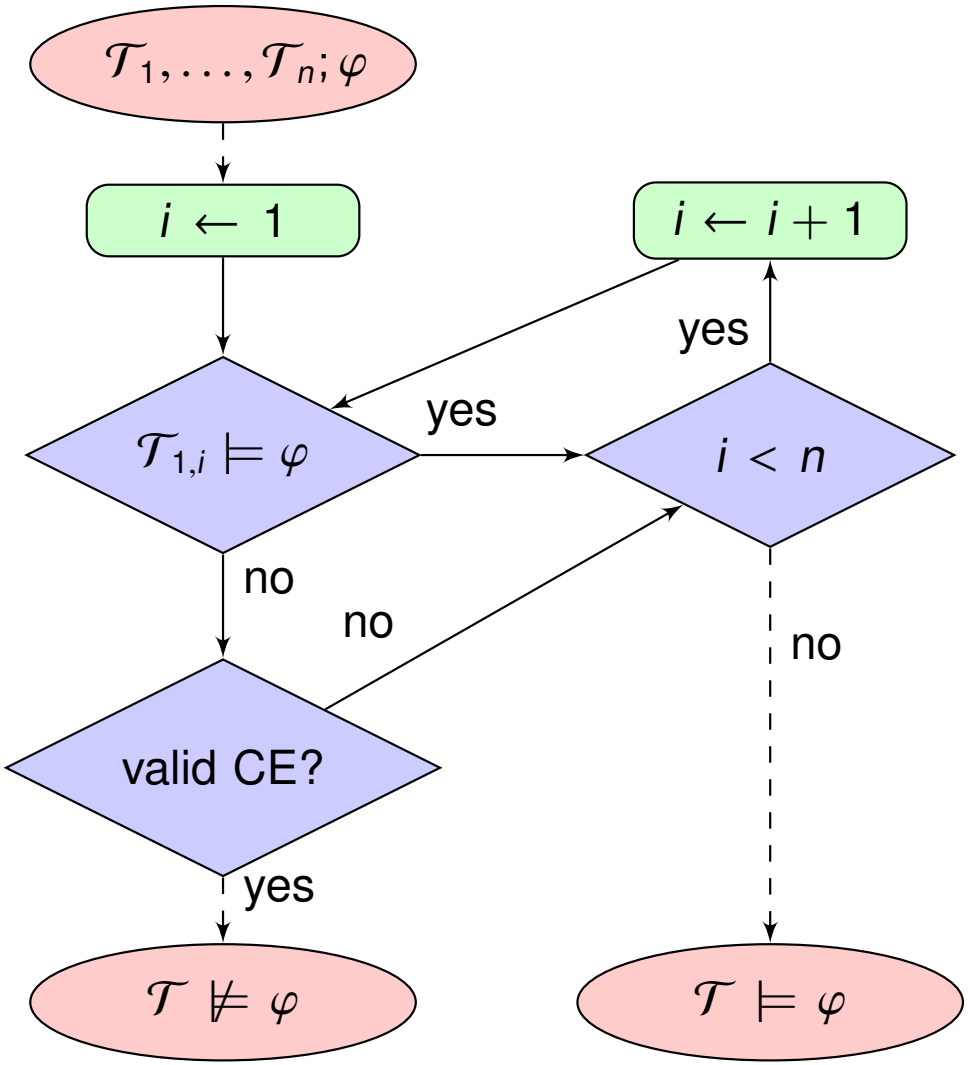
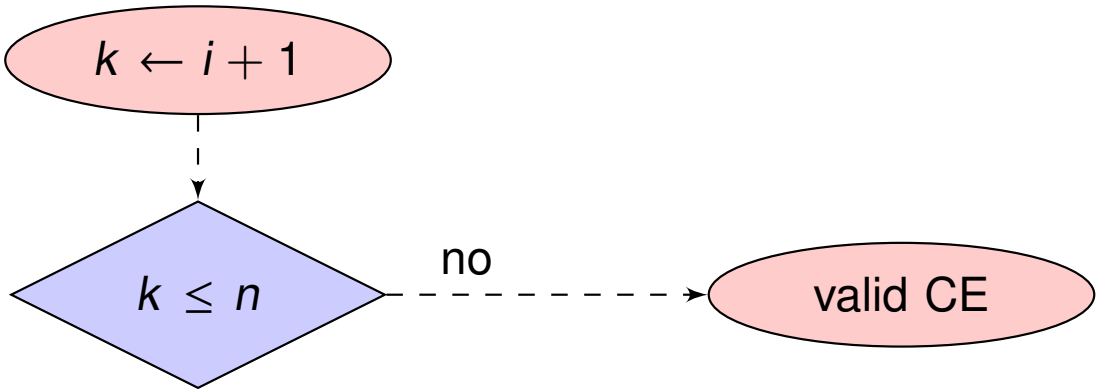


