Counterexample searches in Spot

Clément Gillard

LRDE
EPITA Research and Development Laboratory

Seminar – 2019-01-16

2019-01-27

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ω-automata Model Checking 101

$$M \models \varphi$$

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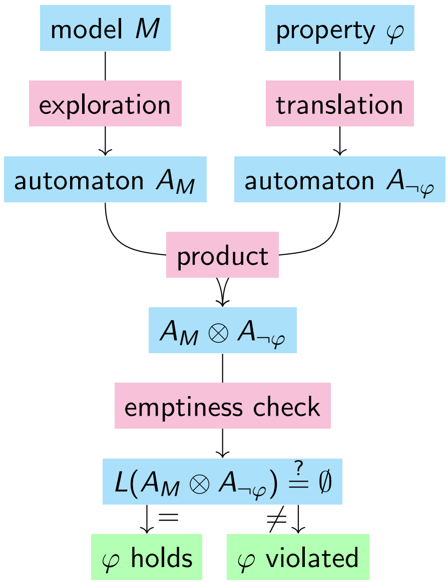
The Model Checking Toolchain



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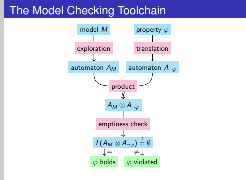

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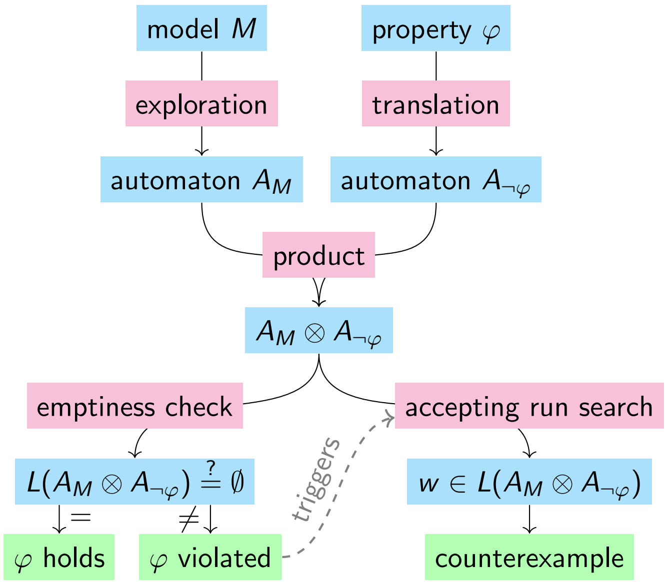

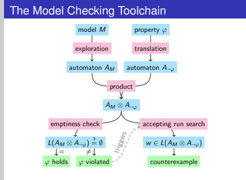

ω-automata Equivalence

$$A_1 \equiv A_2$$

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A counterexample helps us debug.

ω-automata Equivalence

$A_1 \equiv A_2 \iff L(A_1) = L(A_2) \iff L(A_1) \subseteq L(A_2)$ and $L(A_1) \supseteq L(A_2) \iff L(A_1) \cap L(\overline{A_2}) = \emptyset$ and $L(\overline{A_1}) \cap L(A_2) = \emptyset \iff L(A_1 \otimes \overline{A_2}) = \emptyset$ and $L(\overline{A_1} \otimes A_2) = \emptyset$

A counterexample helps us debug.

Spot 2

- Duret-Lutz et al., “Spot 2.0 — a framework for LTL and ω-automata manipulation”, ATVA’16 [2]
- C++ library, Python interface
- algorithms and bridges for model checking
- executables for testing and comparing tools: `ltlcross`, `autcross`

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Multiple algorithms

Name	Type of automata	Emptiness check	Accepting run search
Couvreur New:	TGBA – on-the-fly – explicit	 ✔ ✔	 ✔ ✔
Product EC&CE:	TGBA – on-the-fly – explicit	 ✔ ✔	 ✔ ✔
Generic EC:	Any – explicit	 ✔	

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Product EC&CE:	TGBA – on-the-fly – explicit	 ✔ (2017) ✔ (2017)	 ✔ (2018) ✔ (2018)	 (benches 2019)
Generic EC:	Any – explicit	 ✔	 ✔ (2019)	