Checking Validity of Couterexamples



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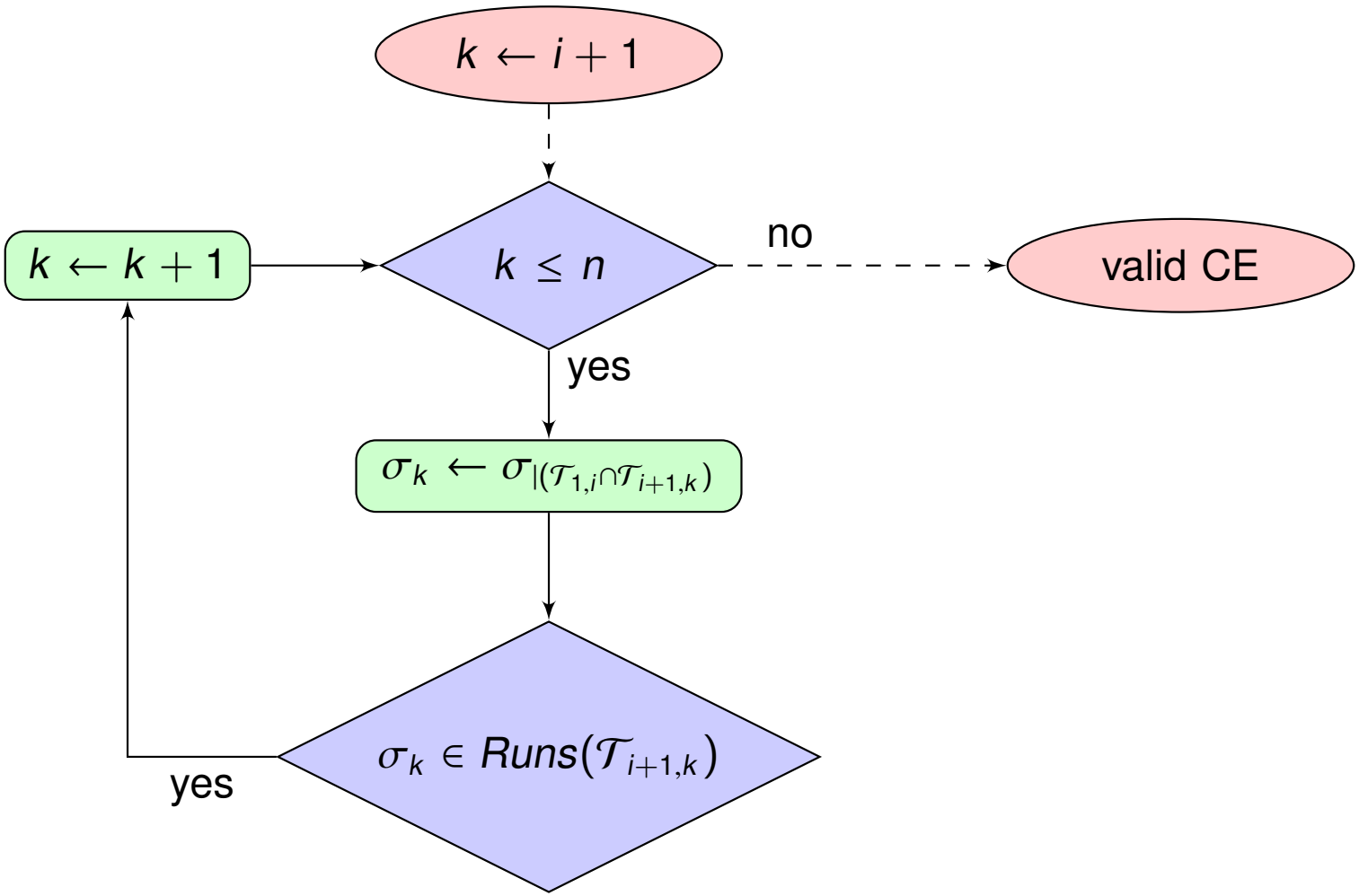