Multiple algorithms

Counterexample searches in Spot

1. Introduction
2. Generalities on accepting run searches
3. Product accepting run search
4. Generic accepting run search
5. Conclusion

Counterexample searches in Spot
Introduction
Generalities on accepting run searches
Product accepting run search
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Generalities on accepting run searches

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└Generalities on accepting run searches

Generalities on accepting run searches

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Papers on efficient counterexample search

- Gastin, Moro, and Zeitoun, “Minimization of counterexamples in SPIN”, SPIN’04 [5]
- Hansen and Kervinen, “Minimal Counterexamples in $O(n \log n)$ Memory and $O(n^2)$ Time”, ACSD’06 [8]
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Quote

From “Minimal Counterexample Generation for SPIN” [4]:

> *“If states are stored in an hash table as usual, one can recover the trace of the counter-example using a BFS algorithm [. . .]. It then suffices to apply this BFS from the initial state i to s_1 to generate ρ_1, then to apply it from s_1 to s_2 to generate ρ_2 and finally to apply it once more from s_2 to s_1 to generate ρ_3.”*
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> Gastin and Moro

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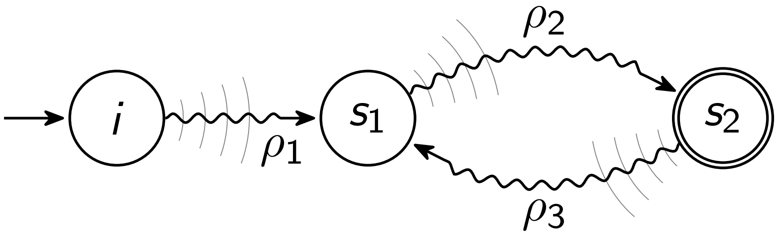
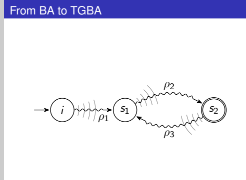
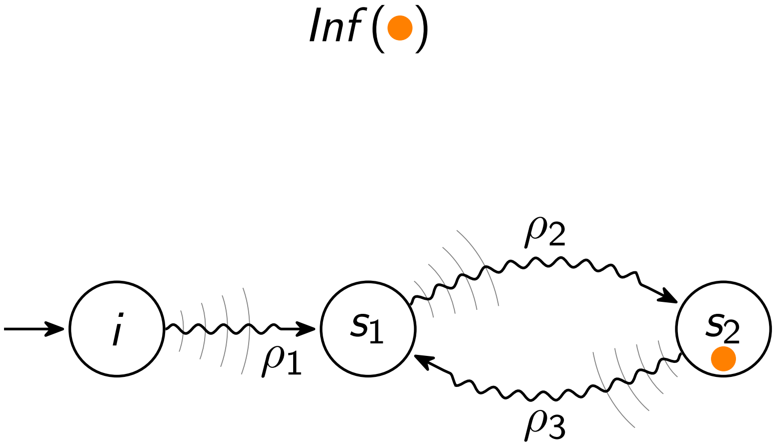




1. acceptance sets, acceptance marks, acceptance condition

From BA to TGBA



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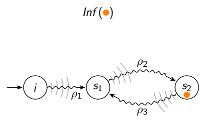
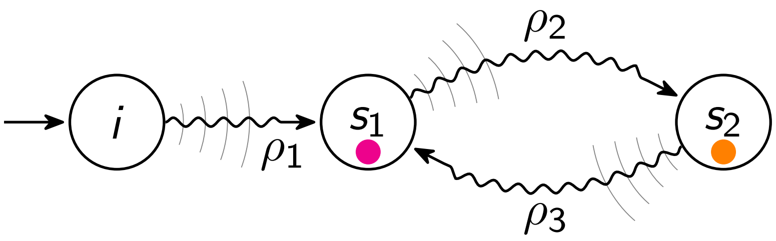


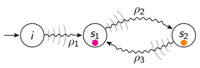
1. more accepting sets

From BA to TGBA

$$Inf(\textcolor{magenta}{\bullet}) \wedge Inf(\textcolor{orange}{\bullet})\ldots$$