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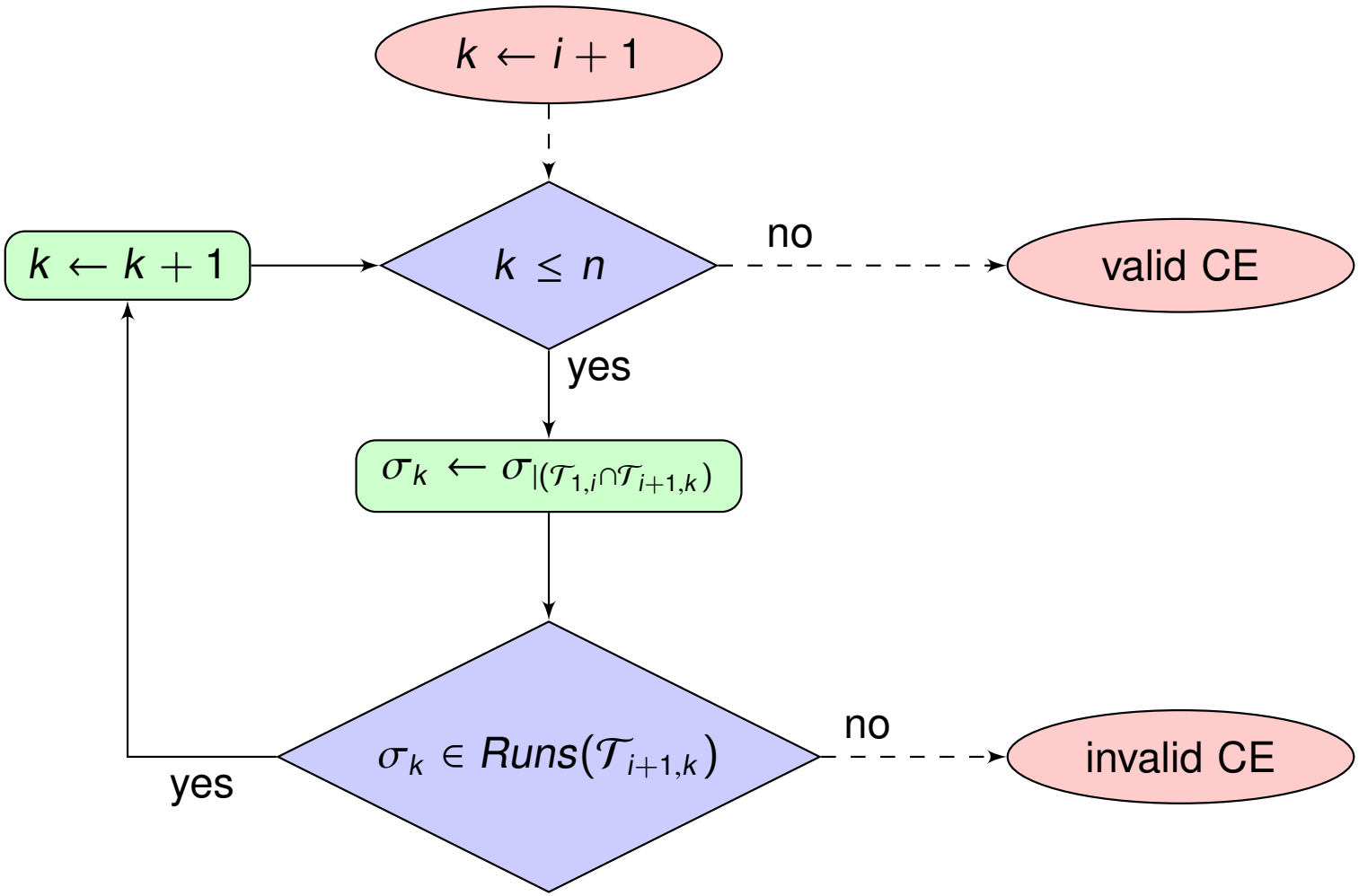

Summary and Advantages

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- Incremental model-checking of LTL\X properties
- On-the-fly construction of a counterexample
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Advantages of the approach

- Reduce complexity with both incremental approach and use of SOGs
- Allow for black box components
- Reuse of components SOGs without additional computation

Perspectives

- Study the impact of components' structure on performances
- Software implementation of the different approaches
- Experiments on different kinds of case studies