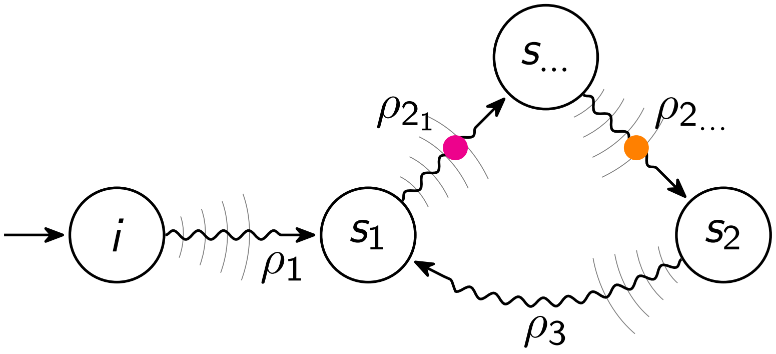
From BA to TGBA
$Inf(\bullet) \wedge Inf(\bullet)\ldots$

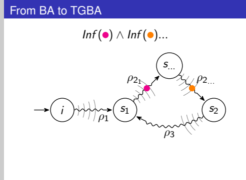


1. accepting marks on transitions

From BA to TGBA

$$Inf(\bullet) \wedge Inf(\bullet)\ldots$$





1. s_2 becomes the last state to see, ρ_2 becomes multiple BFS

Product accepting run search

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└Product accepting run search

Product accepting run search

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The Product Emptiness Check

- Gillard, Two-automaton emptiness check in Spot, 2017 [6]
- Algorithm by Couvreur, “On-the-fly Verification of Temporal Logic”, FM’99 [1]
- Removes a limitation of building the product by simulating it with custom data structures
- Generalised Büchi acceptance condition only

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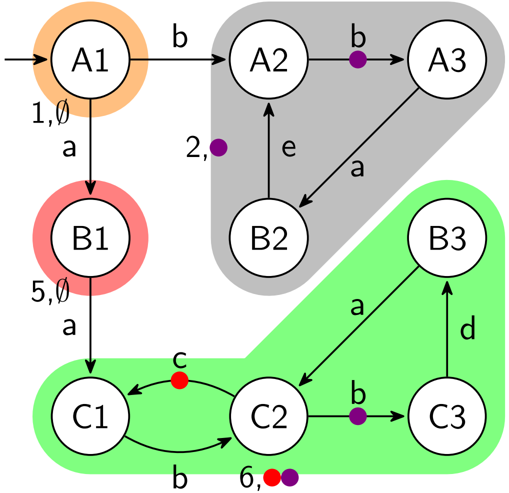
The Product Accepting Run Search



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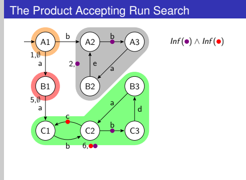
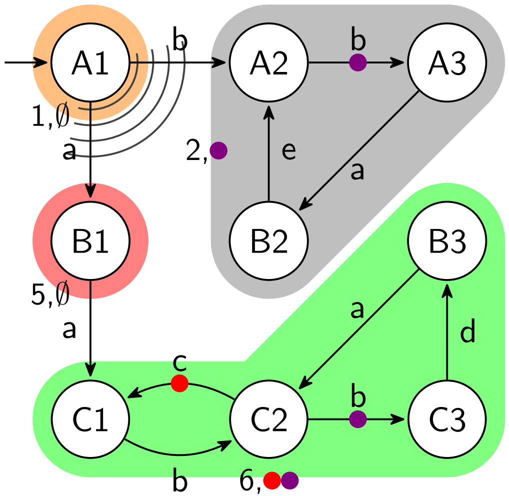


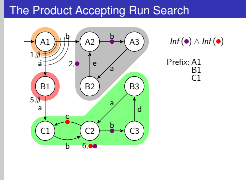
1. States of the SCC
2. Marks of the SCC

The Product Accepting Run Search



$Inf(\bullet) \wedge Inf(\bullet)$

Prefix: A1
B1
C1



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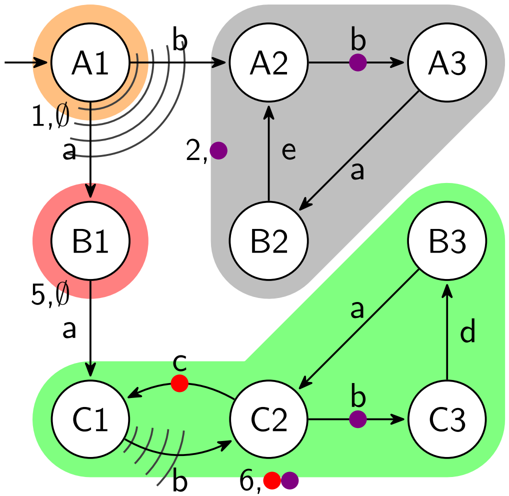
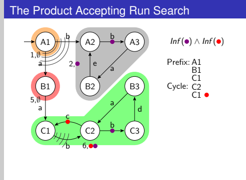


$Inf(\bullet) \wedge Inf(\bullet)$

Prefix: A1
B1
C1
Cycle: C2
C1



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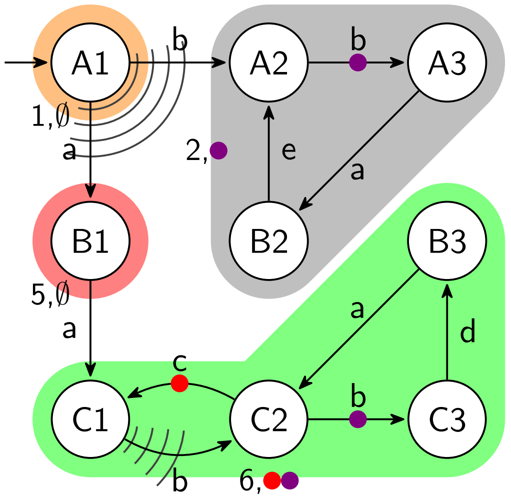
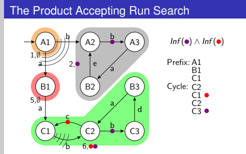


Inf(●) ∧ *Inf*(●)

Prefix: A1
B1
C1
Cycle: C2
C1 ●
C2
C3 ●



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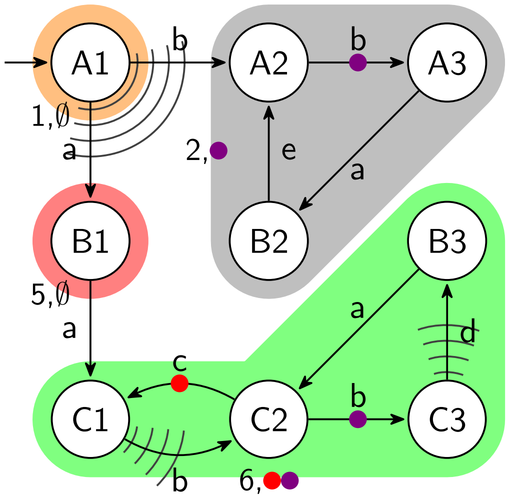
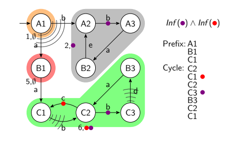


$Inf(\bullet) \wedge Inf(\bullet)$

Prefix: A1
B1
C1
Cycle: C2
C1 •
C2
C3 •
B3
C2
C1

The Product Accepting Run Search



1. States of the SCC
2. Marks of the SCC

- Knowledge:
  - map: *state* of $A_1 \times$ *state* of $A_2 \to$ *order*
  - "*order*" of s_1
  - marks seen in the accepting SCC
- Implementation:
  - Reimplementation of the `bfs_steps` algorithm
  - BFS from i to s_1 $\to \rho_1$
  - repeated BFSs to cross off marks, until s_2 is reached $\to \rho_2$
  - BFS from s_2 to s_1 $\to \rho_3$

The Product Accepting Run Search
- Knowledge:
  - map: *state* of $A_1 \times$ *state* of $A_2 \to$ *order*
  - "*order*" of s_1
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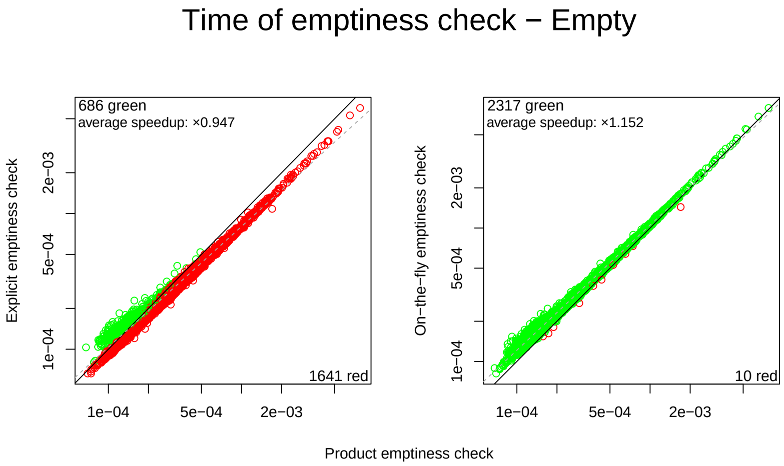
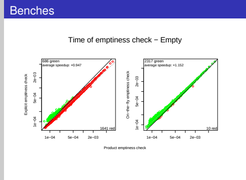
Benches

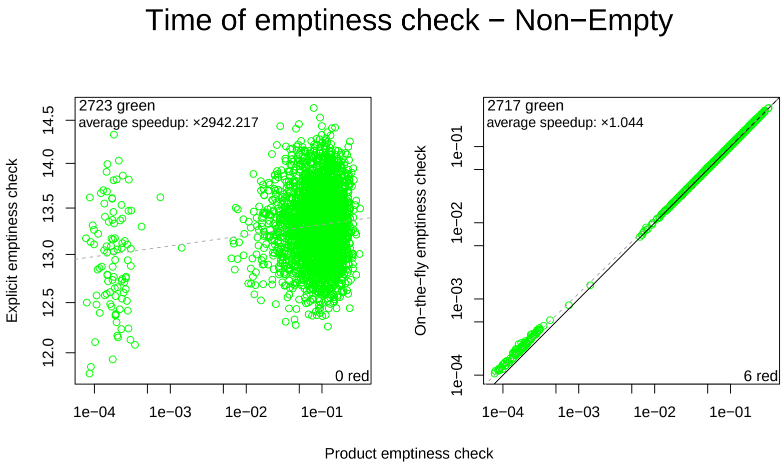


2019-01-27

Counterexample searches in Spot
└Product accepting run search
  └Benches
    └Benches



Benches



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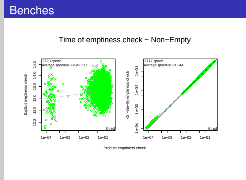
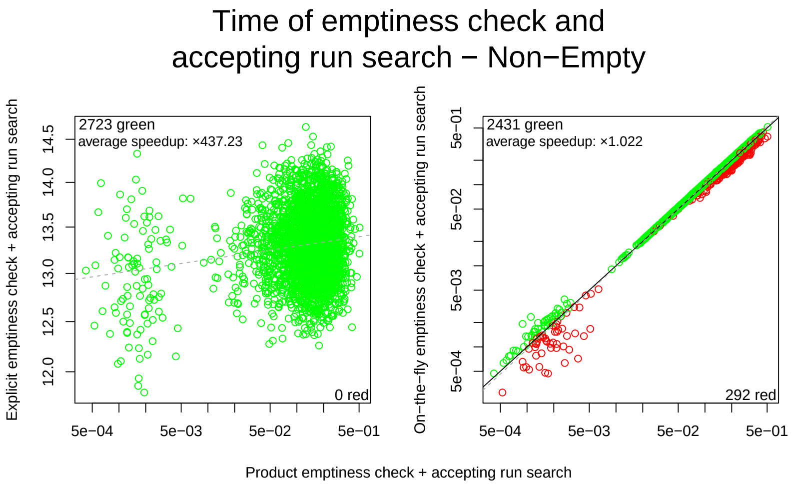


Benches


Time of emptiness check and
accepting run search − Non−Empty
2723 green
average speedup: ×437.23
0 red
Explicit emptiness check + accepting run search
12.0
12.5
13.0
13.5
14.0
14.5
2431 green
average speedup: ×1.022
292 red
On−the−fly emptiness check + accepting run search
5e−04
5e−03
5e−02
5e−01
5e−04
5e−03
5e−02
5e−01
5e−04
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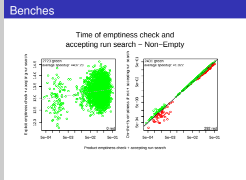
5e−01
Product emptiness check + accepting run search


Benches
Time of emptiness check and
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Generic accepting run search

1 Introduction

2 Generalities on accepting run searches

3 Product accepting run search

4 Generic accepting run search

5 Conclusion

└Generic accepting run search

Generic accepting run search

Introduction
Generalities on accepting run searches
Product accepting run search
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The Generic Emptiness Check

- New recursive algorithm
- Works with any acceptance condition
- NP-complete
  - Emerson and Lei, “Modalities for Model Checking: Branching Time Logic Strikes Back”, SCP’87 [3]

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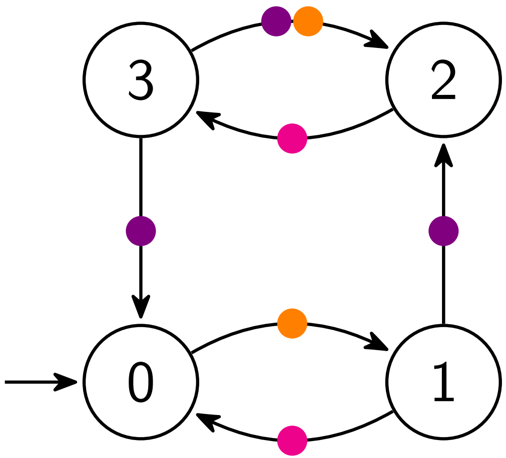
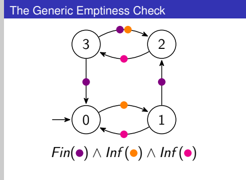


$$Fin(\bullet) \land Inf(\bullet) \land Inf(\bullet)$$



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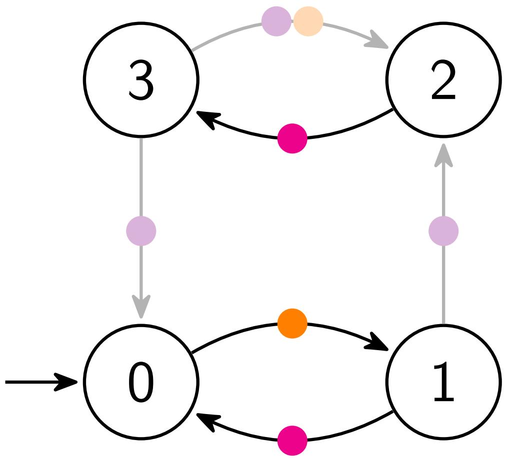
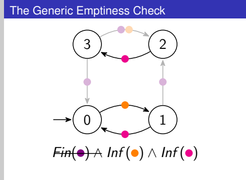


$\cancel{Fin(\bullet) \land}\ Inf(\bullet) \land Inf(\bullet)$



The Generic Accepting Run Search

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  - states of the accepting SCC
  - marks seen in the accepting SCC
  - cut-out acceptance condition
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  - At the deepest recursion level, in `scc_info`
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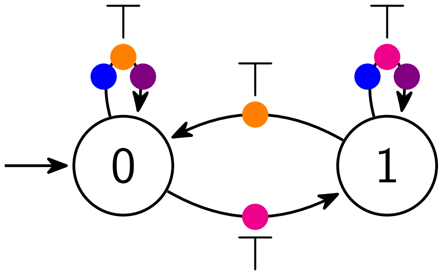
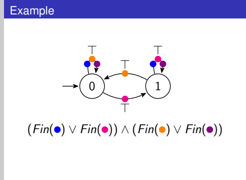
Example



$$(Fin({\color{blue}\bullet}) \vee Fin({\color{magenta}\bullet})) \wedge (Fin({\color{orange}\bullet}) \vee Fin({\color{purple}\bullet}))$$



Conclusion

1. Introduction
2. Generalities on accepting run searches
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4. Generic accepting run search
5. Conclusion

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Counterexample searches in Spot
└Conclusion

└Conclusion

Introduction
Generalities on accepting run searches
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- Multiple ways to do them, with tradeoffs on efficiency
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  - Bench
- Integrate the product emptiness check to Spot
- Better automata for benching

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Questions?

Thank you for your attention!

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